Development and validation of a hospital indicator of resource use intensity for injury admissions

Thèse

Teegwendé Valérie Porgo

Doctorat en épidémiologie
Philosophiæ doctor (Ph. D.)

Québec, Canada

Development and validation of a hospital indicator of resource use intensity for injury admissions

Thèse

Teegwendé Valérie Porgo

Sous la direction de :

Lynne Moore, directrice de recherche

Résumé

Introduction : Les blessures représentent la 5ème cause d'hospitalisation au Canada. En 2010, leur soins ont couté 16 milliards de dollars. Selon des études Américaines, l'utilisation des ressources en traumatologie n'est pas strictement dictée par l'état des patients. Toutefois, le manque d'outil de mesure et de surveillance de l'intensité d'utilisation des ressources a jusque là empêché le développement d'interventions visant à améliorer l'efficience des soins en traumatologie.

Objectifs : Notre objectif général était de développer et valider un indicateur de l'intensité d'utilisation des ressources pour les soins aigus en traumatologie. Nos objectifs spécifiques étaient de (1) faire une synthèse des méthodes d'évaluation des coûts des soins aigus en traumatologie ; (2) estimer l'utilisation des ressources pour les soins aigus en traumatologie, identifier les déterminants de cette utilisation et en évaluer la variation inter-hospitalière et (3) développer un indicateur de l'intensité d'utilisation des ressources pour les soins aigus en traumatologie et en évaluer les validités interne et temporelle.

Méthodes : Pour le premier objectif, nous avons effectué une revue systématique de la littérature. Pour les second et troisième objectifs, nous avons mené des études de cohorte sur les personnes de ≥ 16 ans hospitalisées dans les centres de traumatologie pour adultes au Québec, de 2014 à 2016. Nous avons extrait les données du registre des traumatismes et des rapports financiers des hôpitaux et estimé l'utilisation des ressources avec des coûts par centre d'activité hospitalière. Pour le second objectif, nous avons identifié les déterminants avec un modèle linéaire multi-niveau, déterminé leur importance relative avec le coefficient f^2 de Cohen et évalué la variation avec le coefficient de corrélation intra-classe (CCI) et son intervalle de confiance à 95%. Pour le troisième objectif, nous avons effectué les analyses par niveau de désignation des centres de traumatologie (I/II et III/IV). Nous avons développé des modèles d'ajustement pour tous les patients et pour des groupes diagnostics spécifiques puis évalué les validités interne et temporelle avec respectivement le coefficient de détermination (r^2) et le r^2 annuel.

Résultats : Pour la revue systématique, 10 études étaient éligibles. L'évaluation des hôpitaux était ajustée selon l'état des patients à l'arrivée dans seulement cinq études (50%). Dans la seconde étude (n = 32,411), les plus importantes composantes de l'utilisation des ressources étaient les soins réguliers (57%), le bloc opératoire (23%) et les soins intensifs (13%). Le plus important déterminant était la destination à la sortie de l'hôpital (f^2 = 7%). La plus grande utilisation des ressources était observée pour les blessures médullaires : 11193$ (7115-17606) par admission. Alors que l'utilisation des ressources augmentait avec l'âge pour les soins réguliers, elle diminuait avec l'âge pour le bloc opératoire. L'utilisation des ressources était 19% plus élevée dans les centres de niveau I versus niveau IV. Nous avons observé une variation inter-hospitalière significative de l'utilisation des ressources (CCI = 5% [4-6]), particulièrement pour le bloc opératoire (28% [20-40]). Dans la troisième étude (n = 33124), les modèles expliquaient entre 11% et 30% (r^2 avec correction de l'optimisme) de la variation de l'utilisation des ressources. Globalement, la validité temporelle était élevée avec un r^2 annuel entre 29% et 30% et entre 16% et 17% pour les centres de niveaux I/II et III/IV respectivement. L'utilisation des ressources médiane était de 5014$ (Quartiles 1 et 3 : 3045-8762). Nous avons identifié des centres où l'utilisation des ressources était plus grande ou plus petite que la moyenne géométrique provinciale, globalement et pour les blessures cranio-cérébrales, orthopédiques isolées et thoraco-abdominales isolées.

Conclusions : Nos données suggèrent que 70% à 90% de l'utilisation des ressources en traumatologie au Québec est dictée par des facteurs autres que le statut clinique des patients. Nous avons développé un indicateur pour identifier les variations de l'utilisation des ressources dans un même centre/système de traumatologie, au fil du temps, ou entre centres/systèmes de traumatologie dans un(e) même province/pays. Cet indicateur ainsi que les déterminants de l'utilisation des ressources que nous avons identifiés peuvent servir de données probantes pour l'allocation des ressources et l'élaboration d'interventions visant à améliorer l'efficience des soins en traumatologie. Présentement, des études examinent l'association entre l'intensité d'utilisation des ressources et les résultats cliniques des patients à partir des méthodes développées dans ce projet. Les études futures devraient identifier les déterminants des variations inter-hospitalières de l'utilisation des ressources.

Abstract

Background: Injuries are the 5th leading cause of hospitalization in Canada and their care cost 16 billion dollars in 2010. Studies in the United States suggest that resource use for acute injury care may be driven by factors other than the clinical status of patients. However, the lack of tools to measure and monitor resource use intensity has hampered the development of interventions aiming to improve the efficiency of injury care.

Objectives: Our goal was to develop and validate a hospital indicator of resource use intensity for injury admissions. Our objectives were to (1) review how data on costs have been used to evaluate injury care; (2) estimate patient-level resource use for injury admissions, identify determinants of resource use intensity, and evaluate inter-hospital variations in resource use; and (3) develop a hospital indicator of resource use intensity for injury admissions, and evaluate its internal and temporal validity.

Methods: For the first objective, we conducted a systematic review of the literature. For the second and third objectives, we conducted retrospective, multicenter cohort studies based on ≥ 16-year-olds admitted to adult trauma centers in Quebec from 2014 to 2016. We extracted data from the Quebec trauma registry and hospital financial reports and estimated resource use with activity-based costs. For the second objective, we identified determinants using a multilevel linear model and assessed their relative importance with Cohen's f^2, and evaluated variations with intraclass correlation coefficients (ICC) and 95% confidence intervals. For the third objective, we conducted analyses by trauma center designation level (I/II and III/IV). We developed risk-adjustment models using a competing risks framework for the whole sample and for specific diagnostic groups. We assessed model internal validity with the optimism-corrected coefficient of determination (r^2), and temporal validity with yearly r^2. We performed benchmarking by comparing the adjusted geometric mean cost of each center, obtained using shrinkage estimates, to the provincial geometric mean.

Results: In our systematic review, we identified 10 eligible studies, of which nine were conducted in the United States. Hospital comparisons were adjusted according to patient case mix in only five studies (50%). In our second study (n = 32,411), activity centers associated with the greatest resource use were the regular ward (57%), followed by the operating room (23%) and the intensive care unit (13%). The strongest determinant of resource use was discharge destination (f^2 = 7%). Among injury types, the highest resource use was observed for spinal cord injuries: $11,193 (7115-17,606) per admission. While resource use increased with increasing age for the regular ward, it decreased with increasing age for the operating room. Resource use was 19% higher in level I centers compared to level IV centers and we observed significant variations in resource use across centers (ICC = 5% [4-6]), particularly for the operating room (28% [20-40]). In our third study (n = 33,124), the risk-adjustment models explained between 11% and 30% (optimism-corrected r^2) of the variation in resource use. Temporal validity in the whole sample was high with yearly r^2 between 29% and 31% and between 16% and 17% for level I/II and III/IV centers, respectively. Median resource use in the whole sample was $5014 (Quartiles 1 and 3: 3045-8762). In the whole sample and among patients with traumatic brain, isolated orthopedic and isolated thoracoabdominal injuries, we identified centers with higher or lower than expected resource use.

Conclusions: Our review highlighted the need for more data on trauma center resource use, particularly in single-payer healthcare systems. Results from our second and third studies suggest that between 70% and 90% of the variation in resource use for injury care in Quebec is dictated by factors other than the clinical status of patients on arrival. We developed an indicator to identify variations in resource use intensity within a single trauma center or system over time, or across provinces or countries. This indicator and the determinants of resource use intensity we identified can be used to establish evidence-based resource allocations and design high-impact interventions to improve the efficiency of acute injury care. Research is underway to examine the association between hospital resource use intensity and clinical outcomes for trauma patients based on the methods we developed. Future research should identify determinants of inter-hospital variations in resource use intensity and aspects of resource use that drive optimal patient outcomes.

Table des matières

Liste des tableaux

Liste des figures

Liste des abréviations

AIS score : severity score of the Abbreviated Injury Scale
CI : confidence intervals
CHU : Centre Hospitalier Universitaire
ICC : intraclass correlation coefficients
MED-ECHO : Maintenance et Exploitation des Données pour l'Étude de la Clientèle Hospitalière
mmHg : millimeter of mercury
SAS : Statistical Analysis System
Q1 : quartile 1
Q3 : quartile 3

Dédicace et épigraphe

À mes parents, affectueusement.

« Et quand j'aurais le don de prophétie, la science de tous les mystères et toute la connaissance, quand j'aurais même toute la foi qui transporte les montagnes, si je n'ai pas l'amour, je ne suis rien. »
1 Corinthiens 13 : 2

Remerciements

Si j'ai pu mener ce projet de recherche à terme, c'est parce que, tout au long du processus, j'ai été encadrée et motivée par de merveilleuses personnes. À cet effet, j'adresse mes remerciements au Dr Lynne Moore, ma superviseuse de thèse, pour son mentorat, son soutien moral, sa flexibilité et sa disponibilité. Je remercie également les Drs Gilles Bourgeois, Jean Lapointe, Julien Clément et Catherine Truchon pour leurs conseils et suggestions qui nous ont permis de répondre aux besoins réels de l'Institut national d'excellence en santé et en services sociaux. Mes remerciements s'adressent aussi aux Drs Gaston De Serres, Denis Talbot et James Hanley : les Drs De Serres et Talbot ont évalué mon protocole de recherche et par la suite, avec le Dr Hanley, examiné la version initiale de cette thèse ; leurs excellents commentaires m'ont permis d'améliorer mon travail en vue du dépôt final. J'adresse par ailleurs mes remerciements aux (ex-) membres de l'unité de recherche Traumatologie - Urgence - Soins intensifs de l'Axe Santé des Populations — Pratiques Optimales en Santé (SP-POS), notamment Amina Belcaid, Alexis Turgeon, Xavier Neveu, Ann-Pier Gagnon, Brice Lionel Batomen Kuimi, Brahim Cissé, Pier-Alexandre Tardif, Delwende Laure Jasmine Sawadogo, Coralie Assy, Khadidja Malloub Boukar, Marie-Pier Patton, Imen Farat, Marie-Joelle Cossi et Caroline Léger pour leur support. Mes vifs remerciements vont en outre à Amina pour sa disponibilité et son soutien moral, à Alexis pour ses conseils, à Xavier pour son appui incontestable en statistiques et à Jasmine, Coralie et Khadidja pour les excellentes soirées que nous avons passées les unes chez les autres. Je ne peux oublier de remercier mes camarades, amis et complices José Massougbodji, Rhéda Adekpedjou, Aminata Mboup, Victoria Massamba, David Auguste et Aboubacar James Sidibé pour leur soutien.

En outre, j'exprime ma reconnaissance à mes parrains et amis d'Evangel – Grant Freak, Anne-Claire Charette, maman Aline Boudreau, Caroline Lobè, Gaétan Lensi, Bonita Forget, Annie Gilbert, Hélène Morel, Valérie Péloquin, Simons Paul, Cathy Gérard, Gloria Miranda, Richard Amissah Quansah, Calvine Djouechek, Koffi Dominique Helena Yapi, Peggy Tadi, Prenitha Mercy, Janice Alexandra Allah, Grâce Ngambo, Wayne Cyr et les autres – pour leur soutien quotidien. Je suis également reconnaissante à Richard pour avoir relu chacun des chapitres de cette thèse avant le dépôt initial, et cela même à la dernière minute, et à Helena pour son support inestimable et sa présence en tout temps.

Enfin, je ne peux terminer sans témoigner mon immense gratitude à ma famille – Etienne Judicaël Porgo, mon père, Caroline Kando, ma mère, Brice Anicet, Pegdwendé Diane et Eric Armel Rellebamba Porgo, mes frères et sœur ; Ludovic Sabadja, mon beau-frère ; Alexis Bado, mon oncle maternel, Éloise Ouédraogo, son épouse ; et William Bado, mon cousin – pour m’avoir encouragée et sans cesse cru en moi.

Avant-propos

Cette thèse de doctorat s'inscrit dans le cadre d'un projet de collaboration internationale dont le but est d'évaluer l'association entre l'intensité d'utilisation des ressources hospitalières et la qualité des soins prodigués aux patients hospitalisés pour un traumatisme. Ce projet a reçu le financement des Fonds de la Recherche du Québec - Santé (subvention de recherche numéro 2017-3070) et des Instituts de Recherche en Santé du Canada (subvention de recherche numéro 358052). Exceptionnellement en tant qu'étudiante, j'ai moi-même participé à la demande de subvention aux Instituts de Recherche en Santé du Canada dans le cadre du programme des Partenariats pour l'amélioration des systèmes de santé.

Ma thèse s'articule autour des trois articles scientifiques suivants :

1. Porgo TV, Moore L, Shemilt M, Bourgeois G, Lapointe J. Trauma center performance evaluation based on costs: a systematic review of cohort studies. *J Trauma Acute Care Surg*. 2014;76(2):542-8 (Chapitre 2).
2. Porgo TV, Moore L, Truchon C, Berthelot S, Stelfox HT, Cameron PA, Gabbe BJ, Hoch JS, Evans DC, Lauzier F, Bernard F, Turgeon AF, Clément J. Patient-level resource use for injury admissions in Canada: a multicenter retrospective cohort study. Soumission prochaine (Chapitre 3).
3. Porgo TV, Moore L, Assy C, Turgeon AF. Development and validation of a hospital indicator of resource use intensity for injury admissions. Soumission prochaine (Chapitre 4).

En plus de ces trois articles, j'ai également effectué une revue systématique de la littérature sur la qualité des données dans les registres de traumatismes (Annexe 1) :

Porgo TV, Moore L, Tardif P-A. Evidence of data quality in trauma registries: a systematic review. *J Trauma Acute Care Surg*. 2016;80(4):648-58.

Le nombre d'études réalisées à partir des registres de traumatismes est déjà important et augmente sans cesse. Ces études contribuent non seulement à l'amélioration de la qualité des soins prodigués aux patients blessés, mais aussi à une meilleure allocation des ressources financières aux centres de traumatologie. La piètre qualité des données utilisées pour mener ces études peut avoir des conséquences importantes pouvant aller jusqu'à l'invalidation des conclusions et recommandations issues de ces études. Ma revue systématique de la littérature a donc permis d'identifier les particularités des registres de traumatismes qui nécessitent une amélioration afin de mener des études valides. L'intérêt suscité à la suite de la publication de cette revue a été vif au point qu'il a mené à un échange de lettres aux éditeurs, dont la réponse suivante (Annexe 2) :

Porgo TV, Moore L. Re: Evaluating data quality in trauma registries. *J Trauma Acute Care Surg*. 2016;81(5):993.

En tant qu'auteure principale des articles insérés dans ma thèse, j'ai participé à la conception des études et effectué le nettoyage des données ainsi que les analyses. J'ai également été responsable de l'interprétation des résultats et de la rédaction des manuscrits. De légères modifications ont été apportées aux articles afin d'assurer la cohérence de la thèse.

Mes résultats de recherche ont été présentés à des conférences au niveaux national et international ; à savoir aux/à :

- Journées de la recherche en santé de l'Université Laval, Québec, 24 mai 2018
- L'Institut national d'excellence en santé et en services sociaux, Québec (et Montréal en visio-conférence), 13 juin 2014, 19 juin 2017, 18 mai 2018
- Club de lecture de l'Axe SP-POS à l'Hôpital du Saint-Sacrement, Québec, 17 mai 2018
- Singapore Trauma and Acute Care Conference, Singapore, 12 avril 2014, 20 avril 2018
- Concours Ma thèse en 180 secondes de l'Université Laval, Québec, 1er mars 2018
- Colloque Traumatologie : Défis ! au Château Frontenac, Québec, 26 février 2015, 24 février 2016
- Concours Cogito de l'Université Laval, Québec, 29 octobre 2015
- McGill University Department of Epidemiology, Biostatistics and Occupational Health 50th Anniversary Conference, Montréal, 30 April-1 Mai 2015
- Trauma Association of Canada Annual Scientific Meeting, Whistler, 11-13 avril 2013, Calgary, 10-11 avril 2015
- L'Unité de recherche Traumatologie - Urgence - Soins intensifs de l'Axe SP-POS, Québec, 4 avril 2014, 31 octobre 2014
- Journée scientifique du Centre de recherche du Centre Hospitalier Universitaire (CHU) de Québec, Québec, 20 octobre 2014
- American College of Epidemiology Scientific meeting, Silver Spring (États-Unis), 8 septembre 2014

- Congrès de l'Association Francophone pour le Savoir, Québec, 10 mai 2013

Les présentations ci-dessus indiquées ont conduit à la diffusion d'émissions sur *Canal Savoir*, dont l'importance a été soulignée dans le journal *Lefil*, et à la publication de résumés de conférences :

- Comment évaluer la qualité, l'efficience et le coût moyen des soins en traumatologie au Canada? *Canal Savoir*
- Jeunes et passionnés: Quinze étudiantes et étudiants à la maîtrise ou au doctorat communiquent leur passion pour la recherche sur les ondes de Canal Savoir. *LeFil*. 14 avril 2016; 51(24).
- Porgo TV, Moore L, Lavoie A, Nshimyumukiza L, Turgeon A, Bourgeois G, Lapointe J, Cisse B, Duplantie J. Resource use intensity in a mature, integrated Canadian trauma system: a multicenter cohort study. *CJS*. 2015;58 (2 Suppl 1):8.
- Porgo TV, Moore L, Reinartz D, Bourgeois G, Lapointe J Turgeon A. Resource use intensity in a mature, integrated Canadian trauma system: a multicenter cohort study. *Annals of epidemiology*/Abstract from the American College of Epidemiology. 2014;24(9):690.
- Porgo TV, et al. Trauma Association of Canada, Annual Scientific Meeting, Whistler, BC. Evaluation of acute care hospitalization costs for trauma hospital performance evaluation: a systematic review. *CJS*. 2013;56 (2 Suppl): 2-3.

Durant mon cursus doctoral, 15 prix et bourses m'ont été décernés pour l'excellence de mon dossier et/ou la qualité de mes présentations :

- Prime de dépôt initial de thèse avant la fin de la 13ème session, Faculté des études supérieures et postdoctorales, Université Laval, 2018
- Meilleure communication orale, Journées de la recherche en santé de l'Université Laval, 2018
- Bourse de subvention pédagogique pour conférence, Association des étudiantes et des étudiants de Laval inscrits aux études supérieures, Université Laval, 2018
- Bourse de persévérance de la Faculté de médicine de l'Université Laval, 2018
- Best oral presentation, Singapore Trauma and Acute Care Conference, College of Surgeons of Singapore, 2018
- Bourse pour publication comme premier auteur, Faculté de médecine, Université Laval, 2017
- Student travel award, the Canadian traumatic brain injury research consortium, 2017
- Bourse pour publication comme premier auteur, Faculté de médecine, Université Laval, 2016
- Concours Cogito, Université Laval, 2015-2016
- Prime de réussite de l'examen de doctorat (protocole de recherche) avant la fin de la 5ème session, Faculté des études supérieures et postdoctorales, Université Laval, 2015
- Bourse Éric Dewailly, Centre de recherche du CHU de Québec, 2015

- Bourse pour publication comme premier auteur, Faculté de médicine, Université Laval, 2014
- Bourse pour conférence, Axe SP-POS, 2015
- Bourse Pierre J. Durand, Faculté de médecine, Université Laval, 2014
- Best oral presentation, Singapore Trauma and Acute Care Conference, College of Surgeon of Singapore, 2014

Ces dernières années, j'ai acquis une très grande expérience auprès des membres de mon unité de recherche. Par ailleurs, l'occasion m'a été donnée d'effectuer deux activités extra-universitaires durant mon cursus doctoral, soit un stage à l'Organisation mondiale de la santé (OMS), à Genève, dans le Département d'Informations, d'Évidences et de la Recherche et une consultation au sein du Département Santé, Nutrition et Population de la Banque mondiale, à Washington D.C. Durant le stage à l'OMS, j'ai pu accroître mes connaissances en matière de synthèse d'évidences et acquérir de nouvelles compétences concernant le développement de guides pour la pratique clinique et la santé publique basés sur des données probantes. En tant que consultante à la Banque mondiale, j'ai pu mettre en application les connaissances acquises lors de la préparation de mon doctorat dans le domaine du développement international. Dans le cadre de la consultation, j'ai, entre autres, assisté le ministère de la santé du Togo à identifier les indicateurs de qualité qui devraient être développés pour améliorer la qualité des hôpitaux publics, au niveau central et régional, dans le cadre d'un projet de renforcement du système de santé du pays.

CHAPTER 1. INTRODUCTION

1.1. The healthcare burden of injuries in Canada

Traumatic injury is defined as "the physical damage that results when a human body is suddenly or briefly subjected to intolerable levels of energy."[1] More than 10,000 individuals suffer injury every day in Canada and 93% of these individuals are treated in emergency rooms.[2] Injuries are the 5th leading cause of hospitalization in Canada.[2] Across the nine provinces contributing to the national trauma registry, 15,190 admissions for major injuries (Injury Score Scale > 12) resulted in 218,265 hospital days in 2011.[3] In that year, the average length of stay per admission was 15 days.[3] The estimated direct healthcare cost due to injuries was 15.9 billion Canadian dollars in 2010.[2]

1.2. The societal burden of injuries in Canada

With 43 deaths daily,[2] injury is the leading cause of mortality in individuals between the ages of 1 and 45 years in Canada.[4] Injury is also responsible for 165 physical disabilities every day in Canada[2] and for more potential years of life lost than cancer and cardiovascular diseases combined.[5] The estimated indirect cost (loss of productivity due to hospitalization, disability, and premature death) due to injuries was 10.9 billion Canadian dollars in 2010.[2]

1.3. Trauma systems

Trauma systems are designed to provide timely care to injured patients on a 24-hour basis in a given geographical area.[6, 7] Trauma systems are characterized by a continuum of care from pre-hospital to social re-integration services.[8, 9] In the acute phase of injury, patients are treated in specialized and ultra-specialized hospitals called trauma centers.[10] Trauma centers in North America are generally designated according to four levels of care from highly specialized urban level I to rural community level IV.[10] Trauma centers are designated by the Ministry of Health and Social Services in Quebec. Trauma center accreditation/verification is conducted by the Institute of healthcare excellence (Institut national d'excellence en santé et services sociaux) in Quebec, by Accreditation Canada in collaboration with the Trauma Association of Canada elsewhere in Canada, and by the American College of Surgeons Committee on Trauma and/or state agencies in the United States.[6, 7, 9, 11] In Quebec, implementation of the trauma system began in 1993 and was completed in 1996.[12] The system encompasses 59 trauma centers: 5 level I (2 are pediatric), 5 level II, 21 level III, and 28 level IV centers.

Trauma systems are either inclusive (also referred to as integrated or regionalized) or exclusive. Inclusive trauma systems, such as the trauma system in Quebec, comprise different levels of injury care and standardized pre-hospital protocols ensure that severe cases are transported directly to definitive care or stabilized in the closest center before being transferred to a higher level center if necessary (see the Quebec trauma care continuum in Table 1.1).[9, 13, 14] Conversely, exclusive trauma systems, like in Ontario, are based uniquely on highly specialized trauma centers.

The implementation of trauma systems has led to significant reductions in injury mortality and morbidity.[12, 15, 16] It is estimated that patients who are treated in a trauma center have a 30% lower mortality risk compared to patients treated in a non-designated hospital.[16]

1.4. Resource use in trauma centers

The Agency for Healthcare Research and Quality of the United States Department of Health and Human Services defines resource use as the amount or cost of equipment and services involved in an episode of care.[17] 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. In addition, risk-adjusted costs of injury care, estimated using patient charges, are higher in trauma centers than in non-designated hospitals.[18-20] In the United States, patients with moderate and major injuries (Abbreviated Injury Scale ≥ 3) treated in trauma centers generated a total adjusted mean cost of 47,933 American dollars compared to 27,986 American dollars for patients treated in non-designated hospitals in 2010.[20] Moreover, the incremental cost per life saved for treatment at a trauma center compared to non-designated hospitals has been estimated to be 790,931 American dollars.[20]

Significant variations in risk-adjusted resource use among trauma centers in the United States have been observed but centers with higher risk-adjusted resource use did not have better patient outcomes.[21-23] For example, the adjusted costs for trauma centers with adjusted mortality rates below average were 22% lower than that for centers with average adjusted mortality rates.[21] These variations have important implications. First, they suggest that resource use for trauma patients may be dictated by factors other than the clinical status of patients. This means that there still exist areas that require better resource allocation and costs containment in injury care.[24, 25] Second, these variations raise important concerns about the safety of patients since overuse of resources may increase patients' risk of complications due to unnecessary interventions as well as hospital-acquired infections, and functional decline due to unnecessary hospital days.[26-28] Limitations of previous studies on the cost of injury care include the use of patient charges converted into costs of care.[21-23] Cost estimates based on patient charges may not represent real resource use (see Valuation methods).[29, 30] Moreover, in these studies, robust adjustment for all potential patient confounders was not always used in inter-hospital comparisons of costs.[21-23]

Attempts to improve resource use for injury care have been hampered by the lack of data on patient-level resource use, especially in countries with a single-payer healthcare system such as Canada.[31-35]

Table 1.1. The Quebec injury care continuum

Level	Definition	Clientele	Goal
Rural: Medical stabilization services	This type of facility is located more than 30 minutes from a trauma center. It ensures that accident victims are medically stable within 10 minutes and provides a medical escort during ambulance transport for victims in need of emergency care.	Trauma victims with a prehospital index of four or over or who have been involved in a high-speed collision.	Perform medical resuscitation where a victim shows no vital signs and rapidly transport a victim to the nearest designated trauma care and services center.
IV: Primary trauma care and services centres	Facilities offering general surgery and anesthesia, located more than 30 minutes away from a secondary or tertiary trauma care and services center.	Victims of trauma not showing systemic complications yet needing surgical stabilization prior to transfer to a facility offering more specialized care.	To provide critical and acute care to victims of trauma who do not show life-threatening local or systemic complications; after stabilization, transfer of trauma victims to a secondary or tertiary trauma care and services centre.
III: Secondary trauma care and services centres	Facilities offering general surgery, orthopaedic care, critical care and early rehabilitation. Some regional secondary trauma centers, which are part of a consortium of care and social facilities. They are responsible for providing highly specialized neurotrauma services in their region.	Severe trauma and multiple trauma victims who do not require the services of tertiary trauma care and services centres or expert care centers.	Provide immediate and on-site critical and acute care to victims of severe trauma who do not require tertiary trauma care. Provide early rehabilitation, when needed, and rapidly transfer trauma victims who require tertiary centre care or expert care to the appropriate facility.
II: Tertiary trauma care and services centers	Facilities that offer specialized and highly specialized trauma care, neurosurgery, specialized intensive care and early interdisciplinary rehabilitation. These facilities carry out some of their work as part of a consortium or expert care centers.	Severe multiple trauma, neurotrauma and pediatric victims.	Provide critical and acute care where needed and offer interdisciplinary early rehabilitation. Transfer victims in need of rehabilitation according to service corridors.
I: Expert care centers for specific types of trauma	Facilities that provide expert care for victims of spinal cord injuries, severe burns or individuals who require emergency reimplantation microsurgery. These facilities carry out their work as part of a consortium known as an expert care center.	Victims of spinal cord injuries, severe burns and individuals who require emergency reimplantation microsurgery.	Provide expert care and early interdisciplinary rehabilitation services to individuals who require it. Facilities that comprise the expert care center share responsibility to ensure the optimal transfer of trauma victims to regional rehabilitation facilities.

Obtained from the Quebec Institute of healthcare excellence (Institut national d’excellence en santé et services sociaux) website.[9]

1.5. Hospital indicators

In order to ensure high-quality care and optimal outcomes for patients, many trauma systems monitor trauma centers using hospital indicators.[6] These indicators classically measure performance according to the three elements of Dr. Avedis Donabedian's model of healthcare quality, proposed in 1960: structure, process, and outcome.[36-38] Structure represents the characteristics of the healthcare setting, process describes the set of interventions provided in the healthcare setting, and outcome indicates the end result of the clinical process.[38] Outcome indicators involve mortality, complications, unplanned re-admissions, resource use, ability to function in daily life, and patient satisfaction.[38]

In the absence of quality standards, hospital indicators are designed to identify potentially unwarranted inter-provider variations.[39, 40] Hospital indicator scores are thus compared to an expected (benchmark) value, for example average mortality in a trauma system, and hospitals with high or low indicator scores are noted for further investigation to identify root causes for quality improvement.[39] For example, in the United Kingdom, the Trauma Audit and Research Network identified a trauma center whose adjusted mortality rate was higher than expected for more than a year.[41] Investigations revealed that this situation was attributable to a low rate of transfers of patients with major head trauma from the trauma center to the local neuroscience center. The local neuroscience center could not accept these patients because of a lack of neurointensive care beds. After beds were added to the neuroscience center, the rate of transfers increased thus improving the adjusted mortality rate in the trauma center in question. In Quebec, as part of the trauma system quality improvement program, the trauma research unit produces benchmark reports using hospital indicators of mortality, complications, unplanned re-admission, and length of hospital stay.[12, 42-44] These reports are published on the website of the Institute of healthcare excellence over verification cycles, and are made accessible to hospital trauma committees. Committees also have access to a document providing definitions and references for each quality indicator, a document and video capsule that explain how to interpret results and how to act upon them, algorithms to identify patients flagged by indicators (charts are then extracted and discussed in committee meetings), and analytical support to drill down data.

Reports are confidential such that only the trauma center targeted by the report is identified. Committees are then required to submit an audit-feedback report to the Institute of healthcare excellence targeting root causes and possible solutions for indicators for which they are flagged (performance lower than the provincial mean). They are then re-evaluated in a subsequent cycle.

1.5.1. The need for a hospital indicator of resource use intensity for injury care

Although waste avoidance is one of the key properties of a high-quality healthcare system,[45] between 20% and 40% of health budgets in the world is wasted on low-value care according to the World Health Organization.[46] The consequences of this waste could be particularly important in Canada since provinces and territories spend nearly 40% of their budgets on hospital services.[47] Furthermore, given limited existing healthcare resources, optimizing resource use has become a priority among decision-makers and stakeholders worldwide.[45, 48-50] These past years, addressing unjustified variations in resource use intensity has been one of the main ways to address healthcare waste.[50-52] Indeed, by emulating the Dartmouth Atlas Project which has examined regional variations in the practice of and expenditure for healthcare in the United States for more than two decades,[52] projects on medical practice variations have been developed in more than 10 countries in America, Europe, and Oceania.[50] In the context of injury care, a 2013 scoping review of the literature found that hospital length of stay, intensive care unit length of stay, ventilator length of stay, inappropriate hospital stay, and potentially unnecessary care have all been used to describe resource use.[53] However, as shown in this review and another scoping review, there is currently no hospital indicator of resource use intensity based on costs available to monitor injury care.[53, 54] Such an indicator will not only reflect hospital length of stay but also intensity of care.[35]

1.5.2. Developing hospital indicators

Uniform reporting and coding procedures across hospitals are prerequisites for meaningful inter-provider comparisons.[39, 55] Moreover, patient characteristics that (1) explain severity of illness on arrival and (2) are significantly associated with the outcome of interest can lead to confounding.[56, 57] Consequently, hospital indicators should always be adjusted according to the type of patients treated in hospitals (patient case mix)[40, 57, 58] using validated risk-adjustment models.[57]

In the field of trauma, baseline risk encompasses three spheres: pre-injury physiological reserve, anatomical injury severity, and the physiological response to injury. Pre-injury physiological reserve is the health of patients before they sustain an injury; it is generally described using patients' age, sex, and comorbidities. Anatomical injury severity relates to the severity of injuries and is usually described using metrics based on the severity score of the Abbreviated Injury Scale (AIS score).[59] These metrics include the Maximum Abbreviated Injury Scale, the Injury Severity Score, and the New Injury Severity Score. The Maximum Abbreviated Injury Scale is the highest AIS score, the Injury Severity Score is the sum of squares of the highest AIS scores for the three most severely injured body regions, and the New Injury Severity Score is the sum of squares of the three highest AIS scores; that is, the three most severe injuries, irrespective of body region.[59] Lastly, physiological response to injury is generally described with the Glasgow Coma Score, respiratory rate and systolic blood pressure, measured on arrival at the acute care center under evaluation (before care is dispensed so they are independent of quality of care).

1.6. Estimating resource use for acute injury care

1.6.1. Steps for resource use estimation

The Canadian Agency for drugs and technologies recommends the following five steps for estimating resource use: (1) determine the decision problem, (2) identify relevant resources, (3) measure resources, (4) conduct valuation of resources, and (5) report costs.[35] The first step involves defining the target population, setting, and time horizon for resource use valuation. Thereafter, all relevant interventions pertaining to the target population, setting, and time horizon should be identified. Resources should then be measured using physical units, for example, the number of hospital days. Valuation of resources consists of assigning costs or fees (charges) to resources. At this step, costs are preferred over fees. Indeed, cost is the amount needed for an intervention while a fee is the amount charged for an intervention. Lastly, descriptive data on the physical units measured as well as the costing method chosen, cost of each physical unit, databases used, and calculations performed should be transparently presented.

1.6.2. Valuation methods

There are four main approaches for valuing acute care resource use using costs: cost-to-charge ratios, per diem, case mix (or diagnosis-related) groups, and activity-based costing methods. The cost-to-charge ratios costing method is used in countries with a for-profit healthcare system such as the United States. It involves converting patient charges for each medical service to cost estimates using the corresponding cost-to-charge ratio in the hospital's costs report.[29] Research demonstrates that this approach grossly over- or under-estimates real costs.[30] The per diem costing method involves multiplying a uniform daily cost by patient length of stay. This method can yield resource use data for each patient.[35] However, it only captures differences in length of stay rather than differences between levels of care (for example regular ward versus intensive care). 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.[35] Each case mix group is then assigned a uniform cost regardless of the hospital where patients are treated. Inter-provider comparisons are not possible with this method since it cannot be used to discriminate resource use across hospitals. Moreover, research has shown that this method of costing underestimates actual costs in trauma patients, particularly in patients with major injuries.[31-34] Activity-based costing is the most precise and patient-specific costing method because it accounts for each patient's individual care trajectory.[35, 60-64] It is similar to the patient costing method or the case, unit, micro-, or bottom-up costing methods in Canada.[35] 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.[60-66] Moreover, it can be used to evaluate inter-provider variations in resource use since resource use is patient-specific. Activity-based costing also facilitates the identification of areas of sub-optimal utilization of resources that are directly actionable because it relates costs to hospital activity centers. Moreover, the activity-based costing method can yield estimates of resource use that are not influenced by temporal or geographical variations, in line with guidelines of the Grading of Recommendations Assessment, Development and Evaluation group.[66]

1.6.3. The use of activity-based costing for injury care

The activity-based costing approach is rarely used in the Canadian setting since it requires detailed information on each patient's medical care which is rarely available in existing databases.[35] However, in the context of trauma, these data are available through trauma registries. Trauma registries are clinical databases[41] designed to systematically and continuously capture information on patient demographics; type, mechanism and severity of injuries; physiological data; diagnostic and therapeutic interventions; complications; outcomes; and discharge destinations. Detailed clinical data are not available in administrative databases.[41]

Despite the availability of trauma registries and the advantages of the activity-based costing method, only a limited number of studies have estimated patient-level resource use for acute injury care using activity-based costs. We identified four studies conducted in global injury populations (non-specific pathologies) available in English, Spanish, Italian, or French. Two were conducted in the United Kingdom (England and Wales), one on blunt injuries[67] and the other on penetrating injuries.[68] These two studies used the Trauma Audit Research Network database, from 2000 to 2005, which only included data from 50% of all hospitals receiving trauma patients in the United Kingdom during the study period.[67, 68] In addition, these studies neither assessed patient comorbidities as a determinant of resource use nor investigated inter-hospital variations in resource use. The other two studies used 2008-2009 data from the New South Wales regional trauma registry, Australia.[34, 69] However, the inclusion criteria in this registry were not uniform for all trauma centers, and neither the distribution of costs across activity centers nor the variations in resource use across hospitals were assessed.

