Can J Anesth/J Can Anesth (2023) 70:1350–1361
https://doi.org/10.1007/s12630-023-02522-2

REPORTS OF ORIGINAL INVESTIGATIONS

Injury outcomes across Canadian trauma systems: a historical cohort study

Devenir des blessures dans les systèmes de traumatologie canadiens : une étude de cohorte historique

Lynne Moore, PhD · Jaimini Thakore, MBA · David Evans, MD · Henry T. Stelfox, MD, PhD · Tarek Razek, MD · John Kortbeek, MD · Ian Watson, MHSc · Christopher Evans, MD, MSc · Mete Erdogan, PhD, MHI · Paul Engels, MD · Barbara Haas, MD, PhD · Rosmin Esmail, PhD · Robert Green, MD · Jacinthe Lampron, MD · Micheline Wiebe, RN · Julien Clément, MD, MSc · Recep Gezer, MSc · Jennifer McMillan, MSc · Xavier Neveu, MSc · Pier-Alexandre Tardif, MSc · Angela Coates, MEd · Natalie L. Yanchar, MD, MSc

Received: 15 June 2022 / Revised: 6 December 2022 / Accepted: 13 December 2022 / Published online: 29 June 2023

Abstract

Purpose *Most North American trauma systems have designated trauma centres (TCs) including level I (ultraspecialized high-volume metropolitan centres), level II (specialized medium-volume urban centres), and/or level III (semirural or rural centres). Trauma system configuration varies across provinces and it is unclear how these differences influence patient distributions and outcomes. We aimed to compare patient case mix, case volumes, and risk-adjusted outcomes of adults with major trauma admitted to designated level I, II, and III TCs across Canadian trauma systems.*

Methods *In a national historical cohort study, we extracted data from Canadian provincial trauma registries on major trauma patients treated between 2013 and 2018 in all designated level I, II, or III TCs in British Columbia, Alberta, Quebec, and Nova Scotia; level I and II TCs in New Brunswick; and four TCs in Ontario. We used multilevel generalized linear models to compare mortality and intensive care unit (ICU) admission and competitive risk models for hospital and ICU length of stay (LOS).*

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s12630-023-02522-2.

L. Moore, PhD (✉)
Santé des Populations et Pratiques Optimales en Santé (Traumatologie – Urgence – Soins intensifs), Centre de Recherche du CHU de Québec, Quebec City, QC, Canada

Department of Social and Preventive Medicine, Enfant-Jésus Hospital, Université Laval, 1401, 18e rue, local H-012a, Quebec City, QC G1J 1Z4, Canada
e-mail: lynne.moore@fmed.ulaval.ca

J. Thakore, MBA · D. Evans, MD
Department of Surgery, The University of British Columbia, Vancouver, BC, Canada

H. T. Stelfox, MD, PhD
Department of Critical Care Medicine, University of Calgary, Calgary, AB, Canada

T. Razek, MD
Department of Surgery, McGill University, Montreal, QC, Canada

J. Kortbeek, MD · N. L. Yanchar, MD, MSc
Department of Surgery, University of Calgary, Calgary, AB, Canada

I. Watson, MHSc
New Brunswick Trauma Program, Saint John, NB, Canada

C. Evans, MD, MSc
Kingston Health Sciences Centre, Kingston, ON, Canada

Department of Emergency Medicine, Queen's University, Kingston, ON, Canada

M. Erdogan, PhD, MHI
Nova Scotia Health Trauma Program, Nova Scotia Health, Halifax, NS, Canada

Ontario could not be included in outcome comparisons because there were no population-based data from this province.

Results *The study sample comprised 50,959 patients. Patient distributions in level I and II TCs were similar across provinces but we observed significant differences in case mix and volumes for level III TCs. There was low variation in risk-adjusted mortality and LOS across provinces and TCs but interprovincial and intercentre variation in risk-adjusted ICU admission was high.*

Conclusions *Our results suggest that differences in the functional role of TCs according to their designation level across provinces leads to significant variations in the distribution of patients, case volumes, resource use, and clinical outcomes. These results highlight opportunities to improve Canadian trauma care and underline the need for standardized population-based injury data to support national quality improvement efforts.*

Résumé

Objectif *La plupart des systèmes de traumatologie nord-américains disposent de centres de traumatologie (CT) désignés, y compris de niveau I (centres métropolitains ultraspécialisés à volume élevé), de niveau II (centres urbains spécialisés à volume moyen) et/ou de niveau III (centres semi-ruraux ou ruraux). La configuration des systèmes de traumatologie varie d'une province à l'autre et nous ne savons pas comment ces différences influent sur la répartition de la patientèle et sur les issues. Notre objectif était de comparer le mélange de cas des patient·es, le volume de cas et les issues ajustées en fonction du risque des adultes ayant subi un traumatisme majeur admis·es dans des CT désignés de niveaux I, II et III dans l'ensemble des systèmes de traumatologie canadiens.*

Méthode *Dans une étude de cohorte historique nationale, nous avons extrait des données des registres provinciaux canadiens de traumatologie sur les patient·es ayant subi un traumatisme majeur traité·es entre 2013 et 2018 dans tous les CT désignés de niveau I, II ou III en Colombie-Britannique, en Alberta, au Québec et en Nouvelle-Écosse, les CT de niveau I et II au Nouveau-Brunswick, et dans quatre CT en Ontario. Nous avons utilisé des modèles linéaires généralisés à plusieurs niveaux pour comparer la mortalité, les admissions en unité de soins intensifs (USI) et les modèles de risque compétitif pour la durée du séjour à l'hôpital et à l'USI. L'Ontario n'a pas pu être inclus dans les comparaisons des devenirs parce qu'il n'y avait pas de données démographiques pour cette province.*

Résultats *L'échantillon de l'étude comptait 50 959 patient·es. La répartition des patient·es dans les CT de niveaux I et II était similaire d'une province à l'autre, mais nous avons observé des différences significatives dans le mélange des cas et les volumes pour les CT de niveau III. Il y avait une faible variation de la mortalité ajustée en fonction du risque et des durées de séjour entre les provinces et les CT, mais la variation interprovinciale et intercentre des admissions à l'USI ajustées en fonction du risque était élevée.*

Conclusion *Nos résultats suggèrent que les différences dans le rôle fonctionnel des CT selon leur niveau de désignation d'une province à l'autre entraînent des variations importantes dans la répartition des patient·es, le nombre de cas, l'utilisation des ressources et les issues*

P. Engels, MD
Department of Surgery, McMaster University, Hamilton, ON, Canada

B. Haas, MD, PhD
Sunnybrook Health Sciences Centre, Toronto, ON, Canada

R. Esmail, PhD
Trauma Services, Foothills Medical Centre, Alberta Health Services, Calgary, AB, Canada

Departments of Oncology and Community Health Sciences, O'Brien Institute for Public Health, University of Calgary, Calgary, AB, Canada

