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Identifying Predictors of Higher Acute Care Costs for Patients With Traumatic Spinal Cord Injury and Modeling Acute Care Pathway Redesign: A Record Linkage Study

Bharat Phani Vaikuntam, MHEcon,[*] James Walter Middleton, PhD,[*,†] Patrick McElduff, PhD,[‡] Luke Connelly, PhD,[§] Jim Pearse, MS,[‡] Ralph Stanford, PhD,[¶] John Walsh, AM,[*] and Lisa Nicole Sharwood, PhD[*]

Study Design. Record linkage study using healthcare utilization and costs data.

Objective. To identify predictors of higher acute-care treatment costs and length of stay for patients with traumatic spinal cord injury (TSCI).

Summary of Background Data. There are few current or population-based estimates of acute hospitalization costs, length of stay, and other outcomes for people with TSCI, on which to base future planning for specialist SCI health care services.

Methods. Record linkage study using healthcare utilization and costs data; all patients aged more than or equal to 16 years with incident TSCI in the Australian state of New South Wales (June 2013–June 2016). Generalized Linear Model regression to identify predictors of higher acute care treatment costs for patients with TSCI. Scenario analysis quantified the proportionate cost impacts of patient pathway modification.

Results. Five hundred thirty-four incident cases of TSCI (74% male). Total cost of all acute index episodes approximately AUD$40.5 (95% confidence interval [CI] ±4.5) million; median cost per patient was AUD$45,473 (Interquartile Range: $15,535–$94,612). Patient pathways varied; acute care was less costly for patients admitted directly to a specialist spinal cord injury unit (SCIU) compared with indirect transfer within 24 hours. Over half (53%) of all patients experienced at least one complication during acute admission; their care was less costly if they had been admitted directly to SCIU. Scenario analysis demonstrated that a reduction of indirect transfers to SCIU by 10% yielded overall cost savings of AUD$3.1 million; an average per patient saving of AUD$5,861.

Conclusion. Direct transfer to SCIU for patients with acute TSCI resulted in lower treatment costs, shorter length of stay, and less costly complications. Modeling showed that optimizing patient-care pathways can result in significant acute-care cost savings. Reducing potentially preventable complications would further reduce costs and improve longer-term patient outcomes.

Key words: complications, costs, length of stay, record linkage, traumatic spinal cord injury.

Level of Evidence: 3

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From the [*]John Walsh Centre for Rehabilitation Research, Kolling Institute, Sydney Medical School - Northern, Faculty of Medicine and Health, The University of Sydney, Sydney, Australia; [†]NSW State-wide Spinal Cord Injury Service, Agency for Clinical Innovation, Australia; [‡]Health Policy Analysis Pty Ltd, Sydney, Australia; [§]Centre for Business and Economics of Health, The University of Queensland, Australia; and [¶]Prince of Wales Hospital, Sydney, New South Wales, Australia.

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Address correspondence and reprint requests to Bharat Phani Vaikuntam, MHEcon, John Walsh Centre for Rehabilitation Research, Kolling Institute, Sydney Medical School - Northern, Faculty of Medicine and Health, The University of Sydney, Sydney, 2065, Australia; E-mail: bvai6198@uni.sydney.edu.au

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Traumatic spinal cord injury (TSCI) is a devastating, costly injury resulting predominantly from motor vehicle crashes and falls. Despite relatively low annual incidence in Australia (~21.0–32.3 cases/million population),[1] resulting treatment costs are exorbitant. The high economic burden on health care systems due to TSCI have been previously highlighted in several population-based studies in the United States of America (USA) and Canada[2]; delayed admission to specialist care for TSCI contributing to higher cost burden in Canada.[3,4] The estimated total national costs attributable to SCI-related hospitalizations in 2009 in the United States were approximately $1.69 billion,[5] however, this included both nontraumatic and traumatic SCI without acute-care costs itemised separately. Acute-care costs for TSCI have been increasing steadily despite decreasing lengths of stay (LOS),[6] predominantly due to medical advances and the resource intensive nature of specialist care. Examination of the true cost of acute-care for TSCI and its determinants is vital, in order to identify those factors potentially amenable to change.

Recent studies have examined complications and readmissions in TSCI,[7,8] however, these studies did not provide robust cost estimates to evaluate the impact of these and other potential cost drivers in TSCI acute care. Early direct transfer to a specialist spinal cord injury (SCI) unit (SCIU) has proven efficacious in reducing risks of secondary neurological deterioration, leading to improved patient outcomes,[9–12] and implicit reduced health service expenditure. Expert consensus recommends transfer to SCIU within 24 hours post-injury. In Australia and the United Kingdom, studies have identified poor adherence to this recommendation[13–15]; proposing resultant impact on acute-care resource utilization. Strategic use of population-based data has been called for; for example, to inform effective clinical pathway redesign.[16]

Undertaking prospective studies to quantify the impact and potential savings of clinical pathway redesign is time consuming and costly, even with demonstration of cost-effectiveness and improved outcomes.[17] Other methods, such as the strategic use of modeling techniques using accurate epidemiological health data, have provided validation of robust means to make substantial cost savings by redesigning care pathways.[18] Such evidence can be used to inform future funding decisions, by identifying cost-effective, and optimal acute-care pathways for patients, assisting in the pre-implementation phase.