The Quebec trauma system represents an ideal setting to assess resource use in injury care. Contribution to the registry is mandatory for all 59 trauma centers in the system. Inclusion criteria are uniform across hospitals (death due to injury, intensive care unit admission, hospital stay > 2 days or transfer from another hospital). The registry offers high population coverage; it is estimated that it contains data on 92% of major injury admissions in the province.[70] As for data on costs, they can be accessed from hospital financial reports (AS-471 files), which are freely available on the website of the Ministry of Health and Social Services.[71] The AS-471 files contain unit costs by hospital activity center and are released annually.[71] Unit costs include variable direct costs related to expenditures for non-physician personnel, services, and materials.[72]

1.7. Summary

The high cost of injury care coupled with the unjustified variations in resource use intensity observed across trauma centers in the United States makes injury care an extremely promising area for resource use improvement. Yet, there is still a knowledge gap on patient-level resource use for injury admissions due in part to methodological limitations with regard to resource use valuation[35] and lack of a hospital indicator of resource use intensity.[53, 54] On the one hand, patient-level data on resource use are needed to identify drivers of resource use to inform resource allocation strategies.[24, 25, 73] On the other hand, a hospital indicator of resource use intensity is needed to address unwarranted variations across trauma centers.[40, 50, 51] A hospital indicator of resource use will inform quality improvement interventions which have the potential to alleviate the financial burden of injury care and reduce the risk of complications, hospital-acquired infections and functional decline,[26-28] but also allow “saved” resources to be directed to more patients who need them.[50] A hospital indicator of resource use intensity is also needed to set priorities, evaluate the progress of hospitals towards achieving specific objectives, and identify persistent variations over time.[9]

1.8. Objectives

This project is a direct response to a need expressed by our provincial Institute of healthcare excellence to develop a hospital indicator of resource use intensity to be implemented in the Quebec trauma system quality improvement program.[42] Our goal was to develop and validate a hospital indicator of resource use intensity for injury admissions. We achieved this goal with the following three objectives:

1. Review how data on costs have been used to evaluate injury care;
2. Estimate patient-level resource use for injury admissions, identify determinants of resource use intensity, and evaluate inter-hospital variations in resource use; and
3. Develop a hospital indicator of resource use intensity for injury admissions and evaluate its internal and temporal validity.

1.9. Thesis layout

In the following pages, I first present the three studies undertaken to fulfill our goal, each with its objective(s), methods, results, discussion, and conclusions. These studies are entitled:

1. Trauma center evaluation based on costs: a systematic review of cohort studies (Chapter 2);
2. Patient-level resource use for injury admissions in Canada: a multicenter retrospective cohort study (Chapter 3); and
3. Development and validation of a hospital indicator of resource use intensity for injury admissions (Chapter 4).

I then wrap up by discussing the overall project, its impact and external validity, and future research.

1.10. References

1. The World Health Organization. Injuries and Violence: the fact. Geneva: the World Health Organization; 2010.
2. Parachute (2015). The Cost of Injury in Canada. Parachute: Toronto, ON. Available at: http://www.parachutecanada.org/downloads/research/Cost_of_Injury-2015.pdf. Accessed August 25, 2015.
3. The Canadian Institute for Health Information. National Trauma Registry Report 2013: Hospitalizations for Major Injury in Canada, 2010-2011. Ottawa, ON: The Canadian Institute for Health Information; 2013.
4. The Public Health Agency of Canada. Facts on injury. https://www.canada.ca/en/public-health/services/injury-prevention/facts-on-injury.html. Modified: March 1, 2016. Accessed March 8, 2018.
5. The Public Health Agency of Canada. Leading causes of death and hospitalization in Canada. http://www.phac-aspc.gc.ca/publicat/lcd-pcd97/table1-eng.php. Modified: March 1, 2016. Accessed August 25, 2015.
6. The Trauma Association of Canada. Trauma system accreditation guidelines. Fourth revision. Toronto, ON: the Trauma Association of Canada; 2011.
7. The American College of Surgeons Committee on Trauma. Resources for optimal care of the injured patient. Chicago, IL: the American College of Surgeons; 2014.
8. Nova Scotia Health Authority, Capital Health. Trauma System. http://www.cdha.nshealth.ca/trauma-program/system. Accessed September 4, 2015.
9. Institut national d'excellence en santé et en services sociaux. Trauma Care Continuum website. http://www.fecst.inesss.qc.ca/en.html. Accessed January 30, 2018.
10. Centers for Disease Control and Prevention. Access to trauma centers in the United States. Atlanta, GA: Centers for Disease Control and Prevention; 2009.
11. Trauma Services British Columbia. A program of the Provincial Health Services Authority. Vancouver, BC: Trauma Services British Columbia; 2014.
12. Moore L, Turgeon AF, Lauzier F, et al. Evolution of patient outcomes over 14 years in a mature, inclusive Canadian trauma system. *World J Surg*. 2015;39(6): 1397-405. .
13. Lansink KW, Leenen LP. Do designated trauma systems improve outcome? *Curr Opin Crit Care*. 2007;13(6): 686-90.
14. Sasser SM, Hunt RC, Faul M, et al. Guidelines for field triage of injured patients: recommendations of the National Expert Panel on Field Triage, 2011. *MMWR Recomm Rep*. 2012;61(RR-1): 1-20.
15. 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(2): 371-8; discussion 378.
16. Haas B, Stukel TA, Gomez D, et al. The mortality benefit of direct trauma center transport in a regional trauma system: a population-based analysis. *J Trauma Acute Care Surg*. 2012;72(6): 1510-5; discussion 1515-7.
17. The Agency for Healthcare Research and Quality. Selecting Quality and Resource Use Measures: A Decision Guide for Community Quality Collaboratives. Part III. Introduction to Resource Use/Efficiency Measures.

https://www.ahrq.gov/professionals/quality-patient-safety/quality-resources/tools/perfmeasguide/perfmeaspt3.html. Last modified: October 2014. Accessed January 29, 2018.
18. Goldfarb MG, Bazzoli GJ, Coffey RM. Trauma systems and the costs of trauma care. *Health Serv Res*. 1996;31(1): 71-95.
19. Durham R, Pracht E, Orban B, Lottenburg L, Tepas J, Flint L. Evaluation of a mature trauma system. *Ann Surg*. 2006;243(6): 775-83; discussion 783-5.
20. MacKenzie EJ, Weir S, Rivara FP, et al. The value of trauma center care. *J Trauma*. 2010;69(1): 1-10.
21. Glance LG, Dick AW, Osler TM, Meredith W, Mukamel DB. The association between cost and quality in trauma: is greater spending associated with higher-quality care? *Ann Surg*. 2010;252(2): 217-22.
22. Clancy TV, Maxwell GJ, Covington DL, Brinker CC, Blackman D. A statewide analysis of level I and II trauma centers for patients with major injuries. *J Trauma*. 2001; 51(2): 346-51.
23. Obirieze AC, Gaskin DJ, Villegas CV, et al. Regional variations in cost of trauma care in the United States: who is paying more? *J Trauma Acute Care Surg*. 2012;73(2): 516-22.
24. Porter ME. What is value in health care? N Engl J Med. 2010; 363(26):2477-81.
25. Kaplan RS, Porter ME. How to solve the cost crisis in health care. *Harv Bus Rev*. 2011; 89(9):46-52, 54, 56-61.
26. Shojania KG, Duncan BW, McDonald KM, Wachter RM. Safe but sound: patient safety meets evidence-based medicine. *JAMA*. 2002;288(4): 508-13.
27. Covinsky KE, Palmer RM, Fortinsky RH, et al. Loss of independence in activities of daily living in older adults hospitalized with medical illnesses: increased vulnerability with age. *J Am Geriatr Soc*. 2003;51(4): 451-8.
28. Carey MR, Sheth H, Braithwaite RS. A prospective study of reasons for prolonged hospitalizations on a general medicine teaching service. *J Gen Intern Med*. 2005;20(2): 108-15.
29. Research data assistance center (ResDAC). Calculating "costs": cost-to-charge ratios. http://resdac.umn.edu/sites/resdac.umn.edu/files/Calculating%20Cost%20-%20Cost-to-Charge%20Ratios%20(Slides).pdf. Accessed March 16, 2018.
30. Shwartz M, Young DW, Siegrist R. The ratio of costs to charges: how good a basis for estimating costs? Inquiry. 1995;32(4): 476-81.
31. Curtis K, Mitchell R, Dickson C, Black D, Lam M. Do AR-DRGs adequately describe the trauma patient episode in New South Wales, Australia? *HIM J*. 2011;40(1): 7-13.
32. Grotz M, Schwermann T, Lefering R, et al. DRG reimbursement for multiple trauma patients -- a comparison with the comprehensive hospital costs using the German trauma registry. *Unfallchirurg*. 2004;107(1): 68-75.
33. Taheri PA, Butz DA, Greenfield LJ. Paying a premium: how patient complexity affects costs and profit margins. *Ann Surg*. 1999;229(6): 807-11; discussion 811-4.
34. Curtis K, Lam M, Mitchell R, et al. Acute costs and predictors of higher treatment costs of trauma in New South Wales, Australia. *Injury*. 2014;45(1): 279-84.
35. The Canadian Agency for Drugs and Technologies in Health. Guidance document for the Costing of health care resources in the canadian setting. 2nd Edition. Ottawa, ON: the Canadian Agency for Drugs and Technologies in Health; 2015.

36. Donabedian A. Evaluating the quality of medical care. *Milbank Quartely*. 1966;44(3): Suppl:166-206.
37. Loeb JM. The current state of performance measurement in health care. *Int J Qual Health Care*. 2004;16 Suppl 1:i5-9.
38. Donabedian A. An introduction to quality assurance in health care. New York, NY: Oxford University Press; 2003.
39. Adab P, Rouse AM, Mohammed MA, Marshall T. Performance league tables: the NHS deserves better. *BMJ*. 2002;324: 95– 8.
40. Shafi S, Nathens AB, Cryer HG, et al. The Trauma Quality Improvement Program of the American College of Surgeons Committee on Trauma. *J Am Coll Surg*. 2009;209(4): 521-530 e1.
41. Lecky F, Woodford M, Edwards A, Bouamra O, Coats T. Trauma scoring systems and databases. *Br J Anaesth*. 2014;113(2): 286-94. doi: 10.1093/bja/aeu242.
42. Institut national d'excellence en santé et en services sociaux. Trauma Care Continuum. Continuous quality improvement objectives. http://fecst.inesss.qc.ca/en/aboutus/continuous-quality-improvement-objectives/. Accessed January 30, 2018.
43. Truchon C, Moore L, Belcaid A, et al. Shaping Quality through Vision, Structure, and Monitoring of Performance and Quality Indicators: Impact Story from the Quebec Trauma Network. *Int J Technol Assess Health Care*. 2017;33(4): 415-419.
44. Institut national d'excellence en santé et en services sociaux. Bilan de qualité et de performance en traumatologie: Guide d'accompagnement. Québec, QC: Institut national d'excellence en santé et en services sociaux; 2017.
45. Institute of Medicine (IOM). Crossing the Quality Chasm. Washington, DC: National Academies Press; 2001.
46. The World Health Organization (WHO). WHO Global Health Expenditure Atlas. September 2014. Geneva: WHO; 2014.
47. The Canadian Institute for Health Information. National Health Expenditure Trends, 1975 to 2017. Data tables. Ottawa, ON: the Canadian Institute for Health Information; 2017.
48. World Health Organization. Financing for universal coverage. Using available resources in the most efficient and equitable way. Available at: http://www.who.int/health_financing/strategy/equity_efficiency/en/. Accessed October 16, 2017.
49. The African Development Bank. High level dialogue between ministers of finance and health towards and beyond the MDGs. Tunis Declaration on value for money, sustainability and accountability in the health sector - A joint declaration by the ministers of finance and ministers of health of Africa. Available at: https://www.afdb.org/fileadmin/uploads/afdb/Documents/Generic-Documents/Tunis%20declaration%20english%20july%206%20(2).pdf. Accessed November 28, 2017.
50. Peiró S, Maynard A. Variations in health care delivery within the European Union. *Eur J Public Health*. 2015;25 Suppl 1:1–2.
51. The Lown Institute. Overuse 101. http://lowninstitute.org/learn/overuse-101/. Accessed March 19, 2018.
52. The Dartmouth Institute for Health Policy and Clinical Practice. The Dartmouth atlas of health care. http://www.dartmouthatlas.org/. Accessed March 20, 2018.

53. Moore L, Stelfox HT, Boutin A, Turgeon AF. Trauma center performance indicators for nonfatal outcomes: a scoping review of the literature. *J Trauma Acute Care Surg*. 2013;74(5): 1331-43.
54. Stelfox HT, Bobranska-Artiuch B, Nathens A, Straus SE. Quality indicators for evaluating trauma care: a scoping review. *Arch Surg*. 2010;145(3): 286-95.
55. Kardooni S, Haut ER, Chang DC, et al. Hazards of benchmarking complications with the National Trauma Data Bank: numerators in search of denominators. *J Trauma*. 2008;64(2): 273-7; discussion 277-9.
56. Hernán MA, Hernández-Díaz S, Robins JM. A structural approach to selection bias. *Epidemiology*. 2004;15(5): 615-25.
57. Iezzoni L. Risk adjustment for measuring health care outcomes, Fourth edition. Chicago, IL: Health Administration Press; 2013.
58. Willis CD, Gabbe BJ, Cameron PA. Measuring quality in trauma care. *Injury*. 2007; 38(5): 527-37.
59. Stevenson M, Segui-Gomez M, Lescohier I, Di Scala C, McDonald-Smith G. An overview of the injury severity score and the new injury severity score. *Injury Prevention*. 2001;7: 10-13.
60. West TD, Balas EA, West DA. Contrasting RCC, RVU, and ABC for managed care decisions. A case study compares three widely used costing methods and finds one superior. *Healthc Financ Manage*. 1996;50(8): 54-61.
61. Young DW. The folly of using RCCs and RVUs for intermediate product costing. *Healthc Financ Manage*. 2007;61(4):100-6, 108.
62. Ross TK. Analyzing health care operations using ABC. *J Health Care Finance*. 2004;30(3): 1-20.
63. Chan YC. Improving hospital cost accounting with activity-based costing. *Health Care Manage Rev*. 1993;18(1): 71-7.
64. Canby JB 4th. Applying activity-based costing to healthcare settings. *Healthc Financ Manage*. 1995;49(2): 50-2, 54-6.
65. The US Agency for International Development. Cost and quality in healthcare: reference manual. In Core Training Series. Bethesda, MD: The Quality Assurance Project; 2001.
66. Guyatt GH, Oxman AD, Kunz R, et al. Incorporating considerations of resources use into grading recommendations. *BMJ*. 2008;336(7654): 1170-3.
67. Christensen MC, Ridley S, Lecky FE, Munro V, Morris S. Outcomes and costs of blunt trauma in England and Wales. *Crit Care*. 2008;12(1): R23.
68. Christensen MC, Nielsen TG, Ridley S, Lecky FE, Morris S. Outcomes and costs of penetrating trauma injury in England and Wales. Injury. 2008;39(9): 1013-25.
69. Curtis K, Lam M, Mitchell R, Dickson C, McDonnell K. Major trauma: the unseen financial burden to trauma centres, a descriptive multicentre analysis. *Aust Health Rev*. 2014;38(1): 30-7.
70. Batomen BL, Moore L, Cisse B, et al. Access to an integrated trauma system: A population based-cohort study. *Injury*. 2015;46(7): 595-601.
71. Ministère de la Santé et des Services sociaux du Québec. Rapports financiers annuels des établissements 2015-2016, statsitiques et données. http://publications.msss.gouv.qc.ca/msss/document-001671/. Published 2016. Accessed March 16, 2018.

72. Ministère de la Santé et des Services sociaux du Québec. Normes et pratiques de gestion, Tome II, Répertoire. http://msssa4.msss.gouv.qc.ca/fr/document/d26ngest.nsf/1f71b4b2831203278525656b0004f8bf/c1bc430d41b48eea85257f9500673c97?OpenDocument. Published 2016. Accessed February 20, 2018.
73. The African Development Bank. Capacity building for Senior Officials and Implementers on Value for Money, Sustainability and Accountability in health and Social Sectors. Available at: https://www.afdb.org/fileadmin/uploads/afdb/Documents/Generic-Documents/Concept%20Note_02.pdf. Accessed January 29, 2018.

CHAPTER 2. ARTICLE. TRAUMA CENTER EVALUATION BASED ON COSTS: A SYSTEMATIC REVIEW OF COHORT STUDIES

Teegwendé Valérie Porgo MSc[1,2], Lynne Moore PhD[1,2], Michèle Shemilt MSc[1,2], Gilles Bourgeois MD[3], Jean Lapointe MD[3]

[1]Population Health and Optimal Health Practices Research Unit (Trauma-Emergency-Intensive care), Centre de Recherche du CHU de Québec - Hôpital de l'Enfant-Jésus, Université Laval, Quebec City, Quebec, Canada;
[2]Department of social and preventive medicine, Université Laval, Quebec City, Quebec, Canada;
[3]Institut national d'excellence en santé et en services sociaux, Montréal, Quebec, Canada

Running head: Trauma center evaluation based on costs

Key words: Trauma, evaluation, costs, systematic review

2.1. Résumé

Notre objectif était de faire une synthèse des méthodes d'évaluation des coûts des soins aigus en traumatologie. Nous avons mené une revue systématique de la littérature. Deux auteurs, de façon indépendante, ont sélectionné les études puis extrait les données. Parmi les 6635 études identifiées, 10 étaient éligibles dont neuf étaient menées aux États-Unis et une dans 10 pays Européens. Le coût des soins était utilisé dans quatre études ; la méthode d'allocation journalière était utilisée dans l'une d'elles et la méthode de calcul par centre d'activité dans une autre. Les factures des patients étaient utilisées dans les six autres études dont quatre ont utilisé la méthode rapports coûts-facturation. Les comparaisons hospitalières étaient ajustées selon l'état des patients à l'arrivée dans seulement cinq études (50%). La revue montre la nécessité de développer un outil de surveillance de l'intensité d'utilisation des ressources pour les hospitalisations en traumatologie basé sur un modèle d'ajustement validé.

2.2. Abstract

Background: More than 200,000 Canadians were admitted to hospitals following injury in 2010, with costs estimated at 15.9 billion Canadian dollars, yet data on the performance of trauma centers in terms of costs are lacking.

Objective: To review how data on costs have been used to evaluate hospitals regarding the treatment of trauma inpatients.

Methods: We performed a systematic review using MEDLINE, EMBASE, WEB OF SCIENCE, The Cochrane Library, CINAHL, and TRIP. The last search was run in December 2012. Cohort studies that evaluated hospitals regarding the treatment of injury admissions in terms of costs were considered eligible. Two authors conducted study screening and data extraction independently. Study methodological quality was evaluated using seven criteria from the Strengthening the Reporting of Observational Studies in Epidemiology statement, and the Downs and Black tool.

Results: The search retrieved 6635 studies of which 10 were eligible for inclusion. Nine studies were conducted in the United States and one in 10 European countries. Costs of care were used in four studies. The per diem costing method was used in one of these studies and the activity-based costing method was used in another study. Patient charges were used in the remaining six studies to estimate costs of care. Four of these six studies used the cost-to-charge ratios method. Average costs per patient in the 10 studies varied between 2641 and 77,710 American dollars. Hospital comparisons were adjusted according to patient case mix in only five studies (50%). Four studies (40%) were considered to be of good quality.

Conclusions: Most studies that have evaluated the performance of trauma centers in terms of costs were conducted in a for-profit healthcare system and were based on patient charges. Hospital comparisons were often performed without adjustment for patient case

mix and costs were highly variable. The review highlighted the need to develop a hospital indicator of resource use intensity for injury care based on a validated risk-adjustment model.

2.3. Introduction

Injuries have a major impact in terms of quality of life, mortality, and financial expenditure.[1,2] They are the leading cause of death among people less than 45 years of age in most industrialized countries.[1,3,4] In 2010, more than 200,000 Canadians were admitted to hospital following injuries with costs estimated at 16 billion Canadian dollars.[5] In addition, injuries ranked third healthcare condition for acute care expenditure in the United States in 2013, with costs of 99 billion American dollars.[6]

In order to ensure the quality of injury care, trauma centers must be monitored.[7] Monitoring enables decision-makers to identify and resolve problems related to the healthcare system and to better use the financial resources allocated to hospitals.[8,9] Hospital indicators available in the literature are often based on clinical outcomes such as mortality and morbidity.[10,11] Nevertheless, considering the financial burden of trauma, more data relating to the costs of injury care in individual hospitals are needed.

To date, no hospital indicator based on resource use intensity has been developed and validated specifically for acute injury care. In addition, information on the current use of cost data to monitor injury care is lacking. The objective of this study was to review how data on costs have been used to evaluate hospitals for injury admissions.

2.4. Methods

We designed a systematic review of the literature in compliance with recommendations from the Cochrane Handbook for Systematic Reviews of Interventions[12] and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement.[13]

2.4.1. Search strategy

We searched MEDLINE, EMBASE, WEB OF SCIENCE, The Cochrane Library, CINAHL, and TRIP databases using combinations of multiple search terms on the themes of trauma and costs (see Table 2.1 for search strategy in MEDLINE). The last search was run in December 2012. In addition, we manually screened the bibliographies of relevant studies to identify potentially eligible publications. No language or publication type restriction was applied.

2.4.2. Study selection

Retrospective and prospective peer-reviewed cohort studies that evaluated hospitals regarding the treatment of global trauma inpatients (that is, non-specific pathologies) using data on costs were considered eligible. Only studies conducted in high-income countries were included.

We sorted duplicates with EndNote software version X4 (Thomson Reuters, 2010, New York, United States). Two reviewers independently screened studies for eligibility by titles and abstracts, and by full text publications, when appropriate.

2.4.3. Data extraction

Two authors (TVP, LM) independently collected information on study designs (period, sample size, and inclusion criteria), study settings, primary data source, method used to evaluate hospitals, costs data, and methodological quality from eligible studies. Data on costs encompassed type of costs (real costs, charges, cost-to-charge ratios, and other cost estimations), mean (or median) cost per patient, details of costing method, cost items included, and determinants of costs. Data extraction was performed using a data extraction form previously piloted on a representative sample of three articles.

2.4.4. Study methodological quality

Study methodological quality was evaluated using the following seven elements selected from the Strengthening the Reporting of Observational Studies in Epidemiology statement[14] and the Downs and Black tool:[15] (1) sufficient sample size, (2) details of cost calculation method, (3) data quality assurance efforts, (4) case-mix adjustment, (5) measure of variation for cost outcome (that is, confidence interval or standard error), (6) appropriate treatment of missing data, and (7) sensitivity analyses. Sample size was considered sufficient if at least 100 patients per hospital were available for analysis.[16] Treatment of missing data was considered adequate if the absence/presence and proportion of missing data were reported, and if more than 10% of subjects had missing data, multiple imputation techniques and/or sensitivity analyses were used.[17]

2.4.5. Statistical analysis

The primary outcome measure was the global mean cost per patient. All costs are presented in 2013 American dollars. Studies were considered to be of good methodological quality when half (that is, at least four) of the seven quality criteria were respected.

2.5. Results

2.5.1. Search results

The search retrieved 6635 published articles. Of these, 50 full-text articles were assessed for eligibility (Figure 2.1).

2.5.2. Characteristics of included studies

Ten studies met the inclusion criteria for this review.[18-27] All were retrospective studies, and involved a total of 156 hospitals and 2,608,395 participants. Data on the number of hospitals were not available for two studies (Table 2.2).[18,19] Nine studies were conducted in the United States[19-27] and one in several European countries.[18] These studies contained data collected from 1994[21] through 2008.[19]

The inclusion criteria were mainly based on admission for injuries, for example admissions to a trauma service,[21] or admissions with a principal diagnosis of injury (international classification of disease 9th revision = 901.1,[22] 864.04, 864.14, 861.21, 861.31, 808.43, 808.53;[18] Table 2.2). One study also selected patients based on injury severity.[24] The common exclusion criteria were burns or late effect of injury, isolated hip fractures, patients with missing data, and transferred patients. The mean age for patients varied between 35[22] and 43 years[20], and the percentage of men ranged from 59%[26] to 72%.[19,27] The proportion of patients with blunt trauma varied between 46%[26] and 94%,[25] the mean Injury Severity Score varied between 8[26] and 16,[27] and the mean length of stay varied between 6[19] and 13 days.[22]

2.5.3. Cost outcome

Five studies compared groups of hospitals between: 10 European countries,[18] United States regions,[19] level I and II centers,[22] according to quartiles of risk-adjusted mortality,[26] and trauma centers versus non-designated hospitals (Table 2.3).[24] The other five studies evaluated a single hospital before and after organizational changes: verification by the American College of Surgeons,[20] oversight of the patient management system by the trauma team,[23] implementation of the improvement program of the American College of Surgeons,[25] transitioning to a new academic year,[21] and length of trauma attending rotation.[27]

Three studies were based on costs obtained from a hospital accounting system (Table 2.3).[21,23,25] The study from Europe estimated costs using average unit costs for an emergency department visit and spending a day in the hospital (the per diem costing method).[18] The remaining six studies used patient charges as a proxy for patient costs.[19,20,22,24,26,27] Two of these directly used patient charges[27] and the other four multiplied charges by the cost-to-charge ratio to estimate costs.[19,20,24,26] Average costs per patient in the 10 studies varied between $2568[25] and $75,435.[27]

2.5.4. Study methodological quality

Only four studies (40%) were considered to be of good methodological quality.[19,22,25,26] Two studies did not report the number of patients per hospital[18,26] while the other studies had an adequate sample size (Table 2.4).[19-25,27] Four studies did not describe the method used to calculate costs.[21-23,27] Four studies reported data quality assurance efforts.[22-24,26] Five studies adjusted cost comparisons for patient-level risk factors, namely demographics (age, sex, gender, and race),[18,19,22,24,26] injury characteristics (diagnoses, mechanism, comorbidities, severity),[19,22,24,26] and length of stay,[19] while three studies adjusted costs according to hospital factors (size, teaching status, ownership status, geographic region, and relative hospital wage level).[19,22,26] Measures of variation were reported in eight studies.[19-24,26-27] Only one study reported sensitivity analyses.[19] Appropriate treatment of missing data was not reported in any study.

2.6. Discussion

In this systematic review, we identified as few as 10 studies that used data on costs to evaluate acute care hospitals treating trauma. Furthermore, six of these studies were based on charges, which are known to represent an inaccurate estimate of costs.[21] Nine studies were conducted in the United States, and only one study was based on a single-payer healthcare system. These findings suggest a need to develop accurate methods for estimating individual patient resource use that can be used to evaluate trauma centers in terms of resource use intensity, particularly in single-payer healthcare systems where cost data is rarely available.

Trauma center evaluation is a key element of injury care quality at regional, national, and international levels.[29] According to Gruen et al. (2012), healthcare systems cannot be dissociated from evaluation and feedback.[30] Evaluating resource use helps governments to identify specific economic health burdens and provides payers with evidence-based data for setting priorities. Hospital managers must be aware of their performance in terms of resource utilization in order to identify problems and improve the efficiency of care. Yet, as we observed in this review, no hospital indicator based on costs has been validated for injury care. Indeed, after reviewing 192 articles, which evaluated injury care, Stelfox et al. (2010) found that none of the 1572 identified quality indicators were based on costs.[31]

Similar to Stelfox et al. (2010), we observed that studies evaluating injury care generally had low methodological quality.[31] Rigorous methodological quality is essential to the validity and comparability of hospitals.[16] Quality indicators reviewed by Stelfox and his colleagues were generally not well defined.[31] In our review, four studies did not give a clear definition of their cost calculation method. The absence of a standardized definition is another impediment to obtaining comparable information on resource use intensity.[16] Sensitivity analyses could have been used to test the robustness of the results to cost estimation methods and included cost items, but only one study performed such analyses. We observed two other shortcomings that may have compromised the validity of evaluations: inappropriate treatment of missing data and lack of case-mix adjustment.[16]

2.6.1. Strengths and limitations

We conducted a systematic review of the literature in accordance with recommendations from the Cochrane Handbook for Systematic Reviews of Interventions[12] and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement.[13] We developed a rigorous search strategy in five medical databases with no restriction on language or publication type. Two authors independently screened studies, including the bibliographies of relevant studies, and extracted data. Additionally, the same authors independently evaluated the methodological quality of included studies using the Strengthening the Reporting of Observational Studies in Epidemiology statement[14] and the Downs and Black tool.[15] However, we did not search the grey literature, which may have resulted in us missing some studies. Nevertheless, publication bias is unlikely since we focused on studies that compared the costs of injury care across hospitals or after an institutional change, and the fact that costs would change or remain the same is very unlikely to influence the decision to submit a manuscript to peer-reviewed journals or to have a manuscript accepted for publication. Moreover, articles that did not report information on specific methodological quality criterion were considered as not meeting that criterion. This may have led to an underestimation of methodological quality. However, reporting important information is an essential part of methodological quality assurance efforts.[14]

2.6.2. Implications and future directions

This study emphasizes the urgent need to develop a standardized and robust method for evaluating resource use intensity for acute injury care. First, we need to develop an accurate, reproducible method to estimate costs from routinely collected trauma data. Activity-based costing, which consists of multiplying units of resource use by activity-based unit costs, has been identified as one of the most accurate methods for estimating healthcare costs.[32-34] This approach provides information on resource use rather than costs, which are subject to regional and temporal price fluctuations, in line with guidelines of the Grading of Recommendations Assessment, Development and Evaluation group.[35] In addition, as it relates costs to activity drivers, it facilitates the identification of areas of resource use that require investigation.[36] Secondly, any inter- or intra-hospital comparison of resource use should be based on robust case-mix adjustment for the level of illness of patients on arrival. We therefore need to develop a risk-adjustment model for trauma acute care resource use intensity. The model should be derived from a sample of trauma admissions using high-quality data.[37] Third, information on resource use should always be presented alongside information on quality of care (for example risk-adjusted rates of mortality, complications, or unplanned readmissions) to improve injury care resource use without negative impact on patient outcomes.

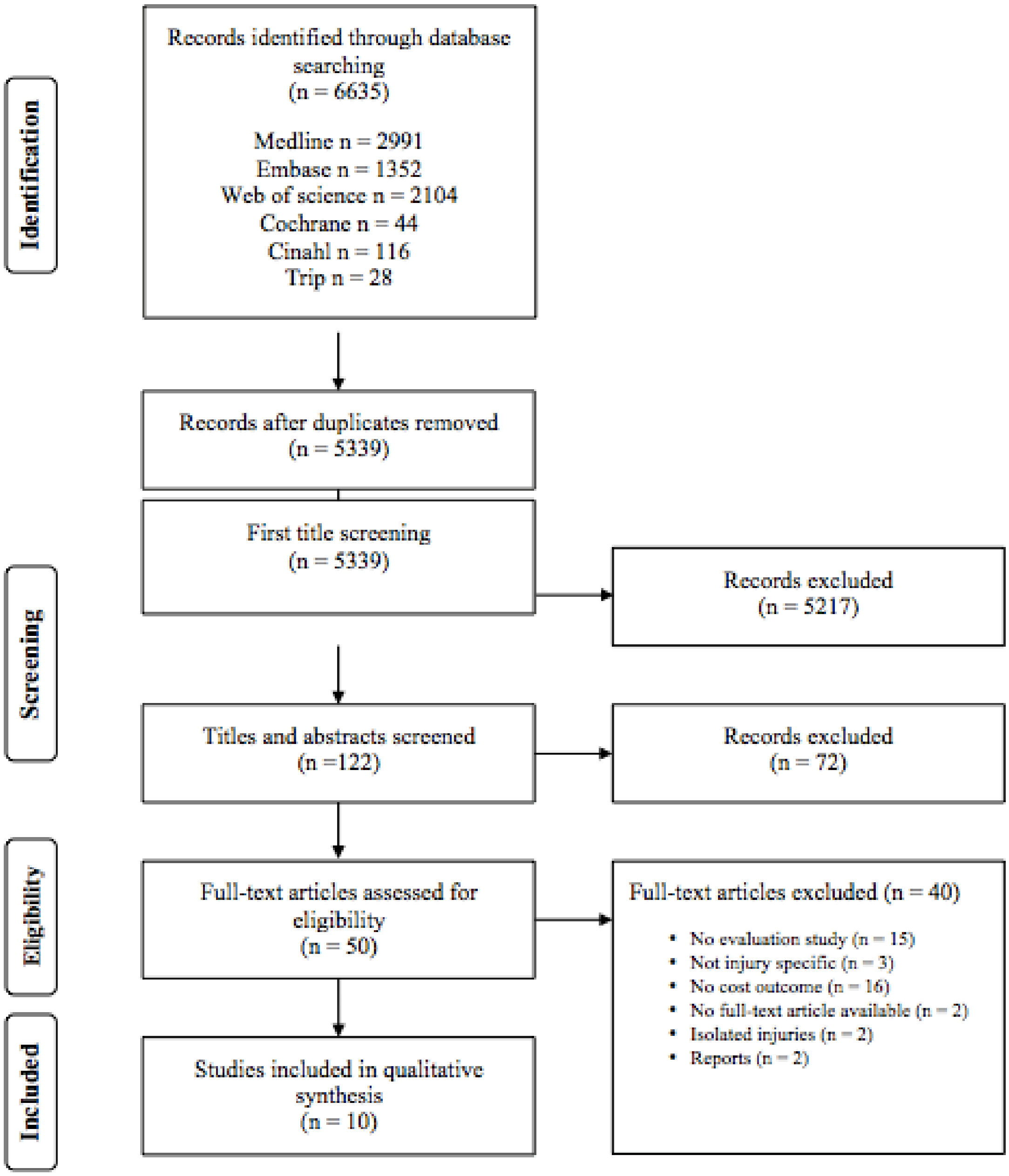
2.7. Conclusions

Most studies that have evaluated the performance of trauma centers in terms of costs were conducted in a for-profit healthcare system and were based on patient charges. The majority of studies had low methodological quality, which compromises the validity of hospital comparisons. Further research is needed to develop methods to estimate patient resource use in single-payer healthcare systems with the goal of developing a valid and reliable hospital indicator that can be used to monitor trauma center resource use intensity.

