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Patient-level resource use for injury admissions in Canada: A multicentre retrospective cohort study

Teegwendé V. Porgo[a,b], Lynne Moore[a,b,*], Catherine Truchon[c], Simon Berthelot[b,d], Henry T. Stelfox[e], Peter A. Cameron[f], Belinda J. Gabbe[f], Jeffrey S. Hoch[g,h], David C. Evans[i], François Lauzier[b,j], Francis Bernard[k], Alexis F. Turgeon[a,b,j], Julien Clément[c,l]

[a] Department of Social and Preventive Medicine, Université Laval, Québec, QC, Canada
[b] Axe Santé des Populations et Pratiques Optimales en Santé (Population Health and Optimal Health Practices Research Unit), Traumatologie - Urgence - Soins intensifs (Trauma - Emergency - Critical Care Medicine), Centre de Recherche du CHU de Québec (Hôpital de l'Enfant-Jésus), Université Laval, Québec, QC, Canada
[c] Institut national d'excellence en santé et en services sociaux (INESSS), Québec, QC, Canada
[d] Department of family medicine, Université Laval, Québec, QC, Canada
[e] Departments of Critical Care Medicine, Medicine and Community Health Sciences, O'Brien Institute for Public Health, University of Calgary, Calgary, AB, Canada
[f] Department of Epidemiology and Preventive Medicine, Monash University, Melbourne, Australia
[g] Institute for Health Policy, Management, and Evaluation, University of Toronto, Toronto, ON, Canada
[h] Department of Public Health Sciences, University of California, Sacramento, CA, United States
[i] Department of Surgery, University of British Columbia, Vancouver, BC, Canada
[j] Department of Anaesthesiology and Critical Care Medicine, Division of Critical Care Medicine, Université Laval, Québec, QC, Canada
[k] Department of Medicine, Université de Montréal, Montréal, QC, Canada
[l] Department of Surgery, Université Laval, Québec, QC, Canada

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ABSTRACT

Background: Variations in adjusted costs have been observed among trauma centres in the United States but patient outcomes were not better in centres with higher costs. Attempts to improve injury care efficiency are hampered by insufficient patient-level information on resource use and on the drivers of resource use intensity.
Objectives: To estimate patient-level resource use for injury admissions, identify determinants of resource use intensity, and evaluate inter-hospital variations in resource use.
Methods: We conducted a retrospective cohort study including $\geq$16-year-olds admitted to adult trauma centres in a mature, inclusive Canadian trauma system between 2014 and 2016. We extracted data from the trauma registry and hospital financial reports. We estimated resource use with activity-based costs, identified determinants of resource use intensity using a multilevel linear model and assessed the relative importance of each determinant with Cohen's f^2. We evaluated inter-provider variations with intraclass correlation coefficients (ICC) and 95% confidence intervals.
Results: We included 32,411 patients. Median costs per admission were $4857 (Quartiles 1 and 3 2961–8448). The most important contributors to total resource use were the medical ward (57%), followed by the operating room (OR; 23%) and the intensive care unit (13%). The strongest determinant of resource use intensity was discharge destination (Cohen's f^2 = 7%). The most resource intense patient group was spinal cord injuries with $11,193 (7115–17,606) per admission. While resource use increased with increasing age for the medical ward, it decreased with increasing age for the OR. Resource use was 18% higher in level I centres compared to level IV centres and we observed significant variations in resource use across centres (ICC = 5% [4–6]), particularly for the OR (28% [20–40]).
Conclusions: Resource use for acute injury care in Quebec is not solely due to the clinical status of patients. We identified determinants of resource use that can be used to establish evidence-based resource allocations and improve injury care efficiency. The method we developed for estimating patient-level, in-hospital resource use for injury admissions and identifying related determinants could be reproduced using local trauma registry data and our unit costs or unit costs specific to each setting.

* Corresponding author at: CHU de Québec Research Center (Enfant-Jésus Hospital), Axe Santé des Populations et Pratiques Optimales en Santé (Population Health and Optimal Health Practices Research Unit), Traumatologie – Urgence - Soins intensifs (Trauma – Emergency – Critical Care Medicine), 1401, 18e rue, local Z215, Québec, QC, G1J 1Z4, Canada.
E-mail address: lynne.moore@fmed.ulaval.ca (L. Moore).

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Introduction

Injuries represent a major public health burden not only with regard to mortality [1] but also in terms of resource use, defined as the amount or cost of equipment and services involved in an episode of care [2]. A 2012 systematic review on acute treatment costs of injuries in high-income countries reported an overall median cost of 22,448 American dollars per patient [3]. In Canada, healthcare costs due to injuries were 16 billion Canadian dollars in 2010 [4]. In the United States, significant variations in adjusted resource use, estimated using the cost-to-charge ratios costing method, have been observed among trauma centres [5–7]. Furthermore, centres with higher costs did not have better patient outcomes [5–7]. These data suggest that there are important opportunities to improve injury care efficiency.