Our study objectives were to (a) determine true acute-care treatment costs for TSCI across New South Wales (NSW) using record-linked healthcare data, (b) determine predictors of higher costs and LOS, (c) apply scenario analysis modeling to measure proportionate cost impacts of potential health service pathway modifications.

MATERIALS AND METHODS

Study Population

Study setting: NSW, Australia's most populous state,[19] with the highest number of public and private hospitals and consequent hospital expenditure nationally.[20]

Inclusion criteria: Acute-care for patients aged more than or equal to 16 years with incident TSCI from June 2013 to June 2016, identified using specific TSCI-related International Classification of Diseases (ICD-10AM)[21] diagnostic codes (Appendix - 1, http://links.lww.com/BRS/B419) within hospital separations data.

Exclusion criteria: Any rehabilitation admissions (diagnosis code prefix "Z"), injury incident preceding study period, missing ICD-10AM codes for injury mechanism at time of injury (Appendix - 1, http://links.lww.com/BRS/B419), AR-DRG code for chronic para/quadriplegia (B82A/B/C) in index episode (indicating previous—not incident—injury) (Figure 1).

Data Sources and Linkage

Figure 1 illustrates the data linkage process. The Centre for Health Record Linkage linked patients with Appendix codes in any diagnosis field within the Admitted Patient Data Collection (APDC), with all corresponding records in administrative datasets (Appendix, http://links.lww.com/BRS/B419), using probabilistic linkage methods and developed by ChoiceMaker Technologies, Inc., New York (Figure 1).[22] The first hospital episode for the patient satisfying these conditions and constituent of all contiguous episodes of care, including nested/non-nested transfers, was recognized as the "index event." Acute-care completeness was ascertained when separation modes indicated either hospital discharge or transfer to a rehabilitation or private hospital. Socio-Economic Indexes for areas quantiles derived from patient residence postcodes were used as a socio-economic measure for the study population.[23]

Injury Severity

The International Classification of Diseases Injury Severity Score (ICISS) provided an injury severity measure for participants[24]; a well validated metric offering diagnosis-specific survival probabilities.[25] An injury's severity is inverse to its ICISS; a lower ICISS represents higher injury severity; higher ICISS less severe injury. Charlson Comorbidity Indices (CCI) were derived from ICD-10AM diagnostic codes[26]; applying the highest CCI across episodes. Higher CCI represents higher mortality probability; absent comorbidities a CCI of zero. Multiple-trauma (defined Appendix -1, http://links.lww.com/BRS/B419) identified injuries to other body regions, including arm or shoulder, hip or leg, chest, abdomen, skull/face, and brain. Secondary complications associated with TSCI in the acute episode were categorized into three "major complication" classes; pressure injuries, respiratory related and urinary related (Appendix-1, http://links.lww.com/BRS/B419).

Costing Method

All costs represent 2016 Australian dollars. Analyses stratified direct patient level costs by demographic and clinical characteristics. Total "per patient" treatment costs were estimated with a bottom-up costing approach using the NSW activity-based funding District Network Return (DNR) data. DNR data captures the "true costs" incurred by health service providers, most, but not of which comprises staff salaries and operating costs, for all admitted hospital and emergency department separations included in index admissions (Appendix - 1, http://links.lww.com/BRS/B419). Costs are presented as both median (Interquartile Range [IQR]), accounting for non-normal distribution, and mean (SD), for cross-disciplinary interpretability.