R. Green, MD
Nova Scotia Health Trauma Program, Nova Scotia Health, Halifax, NS, Canada

Department of Critical Care, Dalhousie University, Halifax, NS, Canada

J. Lampron, MD
Division of General Surgery, The Ottawa Hospital, Ottawa, ON, Canada

M. Wiebe, RN · J. McMillan, MSc
BC Trauma Registry, Provincial Health Services Authority of British Columbia, Vancouver, BC, Canada

J. Clément, MD, MSc
Institut National d'Excellence en Santé et en Services Sociaux, Quebec City, QC, Canada

Department of Surgery, Université Laval, Quebec City, QC, Canada

R. Gezer, MSc
Trauma Services BC, Provincial Health Services Authority of British Columbia, Vancouver, BC, Canada

X. Neveu, MSc · P.-A. Tardif, MSc
Santé des Populations et Pratiques Optimales en Santé (Traumatologie – Urgence – Soins intensifs), Centre de Recherche du CHU de Québec, Quebec City, QC, Canada

A. Coates, MEd
Department of Surgery, McMaster University, Hamilton, ON, Canada

cliniques. Ces résultats mettent en évidence les possibilités d'amélioration des soins de traumatologie au Canada et soulignent la nécessité de disposer de données normalisées sur les blessures dans la population pour appuyer les efforts nationaux d'amélioration de la qualité.

Keywords injury outcomes · national comparisons · trauma systems

Organized trauma systems have evolved in most North American health jurisdictions in the past four decades. These systems encompass injury prevention and clinical care across all phases of the patient trajectory, including prehospital care, stabilization, definitive acute care, rehabilitation, and community reintegration.[1–3] Acute trauma care is generally delivered across a network of level I to V trauma centres (TCs) where prehospital and patient transport systems direct patients to higher levels of care as required.[2] Level I centres are high-volume urban academic centres in metropolitan regions that provide all tertiary and specialized quaternary services. Level II centres generally offer the same services as level I but may have lower case volumes and don't have the same academic mandate. Level III centres are commonly hospitals in small towns with general surgery capacity. Their role is to stabilize and transfer most major trauma patients to level I/II TCs, particularly those requiring neurosurgery, complex orthopedic surgery, or nonoperative management of solid organ injuries.[1–3] In Canada, the designation of TCs is conducted by provincial health authorities, usually guided by standards published by accreditation bodies.[1–3] Accreditation is a formal process whereby accrediting bodies verify whether their standards are actually met. Trauma centre accreditation in Canada was conducted by the Trauma Association of Canada (TAC) until 2017 and Accreditation Canada (AC) thereafter and has been conducted by the *Institut National d'excellence en santé et services sociaux* in Quebec since 1993.[4] Accreditation is not mandatory outside of Quebec and, as such, many Canadian trauma systems/centres do not participate in a national accreditation process. Therefore, the functional roles of TCs could differ from national standards and may vary across provinces, which may have an influence on patient outcomes.

Organized systems of trauma care reduce major trauma mortality by an estimated 15%[5] and patients with moderate to severe injury have better functional and quality-of-life outcomes when treated at higher level TCs.[6–9] Nevertheless, there is a knowledge gap on how differences in the functional roles of same-designated TCs across jurisdictions influence patient orientations and outcomes.[10] We aimed to compare patient case mix, case volumes, and risk-adjusted outcomes of adults with major trauma admitted to TCs across Canadian trauma systems according to designation level.

Methods

We conducted a national historical cohort study. The study protocol, including a data analysis and statistical plan, was approved by all authors and filed with the CHU-de-Québec research ethics committee before data were accessed. We report results according to the Strengthening of Reporting of Observational Studies in Epidemiology (STROBE) statement (Electronic Supplementary Material [ESM] eAppendix).[11]

Study population

We included adults ($\geq$ 16 yr old) hospitalized for major trauma (Injury Severity Score [ISS] $\geq$ 12) between 1 April 2013 (change in Abbreviated Injury Scale [AIS] coding) and 31 March 2018 (most recent data across provinces) in all designated level I, II, and III TCs in the Canadian provinces of British Columbia (BC), Alberta (AB), Québec (QC), and Nova Scotia (NS); all designated level I and II centres in New Brunswick (NB); and four TCs in Ontario (ON). In the case of multiple acute-care admissions for the same event (approximately 6% of admissions),[12] only the admission to the TC with the highest designation level (i.e., the definitive care TC) was considered. Hospital stays following repatriation were not considered.

Data collection

The following patient-level data were extracted from provincial or institutional trauma registries: age, sex, comorbidities, AIS score of the three most severe injuries,[13] Glasgow Coma Scale (GCS) and systolic blood pressure (SBP) measured on arrival at the emergency department (ED), intensive care unit (ICU) admission, hospital and ICU length of stay (LOS), and in-hospital death. Data were centralized in Research Electronic Data Capture (REDCap, Vanderbilt University, Nashville, TN, USA).[14] Data sharing agreements were obtained from all participating institutions and ethics approval was obtained from the CHU-de-Québec research ethics committee.

Outcomes

Outcomes were in-hospital mortality, ICU admission, and hospital and ICU LOS. In-hospital mortality was defined as any death in the index hospital. ICU admission was any admission (immediate or late) to an ICU during the index stay. Admissions to step-down or transition units were not considered. Hospital and ICU LOS were calculated as the number of days between admission and discharge at the index hospital.

Statistical analyses

Patient distributions

We compared the case mix of patients admitted to level I, II, and III TCs across provinces by calculating absolute and relative frequencies according to age and injury type. We compared patient volume by calculating average annual admissions for each TC and for all TCs by designation level for each province.

Risk-adjusted outcome comparisons

Mortality and ICU admission were modelled using multilevel logistic regression. Emergency department deaths were excluded for the latter. To account for survival bias, hospital and ICU LOS were modelled using competitive risks models.[15] Risk-adjustment variables for all outcomes were determined *a priori* using previous research on Canadian acute injury populations[16–18] and included age (16–54, 55–64, 65–74, 75–85, and 85+ yr), sex, maximum AIS in each body region (head/face, neck/thorax, abdomen, spine, upper extremities, lower extremities), GCS (3–8, 9–12, 13–15), SBP (< 90, ≥ 90 mm Hg), and injury mechanism (motor vehicle collision, fall from own height, fall from higher than own height, penetrating, other). We chose categories over splines for continuous covariates, as the latter did not change effect or variance estimates of interest. Risk factors were modelled as fixed effects and random intercepts were used to model outcomes on centres and provinces. All models were stratified by designation level. Intercentre and interprovincial comparisons were based on risk-adjusted estimates of the incidence of mortality and ICU admission and of median hospital and ICU LOS with 95% confidence intervals (CIs). We conducted comparisons for all diagnoses combined and for injury cohorts identified *a priori*: traumatic brain injury (TBI), spinal cord injury (SCI), multisystem blunt trauma, and severe orthopedic injury (ESM eTables 1–3). We also stratified by age (< 65 or ≥ 65 yr). Because of low patient volume and low probability of the outcome, we did not assess mortality for SCI and we did not assess mortality, ICU admission, or ICU LOS for severe orthopedic injury. Patients from ON were not included in provincial outcome comparisons as we did not have data from all TCs in the province.