Attempts to improve injury care efficiency are hampered by insufficient information on patient-level resource use and on the drivers of resource use intensity. This is largely due to methodological limitations with regard to resource use estimation, especially in countries with a single-payer healthcare system such as Canada [8–13]. Approaches used for estimating acute care resource use using costs include cost-to-charge ratios, per diem, case mix (or diagnosis-related) groups, and activity-based costing methods. The cost-to-charge ratios costing method involves converting patient charges to cost estimates [14]; research demonstrates that it grossly over- or under-estimates real costs [15]. The per diem costing method involves multiplying a uniform daily cost by patient length of stay and therefore only captures differences in length of stay rather than differences between levels of care (for example regular ward versus intensive care) [12]. In the case mix group costing approach, homogeneous groups of patients (case mix groups) are created based on diagnoses, interventions, and characteristics such as age and comorbidities [12]. Each case mix group is then assigned a uniform cost regardless of the hospital where patients are treated. Research has shown that this method underestimates actual costs in trauma patients, particularly in patients with major injuries [8–11]. Moreover, inter-provider comparisons are not possible with this method since it cannot be used to discriminate resource use across hospitals. Activity-based costing (also called patient costing method or the case, unit, micro-, or bottom-up costing methods in Canada) [12] is the most precise and patient-specific costing method because it accounts for each patient's individual care trajectory [12,16–20]. Activity-based costing yields patient-level estimates of costs that can be used to identify activity centers, patient characteristics, and hospital factors that drive resource use intensity [16–22]. Moreover, it can be used to evaluate inter-provider variations in resource use since resource use is patient-specific. Additionally, the activity-based costing method can yield estimates of resource use that are not influenced by temporal or geographical variations [22].

Despite the advantages of the activity-based costing method, only a limited number of studies have used it to identify drivers of resource use intensity in global adult injury populations [11,23–25]. Nonetheless, important patient characteristics or the distribution of costs across activity centres were not assessed. Moreover, no study has investigated inter-hospital variations in resource use.

The objectives of this study were to estimate patient-level resource use for injury admissions, identify determinants of resource use intensity, and evaluate inter-hospital variations in resource use.

Methods

This study was approved by the *CHU de Québec-Université Laval* research ethics board.

Design

We conducted a retrospective, multicentre, cohort study using data from the inclusive trauma system of Quebec, Canada, which encompasses 57 adult centres (3 level I, 5 level II, 21 level III, and 28 level IV centres).

Participants

We included patients who met at least one of the Quebec trauma registry inclusion criteria between 2014 and 2016: death due to injury, intensive care unit (ICU) admission, hospital stay >2 days or transfer from another hospital. For patients who were transferred, only information from the definitive centre was used. Transfers of trauma patients in Quebec mainly occur between emergency departments.

We excluded patients aged <16 years, patients dead on arrival, and patients who left against medical advice. We also excluded patients ≥65 years old with isolated orthopaedic injuries resulting from falls from standing height. Additionally, we performed analyses for patients who died in hospital separately since their resource use information is not fully observed (right-censored) [26].

Data

Data were retrieved from the Quebec trauma registry [27] except for information on comorbidities which was obtained by linking the registry to the provincial hospital discharge database (MED-ECHO) [28]. We obtained unit costs by hospital activity centre from hospital financial reports (AS-471) for the 2016 fiscal year [29]. These unit costs include variable direct costs related to expenditures for non-physician personnel, services and materials [30].

Estimation of patient-level resource use

Our goal was to estimate resource use rather than the true costs of injury care to reflect practice patterns and highlight units of resources that might be relevant to decision-makers and stakeholders, in line with guidelines of the Grading of Recommendations Assessment, Development and Evaluation group [22]. We therefore used activity-based costs. We applied this method using Canadian guidelines for the economic evaluation of health technologies: identification of relevant resources to include, measurement of resources, and valuation of resources (assigning unit costs to resources) [31].

First, we made an exhaustive list of activity centres from the Ministry of Health and Social Services website [32]. This list was submitted to a committee of experts to identify activity centres considered important for costing acute in-hospital injury care. Experts were also asked to list any relevant cost items that were missing. The committee was composed of a trauma surgeon, a critical care physician, two general practitioners, and two health care administrators. Second, we extracted units of resource use for each admission from the registry. Third, we multiplied units of resource use for each patient by unit costs in corresponding activity centres.

Activity centres comprise the emergency department, medical ward, operating room (OR), intensive care unit (ICU), medical imaging (x-ray radiography and ultrasound performed in the emergency department, and magnetic resonance imaging, computed tomography, and angiography performed in the emergency department and after admission), paraclinical services (physiotherapy, occupational therapy, psychotherapy and respiratory therapy; Table 1). Unit costs for the emergency department were available per visit; thus, the same cost was attributed for all patients. Costs for this activity centre were included in total cost calculations but were not analysed any further. Because of a lack of relevant and/or complete information on drugs, laboratory tests, blood products, and physician fees, these were not

Table 1
Unit costs of resource use items (hospital activity centers).

Activity centre	Unit cost (2016 Can$)
Emergency department	253.37/visit
Intensive care unit	1212.07/day
Medical ward	342.58/day
Operating room	1129.11/h
Medical Imaging	
X-ray radiography[a]	25.07/unit[b]
Ultrasound[a]	27.99/unit[b]
Magnetic resonance imaging	
Head, face, neck, spinal cord	118.20/unit
Thorax	147.75/unit
Abdomen, pelvis	137.90/unit
Orthopaedic	128.05/unit
Full body	216.70/unit
Other	120.17/unit
Computed tomography	
Head, face, neck	39.75/unit
Thorax	47.70/unit
Abdomen, pelvis, rachis	55.65/unit
Full body	143.1/unit
Other	49.29/unit
Angiography	763.20/unit
Paraclinical services	
Physiotherapy	75.74/h[b]
Occupational therapy	76.14/h[b]
Psychotherapy	175.52/h[b]
Respiratory therapy	367.22/treatment[c]