Table 2.1. Search strategy in MEDLINE for studies that evaluated trauma center based on costs

Keyword
Trauma
1. trauma*[tiab] OR injur*[tiab] OR “wounds and injuries”[MeSh]
Costs
2. cost[tiab] OR costs[tiab] OR “costs and cost analysis”[Mesh]
3. #1 AND #2

Figure 2.1. PRISMA diagram showing the selection process for articles reviewed



PRISMA: Preferred reporting items for systematic reviews and meta-analyses

Table 2.2. Description of included studies

Author, year	Setting	Period	Patients/ Centers, n	Inclusion criteria	Exclusion criteria	Age,* y	Blunt trauma, %	Male, %	ISS*	LOS,* d
Claridge et al., 2001[21]	Level I TC, United States	1994-1999	917/1	Adults admitted to trauma service	NR	41	90	68	14	9
Clancy et al., 2001 [22]	Level I/II TC, United States	1995-1996	1 283/9	LOS > 23h + all trauma deaths ICD-9 = 901.1, 864.04, 864.14, 861.21, 861.31, 808.43, 808.53	Death on arrival	35	NR	70	24	13
Cohen et al., 1999[20]	Level I TC, United States	1995-1997	2 090/1	LOS ≥ 1 day, ICD 800-959.9	Burns, bites, foreign bodies, late effects of injuries	43	75	66	9	7
Davis et al., 2008[23]	Level I TC, United States	2005-2006	1 058/1	Patients with trauma team activation	NR	NR	85	NR	13	8
Glance et al., 2010[26]	Level I, II TC, United States	2006	67,124/73	Principal ICD-9 = 800 –959.9	Burns, unspecified or isolated injuries, non-traumatic mechanisms; patients with missing data; patients from hospitals where > 5% of patients were transferred out or were missing data	55	46	59	NR	NR
Jacobs et al., 2008[27]	Level I TC, United States	2006	1 924/1	Unclear	NR	37	82	72	16	8
MacKenzie et al., 2010 [24]	NSCOT, United States	NR	5 043/69	18-84 year-olds treated for a moderately or severe injury (AIS ≥ 3)	Isolated hip fractures	27% ≥ 65	NR	NR	NR	NR
Maggio et al., 2009 [25]	Level I TC, United States	2001-2007	3 891/1	All trauma patients treated in ED	NR	37	94	66	8	NR
Polinder et al., 2005 [18]	Europe	1999	2 462 387 /NR	Injury principal diagnosis	ICD-9: E870–876, E878–879, E930-E949 and E905-E909	27% ≥ 65	NR	NR	NR	7
Obirieze et al., 2012 [19]	NIS, United States	2006-2008	62,678/NR	18-64 years-olds with isolated diagnosis of blunt splenic injury,	Burns, late effects of injury, unspecified injury AIS > 2 in	42	NR	72	31% > 15	6

	liver injury, tibia fracture, moderate traumatic brain injury, and pneumothorax / hemothorax	other body regions, missing data, transferred in or out

n: number; y: years; ISS: injury severity score; LOS: length of stay; d: days; TC: trauma center; NR: not reported; ICD-9: international classification of disease, 9th revision (clinical modification codes); NSCOT: National study on costs and outcomes of trauma; AIS: abbreviated injury scale; ED: Emergency department; NIS: National inpatient sample

*Mean

Table 2.3. Costs outcomes

Study	Primary data source	Comparison	Principal outcome	Details of cost calculation method	Mean cost*
Claridge et al., 2001[21]	Hospital finance data	Before / after transitioning to a new academic year	Costs	NR	14,624
Clancy et al., 2001 [22]	Trauma registry	Level I and II centers	Charges	NR	66,944
Cohen et al., 1999[20]	Medical records + Hospital finance data	Before / after ACS verification	CCR	CCR (Medicare Cost Report) Inflation adjustments were made using the Hospital Producer Price Index from the US Bureau of Labor Statistics, and all financial data were expressed using the 1997 dollar rate	16,874
Davis et al., 2008[23]	Hospital finance data + Physician billing information	Before / after trauma team oversight of patient management system	Costs	NR	23,872
Glance et al., 2010[26]	Nationwide Inpatient Sample	According to quartiles of risk-adjusted mortality	CCR	Total hospital charges × group average CCR	11,345
Jacobs et al., 2008[27]	Trauma registry	Length of trauma attending rotation	Charges	NR	75,435
MacKenzie et al., 2010 [24]	Medicare claims data + Medicaid Services data + Hospital finance data	Trauma centers versus non-designated hospitals	CCR	CCR (Medicare Cost Report) Costs were inflated to constant 2005 dollars using appropriate price indices	45,579
Maggio et al., 2009 [25]	Hospital finance data	Before / after implementation of the ACS improvement program	Costs	Variable direct costs = Expenditures that can be identified directly with the care of individual patients (laboratory tests, medications, radiographs, and disposable supplies) + Fixed direct costs = expenditures that can be identified with a specific hospital department but not with the ICU and ED charges of a particular patient	2568
Polinder et al., 2005 [18]	Hospital discharge registers ED sample-based surveillance systems	10 European countries	Cost estimation	(Sum of the number of ED visits × costs per ED visit) + (Number of hospital admissions × LOS × unit costs per inpatient day)	3427
Obirieze et al., 2012 [19]	Nation-wide Inpatient Sample	US regions	CCR	All-payer CCR, 2006-2009	18,247

NR: not reported; ACS: American College of Surgeons; CCR: Cost-to-charge ratio; ICU: Intensive Care Unit; ED: emergency department; LOS: Length of Stay; US: United States of America
*2013 American dollars

Table 2.4. Study methodological quality

Study	Sufficient Sample Size	Details of Cost Calculation Method	Data quality Assurance Efforts	Case-mix Adjustment	Measure of Variation for Cost Outcome	Appropriate Treatment of Missing data	Sensitivity Analyses
Claridge et al., 2001[21]							
Clancy et al., 2001 [22]							
Cohen et al., 1999[20]							
Davis et al., 2008[23]							
Glance et al., 2010[26]							
Jacobs et al., 2008[27]							
MacKenzie et al., 2010 [24]							
Maggio et al., 2009 [25]							
Polinder et al., 2005 [18]							
Obirieze et al., 2012 [19]							

2.8. References

1. Moore L, Clark DE. The value of trauma registries. *Injury*. 2008;39(6): 686-95.
2. Moore L, Lavoie A, Turgeon AF, et al. A new method for evaluating trauma centre outcome performance: TRAM-adjusted mortality estimates. *Ann Surg*. 2010;251(5): 952-8.
3. Public Health Agency of Canada. Tableau 1 : Principales causes de décès, Canada, 2005, hommes et femmes confondus : nombre (taux brut pour 100 000). http://www.phac-aspc.gc.ca/publicat/lcd-pcd97/table1-fra.php. Accessed September 29, 2011.
4. Centers for Disease Control and Prevention. The incidence and economic burden of injury in the United States. http://www.cdc.gov/ncipc/factsheets/CostBook/Economic_Burden_of_Injury.htm. Accessed June 19, 2013
5. Parachute. The Cost of Injury in Canada. Toronto, ON: Parachute; 2015.
6. Dieleman JL, Baral R, Birger M, et al. US Spending on Personal Health Care and Public Health, 1996-2013. *JAMA*. 2016;316(24): 2627-2646.
7. Donabedian A. Evaluating the quality of medical care. Milbank Memorial Fund Quarterly. 1966;44: 166–203.
8. Steinwachs DM, Hughes RG. Health Services Research: Scope and Significance. In: Hughes RG, editor. Patient Safety and Quality: An Evidence-Based Handbook for Nurses. Rockville, MD: Agency for Healthcare Research and Quality (US); 2008.
9. Tan SS, Rutten FF, van Ineveld BM, Redekop WK, Hakkaart-van Roijen L. Comparing methodologies for the cost estimation of hospital services. *Eur J Health Econ*. 2009;10(1): 39-45.
10. Gabbe BJ, Williamson OD, Cameron PA, Dowrick AS. Choosing outcome assessment instruments for trauma registries. *Acad Emerg Med*. 2005;12(8): 751-8.
11. Peden M, McGee K, Krug E. Injury: A leading cause of the global burden of disease, 2000. Geneva, World Health Organization; 2002.
12. Higgins JPT, Green S. *Cochrane Handbook for Systematic Reviews of Interventions* Version 5.1.0 [updated March 2011]. The Cochrane Collaboration; 2011. www.cochrane-handbook.org. Accessed June 16, 2012.
13. Moher D, Liberati A, Tetzlaff J, Altman DG, PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA Statement. *An Intern Med*. Epub 2009 Jul 20.
14. 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. *Lancet*. 2007;370(9596): 1453-7.
15. Higgins JP, Altman DG, Gøtzsche PC, et al. The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. *BMJ*. 2011;343: d5928.
16. Iezzoni LI. Risk adjustment for measuring health care outcomes, Fourth edition. Chicago, IL: Health Administration Press; 2013.
17. Allison PD. Missing Data. Sage University Papers Series on Quantitative Application in the Social Sciences. Thousand Oaks, CA: Sage Publications;2001.

18. Polinder S, Meerding WJ, van Baar ME, et al. Cost estimation of injury-related hospital admissions in 10 European countries. *J Trauma*. 2005;59(6): 1283-90; discussion 1290-1.
19. Obirieze AC, Gaskin DJ, Villegas CV, et al. Regional variations in cost of trauma care in the United States: who is paying more? *J Trauma Acute Care Surg*. 2012;73(2): 516-22.
20. Cohen MM, Fath JA, Chung RS, Ammon AA, Matthews J. Impact of a dedicated trauma service on the quality and cost of care provided to injured patients at an urban teaching hospital. *J Trauma*. 1999;46(6): 1114-9.
21. Claridge JA, Schulman AM, Sawyer RG, Ghezel-Ayagh A, Young JS. The "July phenomenon" and the care of the severely injured patient: fact or fiction? *Surgery*. 2001;130(2): 346-53.
22. Clancy TV, Gary Maxwell J, Covington DL, Brinker CC, Blackman D. A statewide analysis of level I and II trauma centers for patients with major injuries. *J Trauma*. 2001;51(2): 346-51.
23. Davis KA, Cabbad NC, Schuster KM, et al. Trauma team oversight improves efficiency of care and augments clinical and economic outcomes. *J Trauma*. 2008;65(6): 1236-42; discussion 1242-4.
24. MacKenzie EJ, Weir S, Rivara FP, et al. The value of trauma center care. *J Trauma*. 2010;69(1):1-10.
25. Maggio PM, Brundage SI, Hernandez-Boussar T, Spain DA. Commitment to COT verification improves patient outcomes and financial performance. *J Trauma*. 2009;67(1): 190-4; discussion 194-5.
26. Glance LG, Dick AW, Osler TM, Meredith W, Mukamel DB. The association between cost and quality in trauma: is greater spending associated with higher-quality care? *Ann Surg*. 2010;252(2): 217-22.
27. Jacobs DG, Sarafin JL, Head KE, et al. Trauma attending physician continuity: does it make a difference? *Am Surg*. 2010;76(1):48-54
28. Shwartz M, Young DW, Siegrist R. The ratio of costs to charges: how good a basis for estimating costs? *Inquiry*. 1995-1996;32(4)476-81.
29. Budd H, Almond LM, Oakley PA, McKenzie G, Danne P. A benchmarking study of two trauma centres highlighting limitations when standardising mortality for comorbidity. *World J Emerg Surg*. 2008;3: 2.
30. Gruen RL, Gabbe BJ, Stalfox HT, Cameron PA. Indicators of the quality of trauma care and the performance of trauma systems. *Br J Surg*. 2012;99 Suppl 1: 97-104.
31. Stelfox HT, Bobranska-Artiuch B, Nathens A, Straus SE. Quality indicators for evaluating trauma care: a scoping review. *Arch Surg*. 2010;145(3): 286-95.
32. Ross TK. Analyzing health care operations using ABC. *J Health Care Finance*. 2004;30: 1Y20.
33. West TD, Balas EA, West DA. Contrasting RCC, RVU, and ABC for managed care decisions. A case study compares three widely used costing methods and finds one superior. *Healthc Financ Manage*. 1996;50: 54Y61.
34. Young DW. The folly of using RCCs and RVUs for intermediate product costing. *Healthc Financ Manage*. 2007;61: 100Y106,108.
35. Guyatt GH, Oxman AD, Kunz R, et al. Incorporating considerations of resources

use into grading recommendations. *BMJ*. 2008;336: 1170Y1173.

36. The US Agency for International Development. Cost and quality in healthcare: reference manual. In Core Traning Series. Bethesda, MD: The Quality Assurance Project; 2001.

37. Krumholz HM, Brindis RG, Brush JE, et al. Standards for statistical models used for public reporting of health outcomes: an American HeartAssociation Scientific Statement from the Quality of Care and Outcomes Research Interdisciplinary Writing Group: cosponsored by the Council on Epidemiology and Prevention and the Stroke Council. Endorsed by the American College of Cardiology Foundation. *Circulation*. 2006;113: 456Y462.

CHAPTER 3. ARTICLE. PATIENT-LEVEL RESOURCE USE FOR INJURY ADMISSIONS IN CANADA: A MULTICENTER RETROSPECTIVE COHORT STUDY

Teegwendé V. Porgo MSc,[1,2] Lynne Moore PhD,[1,2] Catherine Truchon PhD,[3] Simon Berthelot MD MSc FRCPC,[2,4] Henry T. Stelfox MD PhD FRCPC,[5] Peter A. Cameron PhD,[6] Belinda J. Gabbe PhD,[6] Jeffrey S. Hoch PhD,[7,8] David C. Evans MD MSc FRCPC,[9] François Lauzier MD MSc FRCPC, [2,10] Francis Bernard MD,[11] Alexis F. Turgeon MD MSc FRCPC,[1,2,10] Julien Clément MD FRCSC[3,12]

[1]Department of Social and Preventive Medicine, Université Laval, Québec (QC), Canada;
[2]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;
[3]Institut national d'excellence en santé et en services sociaux (INESSS), Québec (QC), Canada;
[4]Department of family medicine, Université Laval, Québec (QC), Canada;
[5]Departments of Critical Care Medicine, Medicine and Community Health Sciences, O'Brien Institute for Public Health, University of Calgary, Calgary (AB), Canada;
[6]Department of Epidemiology and Preventive Medicine, Monash University, Melbourne, Australia
[7]Institute for Health Policy, Management, and Evaluation, University of Toronto, Toronto (ON), Canada;
[8]Department of Public Health Sciences, University of California, Sacramento (CA), United States;
[9]Department of Surgery, University of British Columbia, Vancouver (BC), Canada
[10]Department of Anesthesiology and Critical Care Medicine, Division of Critical Care Medicine, Université Laval, Québec (QC), Canada;
[11]Department of Medicine, Université de Montréal, Montréal (QC), Canada
[12]Department of Surgery, Université Laval, Québec (QC), Canada

Running head: Resource use in acute injury care

Key words: Trauma, resource use intensity, activity-based costing, determinants, inter-provider variations

3.1. Résumé

Nos objectifs étaient d'estimer l'utilisation des ressources dans un système de traumatologie régionalisé, en identifier les déterminants et en évaluer la variation inter-hospitalière. À partir d'une étude de cohorte incluant 32411 adultes hospitalisés dans les 57 centres de traumatologie pour adultes du Québec de 2014 à 2016, nous avons identifié les déterminants avec un modèle linéaire multi-niveau, déterminé leur importance relative avec le coefficient f^2 de Cohen et évalué la variation avec le coefficient de corrélation intra-classe (ICC) et son intervalle de confiance à 95%. Le plus important déterminant était la destination à la sortie de l'hôpital (f^2 = 7%). L'utilisation des ressources était 19 % plus élevée dans les centres de niveau I versus IV. Nous avons observé une variation inter-hospitalière significative de l'utilisation des ressources (ICC = 5% [4-6]), particulièrement pour le bloc opératoire (28% [20-40]). Nos résultats pourront éclairer l'allocation des ressources et l'élaboration d'interventions visant à améliorer l'efficience des soins en traumatologie.

3.2. Abstract

Background: Variations in adjusted costs have been observed among trauma centers in the United States but patient outcomes were not better in centers 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 ≥ 16-year-olds admitted to any of the 57 trauma centers 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 regular ward (57%), followed by the operating room (23%) and the intensive care unit (13%). The strongest determinant of resource use intensity was discharge destination (Cohen's f^2 = 7%). Among injury types, the highest resource use was observed for spinal cord injuries with $11,193 (7115-17,606) per admission. While resource use increased with increasing age for the regular ward, it decreased with increasing age for the operating room. Resource use was 19% higher in level I centers compared to level IV centers and we observed significant variations in resource use across centers (ICC = 5% [4-6]), particularly for the operating room (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 the efficiency of acute injury care. 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.

3.3. Introduction

Injury ranked third healthcare condition for acute care expenditure in the United States in 2013, with costs of 99 billion American dollars.[1] In Canada, healthcare costs due to injuries were 16 billion Canadian dollars in 2010.[2] In the United States, significant variations in adjusted costs, estimated using patient charges, have been observed among trauma centers.[3-5] Furthermore, centers with higher costs did not have better patient outcomes.[3-5] These data suggest that there are important opportunities to improve injury care efficiency.

Attempts to improve efficiency are hampered by a lack of a standardized method for evaluating injury care costs.[6] In Canada, healthcare costs are frequently calculated using the case mix group method. Since this method attributes average costs according to diagnostic groups and other risk factors,[7, 8] it cannot be used to compare provider or identify drivers of resource use.

Given the scarcity of funds for healthcare and limited existing healthcare resources,[9] it is paramount to provide stakeholders with patient-level information on resource use.[10, 11] 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.

3.4. Methods

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

3.4.1. Design

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

3.4.2. 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 admission, hospital stay > 2 days or transfer from another hospital. For patients who were transferred, only information from the definitive center 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 orthopedic 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).[12]

3.4.3. Data

Data were retrieved from the Quebec trauma registry[13] except for information on comorbidities which was obtained by linking the registry to the provincial hospital discharge database (MED-ECHO).[14] Data on costs were obtained from hospital financial reports (AS-471) for the 2016 fiscal year.[15] These reports contain unit costs by hospital activity center and include variable direct costs related to expenditures for non-physician personnel, services and materials.[16]

3.4.4. Estimation of patient-level resource use

Our goal was to estimate resource use rather than the true costs of injury care, in line with Grading of Recommendations Assessment, Development and Evaluation recommendations.[17] We therefore used activity-based costs that are not influenced by geographic and temporal fluctuations in pricing and can be used to evaluate provider variations in resource use and identify related determinants.[17-19] We applied this method using Canadian guidelines for the economic evaluation of health technologies: identification of cost items to include, measurement of resource use, and valuation.[20]

First, we made an exhaustive list of activity centers from the Ministry of Health and Social Services website.[21] This list was submitted to a committee of experts to identify activity centers 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 centers.

Activity centers comprise the emergency department, regular ward, operating room, intensive care unit, 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 3.1). Unit costs for the emergency department were available per visit; thus, the same cost was attributed for all patients. Costs for this activity center were included in total cost calculations but were not analyzed any further. Because of a lack of relevant and/or complete information on drugs, laboratory tests, blood products, and physician fees, these were not included. To obtain standardized unit costs that were not influenced by temporal or geographical variations, we extracted unit costs (per activity center) from hospital financial reports (AS-471) for the three level I centers and calculated mean unit costs (per activity center) 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 center. We also calculated the contribution (percentage) of each activity center to total resource use.

3.4.5. 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[6] 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, respiration 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.[22] We also assessed the variation of resource use over center 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.[23] 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 orthopedic injuries) and center 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[24] for total resource use and by activity center.

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 < 12) and type of injury (70% were patients with isolated orthopedic injuries), we considered the missing at random assumption to be plausible and simulated these missing data using multiple imputation.[25] We used the Markov Chain Monte Carlo method with a non-informative single chain.[26-29] 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.[26, 28, 30] This same method has been shown to lead to valid estimates in simulation studies using the Quebec trauma registry and the United State National Trauma Data Bank.[29, 31]

3.4.6. 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 center.

3.4.7. Sensitivity analyses

We repeated analyses under the following conditions: (1) excluding resource use outliers (> 99 percentile),[32] (2) excluding observations with missing physiological data,[28, 29] (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.[12] We compared geometric mean ratios under each sensitivity analysis.

3.4.8. 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 center 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.

3.5. Results

3.5.1. 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 3.2), mean age was 63 years (±22), 2% had penetrating injuries and 23% had major trauma (Injury Severity Score ≥ 12).

3.5.2. 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 regular ward (57%; Figure 3.1), followed by the operating room (23%) and the intensive care unit (13%). The contribution of each activity center 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 centers and isolated orthopedic injuries. The operating room contributed over 20% for younger patients, level I/II centers, spinal cord injuries, multisystem blunt injuries and isolated orthopedic injuries. The intensive care unit contributed over 20% for major injuries, traumatic brain injuries and multisystem blunt injuries.

3.5.3. Determinants of resource use intensity

Determinants (listed in Table 3.2) explained 26% of the variation in resource use. Risk-adjusted resource use increased with increasing age, number of comorbidities and injury severity (Table 3.2). 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 orthopedic injuries were all more resource intensive than traumatic brain injuries. Finally, level IV centers had 18% lower resource use than level I centers.

Results remained stable across strata of age (Table 3.3). Across strata of injury type and designation level, differences observed were related to age (Table 3.4 and Table 3.5): increases in resource use with increasing age were significant only among patients with isolated orthopedic injuries and in level III/IV centers.

Determinants varied little across activity centers. However, while resource use increased with increasing age and comorbidities for the regular ward and intensive care unit, it decreased with increasing age and comorbidities for the operating room (Table 3.6). In the intensive care unit, 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 orthopedic injuries were not significantly different.

3.5.4. Relative importance of determinants

Overall, the strongest determinants were discharge destination (Cohen's f^2 = 6.5%; Figure 3.2), type of injury (3.6%) and injury severity (3.3%). The relative importance of determinants varied by activity center. Discharge destination was the most important determinant in the regular ward; center designation level in the operating room; the Glasgow Coma Score in the intensive care unit; and type of injury for imaging.

3.5.5. Inter-provider variations in resource use intensity

We observed significant inter-provider variations in risk-adjusted resource use intensity, particularly for the operating room and paraclinical services (Table 3.7).

3.5.6. 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 (Table 3.8 and Table 3.9). Similarly, determinants did not change when deaths were included in a competitive risks model (Table 3.8).

3.5.7. Patient-level resource use among in-hospital deaths

Median costs per admission for deaths were $4711 (Q1-Q3: 1933-10,300; Table 3.10), similar to that for survivors ($4858). As expected, the contribution of the intensive care unit to total costs among deaths was greater (35%; Figure 3.3) than its contribution among survivors (13%). The contribution of the operating room 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).

3.6. 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 regular ward (57%), operating room (23%), and intensive care unit (13%). 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 injury types. While resource use increased with increasing age and number of comorbidities for the regular ward and intensive care unit, it decreased with increasing age and number of comorbidities for the operating room. Lastly, risk-adjusted resource use was 18% higher in level I than level IV centers and we observed significant inter-hospital variations in resource use intensity; variation was strongest for the operating room (28%).

Two other studies have estimated acute care resource use in global injury populations using activity-based costs.[33, 34] These studies were conducted among patients with blunt[34] and penetrating injuries[33] 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.[34] This disparity in costs may be explained by differences in unit costs, in cost items considered (pre-hospital transport costs were included) and patient populations.[34] Similar to our results, their study based on blunt injuries showed that the regular ward, operating room, and intensive care unit were the most important contributors to resource use, with individual contributions of 37%, 15% and 29%, respectively.[34] The authors also found that injury severity,[33, 34] the body region of the worst injury,[33] age,[33] and the Glasgow Coma Score[33] 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,[35] 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.[36-38] 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 centers.[39, 40] In other Canadian provinces, the median delay to admission to a long-term care facility for the elderly is approximately 26 days.[39, 40] A study on transfer waiting time in a Canadian level I trauma center 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 (Injury Severity Score of 26-27).[39] This may explain the importance of discharge destination as a determinant of resource use in the regular ward as well as the important contribution of the regular 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,[41] 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.[42-44]

The higher risk-adjusted resource use observed in level I centers compared to level IV centers 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.[45] 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.[45] 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[46] and leads to increased mortality and morbidity.[47-49] 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.[48] Additionally, criteria for transporting/transferring patients with major injuries (for example major traumatic brain injuries and open/depressed skull fractures) to level I/II centers have been established in Quebec.[50] The establishment of criteria for directing less resource intense patients to level III/IV centers could be another option for improving the efficiency of injury care.

3.6.1. Strengths and limitations

We conducted a retrospective cohort study with local and recent data (2014-2016) on patients admitted to 57 trauma centers. We used the Agency for Healthcare Research and Quality of the United States Department of Health and Human Services' definition of resource use[51] and followed Canadian guidelines for the economic evaluation of health technologies.[20] We conducted valuation of resources using a patient-specific costing method[8] and produced resource use estimates which are independent of geographical and temporal fluctuations in pricing.[17] Our estimates reflect practice patterns and highlight units of resources (activity centers) that might be relevant to decision-makers and stakeholders, in line with guidelines of the Grading of Recommendations Assessment, Development and Evaluation group.[17] Moreover, before undertaking the study, we consulted a committee of experts, composed of a trauma surgeon, a critical care physician, two general practitioners, and two health care administrators, to identify hospital activity centers considered important for costing acute in-hospital injury care. Lastly, we conducted multiple sub-group and sensitivity analyses where we identified determinants of resource use intensity similar to those identified in the main analyses.

When interpreting our results, potential limitations should be considered. First, we excluded patients with missing data on comorbidities or injury severity. Since patients with these missing data represented less than 2% of eligible patients, we are confident that excluding them is unlikely to have induced selection bias.[52] Moreover, 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 centers[15] while laboratory tests represent 4% of total hospital costs in Canada.[7] As for blood bank products, they represent ≤ 1% of total hospitalization costs for most diagnostic-related groups in the United States.[53] 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. Moreover, due to lack of information on the number of hours spent in the emergency department, the number of x-ray radiographies and ultrasounds per body region, and on the duration of physiotherapy, occupational therapy and psychotherapy, we applied a fixed cost for these services. This likely led us to underestimate resource use for these activity centers. However, multiple scans using the same imagery technique in the same body regions are unusual and short stays in the emergency department are usually indicative of high resource use (patients with severe injuries require more resource-intense care in the emergency department but are usually admitted more quickly than patients with minor or moderate injuries). Moreover, it is very likely that the regular ward, operating room, and intensive care unit would have still remained the three most important contributors to resource use, as observed in the study conducted in the United Kingdom, another country with a single-payer healthcare system.[34] Nonetheless, we could not identify determinants of resource use intensity nor evaluate inter-provider variation for the emergency department. 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.[54] 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.[25, 55, 56] 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.[57] 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.[25, 58] 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.[29, 31]

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

3.8. Acknowledgments

We thank Gilles Bourgeois, Jean Lapointe, Gaétan Prévost and Christine Rizzo for their role as members of the committee of experts for this study, Amina Belcaid for her expertise on data sources and Xavier Neveu for his invaluable insight on how to address specific statistical analysis.

Table 3.1. Unit costs of resource use items (hospital activity centers)

Activity center	Unit cost (2016 Can$)
Emergency department	253.37/visit
Intensive care unit	1212.07/day
Regular ward	342.58/day
Operating room	1129.11/hour
Medical Imaging	
X-ray radiography*	25.07/unit **
Ultrasound*	27.99/unit **
Magnetic resonance imaging	
Head, face, neck, spinal cord	118.20/unit
Thorax	147.75/unit
Abdomen, pelvis	137.90/unit
Orthopedic	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/hour**
Occupational therapy	76.14/hour**
Psychotherapy	175.52/hour**
Respiratory therapy	367.22/treatment†

*In the emergency department. **We did not have information on the number of x-ray radiographies and ultrasounds or the duration of physiotherapy, ergotherapy 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. †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.

Table 3.2. 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)
Orthopedic	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*			
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*			
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*			
≥ 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)
Trauma center 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

*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.

Figure 3.1. Relative contribution of activity centers to total costs overall and by population subgroups

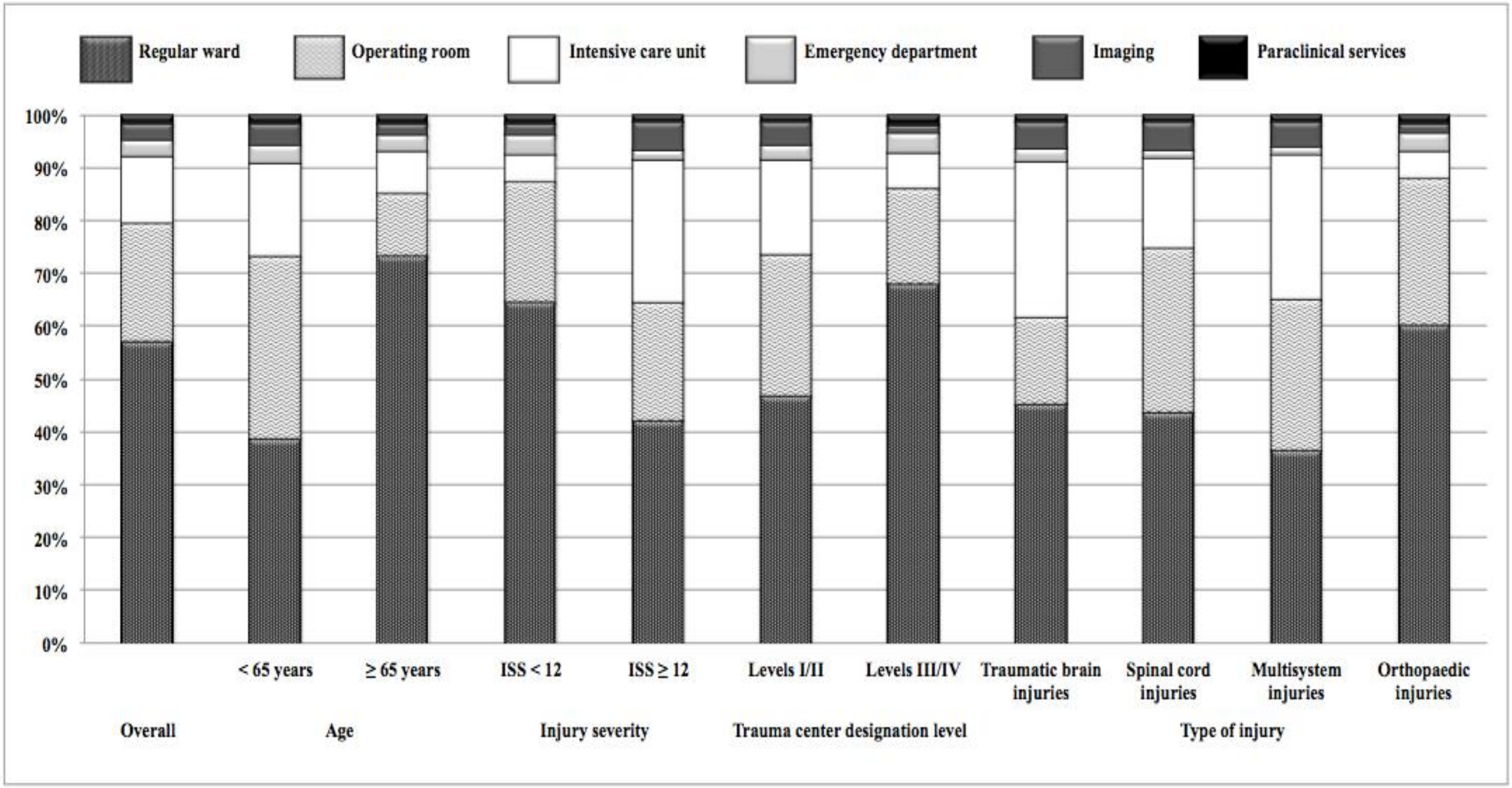


Table 3.3. Determinants of acute injury care resource use by age group (in 2016 Can$)

Variable	Adjusted geometric mean ratio (95% CI)		
	Global	**< 65 years (n = 15,998)**	**≥ 65 years (n = 16,413)**
Age			
16-54		ref.	-
55-64		1.00 (0.97-1.02)	-
65-74		-	ref.
75-84		-	1.04 (1.01-1.08)
≥ 85		-	1.05 (1.02-1.08)
Sex			
Male	ref.	ref.	ref.
Female	1.02 (1.00-1.04)	1.04 (1.01-1.06)	1.00 (0.98-1.03)
Number of comorbidities			
0	ref.	ref.	ref.
1	1.10 (1.08-1.12)	1.08 (1.05-1.11)	1.11 (1.08-1.14)
2	1.23 (1.19-1.26)	1.31 (1.24-1.38)	1.19 (1.15-1.23)
≥ 3	1.31 (1.27-1.35)	1.31 (1.22-1.41)	1.29 (1.25-1.34)
Type of injury			
Traumatic brain	ref.	ref.	ref.
Spinal cord	1.76 (1.65-1.87)	1.69 (1.57-1.82)	1.79 (1.61-1.98)
Multisystem blunt	1.57 (1.49-1.66)	1.58 (1.48-1.68)	1.52 (1.39-1.66)
Orthopedic	1.29 (1.25-1.33)	1.37 (1.31-1.44)	1.22 (1.17-1.28)
Mechanism			
MVC	ref.	ref.	ref.
Fall	0.95 (0.92-0.99)	0.93 (0.90-0.97)	1.02 (0.89-1.15)
Penetrating	1.07 (1.00-1.15)	1.05 (0.98-1.13)	1.18 (0.85-1.64)
Other	0.99 (0.95-1.03)	1.00 (0.96-1.05)	0.98 (0.85-1.13)
New Injury severity score			
< 12	ref.	ref.	ref.
12-24	1.26 (1.24-1.29)	1.27 (1.23-1.30)	1.25 (1.21-1.28)
≥ 25	1.77 (1.70-1.83)	1.86 (1.77-1.95)	1.62 (1.5431.71)
Glasgow coma scale score*			
3-8	1.63 (1.53-1.74)	1.67 (1.55-1.80)	1.52 (1.37-1.68)
9-12	1.24 (1.17-1.32)	1.26 (1.18-1.35)	1.20 (1.11-1.31)
13-15	ref.	ref.	ref.
Respiration Rate*			
11-29	ref.	ref.	ref.
0-10; ≥ 30	1.22 (1.15-1.29)	1.15 (1.08-1.24)	1.30 (1.18-1.43)
Systolic blood pressure*			
≥ 90	ref.	ref.	ref.
0-89	1.33 (1.25-1.42)	1.32 (1.22-1.43)	1.30 (1.17-1.47)

Transfer			
No	ref.	ref.	ref.
Yes	0.80 (0.78-0.82)	0.79 (0.77-0.81)	0.85 (0.82-0.88)
Type of insurance			
Provincial health	ref.	ref.	ref.
Road accidents	1.06 (1.02-1.10)	1.04 (1.00-1.09)	1.04 (0.91-1.18)
Work accidents	1.01 (0.97-1.06)	1.01 (0.97-1.05)	0.94 (0.77-1.16)
Other	1.01 (0.98-1.05)	1.02 (0.97-1.07)	1.00 (0.94-1.06)
None /Unknown	0.97 (0.92-1.02)	0.98 (0.91-1.05)	1.00 (0.92-1.09)
Year of admission			
2014	ref.	ref.	ref.
2015	0.99 (0.98-1.01)	0.98 (0.96-1.01)	1.00 (0.98-1.03)
2016	0.95 (0.93-0.97)	0.98 (0.95-1.00)	0.93 (0.91-0.96)
Discharge destination			
Home	ref.	ref.	ref.
Acute care	1.24 (1.21-1.28)	1.32 (1.27-1.38)	1.17 (1.12-1.22)
Long stay	1.80 (1.74-1.86)	1.87 (1.69-2.05)	1.73 (1.67-1.80)
Rehabilitation	1.67 (1.62-1.72)	1.84 (1.77-1.92)	1.57 (1.52-1.63)
Other	1.27 (1.23-1.30)	1.55 (1.46-1.64)	1.18 (1.14-1.21)
Trauma center designation level			
I	ref.	ref.	ref.
II	0.94 (0.80-1.11)	0.91 (0.75-1.10)	0.99 (0.87-1.12)
III	0.93 (0.81-1.07)	0.86 (0.73-1.02)	1.01 (0.90-1.14)
IV	0.82 (0.71-0.94)	0.72 (0.61-0.85)	0.93 (0.83-1.05)

n: number; Q1: quartile 1; Q3: quartile 3; CI: confidence interval; ref.: reference; MVC: motor vehicle collision

*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.