Missing data

Data on GCS and SBP were missing for 18% and 3% of observations, respectively. Given the data available and missing data mechanisms, we considered the missing-at-random mechanism plausible and used multiple imputation to simulate missing data. We derived separate imputation models for each analysis model (by outcome overall and in each subgroup) and included all variables in respective analysis models. We used the Markov Chain Monte Carlo method with single chains based on a multivariate normal model to generate 25 imputations, corresponding to the highest fraction of missing data.[19]

Sensitivity analyses

We restricted provincial outcome comparisons to observations with no missing data. We then repeated mortality comparisons 1) excluding patients aged ≥ 85 yr and 2) restricted to mortality < 30 days.

Results

Study sample

The study sample comprised 50,959 patients admitted for major trauma between 1 April 2013 and 31 March 2018 (ESM eTable 1). Among provinces that submitted data from all level I, II, and III centres (AB, BC, NS, and QC), the proportion of patients aged ≥ 65 yr varied from 28% in AB to 46% in QC. Injury severity was similar but the proportion of patients with a GCS ≤ 8 on ED arrival varied from 5% in BC to 13% in QC. Over half of patients were transferred in from another hospital in NS whereas transfer proportions were around 35% in BC, AB, and QC. Globally, around one half of patients were admitted for TBI (60% in NS), one quarter for multisystem injury, whereas SCI and severe orthopedic injuries both represented approximately one out of 13 patients.

Comparisons of patient distributions

We observed statistically significant differences in the distribution of patients among level I, II, and III centres across provinces overall and in injury subcohorts (ESM eTables 2–4, Fig. 1).

Case mix

Patients in level I centres in QC were older (42% aged ≥ 65 yr compared with 36% overall) with more severe injuries (44% with ISS ≥ 25 *vs* 41% overall) compared with other provinces (ESM eTable 2). In level II centres (ESM eAppendix 4), patients were older in QC (46% aged ≥ 65 yr compared with 38% overall) and more severely injured in NB (39% with ISS ≥ 25 *vs* 34% overall). Patients in level III centres (ESM eTable 4) in QC and NS were older (56% and 58% aged ≥ 65 yr, respectively

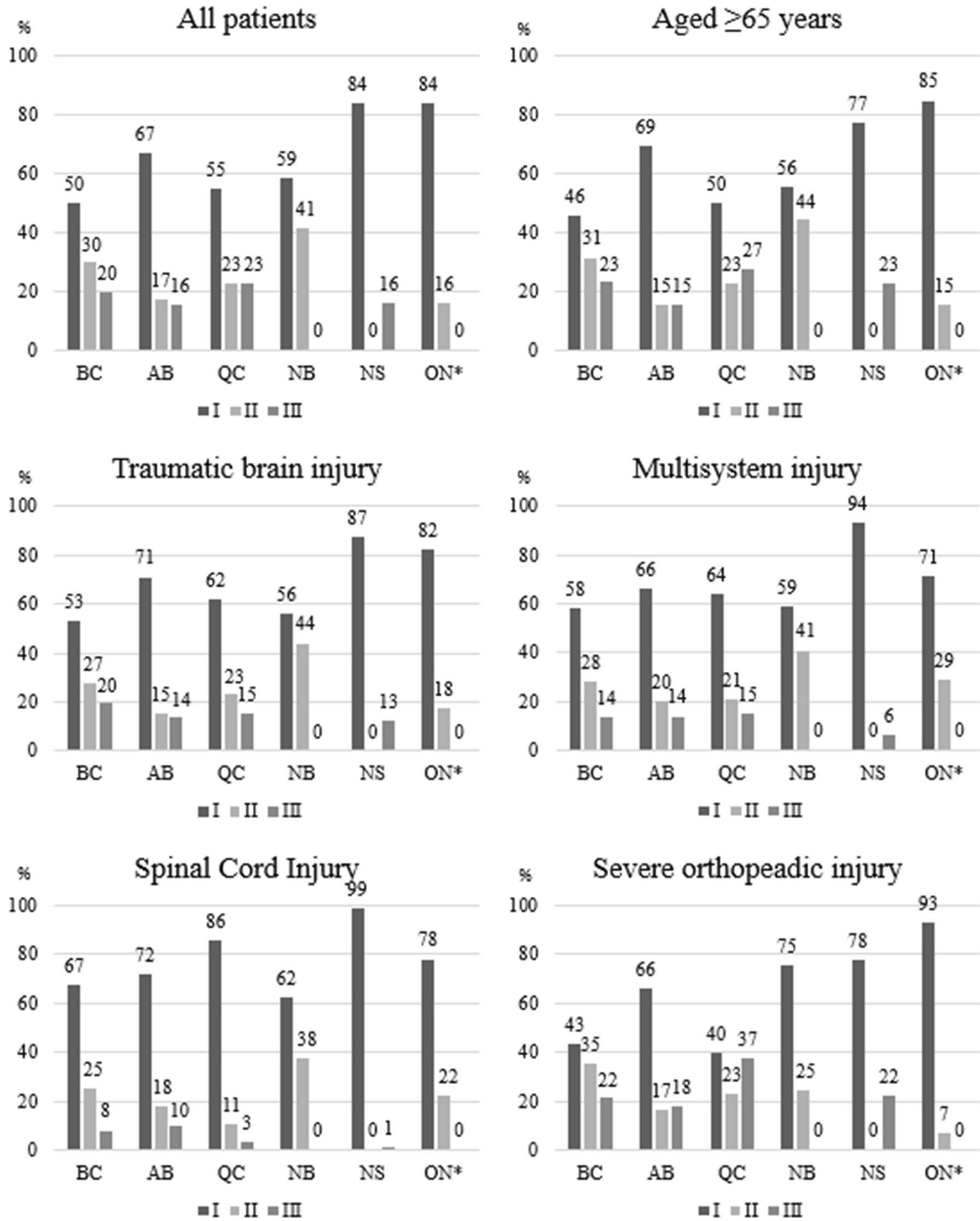

Fig. 1 Distribution of patients in level I, II, and III centres overall and subcohorts. Numbers are percentages.
*Ontario data are not based on all trauma centres.
AB = Alberta; BC = British Columbia; QC = Quebec = NB, New Brunswick; NS = Nova Scotia; ON = Ontario

compared with 45% overall) with lower injury severity (13% and 18% ISS $\geq$ 25 yr, respectively compared with 20% overall) compared with other provinces. Proportions of major trauma patients managed in level I or II centres were similar in the four provinces submitting data from all designated level I–III centres (80% in BC, 84% in AB, 78% in QC, and 84% in NS; Fig. 1) although the distribution between levels I and II varied with two thirds of patients managed in level I centres in AB compared with only about half in BC and QC. Around three quarters of patients aged $\geq$ 65 yr were managed in a level I or II centre in BC, QC, and NS compared with 84% in AB. The

Table Mean annual patient volumes 2013–2018, crude and per 10,000 population estimates[a]