[a] In the emergency department.
[b] We did not have information on the number of x-ray radiographies and ultrasounds or the duration of physiotherapy, occupational therapy and psychotherapy in the trauma registry so a fixed cost of one x-ray radiography and ultrasound, and a fixed treatment period of one hour was applied, respectively.
[c] Supplement of 125.66$ for patients with spinal cord injuries, 18.30$ for patients with thoracic injuries and 103.70$ for those on mechanical ventilation.

included. To obtain standardized unit costs that were not influenced by temporal or geographical variations, we extracted unit costs (per activity centre) from hospital financial reports (AS-471) for the three level I centres and calculated mean unit costs (per activity centre) weighted by mean annual hospital volume. Since the distribution of resource use was highly skewed, we calculated median resource use per admission with quartiles 1 and 3 (Q1–Q3), globally and for each activity centre. We also calculated the contribution (percentage) of each activity centre to total resource use.

Identification of the determinants of resource use intensity

Potential patient-level determinants of acute in-hospital resource use for injury admissions were identified through literature review [13] and consultation with content experts. These determinants were age, sex, number of comorbidities, type of injury, mechanism of injury, anatomical injury severity, Glasgow Coma Score, respiratory rate, systolic blood pressure, transfer-in from another hospital, type of insurance, year of admission, and discharge destination. They were assessed using a multilevel linear model with a random intercept on hospitals [33]. We also assessed the variation of resource use over centre designation levels using a multilevel linear model with a random intercept on designation level. Costs had a log-normal distribution; for such distributions the geometric mean is equivalent to the median [34]. Thus, for both models, costs were log-transformed and the association between independent variables and costs was described using geometric mean ratios with 95% confidence intervals (CI). We evaluated model assumptions using residuals, collinearity and influence statistics. We performed subgroup analyses based on age (<65 and ≥65), type of injury (traumatic brain injuries, spinal cord injuries, multisystem blunt injuries and isolated orthopaedic injuries) and centre designation level (I/II and III/IV). We performed local effect size analyses with Cohen's f^2 to assess the relative importance of each determinant [35] for total resource use and by activity centre.

Data on the Glasgow Coma Score, respiratory rate, and systolic blood pressure on arrival were missing for 45%, 10% and 2% of admissions, respectively. Given that the probability of missing data was highly correlated with injury severity (92% of patients with missing data for at least one of these variables had minor injuries; Injury Severity Score [ISS] <12) and type of injury (70% were patients with isolated orthopaedic injuries), we considered the missing at random assumption to be plausible and simulated these missing data using multiple imputation [36]. We used the Markov Chain Monte Carlo method with a non-informative single chain [37–40]. All independent and dependent variables included in the analysis model were entered in the imputation model and each missing data value was imputed five times [37,39,41]. This same method has been shown to lead to valid estimates in simulation studies using the Quebec trauma registry and the United States National Trauma Data Bank [40,42].

Evaluation of inter-provider variations in resource use intensity

We evaluated inter-provider variations with intraclass correlation coefficients (ICC) and 95% CI, globally and for each activity centre.

Sensitivity analyses

We repeated analyses under the following conditions: (1) excluding resource use outliers (>99 percentile) [43], (2) excluding observations with missing physiological data [39,40], (3) using Poisson and Gamma probability distributions and ordinary least-squares regression, and (4) including in-hospital deaths. In-hospital deaths were included using a Fine and Grey competing risks model [26]. We compared geometric mean ratios under each sensitivity analysis.

Patient-level resource use among in-hospital deaths

We anticipated differences in resource use between deaths and survivors in terms of level of care (for example more intensive care). Therefore we estimated resource use among deaths using the methods described above and compared both the median costs and the contribution of each activity centre to total resource use among deaths and survivors.

All statistical analyses were performed using the Statistical Analysis System (SAS Institute, Cary, NC, version 9.4). Results were considered statistically significant for $p \leq 0.05$. We present resource use in 2016 Canadian dollars.

Results

Participants

The Quebec trauma registry included 51,801 adults admitted between 2014 and 2016. Of these, 1363 (3%) died on arrival, 162 (0.3%) left against medical advice, and 15,258 (30%) were ≥65 year olds with isolated fractures following a fall from standing height. Among eligible patients, 552 (2%) patients with missing data on comorbidities or injury severity were excluded. We included 32,411 survivors and 2055 in-hospital deaths. Among survivors, 49% were men (Table 2), mean age was 63 years (standard deviation: 22), 2% had penetrating injuries and 23% had major trauma (ISS ≥ 12).

Table 2
Determinants of acute injury care resource use (in 2016 Can$).