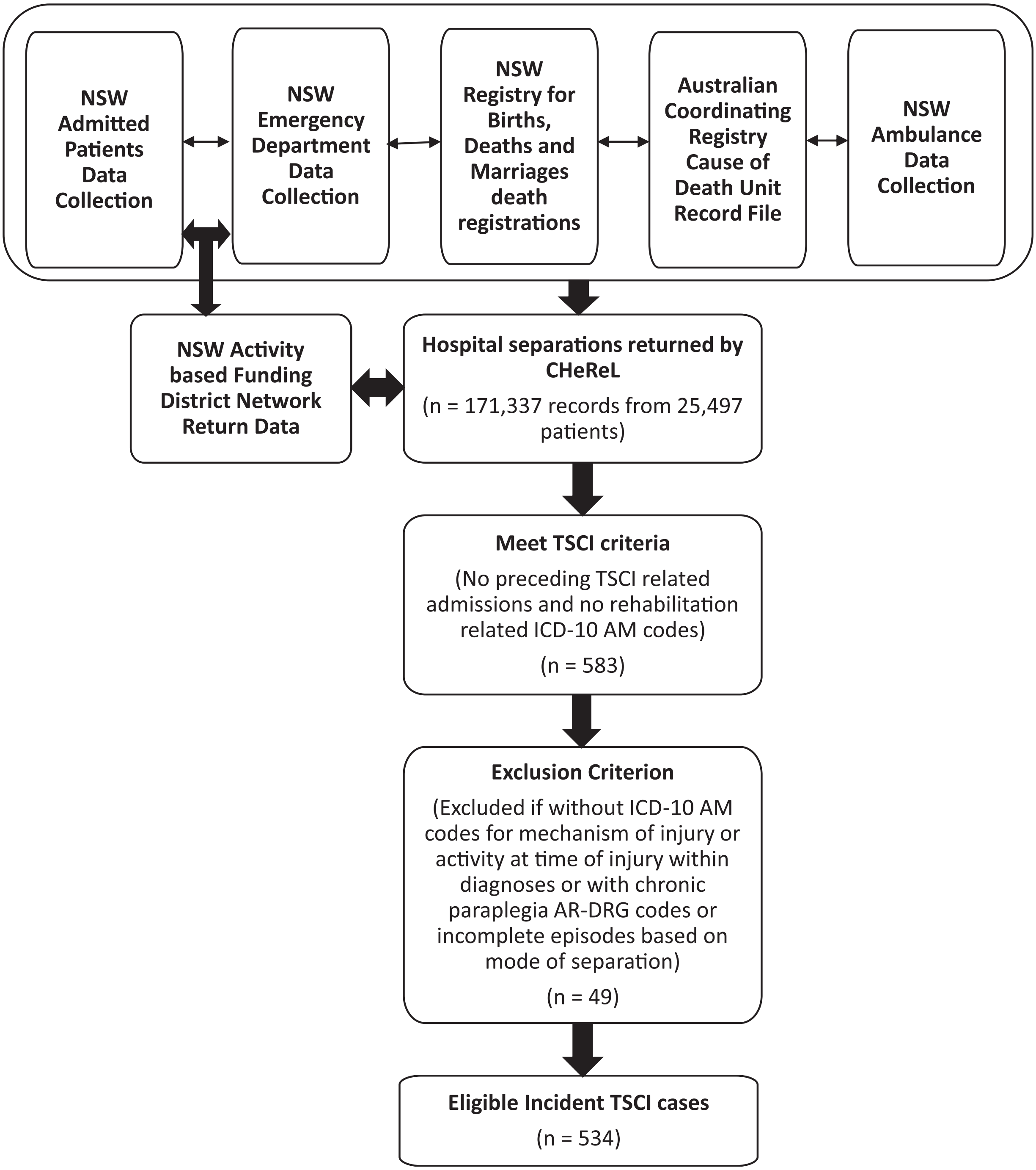

Figure 1. Record linkage and incident TSCI patient identification from record linked data. TSCI indicates traumatic spinal cord injury.

Analysis

Acute-care treatment costs associated with TSCIs were estimated from the healthcare provider perspective. LOS included all days between first separation admission dates and last separation discharge dates. Eligible separations with intermediary time-gaps less than or equal to 24 hours were included as same episode.

Generalized linear model (GLM) regression analysis (log link and gamma error term) used to identify significant determinants of acute-care costs and LOS; variables initially included were those known at time of admission having univariate significance ($P \leq 0.2$). Derived variables added included ICISS, multiple-trauma, secondary complications, and patient pathways. Patients with surgical procedures within the index episode were identified based on the relevant surgical procedure codes from APDC data (Appendix -1, http://links.lww.com/BRS/B419).

Sensitivity Analysis and Scenario Analysis

Comorbid injuries were considered more severe than the TSCI where principal diagnoses were non-SCI related. Sensitivity analysis progressively reduced acute-care costs by

20%, 30%, and 40% to account for the additional costs attributable to such comorbidities.[27]

Scenario analyses examined cost impacts of proportionate variations in patient care pathway; acute-care specifically comparing patient costs and bed days between direct transfers to SCIU and varying levels of indirect transfers from non-spinal hospitals. Bootstrapped mean costs and LOS estimates for patient pathways were derived from GLM regression analyses for the scenario analysis. Indirect transfers to SCIUs were progressively reduced by 10%, 20% then 30%, assessing cost impacts of each pathway variation.

Statistical analyses were performed using STATA version 15.1 (StataCorp LLC, College Station); sensitivity and scenario analyses using Microsoft Excel (Microsoft Corporation, Washington).

RESULTS

Patient Characteristics

There were 534 patients identified with an acute incident TSCI, with a total of 811 separations in the study period; 32 patients (6.0%) died during acute-care admission. Mean (SD) age 53.6 (21.5) years; 396 (74.1%) males. Over half of all patients (n = 284, 53%) had sustained cervical level injury. TSCI was the primary diagnosis for 377 (70.6%); falls the most common injury mechanism (n = 285, 53.4%) overall. Almost one-third (n = 144, 27.0%) were admitted directly to SCIU; 177 (33.1%) transferred there from another acute care service. Patients treated in a SCIU were deemed higher complexity, with 53.6% having cervical injury, the majority (79.4%) with complete SCI lesions and more severe mean ICISS (0.82 *vs.* 0.86, $P < 0.001$).

Hospitalization Costs and Length of Stay

The total cost for all acute TSCI episodes was estimated at $40.5 million; median (IQR) and mean (SD) per patient costs were $45,473 ($15,535–$94,612) and $75,801 ($99,096), respectively. Median (IQR) LOS was 15.4 (6.8–26.2) days; mean (SD) LOS, including hospital and ED episodes, was 22.2 (24.5) days. Table 1 shows acute treatment costs by patient characteristics.

More than half of patients (n = 299, 56%) had surgical procedures within the index acute care episode. Of operated patients, 197 (66%) had their surgical procedure at a SCIU, 86 (29%) were at Major Trauma Service Hospitals (MTS), the remainder at other hospitals. A higher proportion of patients transferred to a SCIU indirectly from a non-SCIU hospital within 24 hours (99%) had the surgical procedure within the SCIU compared with patients transferred after 24 hours (65%). The mean LOS was significantly higher in patients with surgical procedures compared with those with non-surgical procedures (27.2 *vs.* 15.8 d; $P < 0.001$).