Province	Level I	Level II	Level III
Crude numbers			
BC	591 (494–688; 2)	238 (198–315; 3)	94 (53–150; 5)
AB	823 (708–939; 2)	430 (1)	77 (35–128; 5)
QC	596 (575–613; 3)	148 (92–224; 5)	35 (10–79; 21)
NB	127 (1)	89 (1)	-
NS	395 (1)	-	10 (2–32; 8)
ON[b]	593 (583–603; 2)	224 (1)	-
Per 10,000 population[a]			
BC	11.9 (9.9–13.8)	4.8 (4.0–6.3)	1.9 (1.1–3.0)
AB	19.2 (16.5–21.9)	10.0	1.8 (0.8–3.0)
QC	7.1 (6.9–7.3)	1.8 (1.1–2.7)	0.4 (0.1–0.9)
NB	16.5	11.6	-
NS	41.4	-	1.0 (0.2–3.4)
ON[b]	4.2 (4.1–4.2)	1.6	-

Data reflect mean number of patients (min–max; number of centres)

[a]Statistics Canada quarterly population estimates for Q2, 2017 (available from URL: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1710000901&cubeTimeFrame.startMonth=04&cubeTimeFrame.startYear=2018&cubeTimeFrame.endMonth=04&cubeTimeFrame.endYear=2018&referencePeriods=20180401%2C20180401; accessed April 2023)

[b]ON data are not based on all trauma centres

AB = Alberta; BC = British Columbia; NB = New Brunswick; NS = Nova Scotia; ON, Ontario; QC = Quebec

proportions of patients with TBI or multisystem injury treated in a level I or II centre were similar across provinces. Nevertheless, the proportion of patients with SCI treated in a level I centre varied significantly (99%, 86%, 72%, and 67% in NS, QC, AB, and BC, respectively). Patients with severe orthopedic injury were more often managed in level III centres in QC (37%) compared with other provinces (around 20%).

Volumes

Mean annual patient volumes in level I centres were around 800 in AB and 600 in AB and QC (Table; ESM eFig. 1) but were much lower in NS (395) and NB (127). In level II centres, the mean annual volume in the single centre in AB (430) was almost twice that of the three centres in BC (238) and three times that of the five centres in QC (148). The level II centre in NB treated on average 89 patients per year, close to the volume of their level I centre. Mean annual volumes of level III centres varied between 10 in NS and 94 in BC and were inversely related to the number of designated centres per province (between 21 and 5). Volumes per 10,000 population (excluding ON) were lowest in QC for all designation levels (7.1, 1.8, and 0.4 per 10,000 for level I, II, and III, respectively). Volumes were highest in NS for level I centres (41), AB for level II (10), and BC for level III (1.9).

Comparisons of outcomes

Mortality

Crude outcomes data are provided in ESM eTable 5. Little variation in risk-adjusted mortality between provinces was observed for level I or level II centres but QC was below the global mean for the former (9.3% [95% CI; 8.2 to 10.4], Fig. 2). Nevertheless, for level III centres, risk-adjusted mortality was significantly lower than the global mean in BC and AB (7.4% [6.1 to 9.1] and 5.7% [95% CI; 4.4 to 7.2], respectively) and higher in QC and NS (11.7% [10.0 to 13.5] and 15.3% [10.8 to 21.2], respectively). These patterns were similar in the subcohort of patients with TBI (ESM eFig. 2a) and multisystem injuries (ESM eFig. 2b) and when stratifying by age (ESM eFigs 2c, d). Variation in risk-adjusted mortality between TCs within provinces (intraprovincial variation) appeared as large as variation between provinces (interprovincial variation) for level I and II centres (ESM eFig. 2e). Nevertheless, for level III centres, TCs in AB and BC systematically had lower risk-adjusted mortality than that of the same level centres in NS and QC.

Intensive care unit admission

Significant provincial variation in ICU admission remained after risk adjustment for all designation levels (Fig. 3). In

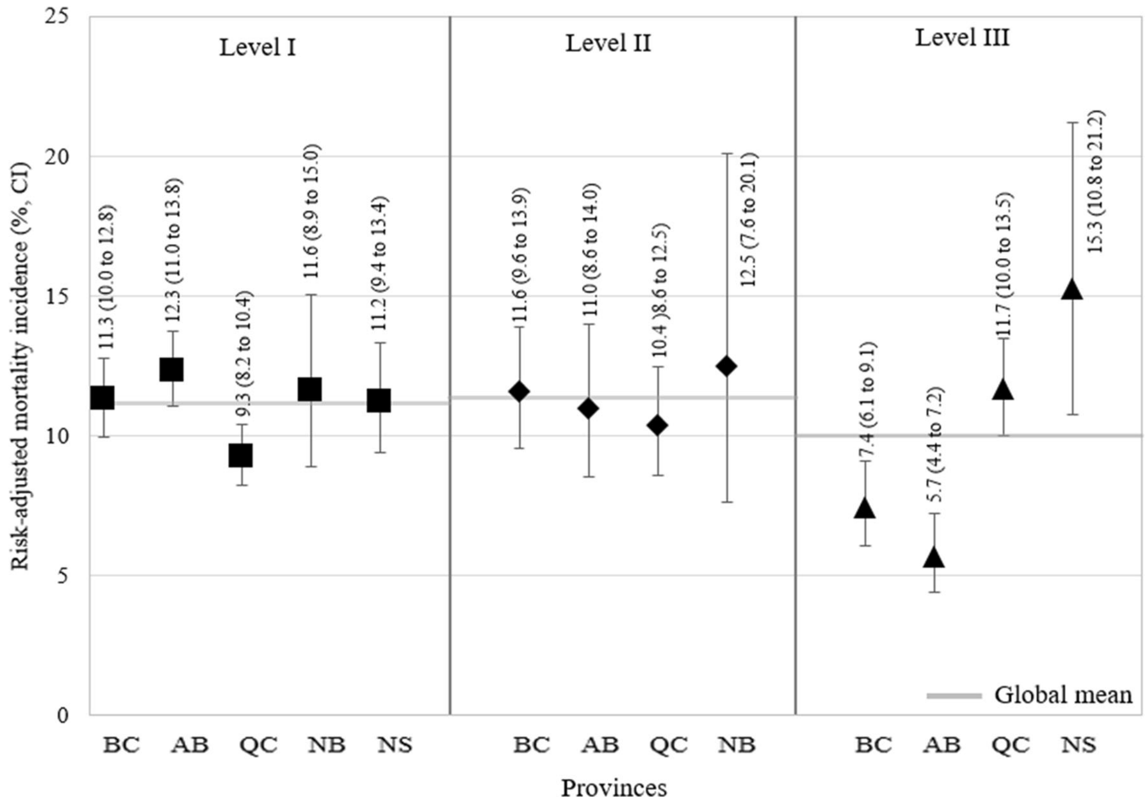

Fig. 2 Risk-adjusted mortality and 95% confidence intervals by trauma centre designation level and province, all patients. AB = Alberta; BC = British Columbia; CI = 95% confidence interval; QC = Quebec; NB = New Brunswick; NS = Nova Scotia; ON = Ontario

level I centres, around one out of four patients were admitted to the ICU in BC (24.5% [95% CI; 24.2 to 26.8]), AB (23.4% [95% CI; 22.2 to 24.5]) and NS (23.5% [95% CI; 21.5 to 25.7]), two out of five in QC (36.6% [95% CI; 35.2 to 38.1]), and two out of three in NB (63.3% [95% CI; 59.1 to 67.0]). A similar pattern was seen in level II and level III centres (Fig. 3) and when we stratified by injury type and age (ESM eFigs 3a–e). Nevertheless, patients with SCI managed in a level I TC in AB had a significantly higher ICU admission incidence than the global mean (54.0% [95% CI; 32.8 to 42.3]; ESM eFig. 3c). Variations in ICU admission were greater between provinces than within (ESM eFig. 3f).