Variable	n (%)	Crude median cost (Q1–Q3)	Adjusted geometric mean ratio (95% CI)
Overall	32,411 (100)	4857 (2961–8448)	
Age			
16–54	10,293 (31.8)	4496 (2763–7832)	ref.
55–64	5705 (17.6)	4356 (2834–7265)	1.00 (0.98–1.03)
65–74	3951 (12.2)	4714 (2800–8341)	1.03 (1.00–1.06)
75–84	5947 (18.4)	5343 (3133–9339)	1.07 (1.04–1.10)
≥85	6516 (20.1)	5716 (3349–9487)	1.07 (1.04–1.10)
Sex			
Male	16,020 (49.4)	4790 (2864–8635)	ref.
Female	16,392 (50.6)	4926 (3042–8279)	1.02 (1.00–1.04)
Number of comorbidities			
0	17,632 (54.4)	4440 (2787–7495)	ref.
1	7460 (23.0)	5067 (3020–8757)	1.10 (1.08–1.12)
2	4144 (12.8)	5695 (3310–9878)	1.23 (1.19–1.26)
≥3	3176 (9.8)	6180 (3515–10,690)	1.31 (1.27–1.35)
Type of injury			
Traumatic brain	4479 (13.8)	5992 (3303–11,917)	ref.
Spinal cord	614 (1.9)	11,193 (7115–17,606)	1.76 (1.65–1.87)
Multisystem blunt	901 (2.8)	10,034 (5550–17,728)	1.57 (1.49–1.66)
Orthopaedic	18,269 (56.4)	4866 (3184–7941)	1.29 (1.25–1.33)
Mechanism			
MVC	5388 (16.6)	5439 (3112–9976)	ref.
Fall	23,285 (71.8)	4866 (3006–8331)	0.95 (0.92–0.99)
Penetrating	519 (1.6)	3970 (2514–8247)	1.07 (1.00–1.15)
Other	3220 (9.9)	4141 (2527–7126)	0.99 (0.95–1.03)
New Injury severity score			
<12	19,766 (61.0)	4236 (2679–6926)	ref.
12–24	8814 (27.2)	5645 (3390–9533)	1.26 (1.24–1.29)
≥25	3832 (11.8)	8416 (4449–17,011)	1.77 (1.70–1.83)
Glasgow coma scale score[a]			
3–8	848 (2.6)	15,230 (7362–30,717)	1.63 (1.53–1.74)
9–12	604 (1.9)	9440 (4751–17,960)	1.24 (1.17–1.32)
13–15	16,277 (50.2)	5092 (3030–8765)	ref.
Respiration Rate[a]			
11–29	28,468 (87.8)	4884 (2988–8488)	ref.
0–10; ≥ 30	602 (1.9)	6902 (3719–12,797)	1.22 (1.15–1.29)
Systolic blood pressure[a]			
≥90	31,459 (97.1)	4851 (2959–8415)	ref.
0–89	464 (1.4)	7229 (3888–16,508)	1.33 (1.25–1.42)
Transfer			
No	23,815 (73.5)	5010 (3078–8515)	ref.
Yes	8597 (26.5)	4399 (2606–8275)	0.80 (0.78–0.82)
Type of insurance			
Provincial health	24,891 (76.8)	4821 (2944–8288)	ref.
Road accidents	3941 (12.2)	5702 (3215–10,611)	1.06 (1.02–1.10)
Work accidents	1249 (3.9)	4318 (2735–7497)	1.01 (0.97–1.06)
Other	1455 (4.5)	4658 (2900–7891)	1.01 (0.98–1.05)
None/Unknown	876 (2.7)	4463 (2930–7064)	0.97 (0.92–1.02)
Year of admission			
2014	10,896 (33.6)	4873 (2974–8486)	ref.
2015	10,781 (33.3)	4974 (3017–8650)	0.99 (0.98–1.01)
2016	10,735 (33.1)	4735 (2890–8184)	0.95 (0.93–0.97)
Discharge destination			
Home	19,101 (58.9)	4019 (2537–6360)	ref.
Acute care	2936 (9.1)	5709 (3456–10,380)	1.24 (1.21–1.28)
Long stay	2248 (6.9)	7910 (4653–13,963)	1.80 (1.74–1.86)
Rehabilitation	3856 (11.9)	8709 (5463–14,597)	1.67 (1.62–1.72)
Other	4270 (13.2)	5439 (3110–9006)	1.27 (1.23–1.30)

Table 2 (*Continued*)

Variable	n (%)	Crude median cost (Q1–Q3)	Adjusted geometric mean ratio (95% CI)
Trauma centre designation level			
I	8869 (27.4)	5885 (3518–10,678)	ref.
II	5956 (18.4)	4815 (3010–8166)	0.94 (0.80–1.11)
III	14,286 (44.1)	4575 (2804–7723)	0.93 (0.81–1.07)
IV	3301 (10.2)	3926 (2403–6792)	0.82 (0.71–0.94)

n: number; Q1: quartile 1; Q3: quartile 3; CI: confidence interval; ref.: reference; MVC: motor vehicle collision.
[a] Data on the Glasgow Coma Score, respiratory rate and systolic blood pressure on arrival were missing for 45.3% (n = 14,683), 10.3% (n = 3342) and 1.5% (n = 489) of admissions, respectively. Missing data were simulated using multiple imputation.

Acute injury care resource use

Median costs per admission among survivors were $4857 (Q1–Q3: 2961–8448). Mean costs were $7287 (95% CI: 7196–7378). Overall, the most important contributors to resource use were the medical ward (57%; Fig. 1), followed by the OR (23%) and the ICU (13%). The contribution of each activity centre varied by age, severity, designation level, and type of injury. The ward contributed 60% or more of total costs for the elderly, minor injury, level III/IV centres and isolated orthopaedic injuries. The OR contributed over 20% for younger patients, level I/II centres, spinal cord injuries, multisystem blunt injuries and isolated orthopaedic injuries. The ICU contributed over 20% for major injuries, traumatic brain injuries and multisystem blunt injuries.