Over half (n = 283, 53%) of all patients with TSCI had at least one major complication within their acute-care episode; 126 patients (24.0%) had two or more major complications. The most common complications were pressure injuries, reported in nearly 20% of patients. Table 2 presents all complications recorded during acute-care. Mean LOS for patients with complications within their acute episode was 31.9 days, compared with 11.3 days for those without complications. Over half of all patients (n = 300, 56.2%) received in-patient rehabilitation within their index admission; the majority of them were treated in SCIU (n = 243, 81%) and were relatively younger (mean age 49.7 yr) compared with those admitted to non-spinal hospitals (mean age 64.1 years).

Predictors of Acute-Care Costs and LOS

Table 3 presents the costs regression analysis. Statistically significant predictors of higher treatment costs were care pathways, complications within acute episodes, multiple-trauma, extent of injury, higher injury severity (lower ICISS), and comorbidities (higher CCI). Patients with complications were comparatively less expensive if transferred to SCIU within the first 24 hours from injury. A patient admitted directly to SCIU, without intervening hospital transfer cost $63,626 (adjusted mean), compared with the significantly higher mean costs for patients transferred to SCIU from either a trauma center (MTS/RTS) ($101,656) or from Metropolitan/Regional hospitals ($86,426). Patients treated entirely either at MTS/RTS ($46,210) or metropolitan/regional hospital ($42,403) incurred lower mean costs. Regression analysis showed complications to be less expensive if patients were admitted to SCIU within 24 hours post-injury (Table 3); except where patients had all three categories of complications.

The regression results for LOS (Table 4) show LOS being incrementally influenced by complications, multiple-trauma, injury severity, comorbidities, and indirect SCIU transfer. LOS was higher if transferred to a SCIU from either MTS/RTS (26 d) or metropolitan/regional hospital (35 d).

Summarizing, both acute-care costs and LOS were higher if the patients were secondarily transferred to SCIU from any non-SCIU hospital type.

Sensitivity Analysis

Applying 40%, 30%, and 20% decreases respectively to acute-care costs of patients without TSCI-related principal diagnosis, median acute-care costs per patient were $38,642 ($12,964–$84,826), $39,655 ($13,373–$86,811), and $41,248 ($14,414–$89,387).

Scenario Analysis

Overall incremental cost savings of $3.1 million, $6.3 million, and $9 million were demonstrated from reductions in indirect transfers to SCIU by 10%, 20%, and 30%, respectively (Table 5). A proportion of these savings (between 44% and 50%) were bed days saved; the remainder as direct savings from patient transfer pathway modifications.

DISCUSSION

This record-linkage study identified 534 patients to have sustained acute incident TSCI over a 3-year period. The

TABLE 1. Summary Study Patient Characteristics and Related Costs

Variable	Total (n = 534)	%	Median Cost** ($)	Mean Cost*** ($)
Sex				
Female	138	26%	36,799 (13,382, 72,675)	59,331 (72,757)
Male	396	74%	48,216 (17,932, 98,975)	81,540 (100,000)
Age				
16–30	101	19%	51,392 (14,695, 98,541)	91,083 (120,000)
31–45	108	20%	43,259 (12,679, 93,474)	79,573 (110,000)
46–60	113	21%	47,029.5 (20,687, 97,965)	70,644 (84,293)
61–75	119	22%	52,261 (21,886, 100,000)	75,484 (86,406)
76+	93	17%	29,332 (14,798, 80,680)	61,495 (84,915)
SEIFA* quantiles				
1 (lowest)	76	14%	57,086 (24,638,110,000)	88,751 (95,249)
2	115	22%	43,035.3 (19,104, 100,000)	81,122 (120,000)
3	121	23%	34,889 (15,535, 69,475)	54,701 (61,800)
4	60	11%	50,045 (14,708, 86,033)	83,582 (120,000)
5 (highest)	146	27%	52,210 (13,382, 110,000)	84,116 (100,000)
Unknown	16	3%	12,212 (5745, 43,206)	31,403 (38,089)
Charlson Comorbidity Index				
0	407	76%	46,514 (14,018, 89,092)	73,833 (97,770)
1	71	13%	38,141 (20,855, 130,000)	84,657 (110,000)
≥2	56	11%	48,456 (18,250, 110,000)	78,875 (99,107)
Multiple-trauma				
Isolated TSCI	266	50%	25,156 (8959, 56,906)	47,960 (70,096)
One additional injury	118	22%	53,117 (22,589, 89,092)	74,597 (81,515)
Two or more injuries	150	28%	87,302 (40,454, 140,000)	130,000 (130,000)
ICISS† score				
<0.7 (more severe)	47	9%	130,000 (47,719, 230,000)	160,000 (160,000)
0.7 to <0.83	176	33%	69,140 (26,547, 120,000)	94,102 (110,000)
0.83 to <0.89	107	20%	35,026 (11,312, 82,333)	61,865 (85,070)
0.89 to <0.95	102	19%	38,133 (17,402, 74,917)	56,921 (73,148)
0.95–1.00	102	19%	29,069 (7665, 51,370)	37,470 (41,806)
Highest level of injury				
Cervical	284	53%	45,473 (17,833, 98,935)	78,212 (99,859)
Thoracic	144	27%	63,475 (24,579, 110,000)	87,994 (100,000)
Lumbar	106	20%	30,424 (9082, 65,134)	52,776 (86,791)
Extent of injury				
Unspecified	131	25%	22,092 (7349, 50,069)	43,777 (67,500)
Incomplete	223	42%	48,720 (20,929, 86,811)	70,759 (75,071)
Complete	82	15%	110,000 (75,459, 200,000)	170,000 (150,000)
Conus medullaris/Cauda equina	98	18%	30,424 (9847, 68,223)	54,446 (89,486)
Died in hospital				
No	502	94%	42,232 (13,753, 87,071)	74,980 (100,000)
Yes	32	6%	70,544 (29,635, 120,000)	88,684 (72,100)
TSCI-related principal diagnosis code				
No	157	29%	29,080 (8959, 65,134)	52,540 (68,195)
Yes	377	71%	49,766 (20,687, 10,000)	85,488 (110,000)
No. of hospital transfers				
No transfers	311	58%	36,742 (11,861, 83,133)	66,803 (92,723)
One or more transfers	223	42%	54,910 (28,278, 100,000)	88,349 (110,000)
Inpatient rehabilitation				
No	234	44%	19,083 (7397, 49,766)	42,503 (63,298)
Yes	300	56%	68,880 (38,085, 120,000)	100,000 (110,000)
Transfer to spinal unit within 24 hrs				
No	275	52%	25,793 (10,546, 55,571)	50,125 (78,001)
Yes	259	48%	73,531 (38,029, 120,000)	100,000 (110,000)