Hospital length of stay

Little variation in hospital LOS was observed between provinces for level I or II TCs after risk-adjustment but LOS (in days) was higher than the global median in BC for level I TCs (9.8 [95% CI; 9.2 to 10.4]) and lower in QC for both levels (8.4 [95% CI; 7.8 to 9.0] for level I and 7.0 [95% CI; 6.4 to 7.8] for level II; Fig. 4). Greater provincial variation was observed for level III centres; median LOS varied from 3.4 days [95% CI; 2.4 to 4.6] in AB to 7.2 days [95% CI; 5.2 to 9.8] in NS. Similar patterns were observed when we stratified by injury type and age except for SCI patients for whom risk-adjusted median LOS was highest in AB in level I centres (23.0 [95% CI; 19.0 to 27.8]; ESM eFigs 4a–f). Interhospital variation in risk-adjusted median LOS varied less within provinces than between provinces (ESM eFig. 4g).

Intensive care unit length of stay

Risk-adjusted median ICU LOS varied from 3.4 days (95% CI; 2.6 to 4.2) for NB to 6.4 days (95% CI; 5.0 to 8.2) for AB in level I centres and from 3.2 days (95% CI; 2.6 to 4.0) in QC to 5.4 days (95% CI; 4.2 to 6.8) in AB for level II centres (Fig. 5). Patterns were similar for all subcohorts (ESM eFigs 5a–e). Again, less variation was observed between than within provinces (ESM eFig. 5f).

Sensitivity analyses

Outcome comparisons restricted to observations with no missing data led to the same provincial outliers. Similarly, mortality comparisons restricted to 30 days and excluding

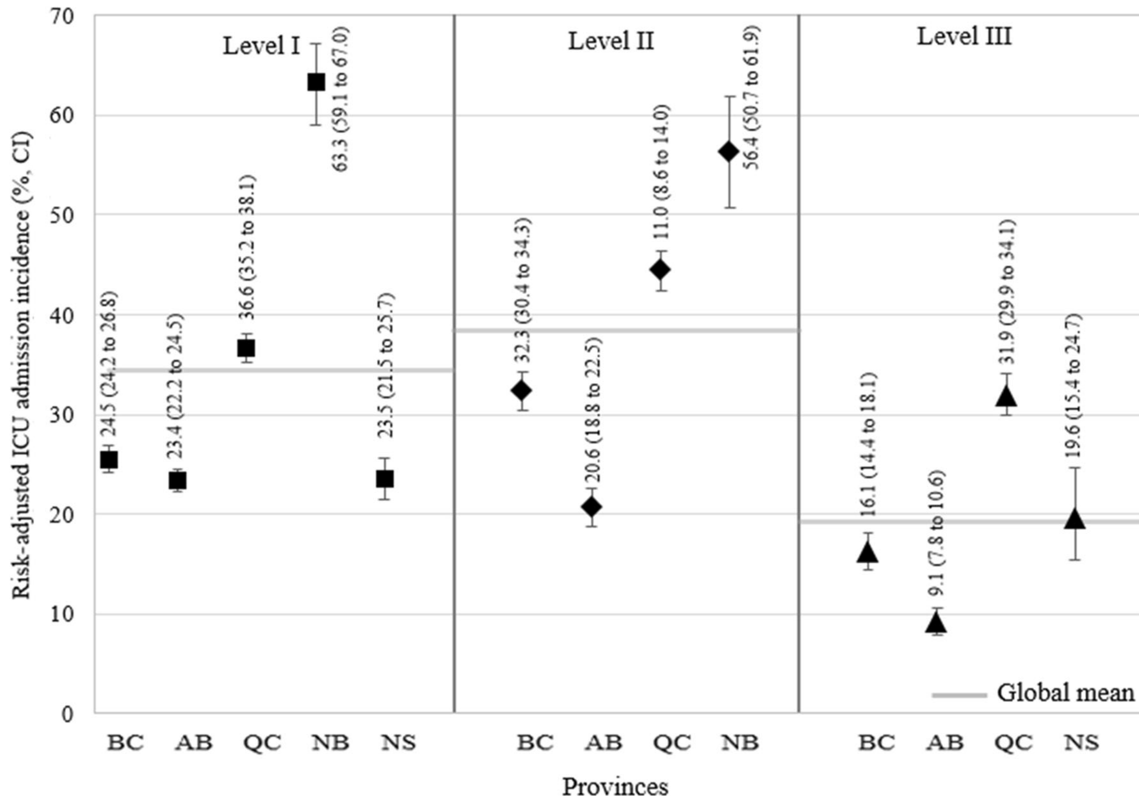

Fig. 3 Risk-adjusted intensive care unit admission and 95% confidence intervals by designation level and province, all patients. AB = Alberta; BC = British Columbia; CI = 95% confidence interval; ICU = intensive care unit; QC = Quebec; NB = New Brunswick; NS = Nova Scotia; ON = Ontario

patients aged ≥ 85 yr did not lead to any significant change in results.

Discussion

In this national historical cohort study, we observed significant differences in the distribution of major trauma patients across Canadian provinces, particularly for level III centres. We observed little variation in risk-adjusted mortality and hospital LOS in level I and II centres but significant variation for level III centres. Finally, we observed significant interprovincial and interhospital variation in propensity to admit to the ICU and ICU LOS for all levels of care.