Determinants of resource use intensity

Determinants (listed in Table 2) explained 26% of the variation in resource use. Risk-adjusted resource use increased with increasing age, number of comorbidities and injury severity (Table 2). It was 63% higher for patients with Glasgow Coma Score <9 on arrival compared to those with Glasgow Coma Score ≥13, and 33% higher for patients in shock (systolic blood pressure <90 mmHg) on arrival. Spinal cord injuries, followed by multisystem blunt injuries and isolated orthopaedic injuries were all more resource intensive than traumatic brain injuries. Finally, level IV centres had 18% lower resource use than level I centres.

Results remained stable across strata of age. Across strata of injury type and designation level, differences observed were related to age: increases in resource use with increasing age were significant only among patients with isolated orthopaedic injuries and in level III/IV centres.

Determinants varied little across activity centres. However, while resource use increased with increasing age and comorbidities for the medical ward and ICU, it decreased with increasing age and comorbidities for the OR (Table 3). In the ICU, we observed weaker variation across injury types; resource use for multisystem injuries was 24% higher than for traumatic brain injuries but spinal cord injuries and isolated orthopaedic injuries were not significantly different.

Relative importance of determinants

Overall, the strongest determinants were discharge destination (Cohen's $f^2 = 6.5\%$; Fig. 2), type of injury (3.6%) and injury severity (3.3%). The relative importance of determinants varied by activity centre. Discharge destination was the most important determinant in the medical ward; centre designation level in the OR; the Glasgow Coma Score in the ICU; and type of injury for imaging.

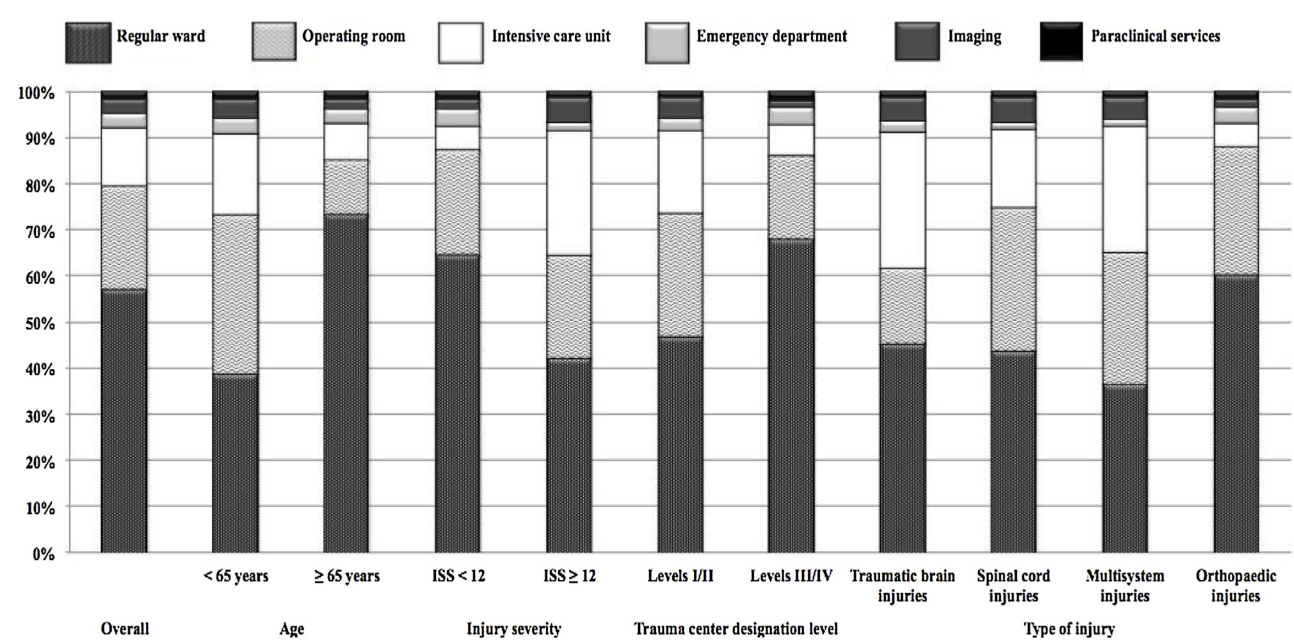

Fig. 1. Relative contribution of activity centres to total costs overall and by population subgroups.

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Table 3
Determinants of acute injury care resource use (in 2016 Can$) by activity centre.