TABLE 1 (*Continued*)

Variable	Total (n = 534)	%	Median Cost** ($)	Mean Cost*** ($)
Surgical procedures				
No	235	44%	15,911 (6855, 38,775)	40,092 (72,377)
Yes	299	56%	74,917 (41,149, 120,000)	100,000 (110,000)
Surgical procedures at SCIU				
No	102	34%	40,380 (21,743, 97,665)	71,327 (88,898)
Yes	197	66%	83,798 (56,831, 130,000)	120,000 (110,000)
Patient pathway				
SCIU‡ only	144	27%	66,041 (24,772, 120,000)	95,899 (110,000)
TS§ only	152	28%	19,272 (102,512, 44,471)	37,872 (51,763)
TS to SCIU ≥24 hrs	37	7%	100,000 (437,734, 140,000)	140,000 (150,000)
TS to SCIU ≤24 hrs	86	16%	83,942 (55,966, 120,000)	120,000 (110,000)
Other to SCIU ≥24 hrs	22	4%	43,678 (27,2845, 67,334)	59,210 (59,441)
Other to SCIU ≤24 hrs	32	6%	54,489 (32,172, 100,000)	92,682 (110,000)
Others	61	11%	13,099 (6096, 31,768)	24,662 (34,913)
Hours in ICU	275	51%	87 (36, 288)	248 (371)

*Socio-Economic Indexes for areas.
**Median (Interquartile Range).
***Mean (Standard Deviation)
†International Classification of diseases-based Injury Severity Score.
‡Specialist spinal cord injury unit.
§Trauma service hospital.

findings provide unique and improved acute-care cost estimates for this group with severe injury from the healthcare provider's perspective. The total cost of all acute index episodes during the study period was around $40.5 million AUD; the "per patient" cost estimated at a mean (SD) of $75,801 ($99,096), inflation-adjusted.

Key findings from this study were that multiple hospital transfers and indirect or delayed transfer (>24 h) to SCIU were key drivers of higher acute-care costs. Importantly, the cost of secondary complications was significantly less expensive for patients who experienced direct transfer to SCIU. The development of complications in addition to the TSCI is detrimental to the patient health and overall patient outcomes. Early recognition with appropriate prehospital management and timely transfers to SCIU can facilitate access to specialist care and reduce preventable complications.[14] Importantly, secondary complications are potentially preventable,[28] and attending to their risk and development offers not only cost savings, but improved longer term quality of life for patients with TSCI.[28,29]

Considering these findings, clinical pathway reform was modeled using scenario analyses to quantify potential cost effects of system manipulation. This model demonstrated significant cost savings by optimizing acute-care pathways.

TABLE 2. Complications Within Acute-Care Treatment

Complication Category	N	%	Mean LOS (d)*	Median LOS (d)†	Median Cost ($)†
No complications	258	48%	11 (10, 13)	8 (4, 16)	19,869 (7570, 49,006)
Urinary related	84	16%	23 (21, 27)	19 (11, 29)	49,807 (25,838, 93,528)
Respiratory related	86	14%	25 (28, 43)	21 (13, 33)	80,020 (43,047, 140,000)
Pressure injuries	106	22%	45 (44, 69)	33 (21, 68)	110000 (58145, 210000)
Number of Complications	**N**	**%**	**Mean LOS (d)***	**Median LOS (d)†**	**Median Cost ($)†**
No complications	258	48%	11 (10, 13)	8 (4, 16)	19,868.80 (7570, 49,006)
Any one complication	84	28%	24 (21, 27)	20 (13, 29)	72,358.50 (31,873, 110,000)
Any two types of complications	89	17%	36 (29, 43)	24 (18, 46)	87,311 (48,239, 150,000)
All three types of complications	37	7%	57 (44, 69)	53 (23, 92)	180,000 (66,321, 350,000)

*Mean (95% confidence intervals).
†Median (inter quartile range).
LOS indicates length of stay.

TABLE 3. GLM Regression Results for Predictors of Total Acute-Care Cost Per Patient.