Table 3.4. Determinants of acute injury care resource use by type of injury (in 2016 Can$)

Variable	Adjusted geometric mean ratio (95% CI)				
	Global	**Traumatic brain injuries (n = 4479)**	**Spinal cord injuries (n = 614)**	**Multisystem blunt injuries (n = 901)**	**Isolated orthopedic injuries (n = 18,269)**
Age					
16-54	ref.	ref.	ref.	ref.	ref.
55-64	1.00 (0.98-1.03)	0.99 (0.92-1.07)	1.01 (0.87-1.18)	0.97 (0.84-1.11)	1.01 (0.98-1.04)
65-74	1.03 (1.00-1.06)	1.05 (0.97-1.13)	1.04 (0.88-1.22)	0.98 (0.83-1.16)	1.03 (0.99-1.08)
75-84	1.07 (1.04-1.10)	1.06 (0.98-1.15)	1.03 (0.84-1.25)	1.04 (0.85-1.28)	1.06 (1.02-1.10)
≥ 85	1.07 (1.04-1.10)	1.03 (0.94-1.13)	0.92 (0.68-1.26)	0.74 (0.58-0.95)	1.06 (1.02-1.10)
Sex					
Male	ref.	ref.	ref.	ref.	ref.
Female	1.02 (1.00-1.04)	1.07 (1.01-1.14)	1.08 (0.95-1.23)	0.99 (0.89-1.11)	1.03 (1.01-1.06)
Number of comorbidities					
0	ref.	ref.	ref.	ref.	ref.
1	1.10 (1.08-1.12)	1.07 (1.01-1.14)	1.03 (0.89-1.19)	0.99 (0.86-1.14)	1.11 (1.08-1.14)
2	1.23 (1.19-1.26)	1.24 (1.14-1.34)	1.31 (1.05-1.62)	1.26 (1.00-1.59)	1.21 (1.17-1.25)
≥ 3	1.31 (1.27-1.35)	1.25 (1.14-1.38)	1.22 (0.82-1.80)	1.35 (1.04-1.76)	1.29 (1.25-1.34)
Mechanism					
MVC	ref.	ref.	ref.	ref.	ref.
Fall	0.95 (0.92-0.99)	0.78 (0.70-0.87)	1.13 (0.92-1.38)	0.99 (0.82-1.18)	0.99 (0.94-1.04)
Penetrating	1.07 (1.00-1.15)	1.21 (0.89-1.64)	1.22 (0.48-3.07)	-	1.00 (0.92-1.08)
Other	0.99 (0.95-1.03)	0.86 (0.76-0.98)	0.94 (0.74-1.21)	1.13 (0.89-1.43)	1.00 (0.95-1.06)
New Injury severity score					
< 12	ref.	ref.	ref.	-	ref.
12-24	1.26 (1.24-1.29)	1.18 (1.08-1.29)	1.10 (0.89-1.36)	ref.	1.32 (1.29-1.35)
≥ 25	1.77 (1.70-1.83)	1.60 (1.47-1.75)	1.48 (1.18-1.85)	1.40 (1.25-1.56)	1.81 (1.67-1.96)

Glasgow coma scale score*					
3-8	1.63 (1.53-1.74)	2.19 (2.03-2.37)	1.95 (1.50-2.54)	1.53 (1.24-1.89)	1.23 (1.11-1.37)
9-12	1.24 (1.17-1.32)	1.55 (1.41-1.69)	1.25 (0.96-1.63)	1.50 (1.13-2.00)	1.10 (0.99-1.23)
13-15	ref.	ref.	ref.	ref.	ref.
Respiration Rate*					
11-29	ref.	ref.	ref.	ref.	ref.
0-10; ≥ 30	1.22 (1.15-1.29)	1.38 (1.19-1.59)	2.00 (1.31-3.07)	1.29 (1.03-1.63)	1.05 (0.96-1.14)
Systolic blood pressure*					
≥ 90	ref.	ref.	ref.	ref.	ref.
0-89	1.33 (1.25-1.42)	1.65 (1.38-1.97)	1.60 (1.15-2.24)	1.27 (1.02-1.57)	1.20 (1.10-1.31)
Transfer					
No	ref.	ref.	ref.	ref.	ref.
Yes	0.80 (0.78-0.82)	0.80 (0.76-0.84)	1.00 (0.88-1.14)	0.98 (0.87-1.10)	0.79 (0.77-0.81)
Type of insurance					
Provincial health	ref.	ref.	ref.	ref.	ref.
Road accidents	1.06 (1.02-1.10)	1.07 (0.95-1.20)	1.17 (0.95-1.46)	1.08 (0.91-1.28)	1.06 (1.01-1.12)
Work accidents	1.01 (0.97-1.06)	1.04 (0.91-1.20)	1.20 (0.94-1.53)	0.99 (0.78-1.25)	1.02 (0.97-1.07)
Other	1.01 (0.98-1.05)	1.09 (0.96-1.23)	0.84 (0.60-1.18)	0.85 (0.65-1.12)	1.01 (0.96-1.06)
None /Unknown	0.97 (0.92-1.02)	0.92 (0.77-1.09)	0.96 (0.60-1.54)	0.78 (0.50-1.23)	0.98 (0.92-1.05)
Year of admission					
2014	ref.	ref.	ref.	ref.	ref.
2015	0.99 (0.98-1.01)	0.98 (0.92-1.03)	1.07 (0.93-1.22)	0.89 (0.78-1.00)	0.99 (0.97-1.02)
2016	0.95 (0.93-0.97)	0.94 (0.88-0.99)	1.01 (0.88-1.15)	0.87 (0.77-0.99)	0.95 (0.92-0.97)

Discharge destination					
Home	ref.	ref.	ref.	ref.	ref.
Acute care	1.24 (1.21-1.28)	1.43 (1.33-1.53)	1.34 (1.12-1.60)	1.40 (1.22-1.62)	1.17 (1.13-1.21)
Long stay	1.80 (1.74-1.86)	2.35 (2.11-2.63)	1.70 (1.15-2.51)	1.98 (1.47-2.68)	1.62 (1.55-1.68)
Rehabilitation	1.67 (1.62-1.72)	1.94 (1.83-2.07)	1.58 (1.33-1.83)	1.99 (1.71-2.31)	1.49 (1.44-1.55)
Other	1.27 (1.23-1.30)	1.48 (1.33-1.64)	1.39 (0.86-2.24)	1.60 (1.30-1.96)	1.22 (1.18-1.26)
Trauma center designation level					
I	ref.	ref.	ref.	ref.	ref.
II	0.94 (0.80-1.11)	0.98 (0.84-1.14)	0.89 (0.70-1.14)	0.88 (0.77-1.00)	0.97 (0.82-1.15)
III	0.93 (0.81-1.07)	1.03 (0.89-1.18)	0.51 (0.38-0.70)	0.79 (0.69-0.91)	0.98 (0.84-1.13)
IV	0.82 (0.71-0.94)	0.92 (0.79-1.06)	0.60 (0.36-0.98)	0.63 (0.51-0.79)	0.87 (0.75-1.01)

n: number; Q1: quartile 1; Q3: quartile 3; CI: confidence interval; ref.: reference; MVC: motor vehicle collision
*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.

Table 3.5. Determinants of acute injury care resource use by designation level (in 2016 Can$)

Variable	Adjusted geometric mean ratio (95% CI)		
	Global	Level I/II (n = 14,825)	Level III/IV (n = 17,587)
Age			
16-54	ref.	ref.	ref.
55-64	1.00 (0.98-1.03)	0.99 (0.96-1.03)	1.01 (0.98-1.05)
65-74	1.03 (1.00-1.06)	1.01 (0.97-1.05)	1.07 (1.03-1.11)
75-84	1.07 (1.04-1.10)	1.00 (0.96-1.04)	1.14 (1.10-1.19)
≥ 85	1.07 (1.04-1.10)	0.96 (0.91-1.00)	1.17 (1.12-1.21)
Sex			
Male	ref.	ref.	ref.
Female	1.02 (1.00-1.04)	1.04 (1.01-1.06)	1.01 (0.99-1.04)
Number of comorbidities			
0	ref.	ref.	ref.
1	1.10 (1.08-1.12)	1.10 (1.06-1.13)	1.10 (1.07-1.13)
2	1.23 (1.19-1.26)	1.23 (1.17-1.28)	1.21 (1.17-1.25)
≥ 3	1.31 (1.27-1.35)	1.27 (1.20-1.34)	1.31 (1.27-1.36)
Type of injury			
Traumatic brain	ref.	ref.	ref.
Spinal cord	1.76 (1.65-1.87)	1.81 (1.69-1.93)	0.96 (0.76-1.20)
Multisystem blunt	1.57 (1.49-1.66)	1.67 (1.57-1.78)	1.40 (1.28-1.54)
Orthopedic	1.29 (1.25-1.33)	1.36 (1.30-1.42)	1.26 (1.20-1.32)
Mechanism			
MVC	ref.	ref.	ref.
Fall	0.95 (0.92-0.99)	0.91 (0.86-0.96)	1.02 (0.97-1.08)
Penetrating	1.07 (1.00-1.15)	1.17 (1.06-1.29)	0.98 (0.89-1.09)
Other	0.99 (0.95-1.03)	0.98 (0.92-1.03)	1.04 (0.97-1.10)
New Injury severity score			
< 12	ref.	ref.	ref.
12-24	1.26 (1.24-1.29)	1.26 (1.22-1.30)	1.28 (1.24-1.31)
≥ 25	1.77 (1.70-1.83)	1.76 (1.68-1.84)	1.58 (1.47-1.70)
Glasgow coma scale score*			
3-8	1.63 (1.53-1.74)	1.88 (1.77-2.00)	1.15 (1.02-1.29)
9-12	1.24 (1.17-1.32)	1.37 (1.29-1.45)	1.07 (0.96-1.19)
13-15	ref.	ref.	ref.
Respiration Rate*			
11-29	ref.	ref.	ref.
0-10; ≥ 30	1.22 (1.15-1.29)	1.24 (1.15-1.35)	1.16 (1.07-1.26)
Systolic blood pressure*			
≥ 90	ref.	ref.	ref.
0-89	1.33 (1.25-1.42)	1.42 (1.29-1.55)	1.22 (1.11-1.33)

Transfer			
No	ref.	ref.	ref.
Yes	0.80 (0.78-0.82)	0.81 (0.79-0.83)	0.76 (0.74-0.79)
Type of insurance			
Provincial health	ref.	ref.	ref.
Road accidents	1.06 (1.02-1.10)	1.06 (1.01-1.12)	1.05 (0.99-1.11)
Work accidents	1.01 (0.97-1.06)	1.05 (1.00-1.12)	0.96 (0.91-1.02)
Other	1.01 (0.98-1.05)	1.04 (0.98-1.12)	0.98 (0.94-1.03)
None /Unknown	0.97 (0.92-1.02)	1.02 (0.95-1.10)	0.92 (0.84-0.99)
Year of admission			
2014	ref.	ref.	ref.
2015	0.99 (0.98-1.01)	0.98 (0.95-1.01)	1.01 (0.98-1.03)
2016	0.95 (0.93-0.97)	0.97 (0.94-1.00)	0.94 (0.91-0.96)
Discharge destination			
Home	ref.	ref.	ref.
Acute care	1.24 (1.21-1.28)	1.45 (1.39-1.50)	1.03 (0.98-1.08)
Long stay	1.80 (1.74-1.86)	1.91 (1.79-2.04)	1.69 (1.63-1.76)
Rehabilitation	1.67 (1.62-1.72)	1.80 (1.74-1.87)	1.43 (1.36-1.50)
Other	1.27 (1.23-1.30)	1.36 (1.30-1.43)	1.18 (1.15-1.22)

n: number; Q1: quartile 1; Q3: quartile 3; CI: confidence interval; ref.: reference; MVC: motor vehicle collision

*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.

Table 3.6. Determinants of acute injury care resource use (in 2016 Can$) by activity center

Variable	N (%)	Adjusted geometric mean ratio (95% CI)		
		Regular 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)
Orthopedic	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*				
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*				
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*				
≥ 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)
Trauma center 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

*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.

Figure 3.2. Relative importance of determinants in predicting acute injury care resource use intensity overall and by activity center

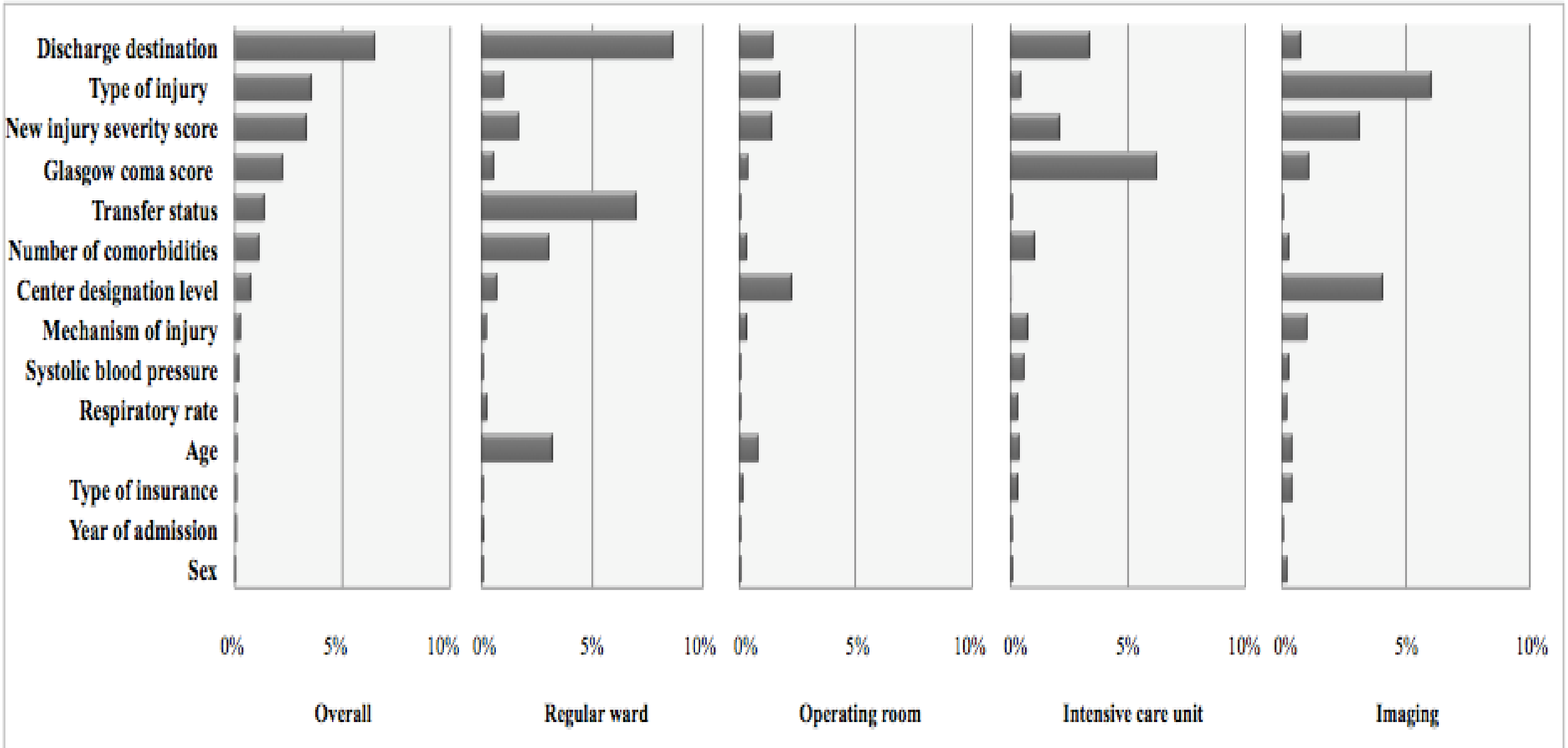


Table 3.7. Inter-provider variations in resource use intensity overall and by activity center

	ICC (95% Confidence interval)
Overall	0.049 (0.040-0.058)
Regular 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

Table 3.8. Supplemental content. Determinants of acute injury care resource use when excluding extreme costs or observations with missing physiological data and when including in-hospital deaths (in 2016 Can$)

Variable	Adjusted geometric mean ratio (95% CI)			Adjusted hazard ratio (95% CI)
	Global	Excluding extreme costs values (n = 32,087)	Excluding observations with missing physiological measures (n = 17,826)	Including in-hospital deaths in a competitive risks framework (n = 34,466)
Age				
16-54	ref.	ref.	ref.	ref.
55-64	1.00 (0.98-1.03)	0.99 (0.97-1.02)	0.99 (0.97-1.02)	1.05 (1.02-1.09)
65-74	1.03 (1.00-1.06)	1.02 (0.99-1.05)	1.03 (1.00-1.06)	1.21 (1.16-1.26)
75-84	1.07 (1.04-1.10)	1.07 (1.04-1.10)	1.07 (1.04-1.11)	1.49 (1.42-1.55)
≥ 85	1.07 (1.04-1.10)	1.08 (1.05-1.11)	1.07 (1.07-1.11)	1.83 (1.76-1.91)
Sex				
Male	ref.	ref.	ref.	ref.
Female	1.02 (1.00-1.04)	1.02 (1.00-1.03)	1.02 (1.00-1.04)	1.07 (1.04-1.10)
Number of comorbidities				
0	ref.	ref.	ref.	ref.
1	1.10 (1.08-1.12)	1.10 (1.08-1.13)	1.11 (1.08-1.13)	1.23 (1.19-1.27)
2	1.23 (1.19-1.26)	1.22 (1.19-1.25)	1.23 (1.20-1.26)	1.49 (1.44-1.55)
≥ 3	1.31 (1.27-1.35)	1.31 (1.27-1.35)	1.32 (1.28-1.37)	1.84 (1.77-1.92)
Type of injury				
Traumatic brain	ref.	ref.	ref.	ref.
Spinal cord	1.76 (1.65-1.87)	1.76 (1.66-1.87)	1.80 (1.70-1.92)	1.67 (1.53-1.83)
Multisystem blunt	1.57 (1.49-1.66)	1.57 (1.49-1.66)	1.64 (1.55-1.73)	1.25 (1.16-1.35)
Orthopedic	1.29 (1.25-1.33)	1.30 (1.26-1.34)	1.33 (1.29-1.38)	1.01 (0.96-1.06)
Mechanism				
MVC	ref.	ref.	ref.	ref.
Fall	0.95 (0.92-0.99)	0.96 (0.92-0.99)	0.97 (0.93-1.01)	0.96 (0.90-1.01)
Penetrating	1.07 (1.00-1.15)	1.05 (0.98-1.13)	1.09 (1.01-1.17)	1.14 (1.03-1.26)
Other	0.99 (0.95-1.03)	1.00 (0.96-1.04)	1.01 (0.97-1.06)	0.98 (0.92-1.05)
New Injury severity score				
< 12	ref.	ref.	ref.	ref.
12-24	1.26 (1.24-1.29)	1.26 (1.24-1.29)	1.26 (1.23-1.28)	1.40 (1.36-1.44)
≥ 25	1.77 (1.70-1.83)	1.68 (1.62-1.74)	1.71 (1.64-1.77)	2.25 (2.13-2.37)
Glasgow coma scale score*				
3-8	1.63 (1.53-1.74)	1.53 (1.43-1.63)	2.14 (2.02-2.25)	2.26 (2.11-2.42)
9-12	1.24 (1.17-1.32)	1.22 (1.15-1.29)	1.47 (1.38-1.56)	1.48 (1.37-1.60)
13-15	ref.	ref.	ref.	ref.
Respiration Rate*				
11-29	ref.	ref.	ref.	ref.
0-10; ≥ 30	1.22 (1.15-1.29)	1.17 (1.11-1.24)	1.21 (1.15-3.29)	1.40 (1.29-1.53)

Systolic blood pressure*				
≥ 90	ref.	ref.	ref.	ref.
0-89	1.33 (1.25-1.42)	1.26 (1.18-1.35)	1.32 (1.23-1.41)	1.48 (1.34-1.64)
Transfer				
No	ref.	ref.	ref.	ref.
Yes	0.80 (0.78-0.82)	0.81 (0.79-0.82)	0.82 (0.80-0.84)	0.75 (0.73-0.78)
Type of insurance				
Provincial health	ref.	ref.	ref.	ref.
Road accidents	1.06 (1.02-1.10)	1.05 (1.01-1.10)	1.06 (1.02-1.11)	1.09 (1.03-1.16)
Work accidents	1.01 (0.97-1.06)	1.00 (0.96-1.04)	1.02 (0.97-1.06)	0.98 (0.92-1.04)
Other	1.01 (0.98-1.05)	1.01 (0.97-1.05)	1.01 (0.97-1.05)	0.97 (0.92-1.03)
None /Unknown	0.97 (0.92-1.02)	0.97 (0.92-1.03)	0.98 (0.92-1.04)	0.89 (0.82-0.97)
Year of admission				
2014	ref.	ref.	ref.	ref.
2015	0.99 (0.98-1.01)	1.00 (0.98-1.02)	1.00 (0.98-1.02)	1.00 (0.97-1.02)
2016	0.95 (0.93-0.97)	0.96 (0.94-0.98)	0.95 (0.94-0.97)	0.95 (0.93-0.98)
Discharge destination				
Home	ref.	ref.	ref.	ref.
Acute care	1.24 (1.21-1.28)	1.21 (1.18-1.25)	1.22 (1.18-1.26)	0.94 (0.90-0.98)
Long stay	1.80 (1.74-1.86)	1.71 (1.65-1.76)	1.78 (1.72-1.84)	1.14 (1.09-1.20)
Rehabilitation	1.67 (1.62-1.72)	1.62 (1.58-1.66)	1.64 (1.59-1.69)	1.06 (1.02-1.11)
Other	1.27 (1.23-1.30)	1.25 (1.22-1.28)	1.27 (1.24-1.31)	0.84 (0.81-0.87)
Trauma center designation level				
I	ref.	ref.	ref.	ref.
II	0.94 (0.80-1.11)	0.94 (0.80-1.10)	0.95 (0.82-1.10)	0.87 (0.69-1.11)
III	0.93 (0.81-1.07)	0.93 (0.81-1.06)	0.95 (0.84-1.09)	0.84 (0.69-1.03)
IV	0.82 (0.71-0.94)	0.81 (0.70-0.92)	0.85 (0.74-0.97)	0.70 (0.57-0.86)

n: number; Q1: quartile 1; Q3: quartile 3; CI: confidence interval; ref.: reference; MVC: motor vehicle collision

*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.

Table 3.9. Supplemental content. Determinants of acute injury care resource use by type of regression (in 2016 Can$)

Variable	Log	Poisson	Gamma	Ordinary least squares
	Geometric mean ratio (95% CI)			Difference of medians (95% CI)
Age				
16-54	ref.	ref.	ref.	ref.
55-64	1.00 (0.98-1.03)	0.98 (0.97-0.98)	0.99 (0.97-1.02)	183 (-71 to 437)
65-74	1.03 (1.00-1.06)	1.04 (1.03-1.05)	1.05 (1.02-1.08)	-198 (-506 to 111)
75-84	1.07 (1.04-1.10)	1.03 (1.02-1.05)	1.08 (1.05-1.11)	-60 (-361 to 240)
≥ 85	1.07 (1.04-1.10)	1.02 (1.01-1.03)	1.09 (1.06-1.12)	106 (-209 to 421)
Sex				
Male	ref.	ref.	ref.	ref.
Female	1.02 (1.00-1.04)	1.04 (1.04-1.05)	1.04 (1.02-1.05)	-259 (-439 to -79)
Number of comorbidities				
0	ref.	ref.	ref.	ref.
1	1.10 (1.08-1.12)	1.11 (1.10-1.11)	1.12 (1.10-1.15)	-615 (-831 to -398)
2	1.23 (1.19-1.26)	1.26 (1.25-1.27)	1.27 (1.24-1.31)	-1644 (-1919 to -1369)
≥ 3	1.31 (1.27-1.35)	1.33 (1.32-1.34)	1.36 (1.32-1.40)	-1987 (-2296 to -1678)
Type of injury				
Traumatic brain	ref.	ref.	ref.	ref.
Spinal cord	1.76 (1.65-1.87)	1.52 (1.51-1.53)	1.64 (1.54-1.74)	-4664 (-5302 to -4025)
Multisystem blunt	1.57 (1.49-1.66)	1.44 (1.43-1.45)	1.52 (1.45-1.60)	-4066 (-4610 to -3522)
Orthopedic	1.29 (1.25-1.33)	1.18 (1.18-1.19)	1.21 (1.17-1.25)	-1297 (-1628 to -966)
Mechanism				
MVC	ref.	ref.	ref.	ref.
Fall	0.95 (0.92-0.99)	0.91 (0.91-0.91)	0.93 (0.89-0.96)	599 (204 to 995)
Penetrating	1.07 (1.00-1.15)	1.22 (1.19-1.24)	1.14 (1.06-1.22)	-1257 (-1987 to -526)
Other	0.99 (0.95-1.03)	0.97 (0.96-0.97)	0.98 (0.94-1.02)	223 (-219 to 666)
New Injury severity score				
< 12	ref.	ref.	ref.	ref.
12-24	1.26 (1.24-1.29)	1.26 (1.26-1.26)	1.27 (1.25-1.30)	-1394 (-1600 to -1188)

≥ 25	1.77 (1.70-1.83)	1.82 (1.80-1.83)	1.81 (1.74-1.88)	-5493 (-5874 to -5112)
Glasgow coma scale score*				
3-8	1.63 (1.53-1.74)	1.79 (1.76-1.83)	1.74 (1.66-1.83)	-4039 (-4636 to -3443)
9-12	1.24 (1.17-1.32)	1.33 (1.26-1.40)	1.30 (1.22-1.39)	2829 (2367 to 3291)
13-15	ref.	ref.	ref.	ref.
Respiration Rate*				
11-29	ref.	ref.	ref.	ref.
0-10; ≥ 30	1.22 (1.15-1.29)	1.26 (1.25-1.28)	1.23 (1.16-1.30)	-2652 (-3250 to -2053)
Systolic blood pressure*				
≥ 90	ref.	ref.	ref.	ref.
0-89	1.33 (1.25-1.42)	1.43 (1.41-1.46)	1.37 (1.29-1.47)	-4446 (-5125 to -3766)
Transfer				
No	ref.	ref.	ref.	ref.
Yes	0.80 (0.78-0.82)	0.84 (0.84-0.85)	0.82 (0.80-0.83)	1222 (1007 to 1436)
Type of insurance				
Provincial health	ref.	ref.	ref.	ref.
Road accidents	1.06 (1.02-1.10)	1.09 (1.08-1.10)	1.07 (1.03-1.12)	-853 (-1277 to -430)
Work accidents	1.01 (0.97-1.06)	1.07 (1.06-1.07)	1.04 (1.00-1.09)	-507 (-942 to -71)
Other	1.01 (0.98-1.05)	1.02 (1.01-1.02)	1.00 (0.96-1.03)	-147 (-549 to 255)
None /Unknown	0.97 (0.92-1.02)	0.93 (0.92-0.95)	0.96 (0.91-1.01)	489 (-84 to 1063)
Year of admission				
2014	ref.	ref.	ref.	ref.
2015	0.99 (0.98-1.01)	0.97 (0.97-0.97)	0.98 (0.96-1.00)	224 (28 to 420)
2016	0.95 (0.93-0.97)	0.91 (0.91-0.92)	0.93 (0.91-0.95)	633 (435 to 830)

Discharge destination				
Home	ref.	ref.	ref.	ref.
Acute care	1.24 (1.21-1.28)	1.32 (1.32-1.33)	1.29 (1.25-1.33)	-1833 (-2135 to -1531)
Long stay	1.80 (1.74-1.86)	2.01 (2.00-2.03)	1.92 (1.85-1.98)	-5932 (-6283 to -5580)
Rehabilitation	1.67 (1.62-1.72)	1.67 (1.66-1.67)	1.62 (1.58-1.66)	-4489 (-4774 to -4204)
Other	1.27 (1.23-1.30)	1.38 (1.37-1.39)	1.31 (1.27-1.34)	-2144 (-2420 to -1869)
Trauma center designation level				
I	ref.	ref.	ref.	ref.
II	0.94 (0.80-1.11)	0.99 (0.97-1.00)	0.99 (0.98-0.99)	-663 (-1387 to 61)
III	0.93 (0.81-1.07)	0.99 (0.98-1.00)	0.99 (0.98-0.99)	-380 (-1521 to 761)
IV	0.82 (0.71-0.94)	0.97 (0.96-0.99)	0.97 (0.97-0.98)	-1390 (-2788 to 8.57)

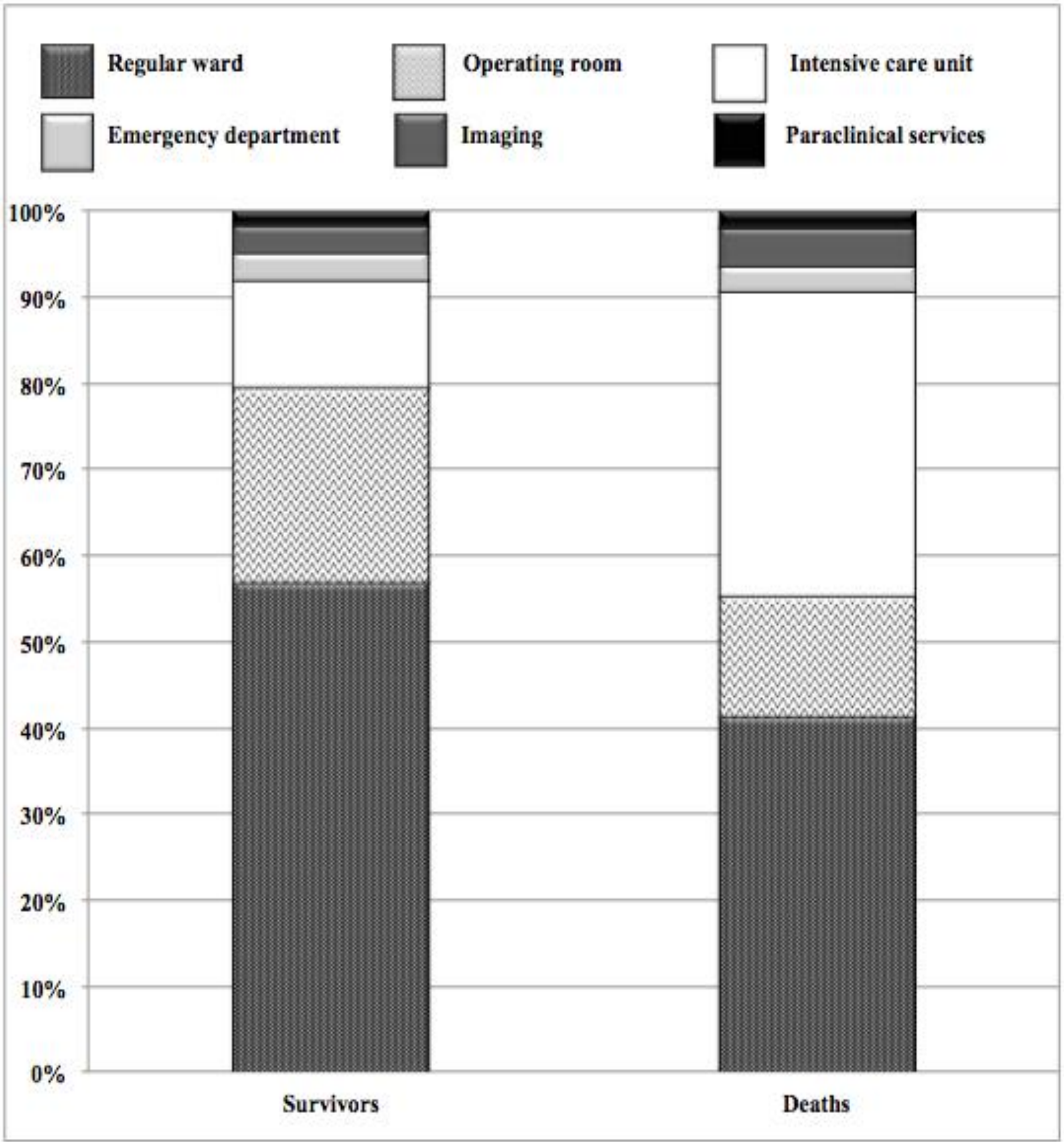
n: number; Q1: quartile 1; Q3: quartile 3; CI: confidence interval; ref.: reference; MVC: motor vehicle collision
*Data on the Glasgow Coma Score, respiratory rate and systolic blood pressure on arrival were missing for 45.3% (n = 14,683), 10.3% (n = 3342) and 1.5% (n = 489) of admissions, respectively.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

Table 3.10. Supplemental content. Median resource use overall and by activity center among survivors and deaths

	Survivors		Deaths	
	n (%)	**Crude median cost (Q1-Q3)**	**n (%)**	**Crude median cost (Q1-Q3)**
Overall	32,411 (100)	4858 (2961-8449)	2056 (100)	4711 (1933-10,300)
Regular ward	31,741 (97.9)	2433 (1292-5060)	1548 (75.3)	2265 (845-5560)
Operating room	16,127 (49.8)	2541 (1769-3821)	611 (29.7)	3012 (2071-4517)
Intensive care unit	4916 (15.2)	3377 (1675-6865)	870 (42.3)	3285 (1305-8642)
Imaging	29,578 (91.3)	80 (40-196)	2013 (97.9)	120 (65-264)
Paraclinical services	21,793 (67.2)	152 (76-152)	1027 (50.0)	152 (76-471)

n: number; Q1: quartile 1; Q3: quartile 3

Figure 3.3. Supplemental content. Relative contribution of activity centers to total costs among survivors and deaths



3.9. References

1. Dieleman JL, Baral R, Birger M, Bui AL, Bulchis A, Chapin A, et al. US Spending on Personal Health Care and Public Health, 1996-2013. *JAMA*. 2016;316(24): 2627-2646.
2. Parachute (2015). The Cost of Injury in Canada. Parachute: Toronto, ON. Available at: http://www.parachutecanada.org/downloads/research/Cost_of_Injury-2015.pdf. Accessed August 25, 2015.
3. Glance LG, Dick AW, Osler TM, Meredith W, Mukamel DB. The association between cost and quality in trauma: is greater spending associated with higher-quality care? *Ann Surg*. 2010;252(2): 217-22.
4. Clancy TV, Maxwell GJ, Covington DL, Brinker CC, Blackman D. A statewide analysis of level I and II trauma centers for patients with major injuries. *J Trauma*. 2001;51(2): 346-51.
5. Obirieze AC, Gaskin DJ, Villegas CV, et al. Regional variations in cost of trauma care in the United States: who is paying more? *J Trauma Acute Care Surg*. 2012;73(2): 516-22.
6. Porgo TV, Shemilt M, Moore L, Bourgeois G, Lapointe J. Trauma center performance evaluation based on costs: A systematic review of cohort studies. *J Trauma Acute Care Surg*. 2014;76(2): 542-8.
7. Canadian Institute for Health Information. The Cost of Acute Care Hospital Stays by Medical Condition in Canada, 2004–2005. Ottawa, ON: the Canadian Institute for Health Information; 2008.
8. The Canadian Agency for Drugs and Technologies in Health. Guidance document for the Costing of health care resources in the canadian setting. 2nd Edition. Ottawa, ON: the Canadian Agency for Drugs and Technologies in Health; 2015.
9. World Health Organization. Financing for universal coverage. Using available resources in the most efficient and equitable way. Available at: http://www.who.int/health_financing/strategy/equity_efficiency/en/. Accessed October 16, 2017.
10. Kaplan RS, Porter ME. How to solve the cost crisis in health care. *Harv Bus Rev*. 2011;89(9): 46-52, 54, 56-61.
11. Finkler SA, Watd DM. The case for the use of evidence-based management research for the control of hospital costs. *Health Care Manage Rev*. 2003;28(4): 348-65.
12. Brock GN, Barnes C, Ramirez JA, Myers J. How to handle mortality when investigating length of hospital stay and time to clinical stability. *BioMed Central*. 2001;11: 144.
13. Ministère de la Santé et des Services Sociaux, Direction générale des services de santé et de la médecine universitaire. Cadre normatif - Registre des traumatismes du Québec (RTQ). Version 1.0, Avril 2004.
14. Ministère de la Santé et des Services sociaux du Québec. Banque de données ministérielles MED-ÉCHO. Régie de l'assurance maladie du Québec.

http://www.ramq.gouv.qc.ca/en/data-statistics/Pages/data-statistics.aspx. Accessed February 20, 2018.
15. Ministère de la Santé et des Services sociaux du Québec. Rapports financiers annuels des établissements 2015-2016, statsitiques et données. http://publications.msss.gouv.qc.ca/msss/document-001671/. Published 2016. Accessed March 16, 2018.
16. Ministère de la Santé et des Services sociaux du Québec. Normes et pratiques de gestion, Tome II, Répertoire. http://msssa4.msss.gouv.qc.ca/fr/document/d26ngest.nsf/1f71b4b2831203278525656b0004f8bf/c1bc430d41b48eea85257f9500673c97?OpenDocument. Published 2016. Accessed February 20, 2018.
17. Guyatt GH, Oxman AD, Kunz R, Jaeschke R, Helfand M, Liberati A, Vist GE, Schunemann HJ; Grade Working Group. Incorporating considerations of resources use into grading recommendations. *BMJ*. 2008;336(7654): 1170-3.
18. West TD, Balas EA, West DA. Contrasting RCC, RVU, and ABC for managed care decisions. A case study compares three widely used costing methods and finds one superior. *Healthc Financ Manage*. 1996;50(8): 54-61.
19. Canby JB 4th. Applying activity-based costing to healthcare settings. *Healthc Financ Manage*. 1995;49(2): 50-2, 54-6.
20. Canadian Agency for Drugs and Technologies in Health. Guidelines for the economic evaluation of health technologies: Canada. 4th Edition. Ottawa, ON: the Canadian Agency for Drugs and Technologies in Health; 2017.
21. Ministère de la Santé et des Services sociaux du Québec. Liste par centre d'activités (établissement). http://msssa4.msss.gouv.qc.ca/fr/document/d26ngest.nsf/lca?OpenView&Start=204. Accessed February 20, 2018.
22. Moore L, Hanley JA, Turgeon AF, Lavoie A. Evaluating the performance of trauma centers: hierarchical modeling should be used. *J Trauma*. 2010;69(5): 1132-7.
23. Daly L, Bourke GJ. Interpretation and uses of medical statistics. 5th ed. Oxford, England: Wiley Blackweell; 2000.
24. Selya AS, Rose JS, Dierker LC, Hedeker D, Mermelstein RJ. A practical guide to calculating Cohen's f 2, a measure of local effect size, from PROC MIXED. *Frontiers in psychology*. 2012;3(111).
25. Porgo TV, Moore L, Tardif PA. Evidence of data quality in trauma registries: a systematic review. *J Trauma Acute Care Surg*. 2016;80(4): 648-58.
26. Little RJA, Rubin DB. Statistical analysis with missing data. Second ed. New York, NY: Wiley; 2002.
27. Allison PD. Missing Data. Sage University Papers Series on Quantitative Application in the Social Sciences. Thousand Oaks, CA: Sage Publications; 2001.
28. Sterne JA, White IR, Carlin JB, et al. Multiple imputation for missing data in epidemiological and clinical research: potential and pitfalls. *BMJ*. 2009;338: b2393.
29. Moore L, Lavoie A, LeSage N, et al. Multiple imputation of the Glasgow Coma Score. *J Trauma*. 2005;59(3): 698-704.