Variable	N (%)	Adjusted geometric mean ratio (95% CI) Medical ward (n = 31,741)	Operating room (n = 16,127)	ICU (n = 4916)
Overall	32,411 (100)			
Age				
16–54	10,293 (31.8)	ref.	ref.	ref.
55–64	5705 (17.6)	1.15 (1.12–1.18)	0.91 (0.89–0.93)	1.09 (1.02–1.18)
65–74	3951 (12.2)	1.31 (1.27–1.36)	0.91 (0.87–0.94)	1.17 (1.07–1.27)
75–84	5947 (18.4)	1.55 (1.50–1.60)	0.82 (0.79–0.85)	1.12 (1.02–1.24)
≥85	6516 (20.1)	1.66 (1.60–1.72)	0.78 (0.75–0.81)	0.97 (0.85–1.10)
Sex				
Male	16,020 (49.4)	ref.	ref.	ref.
Female	16,392 (50.6)	0.97 (0.96–0.99)	1.04 (1.02–1.07)	1.07 (1.01–1.14)
Number of comorbidities				
0	17,632 (54.4)	ref.	ref.	ref.
1	7460 (23.0)	1.22 (1.20–1.25)	0.97 (0.95–0.99)	1.16 (1.08–1.24)
2	4144 (12.8)	1.42 (1.38–1.47)	0.93 (0.90–0.97)	1.23 (1.11–1.36)
≥3	3176 (9.8)	1.57 (1.52–1.63)	0.91 (0.87–0.95)	1.45 (1.29–1.63)
Type of injury				
Traumatic brain	4479 (13.8)	ref.	ref.	ref.
Spinal cord	614 (1.9)	1.68 (1.57–1.80)	1.47 (1.38–1.56)	1.11 (0.96–1.28)
Multisystem blunt	901 (2.8)	1.36 (1.28–1.44)	1.37 (1.29–1.45)	1.24 (1.12–1.37)
Orthopaedic	18,269 (56.4)	1.13 (1.09–1.17)	1.16 (1.11–1.21)	1.07 (0.98–1.17)
Mechanism				
MVC	5388 (16.6)	ref.	ref.	ref.
Fall	23,285 (71.8)	1.02 (0.98–1.07)	0.87 (0.84–0.91)	0.90 (0.81–0.99)
Penetrating	519 (1.6)	0.87 (0.81–0.95)	0.90 (0.84–0.96)	1.07 (0.90–1.29)
Other	3220 (9.9)	0.93 (0.89–0.98)	0.91 (0.87–0.96)	0.88 (0.79–0.98)
New Injury severity score				
<12	19,766 (61.0)	ref.	ref.	ref.
12–24	8814 (27.2)	1.23 (1.20–1.26)	1.18 (1.15–1.20)	1.25 (1.16–1.34)
≥25	3832 (11.8)	1.57 (1.50–1.63)	1.30 (1.24–1.36)	1.58 (1.43–1.73)
Glasgow coma scale score[a]				
3–8	848 (2.6)	1.30 (1.21–1.39)	1.16 (1.10–1.23)	1.83 (1.67–2.00)
9–12	604 (1.9)	1.11 (1.03–1.20)	1.05 (0.98–1.12)	1.39 (1.25–1.54)
13–15	16,277 (50.2)	ref.	ref.	ref.
Respiration Rate[a]				
11–29	28,468 (87.8)	ref.	ref.	ref.
0–10; ≥30	602 (1.9)	1.10 (1.03–1.18)	1.03 (0.96–1.11)	1.26 (1.12–1.41)
Systolic blood pressure[a]				
≥90	31,459 (97.1)	ref.	ref.	ref.
0–89	464 (1.4)	1.19 (1.10–1.28)	1.14 (1.06–1.23)	1.42 (1.25–1.61)
Transfer				
No	23,815 (73.5)	ref.	ref.	ref.
Yes	8597 (26.5)	0.59 (0.57–0.60)	0.97 (0.94–0.99)	0.95 (0.89–1.01)
Type of insurance				
Provincial health	24,891 (76.8)	ref.	ref.	ref.
Road accidents	3941 (12.2)	1.08 (1.03–1.13)	1.08 (1.03–1.12)	0.98 (0.89–1.09)
Work accidents	1249 (3.9)	0.98 (0.94–1.03)	1.07 (1.02–1.11)	1.12 (0.99–1.27)
Other	1455 (4.5)	0.99 (0.95–1.03)	1.06 (1.02–1.11)	1.03 (0.91–1.17)
None/Unknown	876 (2.7)	1.00 (0.94–1.06)	1.04 (0.98–1.11)	0.79 (0.66–0.95)
Year of admission				
2014	10,896 (33.6)	ref.	ref.	ref.
2015	10,781 (33.3)	0.99 (0.97–1.01)	1.00 (0.98–1.03)	1.03 (0.97–1.10)
2016	10,735 (33.1)	0.94 (0.92–0.96)	0.97 (0.95–1.00)	0.98 (0.92–1.04)
Discharge destination				
Home	19,101 (58.9)	ref.	ref.	ref.
Acute care	2936 (9.1)	1.28 (1.23–1.32)	1.19 (1.15–1.23)	1.13 (1.04–1.22)
Long stay	2248 (6.9)	2.10 (2.02–2.18)	1.18 (1.13–1.24)	1.48 (1.26–1.74)
Rehabilitation	3856 (11.9)	1.92 (1.86–1.98)	1.21 (1.17–1.25)	1.50 (1.39–1.62)
Other	4270 (13.2)	1.52 (1.48–1.57)	1.13 (1.08–1.17)	1.16 (1.01–1.33)

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Table 3 (*Continued*)

Variable	N (%)	Adjusted geometric mean ratio (95% CI) Medical ward (n = 31,741)	Operating room (n = 16,127)	ICU (n = 4916)
Trauma centre designation level				
I	8869 (27.4)	ref.	ref.	ref.
II	5956 (18.4)	0.94 (0.80–1.10)	0.97 (0.67–1.38)	0.94 (0.78–1.14)
III	14,286 (44.1)	0.93 (0.81–1.07)	0.90 (0.66–1.22)	0.99 (0.83–1.18)
IV	3301 (10.2)	0.82 (0.71–0.94)	0.62 (0.45–0.84)	0.90 (0.76–1.07)

n: number; CI: confidence interval; ICU: intensive care unit; ref.: reference; MVC: motor vehicle collision.
[a] Data on the Glasgow Coma Score, respiratory rate and systolic blood pressure on arrival were missing for 45.3% (n = 14,683), 10.3% (n = 3342) and 1.5% (n = 489) admissions, respectively. Missing data were simulated using multiple imputation.