Total Cost Per Patient	Coefficient	$P > \|z\|$	[95% Confidence Interval]	
Age				
16–30	1			
31–45	0.97	0.802	0.77	1.22
46–60	1.01	0.915	0.80	1.28
61–75	0.94	0.585	0.74	1.19
76–116	0.92	0.535	0.71	1.19
Sex				
Female	1			
Male	1.04	0.628	0.88	1.24
Highest level of injury				
Cervical	1			
Thoracic	1.11	0.331	0.90	1.39
Lumbar	1.32	0.387	0.70	2.49
Multiple-trauma				
Isolated TSCI	1			
One additional injury	1.22	0.042	1.01	1.48
Two or more injuries	1.73	<0.01	1.40	2.13
ICISS* score				
<0.7 (more severe)	1			
0.7 to <0.83	0.71	0.028	0.53	0.96
0.83 to <0.89	0.55	<0.01	0.39	0.77
0.89 to <0.95	0.62	0.01	0.43	0.89
0.95–1.00	0.49	<0.01	0.32	0.74
TSCI-related principal diagnosis code				
No	1			
Yes	1.02	0.877	0.83	1.24
Transfer to spinal unit within 24 hrs				
No	1			
Yes	1.80	0.255	0.66	4.92
No. of complications no. of transfer to spinal unit within 24 hrs				
Any one complication no. no	2.20	<0.01	1.71	2.84
Any one complication no. yes	1.54	<0.01	1.20	1.98
Any two complications no. no	2.52	<0.01	1.83	3.47
Any two complications no. yes	2.21	<0.01	1.64	2.98
All three complications no. no	2.80	<0.01	1.66	4.71
All three complications no. yes	4.01	<0.01	2.70	5.96
Patient care pathway				
SCIU only	1			
MTS/RTS† only	1.07	0.891	0.40	2.89
MTS/RTS to SCIU ≥24 hrs	2.42	0.089	0.88	6.69
MTS/RTS to SCIU ≤24 hrs	1.50	<0.01	1.19	1.90
Other to SCIU ≥24 hrs	1.76	0.289	0.62	5.04
Other to SCIU ≤24 hrs	1.43	0.042	1.01	2.02
Others	0.91	0.85	0.33	2.49
Extent of injury				
Complete	1			
Unspecified	0.65	<0.01	0.48	0.87
Incomplete	0.83	0.148	0.64	1.07
Conus medullaris/Cauda equina	0.70	0.285	0.36	1.35
Charlson Index	1.11	<0.01	1.03	1.19
_cons	31,744.71	<0.01	10,903.71	92,420.54

*International Classification of diseases-based Injury Severity Score.

†Major trauma service/regional trauma service.

GLM indicates Generalized linear model; SCIU, specialist spinal cord injury unit; TSCI, traumatic spinal cord injury.

TABLE 4. GLM Regression Results for Acute-Care Length of Stay

Length of Stay	Coefficient	$P > \|z\|$	[95% Confidence Interval]	
Age				
16–30	1			
31–45	0.84	0.159	0.66	1.07
46–60	1.01	0.952	0.79	1.28
61–75	0.98	0.85	0.76	1.25
76–116	0.95	0.698	0.72	1.24
Sex				
Female	1			
Male	0.88	0.166	0.73	1.06
Highest level of injury				
Cervical	1			
Thoracic	1.10	0.418	0.88	1.38
Lumbar	0.88	0.714	0.45	1.72
Multiple-trauma				
Isolated TSCI	1			
One additional injury	1.20	0.07	0.99	1.47
Two or more injuries	1.63	<0.01	1.30	2.03
ICISS* score				
<0.7 (more severe)	1			
0.7 to <0.83	0.85	0.303	0.62	1.16
0.83 to <0.89	0.70	0.043	0.49	0.99
0.89 to <0.95	0.78	0.197	0.53	1.14
0.95–1.00	0.70	0.11	0.46	1.08
TSCI-related principal diagnosis code				
No	1			
Yes	0.98	0.852	0.79	1.22
Number of complications				
No complications	1			
One complication	1.62	<0.01	1.34	1.96
Two or more complications	2.58	<0.01	2.07	3.22
Charlson Comorbidity Index				
	1.12	<0.01	1.04	1.21
Patient care pathway				
SCIU only	1			
TS only	0.81	0.07	0.65	1.02
TS to SCIU ≥24 hrs	1.57	<0.01	1.12	2.18
TS to SCIU ≤24 hrs	1.27	0.054	1.00	1.62
Other to SCIU ≥24 hrs	1.07	0.763	0.69	1.64
Other to SCIU ≤24 hrs	1.45	0.041	1.01	2.06
Others	0.82	0.179	0.61	1.10
Extent of injury				
Complete	1			
Unspecified	0.86	0.351	0.63	1.18
Incomplete	0.86	0.276	0.66	1.13
Conus medullaris/ Cauda equina	1.10	0.784	0.55	2.19
_cons	15.67	<0.01	9.72	25.28

*International classification of diseases-based Injury Severity Score.

GLM indicates Generalized linear model; SCIU, specialist spinal cord injury unit; TS, traumatic spinal; TSCI, traumatic spinal cord injury.