30. Schafer JL. Analysis of incomplete multivariate data. London: Chapman and Hall; 1997.
31. Moore L, Hanley JA, Lavoie A, Turgeon A. Evaluating the validity of multiple imputation for missing physiological data in the national trauma data bank. *J Emerg Trauma Shock*. 2009;2(2): 73-9.
32. Ruffieux C, Paccaud F, Marazzi A. Comparing rules for truncating hospital length of stay. *Casemix Quaterly*. 2000;2(1): 1-10.
33. Christensen MC, Ridley S, Lecky FE, Munro V, Morris S. Outcomes and costs of blunt trauma in England and Wales. *Crit Care*. 2008;12(1): R23.
34. Christensen MC, Nielsen TG, Ridley S, Lecky FE, Morris S. Outcomes and costs of penetrating trauma injury in England and Wales. *Injury*. 2008;39(9): 1013-25.
35. Batomen BL, Moore L, Cisse B, et al. Access to an integrated trauma system: A population based-cohort study. *Injury*. 2015;46(7): 595-601.
36. Brasel KJ, Rasmussen J, Cauley C, Weigelt JA. Reasons for delayed discharge of trauma patients. *J Surg Res*. 2002;107(2): 223-6.
37. Thomas SN, McGwin G Jr, Rue LW 3rd. The financial impact of delayed discharge at a level I trauma center. *J Trauma*. 2005;58(1): 121-5.
38. Rogers A, Clark EH, Rittenhouse K, et al. Breaking down the barriers! Factors contributing to barrier days in a mature trauma center. *J Trauma Acute Care Surg*. 2014;76(1): 191-5.
39. McKevitt EC, Calvert E, Ng A, et al. Geriatric trauma: resource use and patient outcomes. *Can J Surg*. 2003;46(3): 211-5.
40. Canadian Institute for Health Information (CIHI). Les personnes âgées et les niveaux de soins alternatifs : mettre à profit nos connaissances [CIHI web site]. Available at: https://secure.cihi.ca/free_products/ALC_AIB_FR.pdf. Accessed Februeary 20, 2018.
41. Bauer M, Fitzgerald L, Haesler E, Manfrin M. Hospital discharge planning for frail older people and their family. Are we delivering best practice? A review of the evidence. *Journal of Clinical Nursing*. 2009;18(18): 2539-2546.
42. Oliver D, Foot C, Humphries R. Making our health and care systems fit for an ageing population, 2014. Available at: https://www.kingsfund.org.uk/sites/default/files/field/field_publication_file/making-health-care-systems-fit-ageing-population-oliver-foot-humphries-mar14.pdf Accessed November 16, 2018.
43. The Queen's Nursing Institute. Best practice in transitions of care, 2016. Available at: https://www.qni.org.uk/wp-content/uploads/2016/09/discharge_planning_report_2015.pdf Accessed November 16, 2018.
44. Sunnybrook Health Sciences Center. Hours Matter, Fall 2009. Available at: https://sunnybrook.ca/uploads/HoursMatter_Nov09.pdf Accessed November 16, 2018.
45. Fisher E, Goodman D, Skinner J, Bronner K. Health care spending, quality, and outcomes, More isn't always better. Lebanon, NH: The Dartmouth Institute for Health Policy and Clinical Practice; 2009.
46. The World Health Organization (WHO). WHO Global Health Expenditure Atlas. September 2014. Geneva: WHO; 2014.

47. Reilly BM, Evans AT. Much ado about (doing) nothing. Annals of internal medicine 2009;150(4): 270-1.
48. The Lown Institute. Overuse 101. http://lowninstitute.org/learn/overuse-101/. Accessed March 19, 2018.
49. Brownlee S, Chalkidou K, Doust J, et al. Evidence for overuse of medical services around the world. *Lancet*. 2007;S0140-6736(16)32585-5.
50. Moore L, Lavoie A, Sirois MJ, Amini R, Belcaid A, Sampalis JS. Evaluating trauma center process performance in an integrated trauma system with registry data. *J Emerg Trauma Shock*. 2013;6(2): 95-105.
51. The Agency for Healthcare Research and Quality. Selecting Quality and Resource Use Measures: A Decision Guide for Community Quality Collaboratives. Part III. Introduction to Resource Use/Efficiency Measures. https://www.ahrq.gov/professionals/quality-patient-safety/quality-resources/tools/perfmeasguide/perfmeaspt3.html. Last modified: October 2014. Accessed January 29, 2018.
52. Kang H. The prevention and handling of the missing data. *Korean J Anesthesiol*. 2013;64(5): 402-6.
53. Jefferies LC, Sachais BS, Young DS. Blood transfusion costs by diagnosis-related groups in 60 university hospitals in 1995. *Transfusion*. 2001;41(4): 522-9.
54. Ridic G, Gleason S, Ridic O. Comparisons of Health Care Systems in the United States, Germany and Canada. *Mat Soc Med*. 2012;24(2): 112-120.
55. Phillips B, Clark DE, Nathens AB, Shiloach M, Freel AC. Comparison of injury patient information from hospitals with records in both the national trauma data bank and the nationwide inpatient sample. *J Trauma*. 2008;64(3): 768-79; discussion 779-80.
56. Hemmila MR, Jakubus JL, Wahl WL, et al. Detecting the blind spot: complications in the trauma registry and trauma quality improvement. *Surgery*. 2007;142(4): 439-48; discussion 448-9.
57. MacKenzie EJ. Injury severity scales: overview and directions for future research. *Am J Emerg Med*. 1984;2(6): 537-49.
58. Moore L, Clark DE. The value of trauma registries. *Injury*. 2008;39(6): 686-95.

CHAPTER 4. ARTICLE. DEVELOPMENT AND VALIDATION OF A HOSPITAL INDICATOR OF RESOURCE USE INTENSITY FOR INJURY ADMISSIONS

Teegwendé V. Porgo MSc,[1,2] Lynne Moore PhD,[1,2] Coralie Assy,[1,2] Alexis F. Turgeon MD MSc FRCPC,[1,2,3]

[1]Department of Social and Preventive Medicine, Université Laval, Québec (QC), Canada;
[2]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;
[3]Department of Anesthesiology and Critical Care Medicine, Division of Critical Care Medicine, Université Laval, Québec (QC), Canada

Running title: Hospital indicator of resource use intensity for injury admissions

Keywords: Trauma, resource use intensity, risk-adjustment model, indicator, benchmark, funnel plot, inter-provider variations

4.1. Résumé

Notre objectif était de développer un indicateur de l'intensité d'utilisation des ressources pour les soins aigus en traumatologie. À partir d'une étude de cohorte incluant 33124 adultes hospitalisés dans les centres de traumatologie pour adultes du Québec entre 2014 et 2016, nous avons construit des modèles d'ajustement pour tous les patients et pour des groupes diagnostiques spécifiques. Les analyses étaient stratifiées par niveau de désignation des centres (I/II et III/IV). Les modèles expliquaient entre 11% et 30% (r^2 avec correction de l'optimisme) de la variation de l'utilisation des ressources. Nous avons identifié des centres où l'utilisation des ressources était significativement plus grande ou plus petite que la moyenne provinciale. Nos données suggèrent que 70% à 90% de l'utilisation des ressources sont dictées par des facteurs autres que le statut clinique des patients. Combinées à des données sur la mortalité et la morbidité, nos données permettront le développement d'interventions visant à améliorer l'efficience des soins en traumatologie.

4.2. Abstract

Introduction: Significant inter-provider variations in risk-adjusted resource use have been observed for injury admissions in Canada, suggesting that injury care may be related to factors beyond patient needs. However, we currently lack tools to evaluate resource use intensity for injury care.

Objective: To develop a hospital indicator of resource use intensity for injury admissions, and evaluate its internal and temporal validity.

Methods: We performed a retrospective cohort study including ≥ 16-year-olds admitted to any of the 57 adult trauma centers in a mature, inclusive Canadian trauma system from 2014 to 2016. We extracted data from the trauma registry and hospital financial reports. We estimated resource use with activity-based costing. Analyses were stratified by trauma center designation level (I/II and III/IV). We developed risk-adjustment models for the whole sample and for specific diagnostic groups. Candidate variables were selected using bootstrap resampling. We assessed internal validity of the model with the optimism-corrected coefficient of determination (r^2) and temporal validity with yearly r^2. We performed benchmarking by comparing the adjusted geometric mean cost of each center, obtained using shrinkage estimates, to the global geometric mean.

Results: We included 33,124 patients. The risk-adjustment models explained between 11% and 30% (optimism-corrected r^2) of the variation in resource use. Temporal validity in the whole sample was high with yearly r^2 between 29% and 31% and between 16% and 17% for level I/II and III/IV centers, respectively. Median resource use in the whole sample was $5014 (Quartiles 1 and 3: 3045-8762). In the whole sample and among patients with traumatic brain and isolated orthopedic injuries, we identified centers with higher or lower than expected resource use, across level I/II and III/IV centres. Among patients isolated thoracoabdominal injuries, we identified centers with higher than expected resource use intensity across level III/IV centers.

Conclusions: Our risk-adjustment models suggest that between 70% and 90% of the variation in resource use for injury care is dictated by factors other than the clinical status of patients on arrival. We propose an algorithm that can be applied using data routinely collected in trauma registries to calculate risk-adjusted geometric mean activity-based costs in a trauma center using our unit costs or local unit costs. If used alongside information on clinical outcomes, this indicator could be used to prompt targeted exploration of potential areas for improvement in resource use for injury admissions.

4.3. Introduction

In 2013, approximately 973 million people worldwide sought medical care following injury.[1] The implementation of trauma systems has improved injury mortality and morbidity.[2-4] However, we recently observed significant inter-provider variations in risk-adjusted resource use for injury admissions in Canada.[5] Similarly, significant variations in adjusted cost estimates based on patient charges have been observed among trauma centers in the United States. However, patient outcomes in centers with high risk-adjusted costs were not better than those in centers with low risk-adjusted costs.[6-8] These variations suggest that resource use for injured patients may be related to factors beyond patient needs and suggest there is room for improvement in resource allocation and cost containment in acute injury care.[9-11]

Identifying unwarranted inter-provider variations is the basis for quality improvement.[12, 13] If used alongside indicators of processes and clinical outcomes, an indicator of resource use intensity could be used to flag potential areas for improvement in resource use and ultimately patient outcomes. Nonetheless, apart from hospital length of stay, which represents a very crude measure of resource use, no hospital indicator of resource use intensity based on costs has been developed for injury admissions.[14, 15]

The objective of this study was to develop a hospital indicator of resource use intensity for injury admissions, and evaluate its internal and temporal validity.

4.4. Methods

The *CHU de Québec-Université Laval* research ethics board approved this study.

4.4.1. Study design

We conducted a retrospective, multicenter cohort study using data from the mature, inclusive, trauma system of the province of Quebec, Canada. The Quebec injury care continuum was established in 1993 and encompasses 57 adult trauma centers including 3 level I, 5 level II, 21 level III, and 28 level IV centers. Trauma centers are designated by the Ministry of Health and Social Services upon accreditation by the provincial Institute of healthcare excellence using criteria inspired by the American College of Surgeons Committee on Trauma.[16, 17]

4.4.2. Study population

Participation in the trauma registry is mandatory for all centers in the provincial trauma system. We included patients who met the following Quebec trauma registry inclusion criteria between the fiscal years 2014 and 2016: death due to injury, intensive care unit admission or hospital stay > 2 days.

Patients aged < 16 years, patients dead on arrival or with no vital signs on arrival and deceased within 30 minutes, patients who left against medical advice, and patients ≥ 65 years who sustained an isolated orthopedic injury resulting from a fall from standing height were not eligible.

4.4.3. Study data

We used three databases held by the Quebec Ministry of Health and Social Services. We extracted data on patient socio-demographics, injury circumstances, injury severity, surgical, medical and diagnostic interventions from the Quebec trauma registry.[18] We retrieved data on comorbidities by linking the registry to the provincial hospital discharge database (MED-ECHO)[19] using a unique health care identifier. We obtained data on costs from hospital financial reports (AS-471 files) for the 2016 fiscal year.[20] These reports contain unit costs by hospital activity center and include variable direct costs related to expenditures for non-physician personnel, services and materials.[21]

4.4.4. Estimation of patient-level resource use

The activity-based costing method yields patient-level estimates of costs, which can be used to evaluate inter-provider variations of resource use intensity.[22-24] We applied this method according to Canadian guidelines for the economic evaluation of health technologies[25] as described in detail elsewhere.[5] In brief, a committee of experts first identified hospital activity centers considered important for costing acute in-hospital injury care.[26] Second, units of resource use (for example days in the regular ward) were extracted for each admission from the registry. Third, units of resource use for each patient were multiplied by unit costs in corresponding activity centers. Hospital activity centers comprise the emergency department, regular ward, operating room, intensive care unit, medical imaging, and paraclinical services (Table 3.1). Medical imaging included 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 included physiotherapy, occupational therapy, psychotherapy and respiratory therapy. Since we did not have relevant and/or complete information on pharmacy, laboratory tests, blood products, and physician fees, these were not included. We used unit costs from 2016 hospital financial reports for the three adult level I trauma centers and calculated mean unit costs weighted by mean annual volume in order to obtain standardized unit costs that were not influenced by temporal or geographical variations.

4.4.5. Derivation of risk-adjustment models

Data on the Glasgow Coma Score (GCS), respiratory rate, and systolic blood pressure on arrival were missing for 43% (9% for traumatic brain injuries), 10% and 1% of admissions, respectively. Since the probability of missing data was highly correlated with injury severity (90% of patients with missing data for at least one of these variables had minor injuries) and type of injury (67% were patients with isolated orthopedic injuries), we considered the missing at random assumption to be plausible. Consequently, we simulated missing data on GCS, respiratory rate and systolic blood pressure using multiple imputation.[27] We used the Markov chain Monte Carlo method with a non-informative single chain.[28-31] We entered all independent and dependent variables included in the analysis model in the imputation model and imputed each missing data value five times.[28, 30, 32] 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.[31, 33]

We followed Transparent Reporting of a multivariable prediction model for Individual Prognosis or Diagnosis guidelines.[34] We derived risk-adjustment models using linear regression for the whole sample, traumatic brain injuries, isolated orthopedic injuries, and isolated thoracoabdominal injuries, for level I/II and III/IV centers. The traumatic brain injuries group includes patients with at least one of the following Abbreviated Injury Scale codes*:* 113000.6, 116002.3, 116004.5, 116000.3, 120202.5-122899.3, 140202.5-140799.3, 150408.4. The isolated orthopedic injuries group includes patients with at least one Abbreviated Injury Scale code between 700000 and 900000, inclusively, with no spinal cord, traumatic brain or multisystem blunt injuries. The isolated thoracoabdominal injuries group includes patients with at least one Abbreviated Injury Scale code between 400000 and 600000, inclusively, with no concomitant injuries with an AIS severity score > 1. These three subgroups were selected as they represent over 80% of all injury admissions (Table 4.1). We modeled resource use (activity-based costs) using the Fine and Grey subdistribution hazard models.[35] These models are used in a competing risks framework to estimate the probability of experiencing a specific outcome by a given time while allowing for the possibility of other events such as deaths to occur. Individuals with the competing event are then assigned the "worst" outcome.[35] Candidate variables and plausible functional forms were identified through previous studies[5, 36] and consultation with clinical experts. These were age, sex, number of comorbidities, type of injury, mechanism of injury, anatomical injury severity, Glasgow Coma Score, respiration rate, systolic blood pressure, and transfer-in from another hospital. We used fractional polynomials to determine the best fitting functional form for continuous variables.[37, 38] We evaluated model assumptions using residuals, collinearity and influence statistics. Variables that were statistically significant in over 70% of 500 bootstrap samples drawn with replacement were included in the final models.[39-42]

4.4.6. Validation of risk-adjustment models

Internal validity of the final models was assessed using the optimism-corrected coefficient of determination r^2, based on the bootstrap technique (200 samples drawn with replacement).[43-45] The optimism-corrected r^2 was calculated by subtracting the optimism estimate (mean difference between the r^2 in the original sample and that in each of the 200 other samples) from the coefficient of determination r^2 in the derivation sample.[43-45] We assessed temporal validity for the whole cohort by fitting the final model to each year of data collection.

4.4.7. Hospital indicator of resource use intensity

Benchmarking was performed by comparing the adjusted geometric mean cost of each hospital, obtained using shrinkage estimates, to the global geometric mean.[46] Costs had a log-normal distribution; for such distributions the geometric mean is equivalent to the median[47] Shrinkage estimates account for regression-to-the-mean bias and inflation of the Type I error due to multiple comparisons, and improve the precision of estimates for low-volume center.[48] We also performed benchmarking by year to identify centers that remained outliers throughout the study period.

4.4.8. Sensitivity analyses

We repeated analyses excluding (1) ≥ 85 year olds, (2) patients who were transferred in from another acute care hospital, and (3) observations with missing physiological data.[30, 31] For each sensitivity analysis, we calculated weighted κ coefficients on outliers with 95% CI.[49] Though there is no formal scale for judging the extent of agreement, agreement is often considered substantial when κ is between 0.61 and 0.80, inclusively, and almost perfect when κ ≥ 0.80.[49, 50] We considered weighted κ coefficients ≥ 0.61 to convey acceptable agreement.[49]

Statistical analyses were performed using SAS (SAS Institute, Cary, NC, version 9.4) and STATA software (StataCorp LLC, College Station, TX). Statistical tests were two-sided with α = 0.05.

4.5. Results

4.5.1. Study population

The Quebec trauma registry included 50,256 adults admitted between 2014 and 2016. We excluded 1359 (3%) patients who died on arrival or with no vital signs on arrival and deceased within 30 minutes, 148 (0.3%) patients who left against medical advice, and 16,612 (33%) patients ≥ 65 years old with an isolated orthopedic injury resulting from a fall from standing height. Among eligible patients, we excluded 520 (2%) patients with missing data on comorbidities or injury severity. The final study population comprised 33,124 patients among whom 5413 (16.3%) had traumatic brain injuries, 17,952 (54.2%) had isolated orthopedic injuries, and 3824 (11.5%) had isolated thoracoabdominal injuries (Table 4.1).

4.5.2. Risk-adjustment models

The risk-adjustment models predicted 30%, 29%, 11% and 21% (optimism-corrected r^2) of the variation in resource use in the whole study population and among patients with traumatic brain, isolated orthopedic and isoaled thoracoabdominal injuries, respectively, for level I/II centers (Table 4.2). They predicted 16%, 16% 14% and 13% of the variation in resource use in the whole study population and among patients with traumatic brain, isolated orthopedic and isoaled thoracoabdominal injuries, respectively, for level II/IV centers. Globally, temporal validity was high with yearly r^2 between 29% and 31% and between 16% and 17% for level I/II and II/IV centers, respectively.

4.5.3. Benchmarking results

Median resource use in the whole study population was $5014 (quartiles 1 and 3: 3045-8762; Table 4.1). We identified centers with higher or lower than expected resource use, across level I/II and level III/IV centers, in the whole study population (Figure 4.1 and Figure 4.2), for traumatic brain injuries (Figure 4.3 and Figure 4.4) and for isolated orthopedic injuries (Figure 4.5 and Figure 4.6). Among patients with isolated thoracoabdominal injuries, no variations were observed across level I/II centers (Figure 4.7) but we identified centers with higher than expected resource use across level III/IV centers (Figure 4.8). We identified centers that remained outliers throughout the study period, for example, one level I center had higher than expected resource use in 2014, 2015 and 2016 (Figure 4.9).

4.5.4. Sensitivity analyses

Excluding ≥ 85 year olds, patients who were transferred in from another acute care hospital or observations with missing physiological measures led to acceptable agreement on outlier hospitals (κ was between 0.63 and 0.87; Table 4.3).

4.6. Discussion

We have developed a hospital indicator of resource use intensity for injury admissions based on risk-adjustment models with good internal and temporal validity. The risk-adjustment models explained between 11% and 30% of the variation in resource use in the whole cohort and among patients with traumatic brain, isolated orthopedic and isolated thoracoabdominal injuries. We identified centers with higher or lower than expected resource use across adult trauma centers in Quebec within designation levels (I/II and III/IV).

Our findings are corroborated by studies in the United States where significant variations in risk-adjusted costs (estimated using patient charges) were observed among trauma centers.[6-8] Furthermore, our risk-adjustment models suggest that approximately 70% to 90% of resource use for injury care is dictated by factors other than the clinical status of patients on arrival, depending on patient subgroups. Little is known about the determinants of inter-provider variations in resource use intensity. Nonetheless, it is suggested that factors related to processes of care and hospital structure may explain differences in resource use intensity.[51-54] These factors include delays in discharge for post-acute care.[55-58] In Quebec, 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.[5] Moreover, discharge destination has been identified as the strongest determinants of resource use intensity for injury care in Quebec.[5] Patients waiting for post-acute care placement overuse resources and are exposed to a greater risk of adverse events.[12, 59-61] Therefore, advanced discharge planning and the provision of access to post-acute care facilities seem to be promising areas to explore in order to decrease injury care resource use and make more beds available for patients who really need them.[62-65] This will be particularly relevant in the coming years with the aging population since it has been shown that discharge delays affect the elderly more than they affect young injured patients.[66]

Highly specialized provision of injury care has also been identified as a determinant of greater resource use intensity in Canada,[5] and the United States.[7, 67] These findings suggest that availability of resources is associated with resource use intensity as it has been shown in the Dartmouth Atlas Project where regions in the United States that spent the most on healthcare were also those with more resources.[68] In this regard, more research on healthcare overuse for injury admissions could be an avenue to reduce the use of low value clinical practices, decrease injury care costs, and improve patient outcomes.[12] Furthermore, step-down units for low demand intensive care unit patients also demonstrate how hospital structures influence resource use intensity. The introduction of these units in a level I trauma center in the United States led to a reduction in intensive care unit length of stay and treatment costs (estimated using patient charges).[69]

We propose an algorithm to reproduce the indicator in other settings using local trauma registries. The indicator can be applied with unit costs from this study or unit costs specific to the local context. It can be used to monitor variations in resource-use intensity within a single trauma center or system over time or across trauma centers or systems. Hospital indicators on resource use intensity should be presented alongside indicators of clinical outcomes such as risk-adjusted mortality, complications, and 30-day readmission rates. Root causes of variations in resource use intensity across trauma centers could be explored by examining indicators of structure and processes of care and drilling down data on resource use intensity by year and activity center. These initiatives will facilitate the design and implementation of high-impact interventions to address unwarranted variations without negatively affecting patient outcomes.[12, 13, 70] Addressing unwarranted variations may decrease costs and delays to appropriate care. It also has the potential to reduce the use of low-value clinical practices and thus unnecessary exposure to adverse events.[59-61] Given the high costs of injury care,[71-73] the indicator of resource use intensity may help alleviate the financial burden of acute injury care on societies. Our methods can be reproduced for injury admissions in other systems but also adapted to other diagnostic groups. Moreover, now that a hospital indicator of resource use intensity has been developed, it will be possible to further our understanding of the association between resource use intensity and quality of care, and identify aspects of resource use related to clinical benefit. Research is underway to examine the association between resource use intensity and clinical outcomes in trauma populations.[74, 75]

4.6.1. Strengths and limitations

We conducted a retrospective cohort study using local and recent data (2014-2016) on 57 trauma centers. We followed Canadian guidelines for the economic evaluation of health technologies to estimate patient-level in-hospital resource use,[76] taking account of each patient's individual care trajectory.[25] For the risk-adjustment models, we followed Transparent Reporting of a multivariable prediction model for Individual Prognosis or Diagnosis guidelines.[34] We identified candidate variables and plausible functional forms through a systematic review of the literature,[36] a cohort study[5] and consultation with clinical experts. Moreover, we used fractional polynomials to determine the best fitting functional form for continuous variables.[37, 38] The indicator we developed is based on a risk-adjustment model for all injury admissions and for specific diagnostic groups, defined in collaboration with knowledge users from the Institute of healthcare excellence. Moreover, we included both survivors and deaths using a competing risks framework and evaluated the robustness of our results with sensitivity analyses.

This study is subject to potential limitations. First, we excluded patients with missing data on comorbidities or injury severity but we are confident that excluding these patients, who represented 2% of the sample, is unlikely to have induced selection bias.[77] Second, resource use estimates cannot be interpreted as true costs. We focused on resource use rather than costs in line with guidelines of the Grading of Recommendations Assessment, Development and Evaluation group to reflect practice patterns and develop a reproducible indicator.[24] Moreover focusing on resource use rather than monetary values makes it possible to highlight activity centers that are relevant to decision-makers and stakeholders.[24] Third, we slightly underestimated resource use because we did not have complete information on drugs, laboratory tests, blood products, the emergency department, x-ray radiographies and ultrasounds per body region, and the duration of physiotherapy, occupational therapy and psychotherapy. Drugs costs represent 2% of the total annual expenditure of the three level I centers[20] while laboratory tests represent 4% of total hospital costs in Canada.[78] Blood bank costs constitute ≤ 1% of total hospitalization costs for most diagnostic-related groups in the United States.[79] Even though this percentage could be higher for injured patients, the contribution of blood products to total costs of acute injury care should be minimal. Therefore, excluding these costs should have little impact on our results. Moreover, due to lack of information on the number of hours spent in the emergency department, the number of x-ray radiographies and ultrasounds per body region, and on the duration of physiotherapy, occupational therapy and psychotherapy, we applied a fixed cost for these services. This likely led us to underestimate resource use. However, multiple scans using the same imagery technique in the same body region are unusual and short stays in the emergency department are usually indicative of high resource use (patients with more severe injuries). Fourth, resource use did not include physician fees, which would have required linking trauma registry data to physician billing data and would have restricted the application of our method elsewhere. Additionally, physician fees are based on service fees subject to geographical and temporal variation, thus limiting the interpretability of inter-hospital comparisons.[80] Fourth, it is possible that our risk-adjustment models do not fully describe the baseline risk of trauma patients because of measurement errors on included variables, for example comorbidities and injury severity, or because of missed variables such as socio-economic status. These limitations may have induced differential information bias and residual confounding leading to false-positive or false-negative hospital outliers. However, we did include all variables that were identified by literature review and expert opinion and that were statistically significant in ≥ 70% of 500 bootstrap samples.[39-42] These variables include the body region of the most severe injury (for the whole cohort), the mechanism of injury, and the Maximum Abbreviated Injury Scale score of concomitant injuries (for patient subgroups). Moreover, inclusion criteria in the Quebec trauma registry are the same for all trauma centers. In addition, the registry is populated by medical archivists who use standardized coding protocols according to the criteria developed by the American College of Surgeons.[81] Medical archivists work under the supervision of a data coordinator and have yearly ongoing training. Moreover, the registry is subject to periodic validation to address data quality issues such as aberrant data values in all data fields, and evaluations of data quality in the trauma registry suggest 98% accuracy (data not published). Lastly, material and social deprivation were not included in our risk adjustment models. These factors were not associated with resource use intensity in our study population, in either univariate or multivariate analyses (results not shown). In addition, adjusting for socio-economic status in hospital comparisons factors our inequitable access to care, which should be highlighted in quality evaluations.

4.7. Conclusions

We have developed a hospital indicator of resource use intensity for injury admissions based on risk-adjustment models with good internal and temporal validity. We identified trauma centers with higher or lower than expected resource use within designation levels (I/II and III/IV). The indicator can be used in addition to information on clinical outcomes to inform the design and implementation of high-impact interventions to improve injury care resource use. We propose an algorithm that can be applied using data routinely collected in trauma registries to calculate risk-adjusted geometric mean activity-based costs in a trauma center using our unit costs or local unit costs.

4.8. Acknowledgments

The authors thank Gilles Bourgeois, Jean Lapointe, Gaétan Prévost and Christine Rizzo for their role as members of the committee of experts for this study, Amina Belcaid for her expertise on data sources and Xavier Neveu for his invaluable assistance with statistical analyses.

Table 4.1. Characteristics of the study population of acute injury care resource use (in 2016 Can$)

Characteristics	n (%)	Crude median cost (Q1-Q3)
Overall	33,124 (100)	5014 (3045-8762)
Age		
16-54	9597 (29.0)	4842 (3068-8472)
55-64	5620 (17.0)	4550 (2974-7593)
65-74	4098 (12.4)	4854 (2856-8735)
75-84	6452 (19.5)	5354 (3083-9458)
≥ 85	7357 (22.2)	5532 (3158-9328)
Sex		
Male	16,245 (49.0)	4981 (2990-9100)
Female	16,879 (51.0)	5036 (3103-8449)
Number of comorbidities		
0	17,040 (51.4)	4674 (2980-7935)
1	7866 (23.8)	5099 (3023-8869)
2	4548 (13.7)	5685 (3242-10,001)
≥ 3	3670 (11.1)	6045 (3347-10,606)
Type of injury		
Traumatic brain	5413 (16.3)	5911 (3121-12,087)
Spinal cord	657 (2.0)	10,914 (6668-17,410)
Multisystem blunt	922 (2.8)	9658 (5213-17,418)
Orthopedic	17,952 (54.2)	5060 (3351-8231)
Thoracoabdominal	3824 (11.5)	3779 (2246-6828)
Other	4411 (13.2)	4003 (2221-7189)
Mechanism		
Motor vehicle collision	5388 (16.3)	5691 (3280-10,5361)
Fall	24,296 (73.4)	4970 (3040-8545)
Penetrating	463 (1.4)	4409 (2793-9556)
Other	2977 (9.0)	4477 (2807-7711)
New Injury severity score		
< 12	19,482 (58.8)	4431 (2794-7213)
12-24	8989 (27.1)	5726 (3429-9677)
≥ 25	4653 (14.1)	7901 (3986-16,168)
Glasgow coma scale score*		
3	690 (2.1)	10,839 (3920-23,902)
4-5	151 (0.5)	11,793 (3774-25,209)
6-8	526 (1.6)	10,578 (4622-22,638)
9-12	742 (2.2)	8613 (3710-16,685)
13-15	16,751 (50.6)	5171 (3069-8921)
Respiration Rate*		

11-29	29,082 (87.8)	5036 (3061-8793)
0-10; ≥ 30	705 (2.1)	6313 (3209-12,219)
Systolic blood pressure*		
≥ 90	32,129 (97.0)	5005 (3043-8714)
0-89	545 (1.6)	6873 (3434-14,917)
Transfer		
No	25,373 (76.6)	4981 (3026-8549)
Yes	7751 (23.4)	5095 (3124-9660)

n: number; Q1: quartile 1; Q3: quartile 3

*Data on the Glasgow Coma Score, respiratory rate and systolic blood pressure on arrival were missing for 43.1% (n = 14,264), 10.1% (n = 3337) and 1.4% (n = 450) of admissions, respectively. Missing data were simulated using multiple imputation.

Table 4.2. Accuracy of risk adjustment models for predicting resource use (activity-based costs) in the whole study population and patients cohorts

	n	Coefficient of determination, r^2	
		Apparent	Optimism-corrected
Level I and II centers			
Whole sample	15,210	29.69	29.46
Traumatic brain injuries	4223	29.51	29.14
Isolated orthopedic injuries	7097	13.05	11.05
Thoracoabdominal injuries	1286	21.80	21.37
Level III and IV centers			
Whole sample	17,914	16.02	15.79
Traumatic brain injuries	1190	16.64	15.97
Isolated orthopedic injuries	10,855	14.68	14.41
Thoracoabdominal injuries	2538	13.18	12.68

n: number

Figure 4.1. Variations in resource use intensity in the Quebec trauma system across level I and II centers, all injuries

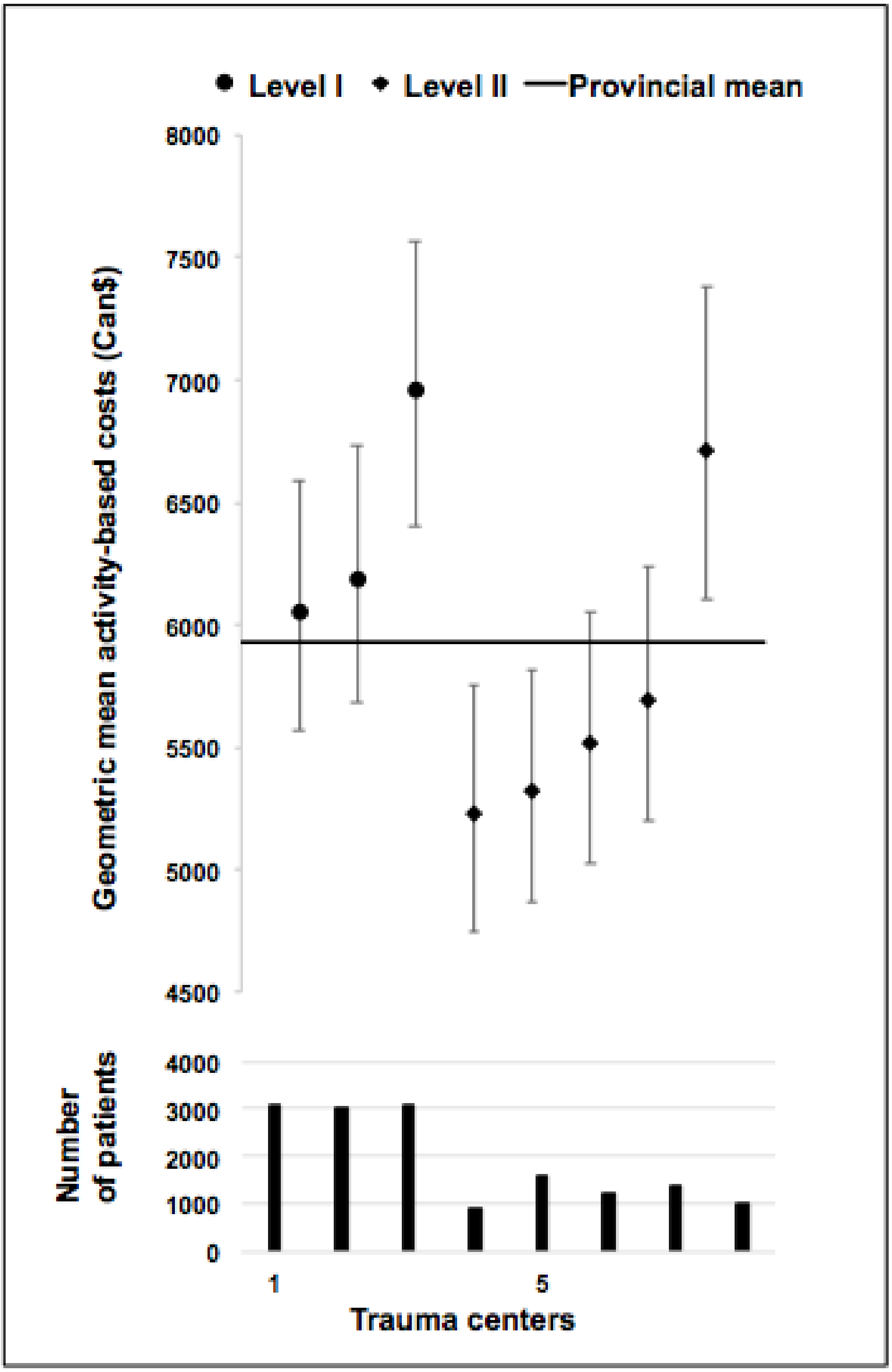


Figure 4.2. Variations in resource use intensity in the Quebec trauma system across level III and IV centers, all injuries