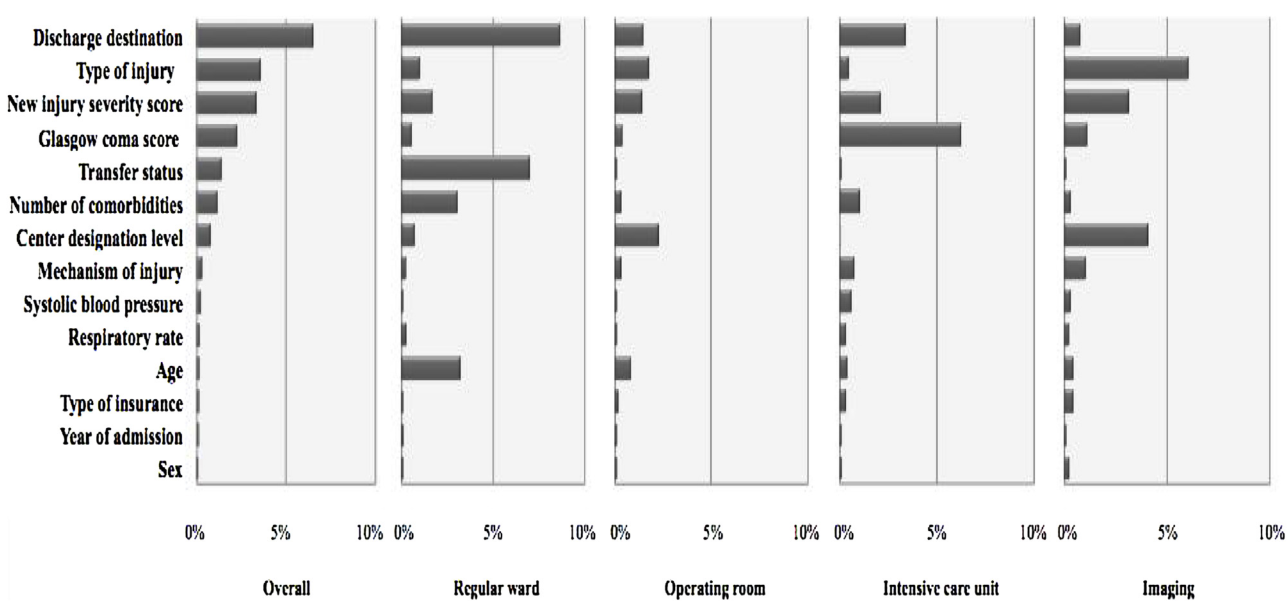

Fig. 2. Relative importance of determinants in predicting acute injury care resource use intensity overall and by activity centre.

Inter-provider variations in resource use intensity

We observed significant inter-provider variations in risk-adjusted resource use intensity, particularly for the OR and paraclinical services (Table 4).

Sensitivity analyses

Truncating cost outliers, excluding observations with physiological measures, or using Poisson, Gamma or ordinary least squares regression did not change study results significantly. Similarly, determinants did not change when deaths were included in a competitive risks model.

Table 4
Inter-provider variations in resource use intensity overall and by activity center.

	ICC (95% Confidence interval)
Overall	0.049 (0.040–0.058)
Medical ward	0.036 (0.031–0.040)
Operating room	0.278 (0.204–0.402)
Intensive care unit	0.079 (0.055–0.157)
Imaging	0.057 (0.051–0.066)
Paraclinical services	0.158 (0.140–0.172)

ICC: intraclass correlation coefficient.

Patient-level resource use among in-hospital deaths

Median costs per admission for deaths were $4711 (Q1–Q3: 1933–10,300; Online supplemental material 1), similar to that for survivors ($4858). As expected, the contribution of the ICU to total costs among deaths was greater (35%; Online supplemental material 2) than its contribution among survivors (13%). The contribution of the OR to total costs among deaths was less (14%) compared to survivors (23%) but the corresponding median costs per admission were higher for deaths ($3012, Q1–Q3: 2071–4517 versus $2541, Q1–Q3: 1769–3821).

Discussion

Median activity-based costs for in-hospital injury care were $4857 per admission in Quebec between 2014 and 2016. The most important contributors to resource use were the medical ward (57%), OR (23%), and ICU (13%). Determinants explained 26% of the variation in resource use. The strongest determinants of resource use intensity were discharge destination, followed by type of injury and injury severity. Spinal cord injuries, followed by multisystem blunt injuries were the most resource intense injuries. While resource use increased with increasing age and number of comorbidities for the medical ward and ICU, it decreased with increasing age and number of comorbidities for the OR. Lastly, risk-adjusted resource use was 18% higher in level I than level IV centres and we observed significant inter-hospital variations in resource use intensity; variation was strongest for the OR (28%).