These findings are in line with previous international studies which have shown the direct transfer to the SCIU to be cost-effective and beneficial.[3,9] While the simultaneous impact on the remainder of the health service was not assessed in this model, the argument for such reform is strong, with clear benefits to both the health service budget and the patient's quality of life. Other studies have also advocated transfer to the SCIU from non-SCIU hospitals

TABLE 5. Scenario Analysis Results

Pathway	n	%	Reduction in Indirect Transfers to SCIU					
			10% Reduction		20% Reduction		30% Reduction	
Base Case (n)			Direct Cost Savings ($)	Bed Days Saved	Direct Cost Savings ($)	Bed Days Saved	Direct Cost Savings ($)	Bed days Saved
SCIU	144	27	−3,245,768	−1155	−6,491,535	−2311	−9,737,303	−3466
TS only	152	28	0	0	0	0	0	0
TS to SCIU	123	23	2,592,928	700	5,185,856	1401	10,371,712	2802
Others to SCIU	54	10	2,204,451	939	4,408,901	1877	4,408,901	1877
Others only	61	11	0	0	0	0	0	0
Direct cost savings ($)			1,551,611	484	3,103,222	967	5,043,310	1213
Bed day savings ($)			1,578,141		3,156,281		3,957,290	
Total savings ($)			3,129,752		6,259,503		9,000,600	
Savings per patient ($)			5,861		11,722		16,855	

SCIU indicates specialist spinal cord injury unit; TS, traumatic spinal.

within a specific time frame to minimize the complications and resource utilization.[4,11] Such findings further encourage the vital need to consider more cost-effective care pathways for patients with serious injury that address not only their needs for evidence based specialized care for their injuries, but rising healthcare costs.

This study has distinct strengths, which include the comprehensive estimation of acute-care costs using the DNR data; a novel method capturing the true treatment costs from the health care provider's perspective, adjusting for patient heterogeneity. Scenario analysis provides evidence of cost savings and reduction in bed days through variation in patient referral pathways to specialist centers.

This study also has several limitations. Firstly, in assessing costs from the healthcare provider perspective over a relatively short time-frame, the long-term care or societal costs such as productivity and earnings losses, or medico-legal costs are not considered. This may result in an under-estimation of the true costs, as long term care costs are a key cost driver for patients with TSCI.[27,30] However, the intentional primary objective was to focus on the acute phase of care. Patients with major trauma will have other immediate healthcare needs in addition to TSCI management and may follow a pathway best suited to these. In order to account for some of this variation, we included measures for patient injury severity, comorbidity, and multiple-trauma in the analyses. Patients with surgical procedures within the index acute care episode had statistically significant higher mean costs and mean LOS than patients without any surgical procedures. Surgical intervention at a SCIU may synergize with the effects of direct admission to SCIU resulting in cost savings. Nevertheless, surgical procedures variable was deliberately not included in the regression models as only those variables already known at the time of admission were included in the prediction models to avoid dilution of the causal effects. Additionally, sensitivity analyses attempted to account for the added costs associated with multiple-trauma, showing median per patient cost decreases of 15%, 13%, and 9% for a corresponding reduction of acute-care costs in patients with non-TSCI-related principal diagnosis by 40%, 30%, and 20%, respectively.

Hospital administrative data are limited by the absence of injury severity scoring. However, ICD-10AM codes-based measures, such as the validated ICISS, are widely used to address this gap. Recent studies show ICISS to better predict in-hospital mortality, with better discriminative ability than AIS-mapping. It is recommended for describing injury severity when using ICD-10 codes.[31]

Previous studies of predictors of higher treatment costs for major trauma patients in Australia are consistent with the current study findings,[7,32] although this study has identified some important additional and potentially modifiable factors. Amongst the predictors of higher costs, optimizing the patient care pathways by promoting transfer to SCIU within 24 hours, reducing the number of transfers and reducing potentially preventable complications within acute episodes are all feasible through reform to achieve more efficient care pathways that reduce costs and improve short term patient outcomes.

The findings from this study provide strong and further evidence to support following consensus recommendations to admit patients with TSCI directly to the SCIU or to transfer them there expeditiously within 24 hours post-injury,[4,9,11] leading to optimization of both costs and patient outcomes. Piloting implementation of these reforms locally, would facilitate better understanding of their impact at a health system level, and assist healthcare providers, insurers and other policy stakeholders in planning for future acute-care services. Further investigation is required to estimate the true financial impact of these variations on the entire Australian healthcare system, mapping patient pathways in detail to inform future healthcare planning for patients with TSCI.

Key Points

- The total cost of all acute index episodes during the study period was $40.5 million and the "per patient" cost (as incurred by the health service provider) was estimated at a median (IQR) of $45,473 ($15,535–$94,612).
- Direct transfer to SCIU resulted in lower treatment costs, shorter length of stay, and less costly complications.
- Optimizing patient transfer pathways can result in significant cost savings at health system level.