Significant variations in patient case mix and volumes for level III centres suggest that the functional roles of these centres differ across provinces, despite similar recommended roles provided by accreditation organizations.[1,3,20] Level III centres in BC and AB are fewer and have higher patient volumes than QC and NS, which may increase the concentration of expertise and resources but does reduce geographical coverage. Level III centres in QC and NS admit more elderly, lower acuity (but still major trauma) patients. These results may reflect undertriage of older adults to level I–II TCs in QC and NS (retention in level III centres) or undertriage to designated TCs in BC and AB (retention in nondesignated hospitals). Population-based data will be required to verify these hypotheses. Other studies have shown that elderly patients with major trauma are less likely to be treated in TCs[21,22] and in level I–II TCs[21,23,24] than their younger counterparts.[21,22] Results may also reflect differences in patient/family–physician-shared decision-making leading to a preference to treat elderly frail patients close to their home and to use less invasive management. The stable proportion of patients with TBI or multisystem injuries treated in level I/II centres suggests little variation in the triage of these patient cohorts across provinces. Differences in the orientation of patients with severe orthopedic injury is likely a reflection of the difficulty establishing clear guidelines on which orthopedic patients should be transferred.[25]

Interprovincial differences in mortality across Canadian level I and II TCs were previously described for 2006–2012 injury admissions[26] and are consistent with

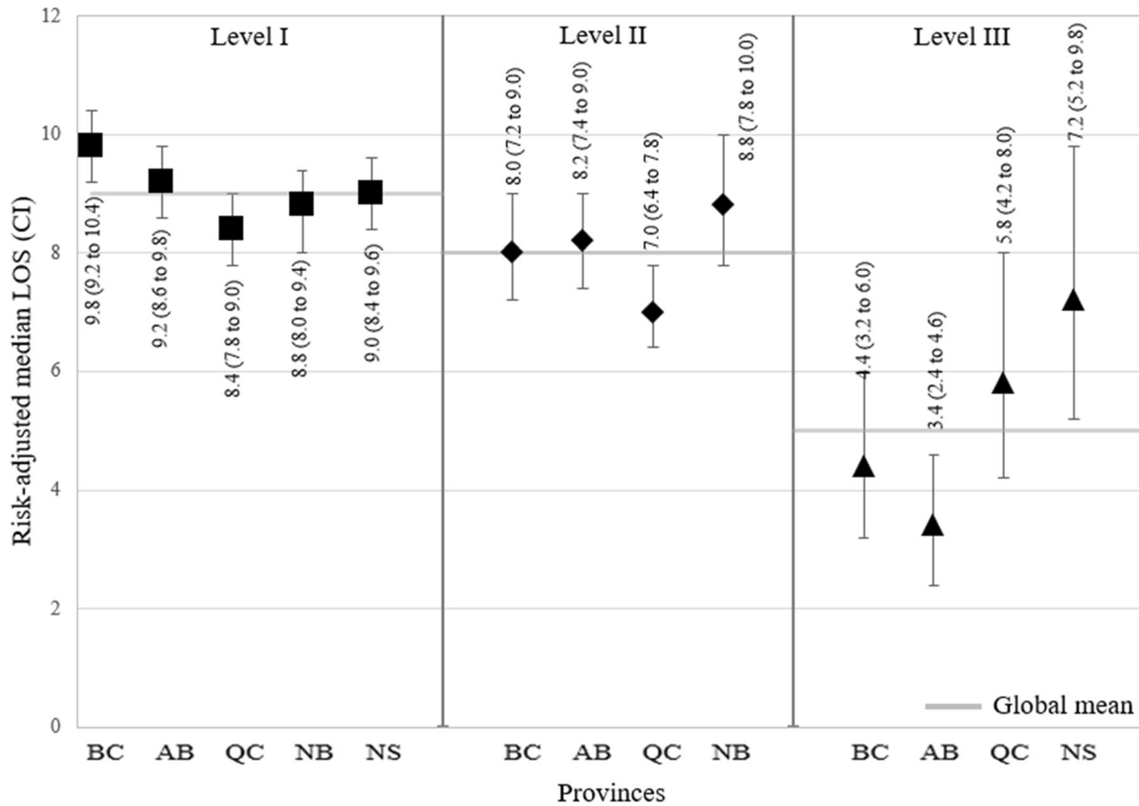

Fig. 4 Risk-adjusted hospital length of stay and 95% confidence intervals by designation level and province, all patients. AB = Alberta; BC = British Columbia; CI = 95% confidence interval; QC = Quebec; LOS = hospital length of stay; NB = New Brunswick; NS = Nova Scotia; ON = Ontario

our observations in this 2013–2017 study.[27,28] Our data also suggest that variations in mortality across level III centres, which were not previously documented, are much greater. The lower mortality observed in level III centres in AB and BC compared with NS and QC could be explained by the lack of comparability between patient cohorts treated in level III centres across the country, even after adjustment for risk factors. Differences could also be partly explained by the higher patient volume in level III centres in AB and BC, which leads to higher concentration of expertise and resources. The association between higher volume and better trauma outcomes has been suggested in some previous studies[29,30] but was not confirmed by others.[31–33]

Differences in risk-adjusted ICU admission incidences suggest a lower threshold to admit to the ICU in QC and NB than other provinces and significant interhospital variation. New Brunswick and QC also had the shortest ICU LOS among level I centres, supporting this hypothesis. These results may be explained by variations in policies regarding the use of ICU beds depending on surge capacity, availability of step-down units, and definitions of an ICU bed.[34] Significant variations in ICU resources across Canada in relation to population density have previously been reported.[35] Variations in ICU admission within and across provinces have also been observed for other diagnostic groups[36,37] and for blunt splenic injury in the USA.[38] The impact of the lack of standardization of ICU bed attribution on service organization and patient care has been highlighted during the COVID-19 pandemic.[39] Similarly, differences in risk-adjusted ICU LOS may reflect system issues whether that be difficulty transferring patients out of the ICU or pressure to release them too early.

Strengths and limitations

This study was based on the largest aggregation of Canadian injury data since the dissolution of the Canadian National Trauma Registry in 2014. It is also the first study to include data from level II and level III centres from multiple provinces.

Several limitations should be considered when interpreting the results. First, despite robust adjustment

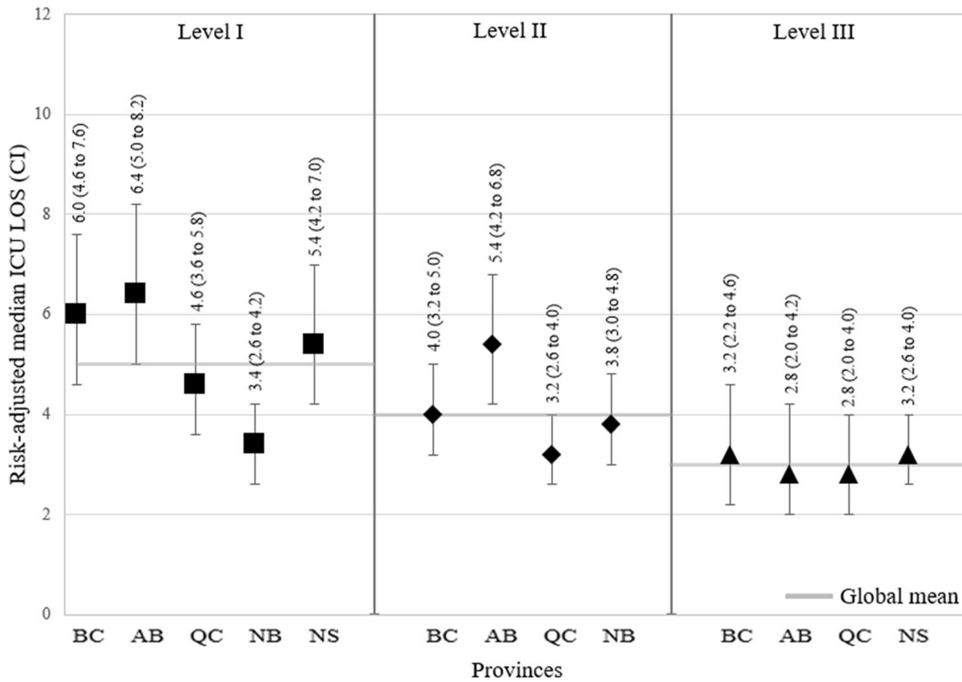

Fig. 5 Risk-adjusted intensive care unit length of stay and 95% confidence intervals by designation level and province, all patients. AB = Alberta; BC = British Columbia; CI = 95% confidence interval; ICU = intensive care unit; LOS = hospital length of stay; QC = Quebec; NB = New Brunswick; NS = Nova Scotia; ON = Ontario