We have identified two studies that estimated acute care resource use in global adult injury populations, with uniform inclusion criteria, using activity-based costs [11,23–25]. These studies were conducted among patients with blunt [24] and penetrating injuries [23] in the United Kingdom using the Trauma Audit Research Network 2000–2005 database, which included data from 50% of hospitals receiving trauma patients in the United Kingdom at that time. Median costs per admission for blunt trauma were £5390 (approximately $8998 Canadian dollars), more than twice those observed in our study [24]. This disparity in costs can be explained by differences in cost items considered since the cost of physician care provided in the medical ward, OR and ICU were included [23]. Similar to our results, their study based on blunt injuries showed that the medical ward, OR, and ICU were the most important contributors to resource use, with individual contributions of 37%, 15% and 29%, respectively [23]. The authors also found that injury severity [23,24], the body region of the worst injury [24], age [24], and the Glasgow Coma Score [24] were determinants of resource use. Our study has gone further by providing resource use estimates using a registry that includes data on 92% of major injury admissions [44], exploring additional determinants, and investigating inter-hospital variation.

Risk-adjusted resource use for patients discharged to long-term care and rehabilitation was 80% and 67% higher, respectively, than that for patients discharged home. Discharge destination may reflect delays in access to post-acute care. Indeed, in the United States, post-acute care delays have been identified as a determinant of discharge delays [45–47]. In Canada, this problem has been pointed out in the elderly population where evidence suggests that the elderly wait in acute hospital beds because of long waiting lists for long-term care facilities or rehabilitation centres [48,49]. In other Canadian provinces, the median delay to admission to a long-term care facility for the elderly is approximately 26 days [48,49]. A study on transfer waiting time in a Canadian level I trauma centre showed that the elderly waited a mean of 31 days for discharge as opposed to 17 days for 20–30 year olds with comparable injury severity (ISS of 26–27) [48]. This may explain the importance of discharge destination as a determinant of resource use in the medical ward as well as the important contribution of the medical ward to total resource use for the elderly (73%). These results suggest that more efficient discharge planning, which has been shown to lead to reduction in the rate of hospital readmission in the elderly [50], and the provision of access to post-acute care facilities may represent key strategies to improve the efficiency of injury care. For example, it has been advised that discharge planning begin at admission or soon after admission [51–53].

The higher risk-adjusted resource use observed in level I centres compared to level IV centres and the significant inter-provider variations that we observed may be partly due to residual confounding. Nonetheless, this finding corroborates the results of the Dartmouth Atlas Project whereby high-spending regions in the United States were those with more medical resources [54]. Furthermore, our determinants only explained one quarter of the variation in resource use and we observed significant inter-hospital variations in risk-adjusted resource use. These results all reinforce the hypothesis that resource use for acute injury care may be related to factors beyond patient needs and suggest that resources may be overused [54]. The potential role that resource overuse plays in the observed variations deserves particular attention as unnecessary medical care monopolizes between 20% and 40% of healthcare budgets [55] and leads to increased mortality and morbidity [56–58]. In this regard, adherence to established protocols could be an avenue to reduce the use of low-value clinical practices and decrease injury care costs [57]. Additionally, criteria for transporting/transferring patients with major injuries (for example major traumatic brain injuries and open/depressed skull fractures) to level I/II centres have been established in Quebec [59]. The establishment of criteria for directing less resource intense patients to level III/IV centres could be another option for improving the efficiency of injury care.

Limitations

When interpreting our results, potential limitations should be considered. First, to identify the determinants of resource use intensity, we excluded in-hospital deaths. Nonetheless, this did not lead to selection bias as shown in the sensitivity analyses where results with deaths included in a competing risks model did not lead to different conclusions to those from the main analyses. Second, resource use did not include information on drugs, laboratory tests and blood products. Nonetheless, drugs costs account for only 2% of the total annual expenditure of the three level I centres [29] while laboratory tests represent 4% of total hospital costs in Canada [60]. As for blood bank products, they represent ≤1% of total hospitalization costs for most diagnostic-related groups in the United States [61]. Even though it is possible that this percentage could be higher for injured patients, the contribution of blood products to total costs of acute injury care should be minimal. Third, resource use did not include physician fees. Including physician fees would have required linking the Quebec trauma registry to the provincial physician billing database. This would have restricted the application of our method in other settings. Additionally, physician fees are variable since Canadian physicians receive payments based on a fee for service that is periodically negotiated [62]. Fourth, it is possible that we did not fully account for the baseline risk of trauma patients: physiological reserve, anatomical injury severity, and physiological response to injury. Indeed, we only had information on the number of comorbidities, not their severity. Moreover, comorbidities may be underreported in trauma patients [36,63,64]. Furthermore, injury severity is calculated using the AIS score, which is based on criteria established by consensus among experts, mainly on the grounds of threat to life [65]. All these limitations may have led to differential information bias or residual confounding. These may have led to an under- or over-estimation of the associations between patient- and hospital-level characteristics and resource use intensity, and the inter-provider variations in resource use intensity. However, we also considered the body region of the most severe injury and the mechanism of injury, which add information on injury severity. Consequently, we expect information bias and residual confounding to have minimal impact on our findings. Lastly, physiological data were missing for a high percentage of patients. In particular, the Glasgow Coma Score (≈40%) and respiratory rate (≈10%). To palliate this problem, we simulated missing data using the multiple imputation technique whereby we imputed each missing data value five times [36,66]. This same method has been shown to lead to valid estimates in simulation studies using the Quebec trauma registry and the United States National Trauma Data Bank [40,42].

Conclusions

Resource use for acute injury care in Quebec is not solely due to the clinical status of patients. We identified determinants of resource use that can be used to establish evidence-based resource allocations and improve the efficiency of acute injury care. The method we developed for estimating patient-level, in-hospital resource use for injury admissions and identifying related

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determinants could be reproduced using local trauma registry data and our unit costs or local unit costs.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.injury.2019.03.038.

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