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References

1. New P, Baxter D, Farry A, et al. Estimating the incidence and prevalence of traumatic spinal cord injury in Australia. *Arch Phys Med Rehabil* 2015;96:76–83.
2. Munce SEP, Wodchis WP, Guilcher SJ, et al. Direct costs of adult traumatic spinal cord injury in Ontario. *Spinal Cord* 2012;51:64.
3. Scivoletto G, Morganti B, Molinari M. Early versus delayed inpatient spinal cord injury rehabilitation: an Italian study. *Arch Phys Med Rehabil* 2005;86:512–6.
4. Richard-Denis A, Feldman DE, Thompson C, et al. Costs and length of stay for the acute care of patients with motor-complete spinal cord injury following cervical trauma: the impact of early transfer to specialized acute SCI center. *Am J Phys Med Rehabil* 2017;96:449–56.
5. Mahabaleshwarkar R, Khanna R. National hospitalization burden associated with spinal cord injuries in the United States. *Spinal Cord* 2014;52:139–44.
6. DeVivo M. Sir Ludwig Guttmann Lecture: trends in spinal cord injury rehabilitation outcomes from model systems in the United States: 1973–2006. *Spinal Cord* 2007;45:713.
7. New PW, Jackson T. The costs and adverse events associated with hospitalization of patients with spinal cord injury in Victoria, Australia. *Spine (Phila Pa 1976)* 2010;35:796–802.
8. Gabbe BJ, Nunn A. Profile and costs of secondary conditions resulting in emergency department presentations and readmission to hospital following traumatic spinal cord injury. *Injury* 2016; 47:1847–55.
9. Furlan JC, Craven BC, Massicotte EM, et al. Early versus delayed surgical decompression of spinal cord after traumatic cervical spinal cord injury: a cost-utility analysis. *World Neurosurg* 2016;88:166–74.
10. Todd N, Skinner D, Wilson-MacDonald J. Secondary neurological deterioration in traumatic spinal injury: data from medicolegal cases. *Bone Joint J* 2015;97:527–31.
11. Mac-Thiong JM, Feldman DE, Thompson C, et al. Does timing of surgery affect hospitalization costs and length of stay for acute care following a traumatic spinal cord injury? *J Neurotrauma* 2012;29:2816–22.
12. Picone GA, Sloan FA, Chou SY, et al. Does higher hospital cost imply higher quality of care?. *Rev Econ Stat* 2003;85:51–62.
13. Barr F. *Preserving & Developing the National Spinal Cord Injury Service*. London: Association SI; 2009; 1–32.
14. Middleton P, Davies S, Anand S, et al. The prehospital epidemiology and management of spinal cord injuries in NSW: 2004–2008. *Injury* 2012;43:480–5.
15. Sharwood L, Boufous S, Muecke S, et al. Health service pathways analysis as evidence base for trauma policy change: a retrospective study of patients with traumatic spinal cord injury. *Emerg Med Open Access* 2017;7:2.
16. Gilbert R, Dutey-Magni P. Researchers need access to NHS data for effective redesign of clinical pathways. *BMJ* 2017; 358:j3787.
17. Vardy J, Jenkins P, Clark K, et al. Effect of a redesigned fracture management pathway and 'virtual' fracture clinic on ED performance. *BMJ Open* 2014;4:e005282.
18. Patel S, Garnham A, Nazir J. The Budget Impact of Treatment Pathway Redesign In Men With Lower Urinary Tract Symptoms (Luts) Associated With Benign Prostatic Hyperplasia (Bph). *J Int Soc Pharmacoeceon Outcomes Res* 2015;18:A186–7; Supplement.
19. Australian Bureau of Statistics. *Australian Demographic Statistics*. Canberra: Australian Bureau of Statistics; 2017.
20. Australian Institute of Health and Welfare. *Hospital resources 2014–15: Australian Hospital Statistics. Healthy Services Series*. Canberra: AIHW; 2016.
21. National Centre for Classification in Health. ICD-10-AM/ACHI/ACS Tenth Edition. In: IHPA, ed. ICD-10-AM/ACHI/ACS TENTH EDITION. Sydney: Australian Consortium for Classification Development; 2017.
22. Goldberg A, Borthwick A. The Choicemaker 2 Record Matching System; 2004.
23. ABS. *Socio-Economic Indexes for Areas (SEIFA) 2016 Technical Paper*. Canberra: Australian Bureau of Statistics; 2018.
24. Gedeborg R, Warner M, Chen LH, et al. Internationally comparable diagnosis-specific survival probabilities for calculation of the ICD-10–based Injury Severity Score. *J Trauma Acute Care Surg* 2014;76:358–65.
25. Gagné M, Moore L, Beaudoin C, et al. Performance of International Classification of Diseases–based injury severity measures used to predict in-hospital mortality: a systematic review and meta-analysis. *J Trauma Acute Care Surg* 2016;80: 419–426.
26. Sundararajan V, Henderson T, Perry C, et al. New ICD-10 version of the Charlson comorbidity index predicted in-hospital mortality. *J Clin Epidemiol* 2004;57:1288–94.
27. Access Economics. The economic cost of spinal cord injury and traumatic brain injury in Australia. Canberra; 2009.
28. Weld K, Dmochowski R. Effect of bladder management on urological complications in spinal cord injured patients. *J Urol* 2000;163:768–72.
29. Street JT, Noonan VK, Cheung A, et al. Incidence of acute care adverse events and long-term health-related quality of life in patients with TSCI. *Spine J* 2015;15:923–32.
30. Krueger H, Noonan V, Trenaman L, et al. The economic burden of traumatic spinal cord injury in Canada. *Chronic Dis Inj Can* 2013;33:113–22.
31. Gagné M, Moore L, Sirois M-J, et al. Performance of International Classification of Diseases–based injury severity measures used to predict in-hospital mortality and intensive care admission among traumatic brain-injured patients. *J Trauma Acute Care Surg* 2017;82:374–82.
32. Mitchell R, Harvey L, Stanford R, et al. Health outcomes and costs of acute traumatic spinal injury in New South Wales, Australia. *Spine J* 2017;18:1172–9.