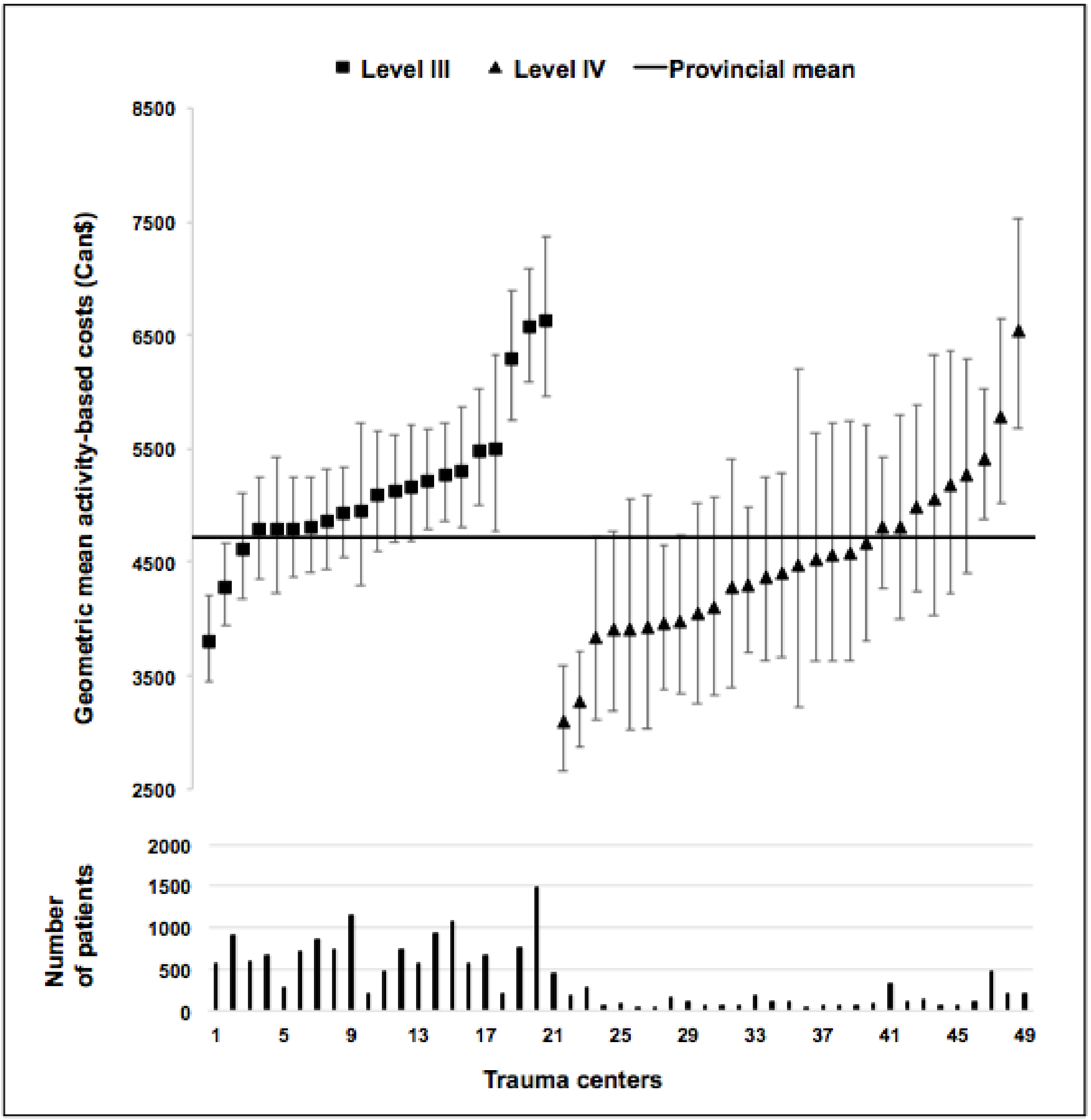


Figure 4.3. Variations in resource use intensity for traumatic brain injuries in the Quebec trauma system across level I and II centers

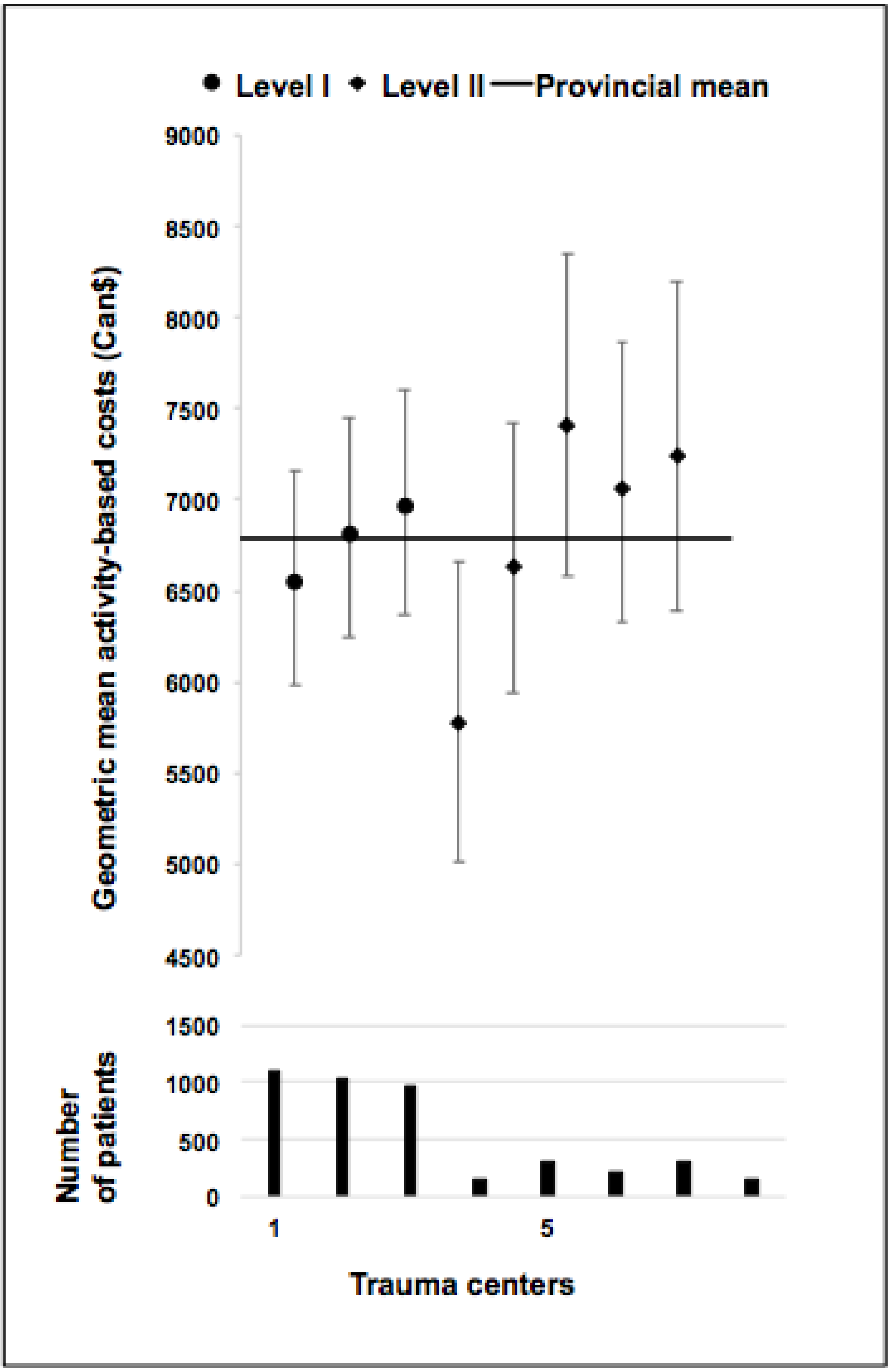


Figure 4.4. Variations in resource use intensity for traumatic brain injuries in the Quebec trauma system across level III and IV centers

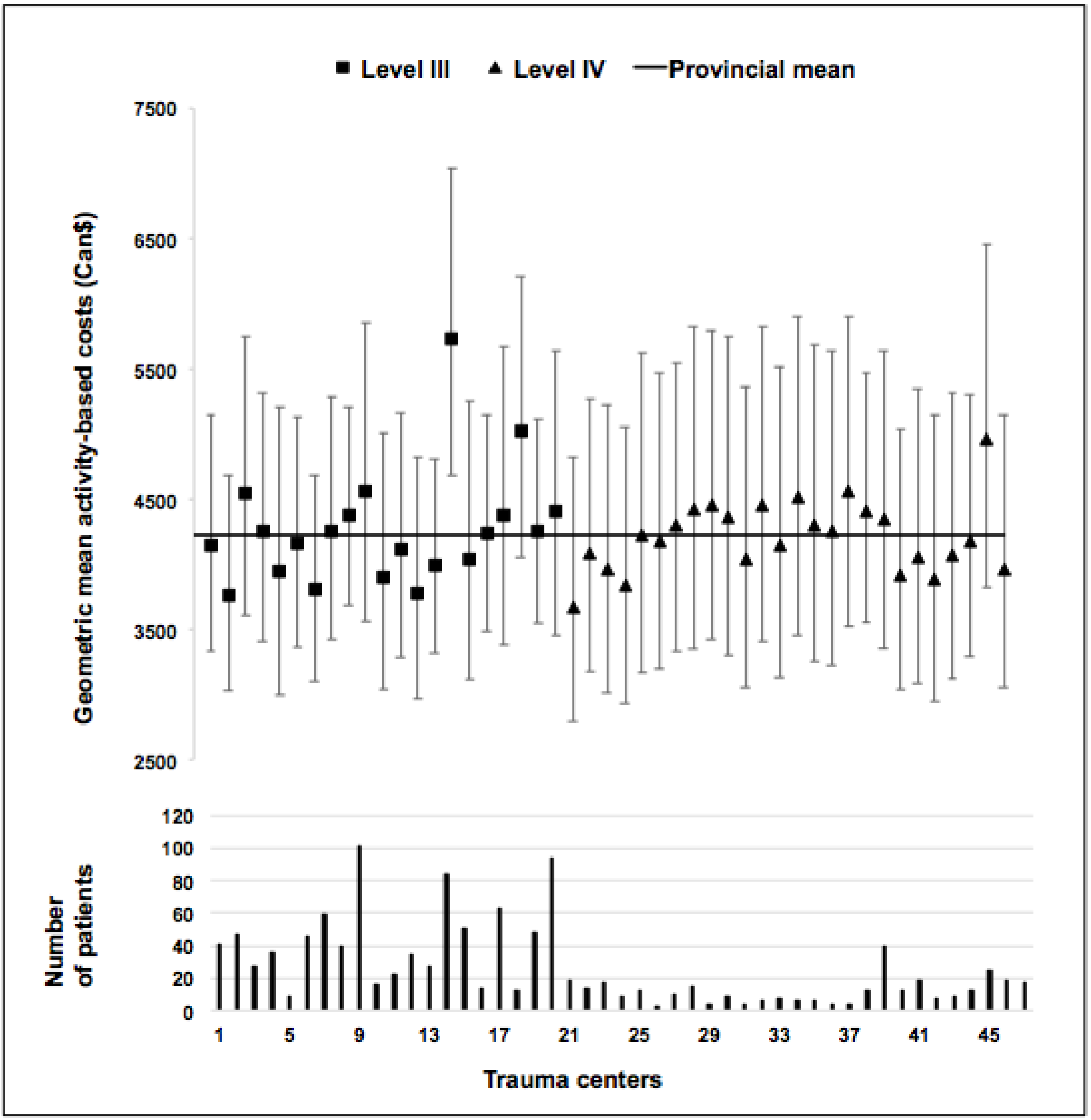


Figure 4.5. Variations in resource use intensity for isolated orthopedic injuries in the Quebec trauma system across level I and II centers

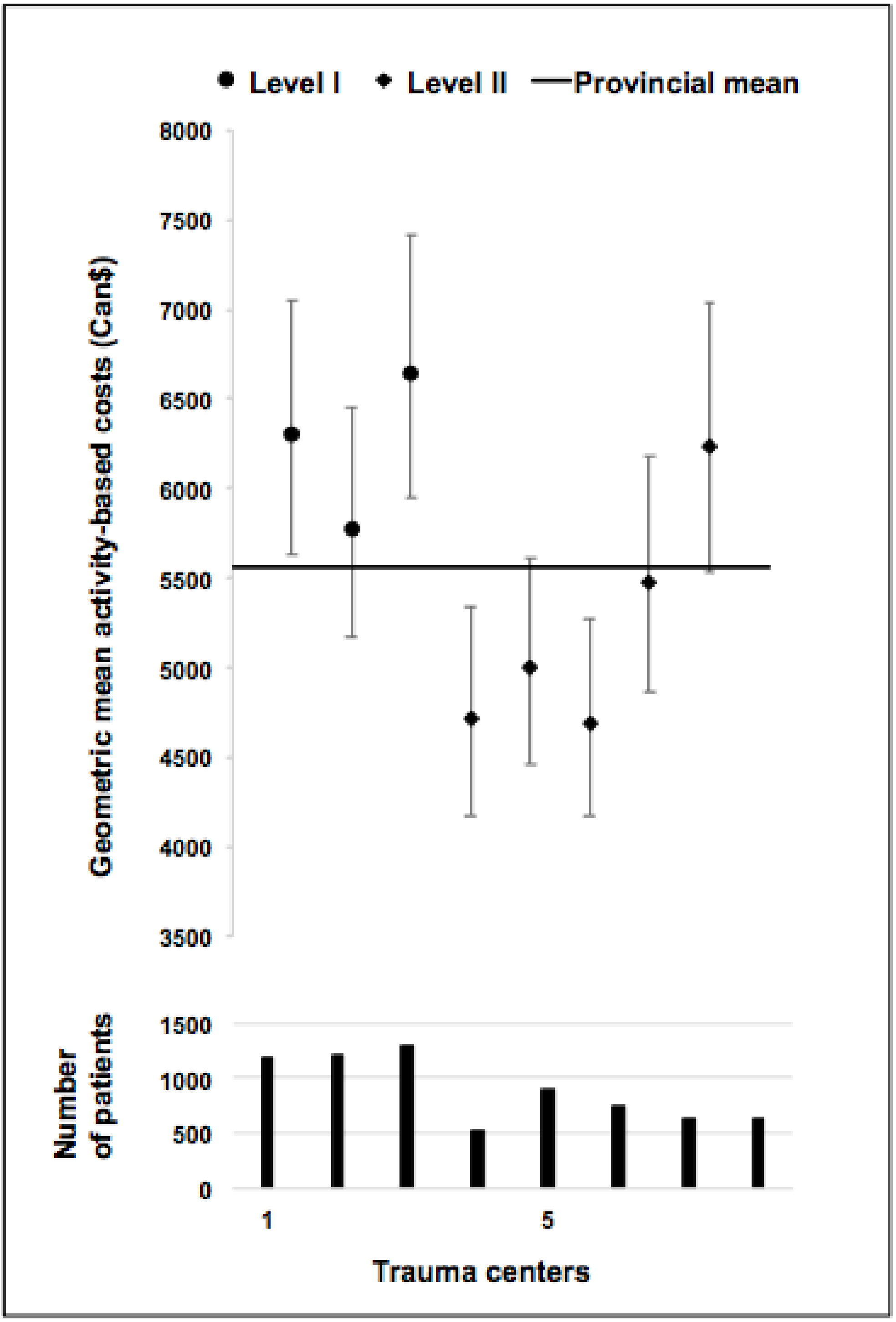


Figure 4.6. Variations in resource use intensity for isolated orthopedic injuries in the Quebec trauma system across level III and IV centers

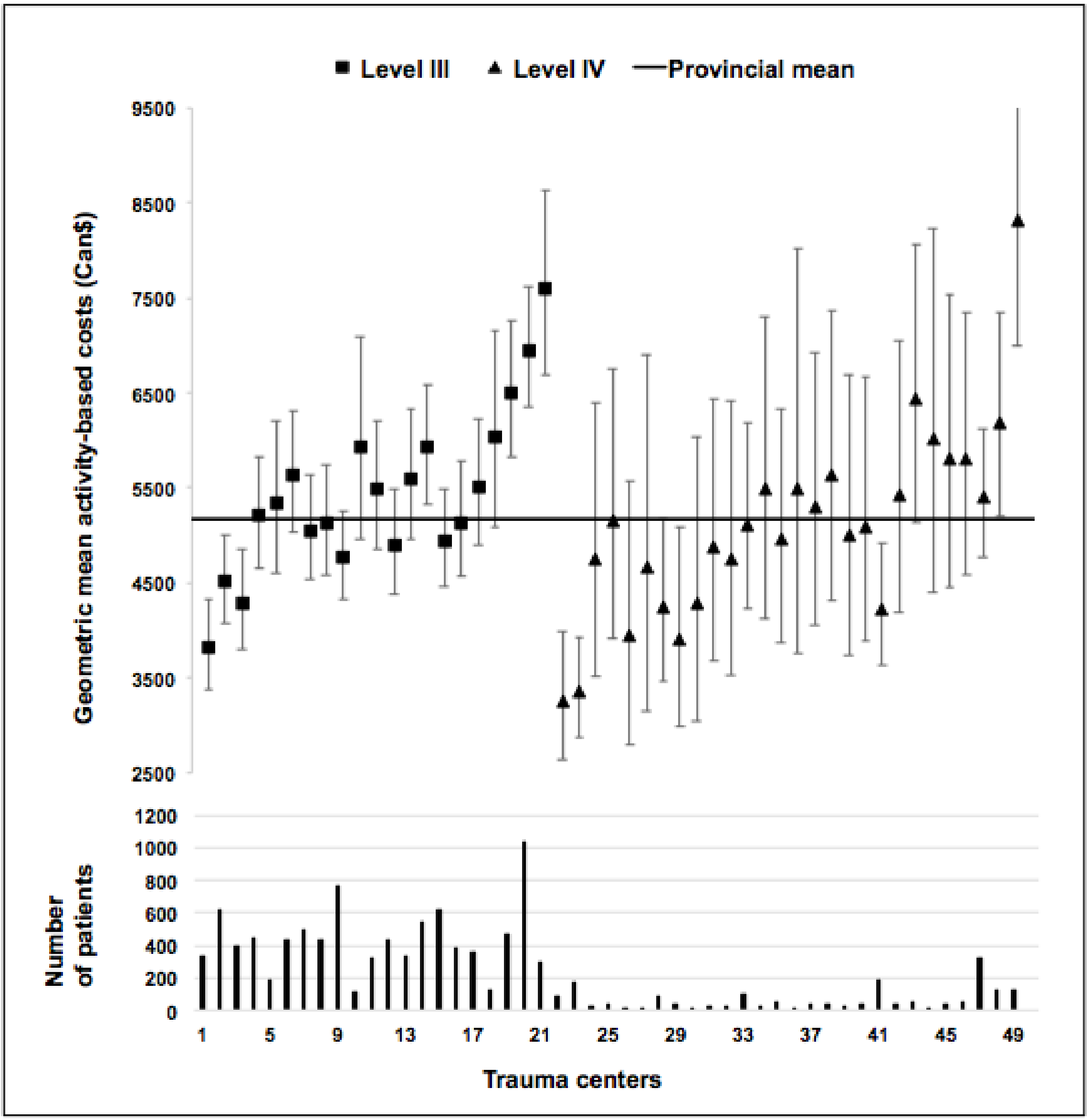


Figure 4.7. Variations in resource use intensity for isolated thoracoabdominal injuries in the Quebec trauma system across level I and II centers

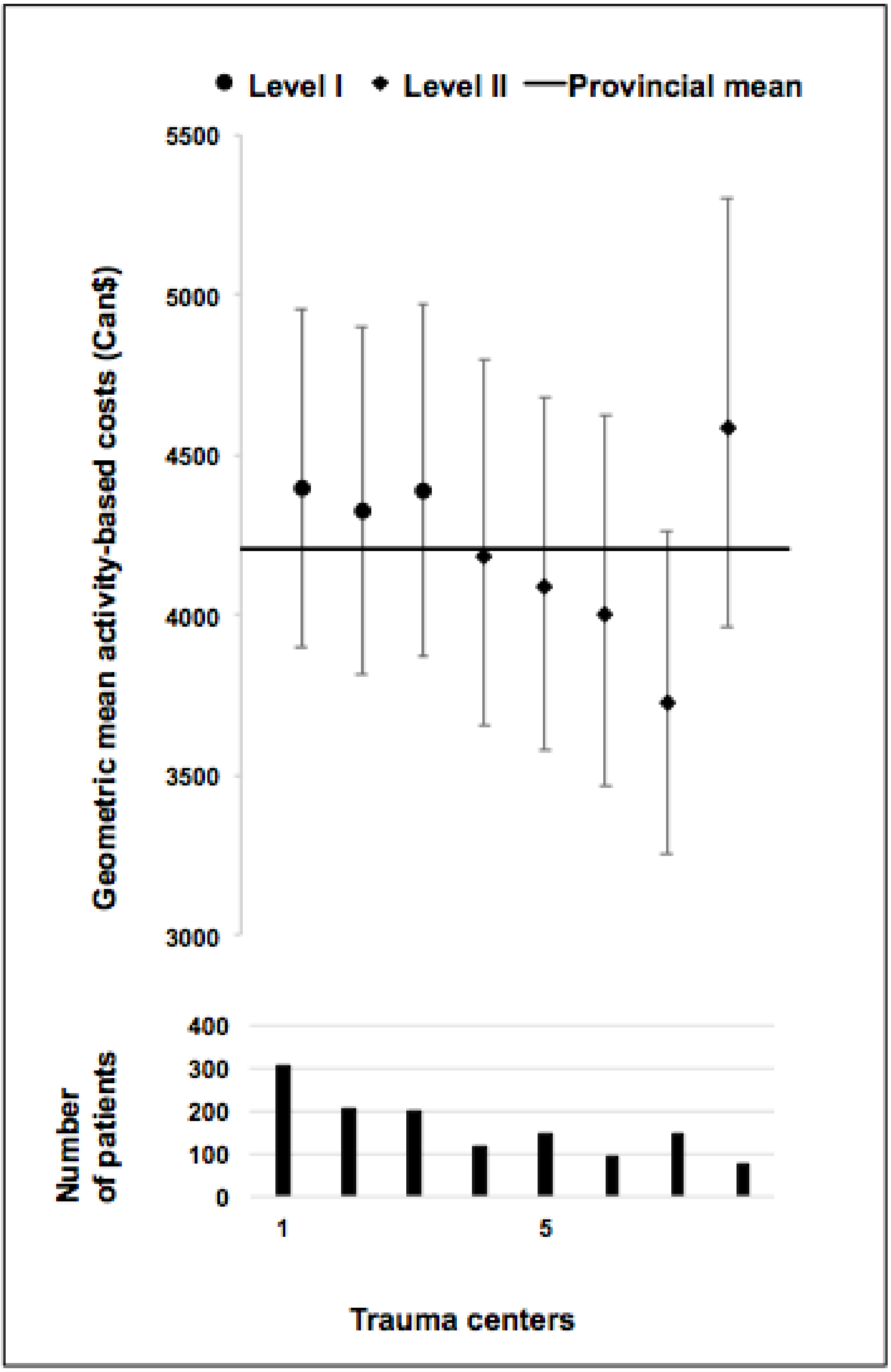


Figure 4.8. Variations in resource use intensity for isolated thoracoabdominal injuries in the Quebec trauma system across level III and IV centers

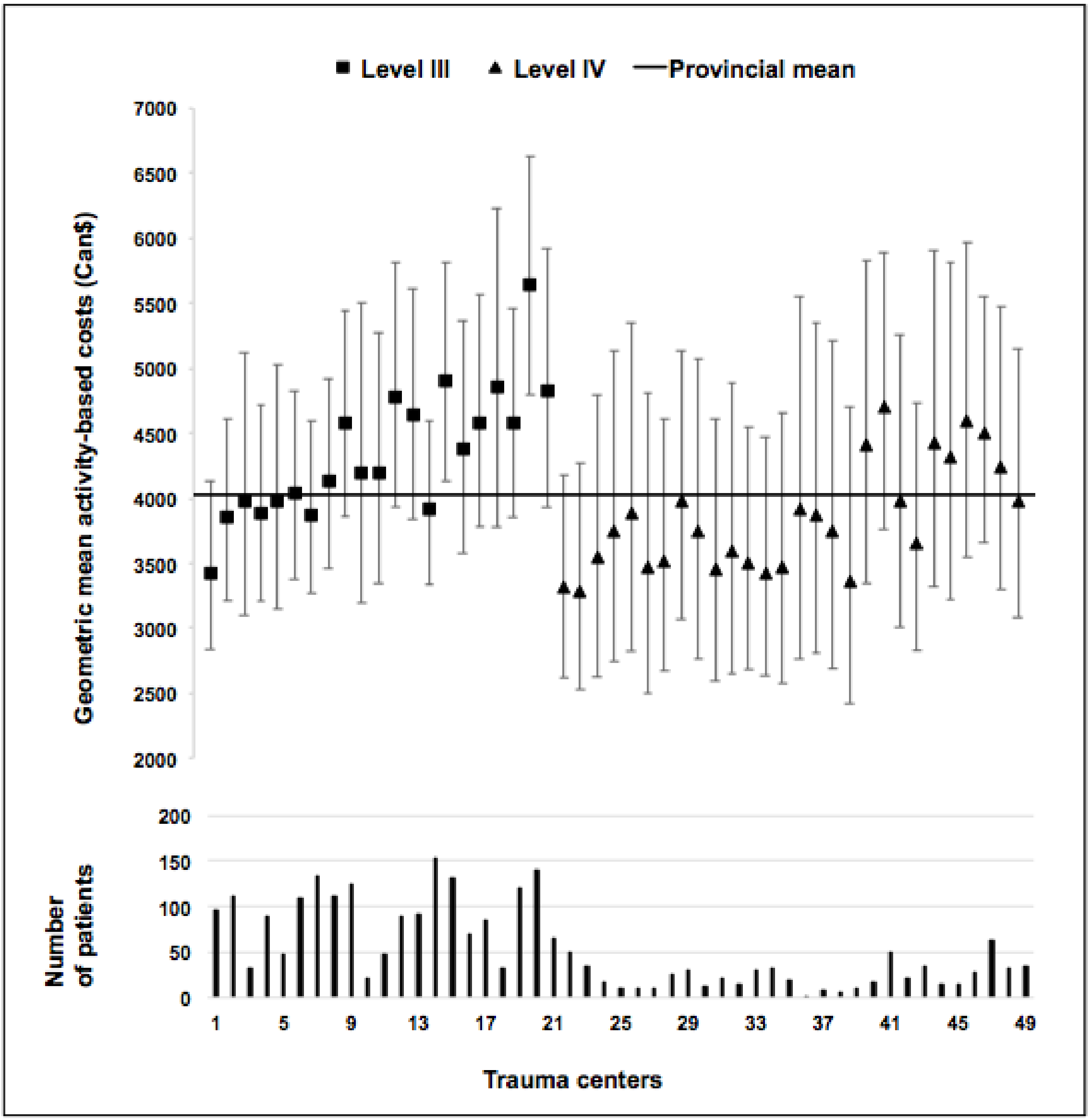


Figure 4.9. Supplemental content. Yearly variations in resource use intensity in the Quebec trauma system across level I and II centers for 2013 (A), 2014 (B) and 2015 (C), all injuries

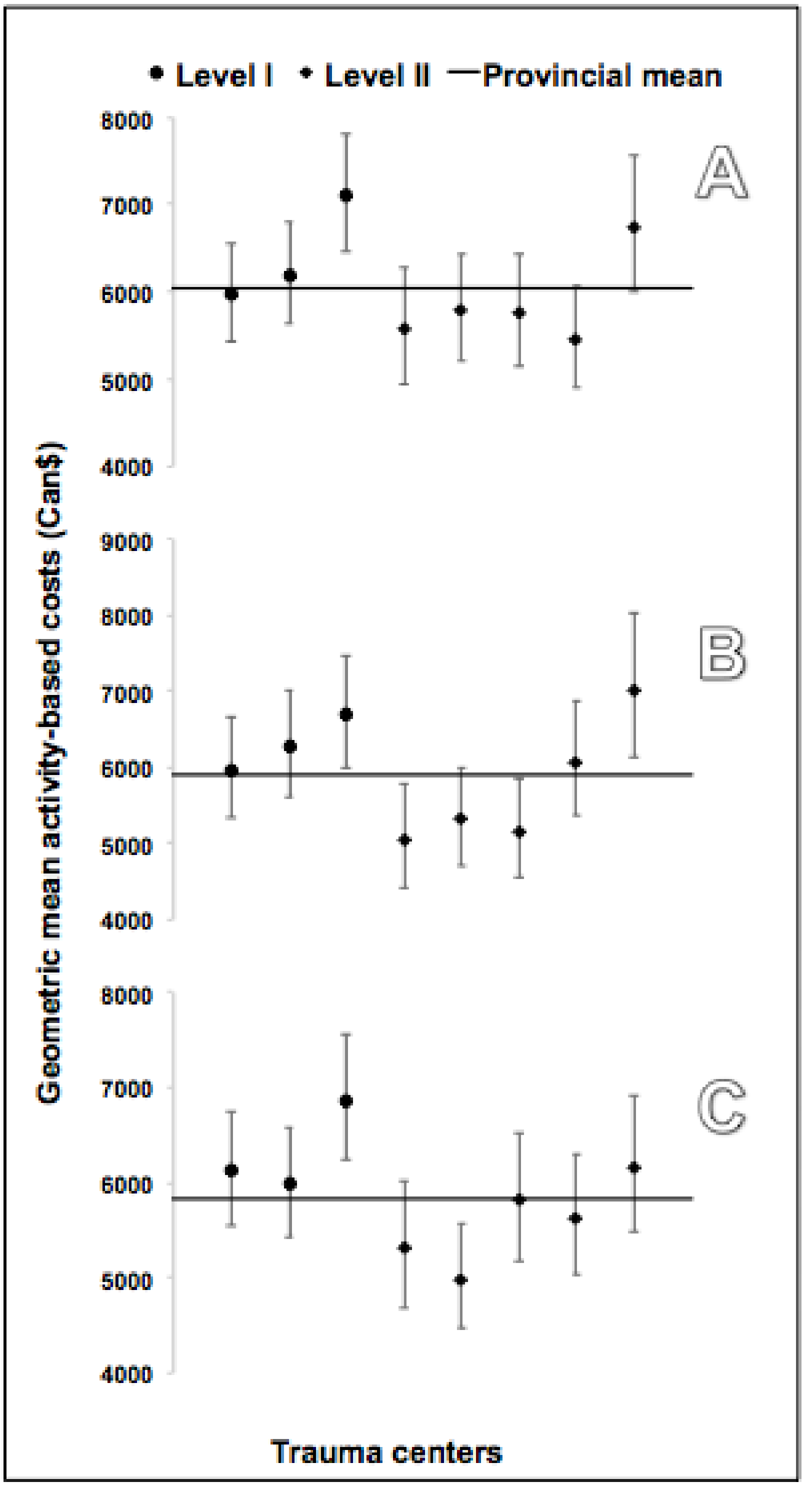


Table 4.3. Sensitivity analyses on hospital outliers in the whole sample

	Weighted κ coefficient (95% confidence interval)	
	Level I and II centers	**Level III and IV centers**
Excluding ≥ 85 year olds	0.86 (0.59-1.00)	0.80 (0.65-0.95)
Excluding transferred patients	0.67 (0.34-0.99)	0.87 (0.74-1.00)
Excluding observations with missing physiological data	0.86 (0.59-1.00)	0.63 (0.40-0.86)

4.9. References

1. Haagsma J, Graetz N, Bolliger Ian, et al. The global burden of injury: incidence, mortality, disability-adjusted life years and time trends from the Global Burden of Disease study 2013. *Inj Prev*. 2016;22(1): 3–18.
2. 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(2): 371-8; discussion 378.
3. Haas B, Stukel TA, Gomez D, et al. The mortality benefit of direct trauma center transport in a regional trauma system: a population-based analysis. *J Trauma Acute Care Surg*. 2012;72(6): 1510-5; discussion 1515-7.
4. Moore L, Turgeon AF, Lauzier F, et al. Evolution of patient outcomes over 14 years in a mature, inclusive Canadian trauma system. *World J Surg*. 2015;39(6): 1397-405. .
5. Porgo TV, Moore L, Truchon C, et al. Patient-level resource use for injury admissions in Canada: a multicenter retrospective cohort study. In preparation.
6. Glance LG, Dick AW, Osler TM, Meredith W, Mukamel DB. The association between cost and quality in trauma: is greater spending associated with higher-quality care? *Ann Surg*. 2010;252(2): 217-22.
7. Clancy TV, Maxwell GJ, Covington DL, Brinker CC, Blackman D. A statewide analysis of level I and II trauma centers for patients with major injuries. *J Trauma*. 2001;51(2): 346-51.
8. Obirieze AC, Gaskin DJ, Villegas CV, et al. Regional variations in cost of trauma care in the United States: who is paying more? *J Trauma Acute Care Surg*. 2012;73(2): 516-22.
9. Porter ME. What is value in health care? *N Engl J Med*. 2010;363(26): 2477-81.
10. Kaplan RS, Porter ME. How to solve the cost crisis in health care. *Harv Bus Rev*. 2011;89(9): 46-52, 54, 56-61.
11. Rojas-García A, Turner S, Pizzo E, Hudson E, Thomas J, Raine R. Impact and experiences of delayed discharge: A mixed-studies systematic review. *Health Expect*. 2018;21(1): 41-56.
12. The Lown Institute. Overuse 101. http://lowninstitute.org/learn/overuse-101/. Accessed March 19, 2018.
13. Shafi S, Nathens AB, Cryer HG, et al. The Trauma Quality Improvement Program of the American College of Surgeons Committee on Trauma. *J Am Coll Surg*. 2009;209(4): 521-530 e1.
14. Stelfox HT, Bobranska-Artiuch B, Nathens A, Straus SE. Quality indicators for evaluating trauma care: a scoping review. Arch Surg. 2010; 145(3):286-95.
15. Moore L, Stelfox HT, Boutin A, Turgeon AF. Trauma center performance indicators for nonfatal outcomes: a scoping review of the literature. *J Trauma Acute Care Surg*. 2013;74(5): 1331-43.
16. The Trauma Association of Canada. Trauma system accreditation guidelines. Fourth revision. Toronto, ON: the Trauma Association of Canada; 2011.
17. The American College of Surgeons Committee on Trauma. Resources for optimal care of the injured patient. Chicago, IL: the American College of Surgeons; 2014.

18. Ministère de la Santé et des Services Sociaux, Direction générale des services de santé et de la médecine universitaire. Cadre normatif - Registre des traumatismes du Québec (RTQ). Version 1.0, Avril 2004.
19. Ministère de la Santé et des Services sociaux du Québec. Banque de données ministérielles MED-ÉCHO. Régie de l'assurance maladie du Québec. http://www.ramq.gouv.qc.ca/en/data-statistics/Pages/data-statistics.aspx. Accessed February 20, 2018.
20. Ministère de la Santé et des Services sociaux du Québec. Rapports financiers annuels des établissements 2015-2016, statsitiques et données. http://publications.msss.gouv.qc.ca/msss/document-001671/. Published 2016. Accessed March 16, 2018.
21. Ministère de la Santé et des Services sociaux du Québec. Normes et pratiques de gestion, Tome II, Répertoire. http://msssa4.msss.gouv.qc.ca/fr/document/d26ngest.nsf/1f71b4b2831203278525656b0004f8bf/c1bc430d41b48eea85257f9500673c97?OpenDocument. Published 2016. Accessed February 20, 2018.
22. West TD, Balas EA, West DA. Contrasting RCC, RVU, and ABC for managed care decisions. A case study compares three widely used costing methods and finds one superior. *Healthc Financ Manage*. 1996;50(8): 54-61.
23. Canby JB 4th. Applying activity-based costing to healthcare settings. *Healthc Financ Manage*. 1995;49(2): 50-2, 54-6.
24. Guyatt GH, Oxman AD, Kunz R, et al. Incorporating considerations of resources use into grading recommendations. *BMJ*. 2008;336(7654): 1170-3.
25. Canadian Agency for Drugs and Technologies in Health. Guidelines for the economic evaluation of health technologies: Canada. 4th Edition. Ottawa, ON: the Canadian Agency for Drugs and Technologies in Health; 2017.
26. Ministère de la Santé et des Services sociaux du Québec. Liste par centre d'activités (établissement). http://msssa4.msss.gouv.qc.ca/fr/document/d26ngest.nsf/lca?OpenView&Start=204. Accessed February 20, 2018.
27. Porgo TV, Moore L, Tardif PA. Evidence of data quality in trauma registries: a systematic review. *J Trauma Acute Care Surg*. 2016;80(4): 648-58.
28. Little RJA, Rubin DB. Statistical analysis with missing data. Second ed. New York, NY: Wiley; 2002.
29. Allison PD. Missing Data. Sage University Papers Series on Quantitative Application in the Social Sciences. Thousand Oaks, CA: Sage Publications; 2001.
30. Sterne JA, White IR, Carlin JB, et al. Multiple imputation for missing data in epidemiological and clinical research: potential and pitfalls. *BMJ*. 2009;338: b2393.
31. Moore L, Lavoie A, LeSage N, et al. Multiple imputation of the Glasgow Coma Score. *J Trauma*. 2005;59(3): 698-704.
32. Schafer JL. Analysis of incomplete multivariate data. London: Chapman and Hall; 1997.
33. Moore L, Hanley JA, Lavoie A, Turgeon A. Evaluating the validity of multiple imputation for missing physiological data in the national trauma data bank. *J Emerg Trauma Shock*. 2009;2(2): 73-9.