for age,[40] the lack of adjustment for comorbidities (considered to be subject to too much interprovincial coding variation) likely led to confounding, particularly for level III centres. Residual confounding may also have been caused by lack of information on other risk factors (e.g., pupillary reaction and hypotension for TBI admissions) or by differential capture of included confounders (e.g., GCS). Nevertheless, in our preparatory analyses, we found variable definitions to be similar across provinces. Second, this study does not account for prehospital deaths or patients treated in nondesignated hospitals. While coverage of major trauma in trauma registries has been shown to be high for patients aged $\leq$ 65 yr, it is as low as 70% for older adults in QC[21] and probably lower in other provinces. Again, this is likely to have led to selection bias in interprovincial comparisons for level III centres and in older adults. Furthermore, we did not have data from all designated level I–III centres from ON or NB. This prevented us from including NB in level III centre comparisons and from making meaningful comparisons with ON, the most populous province in Canada. We also had no data on trauma admissions from provinces without trauma systems (i.e., Saskatchewan, Newfoundland & Labrador, Prince Edward Island) or territories. Lastly, low volumes in some provinces, particularly for subgroups, led to imprecise estimates, shown by wide CIs.

Conclusions and recommendations

In this national historical cohort study of Canadian major trauma patients, we observed significant variations in patient distributions and risk-adjusted outcomes that lead to four recommendations for future research and quality improvement. First, work should be done to describe the functional roles of level I, II, and III TCs across provinces. This could be used to develop system-based accreditation criteria that account for the role of each centre within the system and contextual factors (e.g., geography, population density, patient case mix, health system structure). These may be more appropriate than one-size-fits-all, site-specific criteria. Second, we need to identify optimal care pathways for elderly trauma patients that account for their multidisciplinary clinical needs and can be adapted to patient and family priorities. Third, results suggest a need to assess the comparative effectiveness of restrictive versus liberal ICU admission strategies to inform evidenced-based guidelines for ICU admission across Canada. Fourth, results suggest that TC benchmarking should be conducted at a system level to provide meaningful data for quality improvement activities. This study underscores the limitations of current trauma data collection and reporting for national comparisons and shows the need for sharable, standardized, population-based injury data across Canada to support national quality improvement efforts.

Author contributions All authors contributed to study design. *Lynne Moore*, *Jaimini Thakore*, *David Evans*, *Henry T. Stelfox*, *Tarek Razek*, *John Kortbeek*, *Ian Watson*, *Christopher Evans*, *Mete Erdogan*, *Paul Engels*, *Barbara Haas*, *Rosmin Esmail*, *Robert Green*, *Jacinthe Lampron*, *Micheline Wiebe*, *Julien Clément*, *Recep Gezer*, *Jennifer McMillan*, *Angela Coates*, and *Natalie L. Yanchar* were involved in data acquisition. *Lynne Moore*, *Xavier Neveu*, and *Pier-Alexandre Tardif* were responsible for data analysis. All authors made significant contribution to the interpretation of data and critically appraised the manuscript.

Acknowledgements The authors would like to acknowledge trauma services and trauma registry teams from British Columbia, Alberta, Ontario, Quebec, New Brunswick, and Nova Scotia who provided data for this study, and Sonshire Figueira for contributing to the manuscript.

Disclosures None.

Funding statement None declared.

Prior conference presentations This work was presented at the Trauma Association of Canada 2022 Annual Scientific Meeting and Conference (7–8 April 2022, Montreal, QC, Canada).

Editorial responsibility This submission was handled by Dr. Philip M. Jones, Deputy Editor-in-Chief, *Canadian Journal of Anesthesia/Journal canadien d'anesthésie*.

References

1. *Accreditation Canada*. Trauma distinction information package, 2014. Available from URL: https://accreditation.ca/files/trauma-info-package-en.pdf (accessed January 2023).
2. *Trauma Association of Canada*. Trauma system accreditation guidelines, 2011. Available from URL: https://www.traumacanada.org/wp-content/uploads/2019/05/Accreditation_Guidelines_2011.pdf (accessed January 2023).
3. *INESSS*. Trauma Care Contiuum (TCC), 2022. Available from URL: https://www.inesss.qc.ca/en/themes/sante/traumatology/trauma-care-continuum-tcc.html (accessed January 2023).
4. *Liberman M, Mulder DS, Lavoie A, Sampalis JS*. Implementation of a trauma care system: evolution through evaluation. J Trauma 2004; 56: 1330–5. https://doi.org/10.1097/01.ta.0000071297.76727.8b
5. *Celso B, Tepas J, Langland-Orban B, et al*. A systematic review and meta-analysis comparing outcome of severely injured patients treated in trauma centers following the establishment of trauma systems. J Trauma 2006; 60: 371–8. https://doi.org/10.1097/01.ta.0000197916.99629.eb
6. *Demetriades D, Martin M, Salim A, et al*. Relationship between American College of Surgeons trauma center designation and mortality in patients with severe trauma (injury severity score > 15). J Am Coll Surg 2006; 202: 212–5. https://doi.org/10.1016/j.jamcollsurg.2005.09.027
7. *Glance LG, Osler TM, Mukamel DB, Dick AW*. Impact of trauma center designation on outcomes: is there a difference between Level I and Level II trauma centers? J Am Coll Surg 2012; 215: 372–8. https://doi.org/10.1016/j.jamcollsurg.2012.03.018
8. *Mackenzie EJ, Rivara FP, Jurkovich GJ, et al*. The impact of trauma-center care on functional outcomes following major lower-limb trauma. J Bone Joint Surg Am 2008; 90: 101–9. https://doi.org/10.2106/jbjs.f.01225
9. *Nirula R, Brasel K*. Do trauma centers improve functional outcomes: a national trauma databank analysis? J Trauma 2006; 61: 268–71. https://doi.org/10.1097/01.ta.0000230305.36456.4e
10. *Hemmila MR, Cain-Nielsen AH, Jakubus JL, Mikhail JN, Dimick JB*. Association of hospital participation in a regional trauma quality improvement collaborative with patient outcomes. JAMA Surg 2018; 153: 747–56. https://doi.org/10.1001/jamasurg.2018.0985
11. *von Elm E, Altman DG, Egger M, et al*. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. Ann Intern Med 2007; 147: 573–7. https://doi.org/10.7326/0003-4819-147-8-200710160-00010
12. *Moore L, Stelfox HT, Turgeon AF, et al*. Hospital length of stay after admission for traumatic injury in Canada: a multicenter cohort study. Ann Surg 2014; 260: 179–87. https://doi.org/10.1097/sla.0000000000000624
13. *Association for the Advancement of Automotive Medicine*. Abbreviated Injury Scale (AIS) 2005 update 2008. Illinois: AAAM Publications; 2008.
14. *REDCap*. Homepage. Available from URL: https://www.project-redcap.org (accessed January 2023).
15. *Kalbfleisch JD, Prentice RL*. Competing risks. *In*: Kleinbaum DG, Klein M (Eds.). Survival Analysis: A Self-Learning Text, 3rd ed. New York: Springer; 2016: 247–77.
16. *Moore L, Lavoie A, Turgeon AF, et al*. The trauma risk adjustment model: a new model for evaluating trauma care. Ann Surg 2009; 249: 1040–6. https://doi.org/10.1097/sla.0b013e3181a6cd97
17. *Moore L, Stelfox HT, Turgeon AF, et al*. Derivation and validation of a quality indicator of acute care length of stay to evaluate trauma care. Ann Surg 2014; 260: 1121–7. https://doi.org/10.1097/sla.0000000000000648
18. *Moore L, Lauzier F, Stelfox HT, et al*. Derivation and validation of a quality indicator to benchmark in-hospital complications among injury admissions. JAMA Surgery 2016; 151: 622–30. https://doi.org/10.1001/jamasurg.2015.5484
19. *Carpenter JR, Kenward MG*. Multiple Imputation and Its Application. West Sussex: Wiley; 2013.
20. *Trauma Assoociation of Canada*. TAC committees, 2018. Available from URL: https://www.traumacanada.org/committees/ (accessed January 2023).
21. *Kuimi BL, Moore L, Cissé B, et al*. Access to a Canadian provincial integrated trauma system: a population-based cohort study. Injury 2015; 46: 595–601. https://doi.org/10.1016/j.injury.2015.01.006
22. *Newgard CD, Caughey A, McConnell KJ, et al*. Comparison of injured older adults included in vs excluded from trauma registries with 1-year follow-up. JAMA Surg 2019; 154: e192279. https://doi.org/10.1001/jamasurg.2019.2279
23. *Ruge T, Carlsson AC, Hellstrom M, Wihlborg P, Undén J*. Is medical urgency of elderly patients with traumatic brain injury underestimated by emergency department triage? Ups J Med Sci 2020; 125: 58–63. https://doi.org/10.1080/03009734.2019.1706674
24. *Staudenmayer KL, Hsia RY, Mann NC, Spain DA, Newgard CD*. Triage of elderly trauma patients: a population-based perspective. J Am Coll Surg 2013; 217: 569–76. https://doi.org/10.1016/j.jamcollsurg.2013.06.017

25. *American College of Surgeons and Orthopaedic Trauma Association*. Best practices in the management of orthopeadic trauma, 2015. Available from URL: https://www.facs.org/-/media/files/quality-programs/trauma/tqip/ortho_guidelines.ashx (accessed January 2023).
26. *Moore L, Evans D, Hameed SM, et al*. Mortality in Canadian trauma systems: a multicenter cohort study. *Ann Surg* 2017;265:212-7. https://doi.org/10.1097/sla.0000000000001614
27. *Hameed SM, Schuurman N, Razek T, et al*. Access to trauma systems in Canada. J Trauma 2010; 69: 1350–61. https://doi.org/10.1097/ta.0b013e3181e751f7
28. *Turgeon AF, Lauzier F, Simard JF, et al*. Mortality associated with withdrawal of life-sustaining therapy for patients with severe traumatic brain injury: a Canadian multicentre cohort study. CMAJ 2011; 183: 1581–8. https://doi.org/10.1503/cmaj.101786
29. *Minei JP, Fabian TC, Guffey DM, et al.* Increased trauma center volume is associated with improved survival after severe injury: results of a Resuscitation Outcomes Consortium study. Ann Surg 2014; 260: 456–64. https://doi.org/10.1097/sla.0000000000000873
30. *Nathens AB, Jurkovich GJ, Maier RV, et al*. Relationship between trauma center volume and outcomes. JAMA 2001; 285: 1164–71. https://doi.org/10.1001/jama.285.9.1164
31. *Caputo LM, Salottolo KM, Slone DS, Mains CW, Bar-Or D*. The relationship between patient volume and mortality in American trauma centres: a systematic review of the evidence. Injury 2014; 45: 478–86. https://doi.org/10.1016/j.injury.2013.09.038
32. *Demetriades D, Martin M, Salim A, Rhee P, Brown C, Chan L.* The effect of trauma center designation and trauma volume on outcome in specific severe injuries. Ann Surg 2005; 242: 512–7. https://doi.org/10.1097/01.sla.0000184169.73614.09
33. *Tsai SH, Goyal A, Alvi MA, et al*. Hospital volume-outcome relationship in severe traumatic brain injury: stratified analysis by level of trauma center. J Neurosurg 2020; 134: 1303–15. https://doi.org/10.3171/2020.1.jns192115
34. *Critical Care Services Ontario*. Adult critical care levels of care guidance document, 2020. Available from URL: https://criticalcareontario.ca/wp-content/uploads/2020/11/Adult-LoC-Guidance-Document-Final.pdf (accessed January 2023).
35. *Fowler RA, Abdelmalik P, Wood G, et al*. Critical care capacity in Canada: results of a national cross-sectional study. Crit Care 2015; 19: 133. https://doi.org/10.1186/s13054-015-0852-6
36. *Admon AJ, Seymour CW, Gershengorn HB, Wunsch H, Cooke CR*. Hospital-level variation in ICU admission and critical care procedures for patients hospitalized for pulmonary embolism. Chest 2014; 146: 1452–61. https://doi.org/10.1378/chest.14-0059
37. *Chen R, Strait KM, Dharmarajan K, et al*. Hospital variation in admission to intensive care units for patients with acute myocardial infarction. Am Heart J 2015; 170: 1161–9. https://doi.org/10.1016/j.ahj.2015.09.003
38. *Kaufman EJ, Wiebe DJ, Martin ND, Pascual JL, Reilly PM, Holena DN*. Variation in intensive care unit utilization and mortality after blunt splenic injury. J Surg Res 2016; 203: 338–47. https://doi.org/10.1016/j.jss.2016.03.049
39. *Ma X, Vervoort D*. Critical care capacity during the COVID-19 pandemic: global availability of intensive care beds. J Crit Care 2020; 58: 96–7. https://doi.org/10.1016/j.jcrc.2020.04.012
40. *Moore L, Lavoie A, Le Sage N, et al*. Using information on preexisting conditions to predict mortality from traumatic injury. Ann Emerg Med 2008; 52: 356–64. https://doi.org/10.1016/j.annemergmed.2007.09.007