34. Localio AR, Stack CB. TRIPOD: a new reporting baseline for developing and interpreting prediction models. *Ann Intern Med*. 2015;162(1): 73-4. doi: 10.7326/M14-2423.
35. Brock GN, Barnes C, Ramirez JA, Myers J. How to handle mortality when investigating length of hospital stay and time to clinical stability. *BioMed Central*. 2001;11: 144.
36. Porgo TV, Shemilt M, Moore L, Bourgeois G, Lapointe J. Trauma center performance evaluation based on costs: A systematic review of cohort studies. *J Trauma Acute Care Surg*. 2014;76(2): 542-8.
37. Binder H, Sauerbrei W, Royston P. Comparison between splines and fractional polynomials for multivariable model building with continuous covariates: a simulation study with continuous response. *Stat Med*. 2013;32(13): 2262-77.
38. Royston P, Ambler G, Sauerbrei W. The use of fractional polynomials to model continuous risk variables in epidemiology. *Int J Epidemiol*. 1999;28(5): 964-74.
39. Moore L, Stelfox HT, Turgeon AF, et al. Derivation and validation of a quality indicator for 30-day unplanned hospital readmission in trauma care. *J Trauma Acute Care Surg*. 2014;76(5): 1310-6. .
40. Moore L, Stelfox TH, 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(6): 1121-7.
41. Mannan HR. A Practical Application of a Simple Bootstrapping Method for Assessing Predictors Selected for Epidemiologic Risk Models Using Automated Variable Selection. International Journal of Statistics and Applications. 2017; 7(5): 239-249. .
42. Heinze G, Wallisch C, Dunkler D. Variable selection – A review and recommendations for the practicing statistician. *Biom J*. 2018;60(3): 431–449.
43. Zheng B, Agresti A. Summarizing the predictive power of a generalized linear model. *Stat Med*. 2000;19(13): 1771-81.
44. Harrell FE Jr, Lee KL, Mark DB. Multivariable prognostic models: issues in developing models, evaluating assumptions and adequacy, and measuring and reducing errors. *Stat Med*. 1996;15(4): 361-87.
45. Steyerberg EW, Harrell FE Jr, Borsboom GJ, Eijkemans MJ, Vergouwe Y, Habbema JD. Internal validation of predictive models: efficiency of some procedures for logistic regression analysis. *J Clin Epidemiol*. 2001;54(8): 774-81.
46. Moore L, Hanley JA, Turgeon AF, Lavoie A, Eric B. A new method for evaluating trauma centre outcome performance: TRAM-adjusted mortality estimates. *Ann Surg*. 2010;251(5): 952-8.
47. Daly L, Bourke GJ. Interpretation and uses of medical statistics. 5th ed. Oxford, England: Wiley Blackweell; 2000.
48. Iezzoni L. Risk adjustment for measuring health care outcomes, Third edition. Chicago, IL: Health Administration Press; 2003.
49. Watson PF, Petrie A. Method agreement analysis: a review of correct methodology. *Theriogenology*. 2010;73(9): 1167-79.
50. Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics*. 1977;33: 159–74.

51. Moore L, Lavoie A, Sirois MJ, et al. Evaluating trauma center structural performance: The experience of a Canadian provincial trauma system. *J Emerg Trauma Shock*. 2013;6(1): 3-10.
52. Moore L, Lavoie A, Sirois MJ, et al. A comparison of methods to obtain a composite performance indicator for evaluating clinical processes in trauma care. *J Trauma Acute Care Surg*. 2013;74(5): 1344-50.
53. Donabedian A. An introduction to quality assurance in health care. New York, NY: Oxford University Press; 2003.
54. Moore L, Lavoie A, Sirois MJ, Amini R, Belcaid A, Sampalis JS. Evaluating trauma center process performance in an integrated trauma system with registry data. *J Emerg Trauma Shock*. 2013;6(2): 95-105.
55. Brasel KJ, Rasmussen J, Cauley C, Weigelt JA. Reasons for delayed discharge of trauma patients. *J Surg Res*. 2002;107(2): 223-6.
56. Thomas SN, McGwin G Jr, Rue LW 3rd. The financial impact of delayed discharge at a level I trauma center. *J Trauma*. 2005;58(1): 121-5.
57. Rogers A, Clark EH, Rittenhouse K, et al. Breaking down the barriers! Factors contributing to barrier days in a mature trauma center. *J Trauma Acute Care Surg*. 2014;76(1): 191-5.
58. Ciesla DJ, Sava JA, Kennedy SO, Levinson K, Jordan MH. Trauma patients: you can get them in, but you can't get them out. *Am J Surg*. 2008;195: 78–83.
59. Shojania KG, Duncan BW, McDonald KM, Wachter RM. Safe but sound: patient safety meets evidence-based medicine. *JAMA*. 2002;288(4): 508-13.
60. Covinsky KE, Palmer RM, Fortinsky RH, et al. Loss of independence in activities of daily living in older adults hospitalized with medical illnesses: increased vulnerability with age. *J Am Geriatr Soc*. 2003;51(4): 451-8.
61. Carey MR, Sheth H, Braithwaite RS. A prospective study of reasons for prolonged hospitalizations on a general medicine teaching service. *J Gen Intern Med*. 2005;20(2): 108-15.
62. Bauer M, Fitzgerald L, Haesler E, Manfrin M. Hospital discharge planning for frail older people and their family. Are we delivering best practice? A review of the evidence. *Journal of Clinical Nursing*. 2009;18(18): 2539-2546.
63. Oliver D, Foot C, Humphries R. Making our health and care systems fit for an ageing population, 2014. Available at: https://www.kingsfund.org.uk/sites/default/files/field/field_publication_file/making-health-care-systems-fit-ageing-population-oliver-foot-humphries-mar14.pdf. Accessed November 16, 2018.
64. The Queen's Nursing Institute. Best practice in transitions of care, 2016. Available at: https://www.qni.org.uk/wp-content/uploads/2016/09/discharge_planning_report_2015.pdf. Accessed November 16, 2018.
65. Sunnybrook Health Sciences Center. Hours Matter, Fall 2009. Available at: https://sunnybrook.ca/uploads/HoursMatter_Nov09.pdf. Accessed November 16, 2018.
66. McKevitt EC, Calvert E, Ng A, et al. Geriatric trauma: resource use and patient outcomes. *Can J Surg*. 2003;46(3): 211-5.

67. Newgard CD, Staudenmayer K, Hsia RY, et al. The cost of overtriage: more than one-third of low-risk injured patients were taken to major trauma centers. *Health Aff*. 2013;32(9): 1591-9.
68. The Dartmouth Institute for Health Policy and Clinical Practice. The Dartmouth atlas of health care. http://www.dartmouthatlas.org/. Accessed March 20, 2018.
69. Sise CB, Sise MJ, Kelley DM, et al. Resource commitment to improve outcomes and increase value at a level I trauma center. *J Trauma*. 2011;70(3): 560-8.
70. Peiró S, Maynard A. Variations in health care delivery within the European Union. *Eur J Public Health*. 2015;25 Suppl 1:1–2.
71. Goldfarb MG, Bazzoli GJ, Coffey RM. Trauma systems and the costs of trauma care. *Health Serv Res*. 1996;31(1): 71-95.
72. Durham R, Pracht E, Orban B, Lottenburg L, Tepas J, Flint L. Evaluation of a mature trauma system. *Ann Surg*. 2006;243(6): 775-83; discussion 783-5.
73. MacKenzie EJ, Weir S, Rivara FP, et al. The value of trauma center care. *J Trauma*. 2010;69(1): 1-10.
74. Farhat I, Moore L, Porgo TV, et al. Resource use for elderly injury hospitalisations in a Canadian integrated trauma system: a retrospective multicenter cohort study. In preparation.
75. Assy C, Moore L, Porgo TV, et al. Intensity of resource use following traumatic brain injury : a multicenter cohort study, 2013 - 2016. In preparation.
76. The Canadian Agency for Drugs and Technologies in Health. Guidance document for the Costing of health care resources in the canadian setting. 2nd Edition. Ottawa, ON: the Canadian Agency for Drugs and Technologies in Health; 2015.
77. Kang H. The prevention and handling of the missing data. *Korean J Anesthesiol*. 2013;64(5): 402-6.
78. Canadian Institute for Health Information. The Cost of Acute Care Hospital Stays by Medical Condition in Canada, 2004–2005. Ottawa, ON: the Canadian Institute for Health Information; 2008.
79. Jefferies LC, Sachais BS, Young DS. Blood transfusion costs by diagnosis-related groups in 60 university hospitals in 1995. *Transfusion*. 2001;41(4): 522-9.
80. Ridic G, Gleason S, Ridic O. Comparisons of Health Care Systems in the United States, Germany and Canada. *Mat Soc Med*. 2012;24(2): 112-120.
81. American College of Surgeons Committee on Trauma. Resources for optimal care of the injured patient. Chicago (IL): American College of Surgeons; 2006.

CHAPTER 5. DISCUSSION

5.1. Summary of results

The overarching goal of this project was to develop and validate a hospital indicator of resource use intensity for injury admissions. We did so through three studies. In the first study, we reviewed how data on costs have been used to evaluate injury care. In a systematic review of the literature, we identified 10 eligible studies. Intra and inter-hospital comparisons were adjusted according to patient case mix in five studies (50%). Four studies (40%) were considered to be of good methodological quality. The review highlighted the need for more data on the performance of trauma centers based on costs in single-payer healthcare systems and for a risk-adjusted tool to monitor resource use intensity for injury admissions. In the second study, we developed a reproducible method for estimating patient-level, in-hospital resource use for injury admissions using trauma registry data and the activity-based costing method. We identified determinants of resource use intensity that could be used to establish evidence-based resource allocations and design high-impact interventions to improve the efficiency of acute injury care. In the third study, we developed a hospital indicator of resource use intensity with good internal and temporal validity using trauma registry data. The risk-adjustment models we developed explained between 11% and 30% (optimism-corrected r^2) of the variation in resource use in the whole cohort and among patients with traumatic brain, isolated orthopedic and isolated thoracoabdominal injuries. We identified centers with higher or lower than expected resource use across all adult trauma centers within designation levels (I/II and III/IV) in an inclusive, mature Canadian trauma system. The strengths and limitations of each study are discussed under objectives one, two and three, respectively.

5.2. Interpretation of results

Studies in the United States that have observed significant inter-provider variations in risk-adjusted costs of injury care (estimated using patient charges)[1-3] lend support to our findings. Furthermore, our risk-adjustment models suggest that approximately 70% to

90% of resource use intensity for injury care is driven by factors other than patient case mix. Even though variations in medical practices are now monitored at regional and national levels,[4, 5] research in this area is in its infancy and little is known about the determinants of inter-provider variations in resource use intensity. Nonetheless, it is suggested that factors related to processes of care and hospital structure may explain differences in resource use intensity.[6-9] These factors include the discharge destination and the designation level, as shown in our second study. The higher risk-adjusted resource use observed for patients discharged to long-term care or rehabilitation facilities is likely due to delays in access to post-acute care. This has been observed elsewhere.[10-13] Patients awaiting post-acute care placement have unnecessarily prolonged acute care stays and are exposed to a greater risk of complications, hospital-acquired infections and functional decline.[14-16] In our second study, discharge destination was the strongest determinant of resource use intensity. Therefore, advanced discharge planning and the provision of access to post-acute care facilities seem to be promising areas to explore in order to decrease resource use and make more beds available for patients who really need them.[17-20] This will be particularly relevant in the coming years with the aging population since it has been shown that discharge delays affect the elderly more than they affect young injured patients.[21] Furthermore, we found an association between high designation level and resource use intensity. Designation level can be considered a proxy of the availability of resources since high-level trauma centers are the most specialized centers.[22] The association between availability of resources and resource use intensity was also observed in the Dartmouth Atlas Project.[5] In this two-decade-long project, it was found that regions in the United States that spent the most on healthcare were also those with more resources, for example more hospital beds, intensive care unit beds, and CT scanners.[5] 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.[23] Furthermore, the establishment of criteria for directing less resource intense patients to level III/IV centers could be another option for improving the efficiency of injury care.

5.3. Impact

In this project, we filled a major gap in the literature by producing data on patient-level resource use for injury admissions and identifying drivers of resource use intensity. These data were lacking mainly because of methodological limitations with regard to resource use valuation.[24] This information may be used to inform the implementation of evidence-based resource allocation strategies and interventions to improve the efficiency of acute injury care in Quebec and in other trauma systems in high-income countries. Furthermore, we developed a hospital indicator of resource use intensity for injury admissions in response to a need directly expressed by stakeholders. The indicator can be used to monitor variations in resource-use intensity within a single trauma center or system over time or across trauma centers or systems. Hospital indicators on resource use intensity should be presented alongside indicators of clinical outcomes such as risk-adjusted mortality, complications, and 30-day readmission rates. Root causes of variations in resource use intensity across trauma centers could be explored by examining indicators of structure and processes of care and drilling down data on resource use intensity by year and activity center. These initiatives will facilitate the design and implementation of high-impact interventions to address unwarranted variations without negatively affecting patient outcomes.[4, 23, 25] Addressing unwarranted variations may decrease costs and delays to appropriate care. It also has the potential to reduce the use of low-value clinical practices and thus unnecessary exposure to adverse events.[14-16] The indicator of resource use intensity can also be used to evaluate the progress of trauma centers towards achieving specific objectives.[26] Moreover, given the high costs of injury care,[27-29] the indicator of resource use intensity may help alleviate the financial burden of acute injury care on societies.

The methods we used for estimating patient-level, in-hospital resource use and for developing the hospital indicator can be reproduced in other settings, be it for-profit or single payer healthcare systems. We developed a user-friendly SAS program that can be used to calculate risk-adjusted geometric mean activity-based costs using the unit costs provided or those specific to the system under evaluation, if available. Our methods can be reproduced for injury admissions but also adapted to other diagnostic groups. Moreover, now that a hospital indicator of resource use intensity has been developed, it will be possible to further our understanding of the association between resource use intensity and quality of care, and identify aspects of resource use related to clinical benefit. The association between hospital resource use intensity and quality of care is complex. There is an important knowledge gap in this area and two opposing hypotheses that have not yet been verified. One hypothesis is that quality of care is a result of investments in resources, and that hospitals with high resource use intensity obtain better patient outcomes.[8] The alternative hypothesis is that quality of care is a result of more efficient resource use because high quality structures and processes of care decrease delays and adverse events, which consequently decreases resource use intensity.[6-8] Using the methods developed in this project, research is underway to advance knowledge on the association between resource use intensity and clinical outcomes in trauma populations.[30, 31]

5.4. External validity

Our project is based on the Quebec trauma registry, which only includes data for patients treated in designated trauma centers. Moreover, it is estimated that adjusted costs of injury care (estimated using patient charges) is higher in trauma centers than in non-designated hospitals[27-29] and that patient outcomes are better in trauma centers.[29, 32] Therefore, our results may not be generalizable to non-designated hospitals. Moreover, we focused on in-hospital resource use for ≥ 16-year-olds and our study sample encompasses approximately 2% of patients with penetrating injuries. Therefore, our results are unlikely to be generalizable to pediatric admissions, or trauma centers where there is a large proportion of patients with penetrating injuries. However, we included all adult trauma centers in Quebec using trauma registry data based on mandatory inscription of cases and uniform inclusion criteria. Consequently, the results we obtained may be generalized to other trauma systems with universal health care and low rates of penetrating injury, for example other Canadian provinces, Australia, or the United Kingdom. We expect that there would be greater variations in resource use intensity across trauma centers in for-profit healthcare settings. Lastly, the method that we developed for estimating patient-level resource use and the hospital indicator of resource use intensity are reproducible in other trauma centers or systems, provided there is a local trauma registry. Note that information obtained from hospital discharge data in our studies (comorbidities) is collected in most trauma registries.

5.5. Future research

Before the indicator is integrated into the Québec injury care continuum, stakeholders and knowledge users will be consulted in collaboration with the quality control team of the Institute of healthcare excellence to establish the optimal presentation format for audit-feedback reports and intervention protocols for outlier hospitals. In terms of research, future projects should aim to identify determinants of inter-provider variations in resource use intensity for injury care. Additionally, since we focused on adult patients, future research may also identify drivers of resource use intensity and evaluate variations in resource use intensity among pediatric patients.

5.6. References

1. Glance LG, Dick AW, Osler TM, Meredith W, Mukamel DB. The association between cost and quality in trauma: is greater spending associated with higher-quality care? *Ann Surg*. 2010;252(2): 217-22.
2. Clancy TV, Maxwell GJ, Covington DL, Brinker CC, Blackman D. A statewide analysis of level I and II trauma centers for patients with major injuries. *J Trauma*. 2001;51(2): 346-51.
3. Obirieze AC, Gaskin DJ, Villegas CV, et al. Regional variations in cost of trauma care in the United States: who is paying more? *J Trauma Acute Care Surg*. 2012;73(2): 516-22.
4. Peiró S, Maynard A. Variations in health care delivery within the European Union. *Eur J Public Health*. 2015;25 Suppl 1:1–2.
5. The Dartmouth Institute for Health Policy and Clinical Practice. The Dartmouth atlas of health care. http://www.dartmouthatlas.org/. Accessed March 20, 2018.
6. Moore L, Lavoie A, Sirois MJ, et al. Evaluating trauma center structural performance: The experience of a Canadian provincial trauma system. *J Emerg Trauma Shock*. 2013;6(1): 3-10.
7. Moore L, Lavoie A, Sirois MJ, et al. A comparison of methods to obtain a composite performance indicator for evaluating clinical processes in trauma care. *J Trauma Acute Care Surg*. 2013;74(5): 1344-50.
8. Donabedian A. An introduction to quality assurance in health care. New York, NY: Oxford University Press; 2003.
9. Moore L, Lavoie A, Sirois MJ, Amini R, Belcaid A, Sampalis JS. Evaluating trauma center process performance in an integrated trauma system with registry data. *J Emerg Trauma Shock*. 2013;6(2): 95-105.
10. Brasel KJ, Rasmussen J, Cauley C, Weigelt JA. Reasons for delayed discharge of trauma patients. *J Surg Res*. 2002;107(2): 223-6.
11. Thomas SN, McGwin G Jr, Rue LW 3rd. The financial impact of delayed discharge at a level I trauma center. *J Trauma*. 2005;58(1): 121-5.
12. Rogers A, Clark EH, Rittenhouse K, et al. Breaking down the barriers! Factors contributing to barrier days in a mature trauma center. *J Trauma Acute Care Surg*. 2014;76(1): 191-5.
13. Ciesla DJ, Sava JA, Kennedy SO, Levinson K, Jordan MH. Trauma patients: you can get them in, but you can’t get them out. *Am J Surg*. 2008;195: 78–83.
14. Shojania KG, Duncan BW, McDonald KM, Wachter RM. Safe but sound: patient safety meets evidence-based medicine. *JAMA*. 2002;288(4): 508-13.
15. Covinsky KE, Palmer RM, Fortinsky RH, et al. Loss of independence in activities of daily living in older adults hospitalized with medical illnesses: increased vulnerability with age. *J Am Geriatr Soc*. 2003;51(4): 451-8.
16. Carey MR, Sheth H, Braithwaite RS. A prospective study of reasons for prolonged hospitalizations on a general medicine teaching service. J *Gen Intern Med*. 2005;20(2): 108-15.

17. Bauer M, Fitzgerald L, Haesler E, Manfrin M. Hospital discharge planning for frail older people and their family. Are we delivering best practice? A review of the evidence. *Journal of Clinical Nursing*. 2009;18(18): 2539-2546.
18. Oliver D, Foot C, Humphries R. Making our health and care systems fit for an ageing population, 2014. Available at: https://www.kingsfund.org.uk/sites/default/files/field/field_publication_file/making-health-care-systems-fit-ageing-population-oliver-foot-humphries-mar14.pdf. Accessed November 16, 2018.
19. The Queen's Nursing Institute. Best practice in transitions of care, 2016. Available at: https://www.qni.org.uk/wp-content/uploads/2016/09/discharge_planning_report_2015.pdf. Accessed November 16, 2018.
20. Sunnybrook Health Sciences Center. Hours Matter, Fall 2009. Available at: https://sunnybrook.ca/uploads/HoursMatter_Nov09.pdf. Accessed November 16, 2018.
21. McKevitt EC, Calvert E, Ng A, et al. Geriatric trauma: resource use and patient outcomes. *Can J Surg*. 2003;46(3): 211-5.
22. Centers for Disease Control and Prevention. Access to trauma centers in the United States. Atlanta, GA: Centers for Disease Control and Prevention; 2009.
23. The Lown Institute. Overuse 101. http://lowninstitute.org/learn/overuse-101/. Accessed March 19, 2018.
24. The Canadian Agency for Drugs and Technologies in Health. Guidance document for the Costing of health care resources in the canadian setting. 2nd Edition. Ottawa, ON: the Canadian Agency for Drugs and Technologies in Health; 2015.
25. Shafi S, Nathens AB, Cryer HG, et al. The Trauma Quality Improvement Program of the American College of Surgeons Committee on Trauma. *J Am Coll Surg*. 2009;209(4): 521-530 e1.
26. Institut national d'excellence en santé et en services sociaux. Trauma Care Continuum website. http://www.fecst.inesss.qc.ca/en.html. Accessed January 30, 2018.
27. Goldfarb MG, Bazzoli GJ, Coffey RM. Trauma systems and the costs of trauma care. *Health Serv Res*. 1996;31(1):71-95.
28. Durham R, Pracht E, Orban B, Lottenburg L, Tepas J, Flint L. Evaluation of a mature trauma system. *Ann Surg*. 2006;243(6): 775-83; discussion 783-5.
29. MacKenzie EJ, Weir S, Rivara FP, Jurkovich GJ, Nathens AB, Wang W, Scharfstein DO, Salkever DS. The value of trauma center care. *J Trauma*. 2010;69(1): 1-10.
30. Farhat I, Moore L, Porgo TV, et al. Resource use for elderly injury hospitalisations in a Canadian integrated trauma system: a retrospective multicenter cohort study. In preparation.
31. Assy C, Moore L, Porgo TV, et al. Intensity of resource use following traumatic brain injury : a multicenter cohort study, 2013 - 2016. In preparation.
32. Haas B, Stukel TA, Gomez D, et al. The mortality benefit of direct trauma center transport in a regional trauma system: a population-based analysis. *J Trauma Acute Care Surg*. 2012;72(6): 1510-5; discussion 1515-7.

CHAPTER 6. CONCLUSIONS

We developed a method for estimating patient-level, in-hospital resource use for trauma admissions and for identifying drivers of resource use intensity. This information is crucial to inform resource allocation strategies, particularly in the province of Quebec where these data were not yet available. Moreover, we developed a hospital indicator of resource use intensity for injury admissions based on risk-adjustment models with good internal and temporal validity. Just as in studies conducted in the United States, we identified inter-provider variations in resource use intensity in an inclusive, mature Canadian trauma system, within designation levels (I/II and III/IV). Our results suggest that 70% to 90% of the variation in resource use for injury care in Quebec is dictated by factors other than the clinical status of patients on arrival. The indicator can be used in addition to information on clinical outcomes to address unwarranted variations in risk-adjusted resource use intensity within a single trauma center or system, or across provinces or countries. We propose an SAS program to reproduce the indicator in other settings using local trauma registry data. Using the methods developed in this project, research is underway to examine the association between hospital resource use intensity and clinical outcomes for trauma patients. Future research should identify determinants of variations in resource use intensity and aspects of resource use that drive optimal patient outcomes.

7. APPENDICES

7.1. Appendix 1. Evidence of data quality in trauma registries: a systematic review

Teegwendé Valérie Porgo MSc[1,2], Lynne Moore PhD[1,2], Pier-Alexandre Tardif MSc[1,2]

[1]Population Health and Optimal Health Practices Research Unit (Trauma-Emergency-Intensive care), Centre de Recherche du CHU de Québec - Hôpital de l'Enfant-Jésus, Université Laval, Quebec City, Quebec, Canada;
[2]Department of social and preventive medicine, Université Laval, Quebec City, Quebec, Canada

Running head: Data quality in trauma registries
Key words: Trauma registry, data quality, evaluation, report, systematic review

Abstract

Background: Trauma registries are clinical databases designed for research and quality improvement activities. The effectiveness of trauma registries in improving patient outcomes depends on data quality. However, our understanding of data quality in trauma registries is limited.

Objective: To review evidence of data quality in trauma registries.

Methods: We performed a systematic review using MEDLINE, EMBASE, Web of Science, CINAHL, and The Cochrane Library including studies that evaluated data quality in trauma registries based on completeness, accuracy, precision, correctness, consistency, or timeliness (the last search was run in November 2015). We also searched MEDLINE to identify regional, national, and international trauma registries whose data were used ≥ 10 times in original studies in the last 10 years. We contacted administrators of those registries to obtain their latest data quality report. Two authors conducted study screening and data extraction independently.

Results: The search retrieved 7,495 distinct published articles, of which 10 were eligible for inclusion. We also reviewed data quality reports from five provincial and international trauma registries. Evaluation was mostly based on completeness with values between 46.8% (mechanism of injury) and 100% (age and sex). Accuracy was between 81.0% (operating room time) and 99.8% (sex). Correctness varied from 47.6% (injury severity score) to 83.2% (Glasgow Coma Scale score) and consistency between variables from 87.5% (International Classification of Disease-9th Revision-Clinical Modification /Abbreviated Injury Scale) to 99.6% (procedure time). No evidence of data precision or timeliness was available.

Conclusions: Trauma registries are not exempt from data quality problems. There is a need for criteria for defining data quality as poor, moderate, or good. In addition, the impact of data quality on analyses based on trauma registries such as benchmarking should be formally studied.

Introduction

Trauma registries are clinical databases based on very large patient cohorts and designed to capture detailed information on the care of trauma patients.[1] They represent huge investment in terms of infrastructure and human resources. In 2004, the direct cost of trauma registries in Australia was estimated at more than 100 Australian dollars per patient.[2] Trauma registries are increasingly used to plan and conduct research, monitor injury care and systems, establish clinical guidelines, policies and injury prevention strategies, and plan resource allocation.[1,3-10] Trauma registries have made important contributions to improvements in injury care over the last few decades.[11-13] The effectiveness of trauma registries in improving patient outcomes depends on data quality.[1,14-16] It has been shown that problems with data quality in clinical registries significantly impact patient decision processes[16] and quality of care evaluations.[1,14,15] Like diagnostic tests, studies based on low data quality may miss real quality problems (low sensitivity) and identify problems that are not real (low specificity).

Wang and Strong's conceptual model for measuring data quality, the most widely accepted for healthcare data, describes data quality according to six dimensions: completeness (all necessary data are provided), accuracy (data conformed with a verifiable source), precision (data value is specific), correctness (data are within specified value domains), consistency (data are logical across data points), and timeliness (trauma registry data are available when needed).[17] Taking the variable age as an example, all patients should have a recorded age (completeness); values should correspond to those indicated in the patient file (accuracy), be exact numbers (precision), be within the range of 0 to 150 years (correctness), and correspond to years between date of birth and date of hospital admission (consistency). In relation to timeliness, all observations should be completed in the registry within one year from the end of the diagnosis year or during the last fiscal year.[18,19] Despite the critical importance of data quality for the validity of analyses based on trauma registries, our understanding of data quality in trauma registries is limited. In 2006, a review of trauma registries in North America, Europe, and Australia emphasized the lack of information on data quality.[20]

An exhaustive overview of multiple dimensions of registry data quality is needed to understand the limitations of analyses conducted using data from trauma registries and identify areas for improvement that will facilitate valid clinical patient care decisions. The objective of this study was to review evidence of data quality in trauma registries.

Methods

We performed a systematic review based on recommendations from the Cochrane Handbook for Systematic Reviews of Interventions[21] and Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement.[22]

Information sources and search strategy

We systematically searched MEDLINE, EMBASE, Web of Science, CINAHL, and The Cochrane Library using combinations of multiple search terms on three themes: injury, registry, and data quality (see Table A1.1 for the search strategy in MEDLINE). The last search was run on 24 November 2015. We also manually screened the bibliographies of eligible studies to identify potentially relevant publications. No language or publication date restrictions were applied.

In addition to the aforementioned systematic search, we screened MEDLINE to identify regional, national, and international trauma registries whose data was used ≥10 times in original studies in the last 10 years (see Table A1.2 for search strategy). We contacted the administrators of these registries and requested their latest data quality report, when available.

Study selection

Studies that evaluated data quality in trauma registries in terms of completeness, accuracy, precision, correctness, consistency, and timeliness in global trauma populations (i.e. non-specific pathologies) were considered eligible. Studies reporting registry implementation phases or administrative data accuracy using trauma registries as a gold standard were excluded.

Duplicates were sorted with EndNote software version X7 (Thomson Reuters, 2013). Two authors (TVP, PAT) screened titles, abstracts, and when appropriate, full-text articles independently to identify eligible studies (kappa = 0.85).[23] One author (TVP) followed the same procedure to identify studies using regional, national, and international trauma registries.

Data extraction

Two authors (TVP, PAT) extracted data independently using an electronic form that was previously piloted on three representative studies. The data extraction form was designed to capture information on study setting and design, details of trauma registries used, and data quality evaluation. Disagreements between reviewers were resolved by consensus.

Results

Search results

The search retrieved 7495 distinct published articles of which 176 full-text articles were assessed for eligibility (Figure A1.1). Ten studies were selected for this review.[15,24-32] The search for regional, national, and international trauma registries yielded 2232 publications; they were used in 1208 original research studies. There were 17 regional, national, and international registries that met our inclusion criteria (Table A1.3). Of these, one was no longer functional, three did not have data quality reports, two did not have reports that met the requirements of this review, and six could not be accessed during the study period. Thus, we were left with five de-identified data quality reports, four of which were not available to the public online but were sent to us. These four reports are the National trauma data bank data quality report 2013, United States;[33] the British Columbia trauma registry annual data summary report 2014, Canada;[34] the National trauma registry 2012 data quality report for provinces/territories for the Ontario trauma registry, Canada;[35] and the Quebec trauma registry, Canada.[36] In addition, the German trauma Society sent us their online annual report, the TraumaRegister Deutsch Gesellschaft für Unfallchirurgie annual report 2014, which includes a data quality section.[37]

Characteristics of included studies

Four studies were conducted in the United States,[15,24-26] three in Australia,[27-29] one in Saudi Arabia,[32] one in Canada,[30] and one in Zambia[31] (Table A1.4). The studies involved data collected from 1991[26] through 2012[31] with 8[15] to 32,448[24] participants. Two studies used the same registry[28,29] and one also evaluated the National trauma data bank data,[25] resulting in a total of 11 trauma registries evaluated. Common trauma registry inclusion criteria included hospital admission (8 registries)[15,25,27-30,32-34,37] and deaths in hospital or on arrival (9 registries).[15,24,25,27-30,32-34,37] Samples used for data quality evaluation included patients that met trauma registry inclusion criteria.[15,27-29,31,32] In two studies, a sample of patients or trauma centers was randomly selected.[26,30] Lastly, one study only evaluated data for patients transported by emergency medical services.[24] Reports on data quality were based on data from between 4453 (59 participating facilities)[36] and 814,663 records (758 facilities).[33]

Data quality

Fourteen evaluations (studies and reports) were based on completeness (Table A1.5).[15,24-26,28-37] Variables most frequently evaluated were age (9 evaluations),[15,25,26,28,29,31,33-35] systolic blood pressure (9),[24,26,28,29,32,33,35-37] Glasgow Coma Score (8),[24,28,29,33-37] respiratory rate (7),[24,26,28,29,32,33,37] and gender (6).[25,31,33-36] Age and gender were recorded 93.2%-100% of the time. The lowest and highest completeness proportions for systolic blood pressure, Glasgow Coma Score, and respiratory rate were 71.3%,[26] 79.6,[36] and 61.0%,[37] and 97.6%, 95.1%, and 97.9%, respectively.[33] One study reported that 9 out of 24 (37.5%) hospitals contributing to the National trauma data bank data 2002 data did not submit any comorbidity information in the comorbidity field.[25] In the National trauma data bank data 2013 data, the completeness of the comorbidity variable itself was 94.9%.[33] Completeness of mechanism of injury was 46.8% in one study[26] and between 96.6% and 100% in three other studies/reports.[29,31,34]

Accuracy was assessed in four evaluations by comparison of trauma registry data to either hospital records[27,30,34] or emergency medical service forms.[24] Lower accuracy values were observed for operating room time (81.0%)[30] and intensive care unit length of stay (95.0%).[30] Age, gender, Glasgow Coma Score, intubation attempt, and hospital length of stay were 98.0% to 99.8% accurate.[24, 27, 30]

Data correctness was evaluated in one study based on injury severity score and Glasgow Coma Score, with values of 47.6% and 83.2%, respectively.[26]

Evidence of data consistency was available in two evaluations.[15, 34] In the 2013 data quality report of the British Columbia Trauma Registry, variables were ≥ 98.7% error-free. Examples of errors were pregnancy status in males, greater emergency department length of stay than hospital length of stay, arrival date after admission date, and discharge date before admission date. In the Alberta trauma registry, the variables discharge disposition and destination were 99.8% consistent; transport mode, time values for incident and procedure, and International Classification of Disease-9th Revision-Clinical Modification/Abbreviated Injury Scale codes were ≥ 87.5% error-free.[15]

Sensitivity analyses

When stratifying data quality evidence by decade of data period (1990's, 2000's, and 2010-2015) or by years of existence of the registry (results not shown), no conspicuous relation between high/low data quality values and data period or registry maturity was observed.

Discussion

In this systematic review, we identified only 10 studies that evaluated data quality in trauma registries. Data quality reports of five trauma registries were also reviewed. We observed that evaluation of data quality was mainly based on completeness. Age, systolic blood pressure, Glasgow Coma Score, respiratory rate, and gender were the variables most frequently subjected to completeness evaluation. We found large reported differences in the completeness of systolic blood pressure, Glasgow Coma Score, respiratory rate, and mechanism of injury. Less heterogeneous values were found for data accuracy; intensive care unit and hospital length of stay, age, gender, Glasgow Coma Score, and intubation attempt were almost completely accurate. The Glasgow Coma Score and injury severity score were the only trauma registry variables for which correctness was evaluated as a component of data quality. The correctness value for injury severity score was surprisingly low. The only two evaluations (one study and one report) in which evidence of consistency was available suggest that trauma registries are prone to few consistency errors. No evidence of data precision or timeliness was available for this review. In the sensitivity analyses, there seemed to be no clear relation between data quality and data period or registry maturity.

In the trauma literature, special attention has been given to the problem of missing physiological data.[1,24,38] Physiological data represent the response of patient to injury and thus is particularly difficult to collect in major trauma patients. Several solutions have been proposed for these missing data with multiple imputation appearing to be the most valid method.[1] The lowest data quality values were observed in the 1991-1992 Florida trauma registry data for completeness of mechanism of injury and correctness of injury severity score.[26] According to the study authors, data quality in this registry could be due to lack of familiarity with trauma scoring systems at the time the study was performed, entry of data in wrong fields, or focusing data compilation on major trauma patients or patients with complications.[26] This supports our results in the sensitivity analyses by suggesting that data quality in trauma registries is not so much related to data period, which reflects coding conventions and technical tools complexity, but more importantly to human factors. In this review, data quality of vital status, complications during hospital stay, and emergency department length of stay were each based on only one data quality dimension (completeness or consistency); yet, in a scoping review of quality indicators, these variables were among quality indicators the most frequently used to assess the care given to patients with major trauma.[11]

Despite data quality assurance, data in trauma registries is not exempt from errors. The literature suggests that data quality problems may result from staffing levels, transition to new coding conventions, unclear definitions, lack of training, interface problems, heavy workload, and too much emphasis on speed even if timely results are crucial for pertinent and up-to-date interventions.[39-43] It is worth noting that these potential causes are all based on the opinion of experts. Implementing targeted interventions for the improvement of data quality in trauma registries requires empirical data that identify data quality determinants in those registries. Moreover, trauma registries are based on data abstracted from patient records but evaluation studies on the quality of data in those files are scarce. However a study conducted in 21 Dutch hospitals highlighted problems with missing data, unreadable notes, and inadequacies such as unclear reasons for admission.[44] Of note was the high percentage (19.5%) of missing data found on patient medical history and physical examination at admission.[44] In addition, inter-rater reliability between injury coders, an inherent characteristic of measurement tools (the international classification of disease and the Abbreviated Injury Scale coding systems for example), could explain the inaccuracies found in trauma registries.[45-48] In light of the data quality problems observed in this review, it is critical to evaluate the impact of data quality on quality of care evaluations. In a scoping review designed to identify quality indicators to evaluate injury care quality, 428 (45.4%) out of the 942 quality indicators identified were measured using trauma registries.[11] Data quality evaluation should be based on a standardized and reproducible method for all data quality dimensions. There is also a need to establish criteria that define data quality as poor, moderate, or good as these criteria are not yet available in the literature.

For reports and studies evaluating data quality, data quality should encompass at least completeness, accuracy, precision, correctness, consistency, and timeliness as described in the Wang and Strong's conceptual model for measuring data quality.[17] Results should be reported for each variable in the registry and not only as a whole. Furthermore, if data completeness is solely based on the proportion of data available in the registry, this should be explicitly stated. If available, we recommend reporting the proportion of complete data in the database used as a gold standard. For other types of studies, we advise authors to indicate if a data quality report concerning the registry being used exists. If that is the case, authors should also provide an appreciation of the registry data quality when a clear definition of poor, moderate, and good data qualities are made available in the literature. Lastly, the proportion of missing data should be provided for each variable, as recommended in the Strengthening the Reporting of Observational

Studies in Epidemiology statement.[49]

In this study, we searched for evidence of the most common and relevant dimensions of data quality in healthcare.[50-52] Our systematic review was based on an exhaustive and rigorous search of five electronic databases. Bibliographies of eligible studies were also searched manually. Therefore, it is unlikely that we missed an important number of relevant studies. Though we were not able to obtain quality reports from all eligible regional, national, or international trauma registries, our review should provide a good representation of data quality in trauma registries. In fact, three regional registries did not have data quality reports, two did not have reports that met the requirements of our study and one was no longer functional. In addition, the Victorian State trauma registry was already evaluated in two original studies.

Conclusion

Few studies have evaluated data quality in trauma registries, and evaluation of data quality was mostly based on completeness. This study suggests that a standardized, reproducible method to evaluate data quality in trauma registries based on all data quality dimensions, and criteria to define data quality dimensions as poor, moderate, or good are needed. The impact of data quality on trauma registry analyses such as benchmarking with quality indicators should also be formally explored.

Acknowledgment

We would like to thank the American College of Surgeons, the British Columbia Provincial Health Services Authority, the Quebec Ministry of Health and Social Services, the Canadian Institute for health information, and the German trauma society for giving us access to their data quality reports.

Author Contribution

TVP, LM, and PAT participated in the study design. TVP and PAT completed the literature search. All authors contributed to the data analysis and interpretation, and the writing and critical revision of the manuscript.

Table A1.1. Search strategy in MEDLINE for studies that evaluated trauma registry data quality

Keyword
Trauma
1. Injury[TIAB] OR Injuries[TIAB] OR Injured[TIAB] Trauma[TIAB] OR Traumas[TIAB] OR Traumatic[TIAB] OR Traumatized[TIAB] OR Traumatology[TIAB] OR Wound[TIAB] OR Wounds[TIAB]
2. “Wounds and injuries” [MeSh]
3. “Trauma centers” [MeSh:noexp]
4. # 1 OR #2 OR #3
Registry
5. Registry[TIAB] OR Registries[TIAB] OR “Data bank”[TIAB] OR “Data banks”[TIAB] OR Databank[TIAB] OR Databanks[TIAB] OR Database[TIAB] OR Databases[TIAB] OR Record[TIAB] OR Records[TIAB] OR Index[TIAB] OR Indices[TIAB] OR (discharge[TIAB] AND (hospital[TIAB] OR data[TIAB])) OR “data set” [TIAB] OR “data sets” [TIAB] OR “Data source” [TIAB] OR “Data sources” [TIAB] OR (Administrative[TIAB] AND data[TIAB]) OR “registered-based”[TIAB] OR Documentation[TIAB]
6. Registries[Mesh:noexp] OR “Medical records”[Mesh:noexp] OR “Nursing records”[Mesh:noexp] OR “Data collection” [MeSh:noexp] OR “Database management systems” [MeSh:noexp] OR "Medical Records Systems, Computerized" [MeSh:noexp] OR “Databases, factual” [MeSh:noexp] OR “Databases as topic”[MeSh:noexp]
7. “Trauma Severity Indices” [MeSh:noexp]
8. #5 OR #6 OR #7
Data quality evaluation
9. “Missing data”[TIAB] OR “Missing value”[TIAB] OR “Missing values”[TIAB] OR “Valid data” [TIAB] OR “Validity of data” [TIAB] OR “Data validity” [TIAB] OR “Valid source” [TIAB] OR “Valid sources” [TIAB] OR “Valid value” [TIAB] OR “Valid values” [TIAB] OR “Validity of values” [TIAB] OR “Accurate data” [TIAB] OR “Accurate source” [TIAB] OR “Accurate sources” [TIAB] OR “Accurate value” [TIAB] OR “Accuracy of values” [TIAB] OR “Accurate values” [TIAB] OR “Data accuracy” [TIAB] OR “Accuracy of data” [TIAB] OR “Precision of data” [TIAB] OR “Precise data” [TIAB] OR “Precise source” [TIAB] OR “Precise sources” [TIAB] OR “Precise value” [TIAB] OR “Precise values” [TIAB] OR “Precision of values” [TIAB] OR “Correctness of data” [TIAB] OR “Correct data” [TIAB] OR “Correct source” [TIAB] OR “Correct sources” [TIAB] OR “Correct value” [TIAB] OR “Correct values” [TIAB] OR “Complete data” [TIAB] OR (Completeness[TIAB] AND Data[TIAB]) OR “Complete source” [TIAB] OR “Complete sources” [TIAB] OR “Complete value” [TIAB] OR “Complete values” [TIAB] OR “Completeness of values” [TIAB] OR “Consistency of data” [TIAB] OR “Consistent data” [TIAB] OR “Consistent source” [TIAB] OR “Consistent sources” [TIAB] OR “Consistent value” [TIAB] OR “Consistent values” [TIAB] OR “Consistency of values” [TIAB] OR “Timeliness of data” [TIAB] OR “Timely data” [TIAB] OR “Timely source” [TIAB] OR “Timely sources” [TIAB] OR “Timely value” [TIAB] OR “Timely values” [TIAB] OR “Timeliness of values” [TIAB]

10. "Audit filter" [TIAB] OR "Data audit"[TIAB] OR "Data audits" [TIAB] OR "Data quality" [TIAB]
11. "Quality assurance" [TIAB] OR "Quality control" [TIAB] OR "Quality evaluation" [TIAB] OR "Quality evaluations" [TIAB] OR "Quality assessment" [TIAB] OR "Quality assessments" [TIAB] OR "Quality improvement" [TIAB] OR "Quality improvements" [TIAB] OR "Quality management" [TIAB] OR "Quality measure" [TIAB] OR "Quality measures" [TIAB] OR "Quality measurement" [TIAB] OR "Quality measurements" [TIAB] OR "Quality indicator" [TIAB] OR "Quality indicators" [TIAB] OR "Quality comparison" [TIAB] OR "Quality comparisons" [TIAB] OR "Quality review" [TIAB] OR "Quality reviews" [TIAB] OR "Quality audit" [TIAB] OR "Quality audits" [TIAB]
12. "Evaluation Studies as Topic" [Mesh:noexp] OR "Program evaluation"[Mesh:noexp] OR "Benchmarking" [MeSh:noexp] OR "Validation studies as topic"[Mesh:noexp]
13. "Quality Assurance, Health Care" [MeSh:noexp] OR "Quality of Health care" [MeSh:noexp] OR "Total Quality Management" [MeSh:noexp] OR "Quality improvement" [MeSh:noexp] OR "Facility regulation and control" [MeSh:noexp]

14. "Quality Indicators, Health Care" [MeSh:noexp]

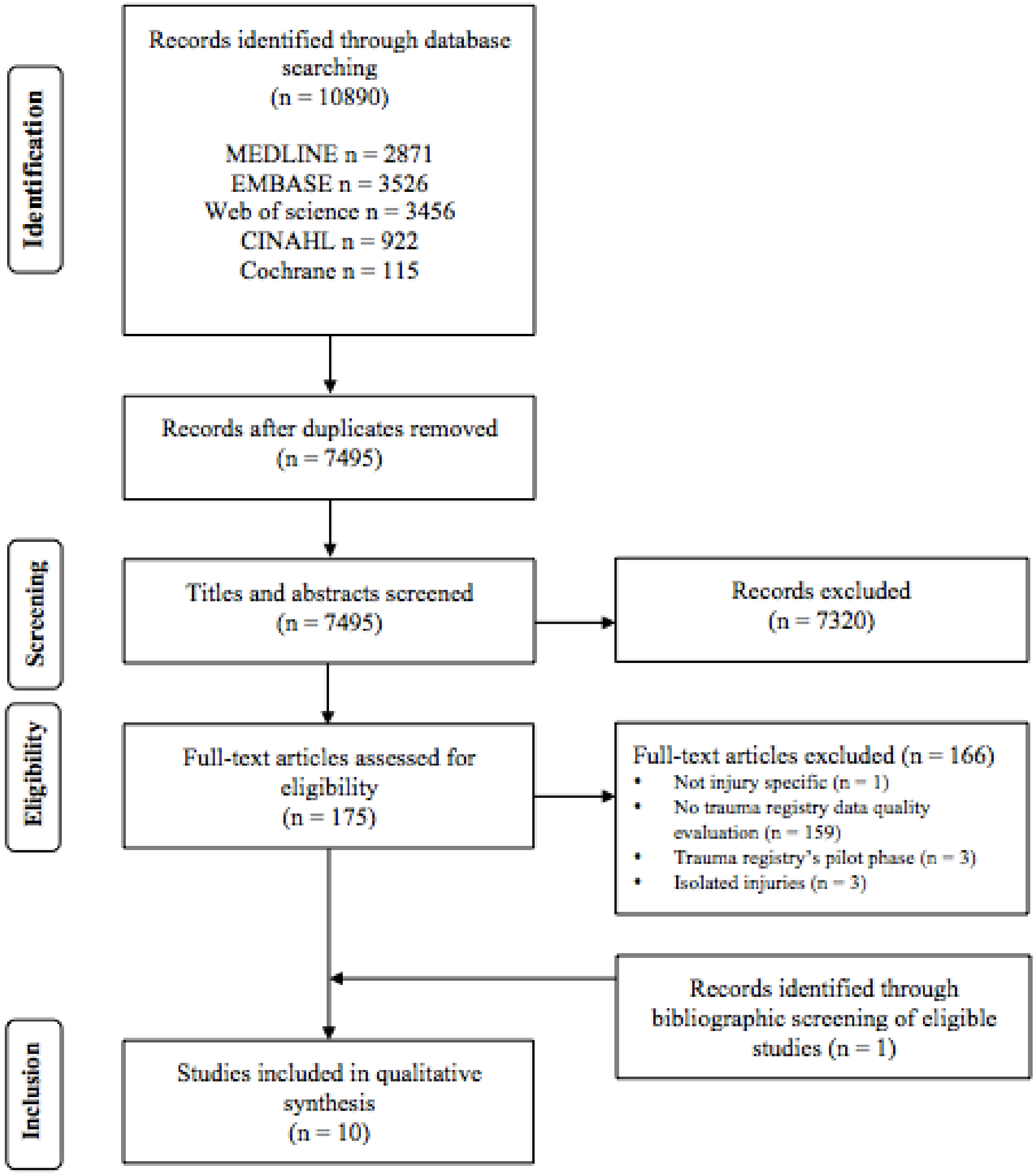
15. #9 OR #10 OR #11 OR #12 OR #13 OR #14

16. #4 AND #8 AND #15

Table A1.2. Search strategy in MEDLINE for regional trauma registries used in original articles

Keyword
Trauma registry **1.** "trauma registry" OR "trauma registries" OR "trauma register" OR "trauma registers" OR "trauma data bank" OR "trauma databank" OR "trauma dataset"
Publication date
2. "2005"[Date - Publication]: "2015/06/22"[Date - Publication]
3. #1 AND #2

Figure A1.1. PRISMA diagram showing the selection process for articles reviewed



PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses

Table A1.3. Regional, national, and international trauma registries used more than 10 times for original research in the last 10 years as identified in MEDLINE

Trauma registry	Number of articles
Alberta Trauma Registry[1]	14
British Columbia Trauma Registry	10
Illinois State Trauma Registry	15
Iowa State Trauma Registry	12
Israel National Trauma Registry[2]	51
Japan Trauma Data Bank	13
National Trauma Data Bank	447
Ontario Trauma Registry	10
Pennsylvania Trauma Registry[1]	11
Quebec Trauma Registry	25
Queensland Trauma Registry[3]	19
Rhone road Trauma Registry	13
San Diego Trauma Registry[2]	12
Trauma Registry Audit Research Network[2]	20
TraumaRegister of the German Trauma Society	113
Victoria State Trauma Registry	53
Washington State Trauma Registry	20

[1]No data quality report
[2]No data quality report that met the requirements of this review
[3]Registry no longer functional

Table A1.4. Description of articles and reports evaluating data quality in trauma registries

Author, year (reference)	Setting	Period (year)	Trauma registry			Data quality evaluation	
			Name (starting year)	Annual volume (year)	Inclusion criteria	Patients (n)	Sample
Alghnam et al., 2014[32]	1 level I TC; Riyadh, Saudi Arabia	2001-2010	King Abdulaziz Medical City Trauma Registry (2001)	1085 (mean, 2001-2010)	Admissions to the hospital ward or ICU from the ED, transfers from the ED to the operating room, indirect admissions (patient discharged from ED and asked to return later), or deaths upon arrival.	10,847	Patients meeting trauma registry inclusion criteria
Datta et al., 2007[30]	1 level I TC; Alberta, Canada	2001-2002	Alberta Trauma Registry; ATR	792 (2001-2002)	ISS $\geq$ 12, admissions to the TC or deaths in the ED of the TC	100	Random selection among patients $\geq$ 16 years meeting trauma registry inclusion criteria
Hlaing et al., 2006[15]	1 level I TC; Indiana, United States	1996-2003	Parkview Hospital Trauma Registry (1991)	>800 (2003)	ICM9-CM 800,00-959,59, admissions to the TC, deaths on hospital arrival, or deaths in the ED	8 to 2,190	Patients meeting trauma registry inclusion criteria
McKenzie et al., 2005[27]	1 teaching hospital; Queensland, Australia	1998	Queensland Trauma Registry; QTR (1998)	1676 (1998)[53]	ICM9-CM 800,00-959,59, admissions to hospital for $\geq$ 24 hours TC, deaths on hospital arrival, or deaths in the ED	1,672	Patients meeting trauma registry inclusion criteria
Newgard, 2006[24]	48 hospitals; Oregon, United States	1998-2003	Oregon Trauma Registry	7120 (2003)[54]	Statewide trauma triage criteria in the field, trauma team activation at ED, injuries requiring a surgeon's evaluation and treatment, transfers to a TC; or ISS > 8, deaths, major operative procedures to the head, chest, or abdomen within 6 hours of hospital arrival, admissions to the ICU within 24 hours of arrival[54]	32,448	Patients meeting statewide trauma triage criteria in the field, alive on hospital arrival, and transported by emergency medical services to the hospital

O'Reilly et al., 2010[28]	139 hospitals including 3 level I TC; Victoria, Australia	2003-2008	Victorian State Trauma Registry; VSTR (2001)	2646 major trauma (2008-2009)	Irrespective of age: 1. In-hospital deaths following injury; 2. admissions to an ICU for $\geq$ 24 hours and requiring mechanical ventilation; 3. ISS > 15 or AIS $\geq$ 2; 4. urgent surgery for intracranial, intrathoracic or intra-abdominal injury, or fixation of pelvic, or spinal fractures; 5. electrical injuries, drowning, and asphyxia patients admitted to an ICU and having mechanical ventilation for $\geq$ 24 hours or death after injury; 6. patients with injury as a principal diagnosis admitted for $\geq$ 3 days; 7. patients with injury as a principal diagnosis transferred to or received from another health service for further emergency care or admitted to a high-dependency area[55]	10,180	Patients meeting VSTR inclusion criteria
O'Reilly et al., 2012[29]	139 hospitals including 3 level I TC; Victoria, Australia	2009-2010	Victorian State Trauma Registry; VSTR (2001)	2745 major trauma (2009-2010)	Same as above	2,520	Patients meeting VSTR inclusion criteria
Phillips et al., 2008[25]	24 TC; United States	2002	National Trauma Data Bank; NTDB (1989)[56]	320778 (2002)	ICM9-CM 800,00-905,0; 940,0-959, 90 and admissions to hospital, transfers via EMS transport, or deaths following injury[57]	24,619	Patients treated in hospitals that had submitted 2002 data to both the NTDB and the NIS.
Rodenberg, 1996[26]	12 hospitals including 4 level I and 4 level II TC; Florida, United States	1991-1992	Florida Trauma Registry (1989)		Any trauma patients identified by pre-health care provider or emergency department personnel	18,961	Patients meeting trauma registry inclusion criteria; random selection of 2 TC among level II TC

Seidenberg et al., 2014[31]	1 level I TC Lusaka, Zambia	2011-2012	(2011)	3498 (2011-2012)	"Evidence of injury as determined by the hospital staff and/or study data collectors"	3,498	Patients meeting trauma registry inclusion criteria
American College of Surgeons, 2013[33, 57]	758 facilities including 230 level I, 265 level II, 205 level III or IV, 32 level I or II pediatric TC; United States /Canada	2012-2013	National Trauma Data Bank; NTDB (1989)	814,663 (2013)	ICM9-CM 800,00-905,0; 940,0-959, 90 and admission to hospital, transfers via EMS transport or deaths following injury	814,663	Patients meeting trauma registry inclusion criteria
British Columbia Provincial Health Services Authority, 2014[34]	11 hospitals including 3 level I, 3 level II and 5 level III TC; British Columbia, Canada	2013-2014	British Columbia Trauma Registry; BCTR (1992)	9243 (2014)	Admissions, within 7 days, for treatment of a traumatic diagnosis caused by external causes with a length of stay > 48 hours or death	9243	Patients meeting trauma registry inclusion criteria
Canadian Institute for Health Information, 2012[35]	11 level I and II, including 2 pediatric, TC; Ontario, Canada	2010-2011	Ontario Trauma Registry; OTR (1992)[58]	4488 (2011)	External code of injury and ISS > 12 and: treatment in the ED, death in the ED after treatment was initiated or admission [59]	4488	Patients meeting trauma registry inclusion criteria
Canadian Institute for Health Information, 2012[36]	59 facilities including 5 (2 pediatric) level I, 5 level II, 21 level III and 28 level IV TC	2010-2011	Quebec Trauma Registry; QTR (1998)[60]	13,688 adults (2010)[61]	Death due to injury, ICU admission, length of stay > 2 days or transfer from another hospital[61]	4453	Patients meeting trauma registry inclusion criteria
German Trauma Society, 2014[37]	614 hospitals; Germany, Switzerland, Austria, Netherlands, Belgium, China, Finland, Luxembourg, Slovenia, the United Arab Emirates	2013-2014	German Trauma Society Trauma Register; TraumaRegister DGU (1993)	34878 (2013)	Severe cases of injury other than "burns, hangings, drowning, and poisonings": patients from all ages, alive on hospital arrival "who either have been admitted to hospital via emergency room with subsequent ICU/ICM care, or reach the hospital with vital signs and die before admission to ICU/ICM.''	32,039	Patients meeting trauma registry inclusion criteria

n: Number; TC: Trauma Center; ICU: Intensive Care Unit; ED: Emergency Department; ISS: Injury Severity Score; NR: Not Reported; ICD9-CM: International Classification of Disease, ninth revision, Clinical Modification; EMS: Emergency Medical Service; NIS: National Inpatient Sample; ICM: Intensive Care Medicine

Table A1.5. Data quality evaluation

Variable	Completeness (%)	Accuracy (%)	Correctness (%)	Consistency (%)
Socio-demographics				
Age	100;[33] 100[34] 100;[35] ≈ 100[28] ≈ 100;[29] 99.3[26] 99.0;[15] 94.0[31] 93.2[25]	98.5[27]		
Gender	100;[33] 100[34] 100;[35] 100[36] 99.7;[25] 99.7[31]	99.8[27]		
Pregnancy status				98.7[1][34]
Personal Health Number	94.9;[35] 94.0[34]			
Occupation	≈ 100[31]			
Name	> 99.0[15]			
Race	86.9[25]			
Address	100;[36] 97.3[35] 97.3[15]			99.2[2][34]
Injury circumstances				
Motivation	99.6[34]			
Setting	98.40;[31] 97.3[33] 91.0[34]			
Protective devices	91.9[35] 80-90.0;[34] 29.8[3][32]			
Passenger position	54.7[3][32]			
Alcohol use indicator	92.5;[33] 87.5[36] 45.0[35]			
Drug use indicator	86.9[33]			
Incident date	100;[34] 100[36] 99.2;[33] 94.1[35]			99.0[15]
Incident time	54.4[33]			99.2[4][34]
Type	100[34]			
Mechanism	100;[29] 100[34] 96.6;[31] 46.8[26]			
Time from incident to arrival	93.7[31]			
Arrival data	99.9[33]			99.0[5][34]
Arrival time	100;[34] 99.0[37]			97.4[15]
Transport mode	98.0-99.0[34]			

	95.8;[31] 95.6[29]			
Transfers	100;[29] 99,8[33] 99.0[34]			
Comorbidity	94.9;[33] 37.5[6][25]			
Injury severity				
ICD9-CM/AIS				
E-code, location	100;[36] 99.8[35] 97,3[33]			
Tracheotomy patients	77.8[15]			
Patients with diaphragmatic surgery	89.5[15]			
Fat emboli complication				87.5[7][15]
Thoracic aorta injury				90.5[7][15]
Carotid artery injury				92.6[7][15]
Spleen injury				97.5[7][15]
MAIS	100[29]			
Injury Severity Score	99.9;[34] 99.9[32] 99.7[28]		47.6[26]	
Signs of life	95.4[33]			
Glasgow Coma Scale	95.1;[33] 91.0[37] 92.5;[35] 84.5[29] 83.0;[34] 83.0[24] 80.1;[28] 79.6[36]	98.0[30]; Weighted kappa = 0.87[24]	83.2[26]	
Glasgow Outcome Scale	90.0[37]			
Systolic Blood Pressure	97.6;[33] 96.8[32] 94.0;[28] 93.8[35] 93.7;[29] 87.0[37] 83.0;[36] 78.0[24] 71.3[26]			
Respiratory Rate	97.9;[33] 96.8[32] 85.8;[28] 83.0[24] 81.9;[29] 66.3[26] 61.0[37]			
Cardio-pulmonary resuscitation	90.0[37]			
Temperature	89.9[33]			
Pulse	98.6[33]			
Base excess (emergency room)	64.0[37]			
Coagulation (emergency room)	86.0[37]			
Hemoglobin (emergency room)	91.0[37]			

Interventions				
Procedure data	≈ 92.0[33]			
Procedure time	86.8[33]	81.0[8][30]		98.9[9];[15] 99.6[10][15]
EMS data	77.0-79.7[33]			
EMS time	66.4-77.0[33]			
EMS form	83.0[34]			
Most responsible physician service	100[33]			
Global health care	93.6[33]			
Respiratory assistance	94.2[33]			
Intubation attempt	91.0[24]	98.0[24]		
Venous thromboembolism prophylaxis				99.2[11][34]
Outcome				
Complications	93.3[33]			
Length of stay				
Emergency department				99.1[12][34]
Hospital	100;[34] 97.1[25]	98.0[30]		
Intensive care unit	91.2[33]	95.0[30]		
Ventilator	90.5[33]			
Deaths in hospital	100[29]			
Total charges	69.5[25]			
Payer	94.4;[33] 76.0[25]			
Discharge destination	99.9;[15] 99.9[33] 98.1;[25] 99.2[13][33]			99.8[14][15]
Discharge date	99.9;[33] 98.6[33]			99.1[15][34]
Discharge time	100;[34] 98.8[33] 98.1[33]			

ICD9-CM: International Classification of Disease, ninth revision, Clinical Modification; AIS: Abbreviated Injury Scale; MAIS: Maximum Abbreviated Injury Scale; EMS: Emergency Medical Service

Consistency evaluation in the British Columbia Trauma Registry; BCTR: [1]Gender is male and pregnancy is yes, no, or unknown; [2]Other postal code is null when incident country is not Canada; [4]Impact type does not = N/A and crash type = single; [5]Accepting facility arrival date is after admission date; [11]Venous thromboembolism prophylaxis is valued and patient is ≤ 15 years of age; [12]Emergency department length of stay is greater than hospital length of stay; [15]Accepting facility discharge date is before admission date.

Consistency evaluation in the Parkview Hospital Trauma Registry: [7] Coding errors; [14]Cross-tabulation between discharge disposition and destination.

[3]Among patients injured in motor vehicle crashes; [6]9/24 (37.50%) hospitals did not submit any comorbidity information to the National Trauma Data Bank in the comorbidity field; [8]Operating room time; [9]Trauma

surgeon call time from trauma team activation; [10]Trauma surgeon arrival time from patient arrival; [13]Discharge from the emergency department

Global evaluations: non-clinical and clinical data elements in the BCTR were 98% and 88% accurate, respectively;[34] 99.4% of data fields in the Alberta Trauma Registry were complete.[30]

References

1. Moore L, Clark DE. The value of trauma registries. *Injury*. 2008; 39(6): 686-95.
2. Cameron PA, Finch CF, Gabbe BJ, Collins LJ, Smith KL, McNeil JJ. Developing Australia's first statewide trauma registry: what are the lessons? *ANZ J Surg*. 2004; 74(6):424-8.
3. Morabito DJ, Proctor SM, May CM. Overview of trauma registries. *J AHIMA*. 1992; 63(2):39-44, 46, 48.
4. Citerio G, Stocchetti N, Cormio M, Beretta L, Galli D, Pesenti A. Application of guidelines for severe head trauma: data from an Italian database. *Eur J Emerg Med*. 2003; 10(1):68-72.
5. Sauerland S, Waydhas C, Raum MR, Neugebauer E. Systematic literature searches for clinical guideline development in the field of out-of-hospital and early in-hospital care of multiply injured patients. *Unfallchirurg*. 2002;105(11):1022-6.
6. Norwood S, Fernandez L, England J. The early effects of implementing American College of Surgeons level II criteria on transfer and survival rates at a rurally based community hospital. *J Trauma*. 1995;39(2):240-4; discussion 244-5.
7. Champion HR, Copes WS, Sacco WJ, et al. The Major Trauma Outcome Study: establishing national norms for trauma care. *J Trauma*. 1990;30(11):1356-65.
8. Grotz M, Schwermann T, Lefering R, Ruchholtz S, Graf v d Schulenburg JM, Krettek C, Pape HC. DRG reimbursement for multiple trauma patients -- a comparison with the comprehensive hospital costs using the German trauma registry. *Unfallchirurg*. 2004; 107(1):68-75.
9. Pape HC, Grotz M, Schwermann T, et al. The development of a model to calculate the cost of care for the severely injured--an initiative of the Trauma Register of the DGU. *Unfallchirurg*. 2003;106(4):348-57.
10. Schwermann T, Grotz M, Blanke M, Ruchholtz S, Lefering R, V d Schulenburg JM, Krettek C, Pape HC. Evaluation of costs incurred for patients with multiple trauma particularly from the perspective of the hospital. *Unfallchirurg*. 2004;107(7):563-74.
11. Stelfox HT, Bobranska-Artiuch B, Nathens A, Straus SE. Quality indicators for evaluating trauma care: a scoping review. *Arch Surg*. 2010;145(3):286-95.
12. Jurkovich GJ, Mock C. Systematic review of trauma system effectiveness based on registry comparisons. *J Trauma*. 1999;47(3 Suppl):S46-55.
13. Mackenzie EJ, Rivara FP, Jurkovich GJ, et al. The National Study on Costs and Outcomes of Trauma. *J Trauma*. 2007;63(6 Suppl):S54-67; discussion S81-6.
14. Pronovost PJ, Miller M, Wachter RM. The GAAP in quality measurement and reporting. *JAMA*. 2007; 298(15):1800-2.
15. Hlaing T, Hollister L, Aaland M. Trauma registry data validation: Essential for quality trauma care. *J Trauma*. 2006;61(6):1400-7.
16. O’Donoghue J, O'Kane T, Gallagher J, et al. Modified Early Warning Scorecard: The Role of Data/Information Quality within the Decision Making Process. *EJISE*. 2011;13(3):100-9.
17. Wang RY, Storey VC, Firth CP. A framework for analysis of data quality research. IEEE Trans Knowl Data Eng. 1995;7(4):623-640.
18. Bray F, Parkin DM. Evaluation of data quality in the cancer registry: principles and methods. Part I: comparability, validity and timeliness. *European Journal of Cancer*. 2009;45(5):747-55.

19. Centers for Disease Control and Prevention; National program of cancer registries. National program of cancer registries program standards, 2012-2017 (Updated Januray 2013). http://www.cdc.gov/cancer/npcr/pdf/npcr_standards.pdf. Accessed on December 3, 2015.
20. Probst C, Paffrath T, Krettek C, Pape HC, The German Trauma Registry. Comparative update on documentation of trauma in seven national registries. *European Journal of Trauma*. 2006;32(4): 357-364.
21. Higgins JPT and Green S. Cochrane Handbook for Systematic Reviews of Interventions Version 5.1.0 [updated March 2011]. The Cochrane Collaboration; 2011. www.cochrane-handbook.org. Accessed September 27, 2015.
22. Moher D, Liberati A, Tetzlaff J, Altman DG, PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA Statement. *An Intern Med*. Epub 2009 Jul 20.
23. Altman DG. Practical statistics for medical care. London. Chapman and Hall; 1991.
24. Newgard CD. The validity of using multiple imputation for missing out-of-hospital data in a state trauma registry. *Acad Emerg Med*. 2006;13:314-24.
25. Phillips B, Clark DE, Nathens AB, Shiloach M, Freel AC. Comparison of injury patient information from hospitals with records in both the national trauma data bank and the nationwide inpatient sample. *J Trauma*. 2008;64(3):768-79; discussion 779-80.
26. Rodenberg H. The Florida trauma system: assessment of a statewide database. *Injury*. 1996;27(3):205-8.
27. McKenzie K, Walker S, Besenyei A, Aitken LM, Allison B. Assessing the concordance of trauma registry data and hospital records. *HIMJ*. 2005;34(1): 3-7.
28. O’Reilly GM, Jolley DJ, Cameron PA, Gabbe B. Missing in action: a case study of the application of methods for dealing with missing data to trauma system benchmarking. *Acad Emerg Med*. 2010;17(10):1122-9.
29. O’Reilly GM, Cameron PA, Jolley DJ. Which patients have missing data? An analysis of missingness in a trauma registry. *Injury*. 2012;43(11):1917-23.
30. Datta I, Findlay C, Kortbeek JB, Hameed SM. Evaluation of a regional trauma registry. *CJS*. 2007;50(3):210–3.
31. Seidenberg P, Cerwensky K, Brown RO, et al. Epidemiology of injuries, outcomes, and hospital resource utilization at a tertiary teaching hospital in lusaka, Zambia. *AfJEM*. 2014;4(3):115-122.
32. Alghnam S, Alkelya M, Al-Bedah K, Al-Enazi S. Burden of traumatic injuries in Saudi Arabia: lessons from a major trauma registry in Riyadh, Saudi Arabia. *Ann Saudi Med*. 2014;34(4):291-296.
33. American College of Surgeons Committee on Trauma. National Trauma Data Bank Data Quality Report 2013.
34. British Columbia Provincial Health Services Authority. Trauma Services BC. British Columbia Trauma Registry Annual Data Summary Report 2014.
35. Canadian Institute for Health Information. National Trauma Registry 2012 Data Quality Report for provinces/Territories. Results for the Ontario Trauma Registry.
36. Canadian Institute for Health Information. National Trauma Registry 2012 Data Quality Report for provinces/Territories. Results for the Quebec Trauma Registry.
37. German Trauma Society, Committee on Emergency Medicine, Intensive Care and Trauma Management (Sektion NIS) and Academy for Trauma Surgery.

TraumaRegister DGU Annual report 2014. http://www.traumaregister.de/images/stories/downloads/englisch/TR-DGU%20annual%20report%202014.pdf. Accessed June 19, 2015.
38. Moore L, Lavoie A, Camden S, et al. Statistical validation of the Glasgow Coma Score. *J Trauma*. 2006;60(6):1238-43; discussion 1243-4.
39. Auerbach S, FitzPatrick MK, Garuffe A, et al. Enhancing data quality through the formation of a trauma registry workgroup. *J Trauma Nurs*. 2002;9(2):46-50.
40. Strickler JC, Collins KA. Going against the grain: a model for trauma registry operations. *J Trauma Nurs*. 2001;8(1):27-30.
41. Pou J. Coding systems changes and the implications for the trauma registry. *J Trauma Nurs*. 2001;8(1):20-2.
42. FitzPatrick MK, Frankel HL, McMaster J, et al. Integration of concurrent trauma registry and performance improvement programs. *J Trauma Nurs*. 2000;7(4):92-7.
43. Pipino LL, Lee YW, Wang RY. Data quality assessment. *Communications of the ACM*. 2002;45(4):211-218.
44. Zegers M, de Bruijne MC, Spreeuwenberg P, Wagner C, Groenewegen PP, van der Wal G. Quality of patient record keeping: an indicator of the quality of care? *BMJ Qual Saf*. 2011;20:314-318.
45. Willis CD, Jolley DJ, McNeil JJ, Cameron PA, Phillips LE. Identifying and improving unreliable items in registries through data auditing. *Int J Qual Health Care*. 2011;23(3):317-23.
46. Cameron PA, Palmer C. Developing consensus on injury coding. *Injury*. 2011;42(1):10-1.
47. Read-Allsopp C. Establishing inter-rater reliability scoring in a state trauma system. *J Trauma Nurs*. 2004;11(1):35-9.
48. Neale R, Rokkas P, McClure RJ. Interrater reliability of injury coding in the Queensland Trauma Registry. *Emerg Med (Fremantle)*. 2003;15(1):38-41.
49. 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. *Lancet*. 2007;370(9596):1453-7.
50. Hubner-Bloder G, Ammenwerth E. Key performance indicators to benchmark hospital information systems - a delphi study. *Methods Inf Med*. 2009;48(6):508-18.
51. Blake R, Mangiameli P. The effects and interactions of data quality and problem complexity on data mining. Proceedings of the 13th International Conference on Information Quality, *ICIQ*. 2008;160-175.
52. Knight SA. A Conceptual Framework for Investigating Information Quality in Information Systems. 2008 Edition. Pember M, Cowan R, editors. Information & Records Management Annual; 2008.
53. Monash University. Queensland Trauma Regsitry. http://www.registries.org.au/registries/queensland_trauma.html. Accessed June 15, 2015.
54. Oregon Health Authority. Public Health Division. Oregon Trauma Registry. https://public.health.oregon.gov/ProviderPartnerResources/EMSTraumaSystems/TraumaSystems/Documents/reports/otr-report.pdf. Accessed June 15, 2015.
55. State of Goverment Victoria, Department of Health and Human Services. Victorian State Trauma Registry Summary Report - 1 July 2013 to 30 June 2014. http://docs2.health.vic.gov.au/docs/doc/4E2375A167894BBDCA257E770001219C/

$FILE/1501013_DHHS%20State%20trauma%20registry%20annual%20report%2013-14%20WEB.pdf. Accessed June 15, 2015.
56. National Trauma Data Standard of the National Trauma Data Bank. http://www.ntdsdictionary.org/thentds/historyofntds.html. Accessed August 23, 2015.
57. American College of Surgeons Committee on Trauma. National Trauma Data Bank 2014: Annual Report. https://www.facs.org/~/media/files/quality%20programs/trauma/ntdb/ntdb%20annual%20report%202014.ashx. Accessed July 17, 2015.
58. Canadian Institute for Health Information. Ontario Trauma Registry 2011 Report: Major Injury in Ontario, 2009-2010 Data. https://secure.cihi.ca/free_products/OTR_CDS_2009_2010_Annual_Report.pdf. Accessed October 1, 2015.
59. Canadian Institute for Health Information. Ontario Trauma Registry 2012 Report: Hospitalizations for Major Injury in Ontario, 2010-2011 Data. https://secure.cihi.ca/estore/productSeries.htm?pc=PCC44. Accessed October 1, 2015.
60. Régie de l'Assurance Maladie du Québec. Banque de données ministérielles du système d'information du Registre des traumatismes du Québec (BDM-SIRTQ). http://www.ramq.gouv.qc.ca/fr/donnees-statistiques/sur-demande/donnees-msss/Pages/bdm-sirtq.aspx. Accessed October 1, 2015.
61. Moore L, Stelfox HT, Turgeon A, et al. Derivation and validation of a quality indicator of acute care length of stay to evaluate trauma care. *Ann of Surg*. 2014; 260(6):1121-7.

7.2. Appendix 2. Re: evaluating data quality in trauma registries

Teegwendé Valérie Porgo MSc[1,2], Lynne Moore PhD[1,2]

[1]Population Health and Optimal Health Practices Research Unit (Trauma-Emergency-Intensive care), Centre de Recherche du CHU de Québec - Hôpital de l'Enfant-Jésus, Université Laval, Quebec City, Quebec, Canada;
[2]Department of social and preventive medicine, Université Laval, Quebec City, Quebec, Canada

In Reply

Thank you for giving us the opportunity to respond to the letter from Dr. Bonilla- Escobar and colleagues concerning our manuscript “Evidence of data quality in trauma registries: A systematic review”.[1] Dr. Bonilla-Escobar and colleagues brought readers’ attention to the International Trauma Registry of the Pan-American Trauma Society (PTS Trauma Registry) and its use in a study by Ordoñez et al.[2] As we explore different ways to improve data quality in trauma registries to maximize their effective- ness in research, the solution to the problem of missing data used by Ordoñez et al.[2] is worthy of note. For every missing data point in the PTS Trauma Registry, the authors reviewed patients’ medical records to obtain a more complete data set for their analyses. Unfortunately, this procedure would be impractical with large study populations (only one trauma center was considered in the study by Ordoñez et al.)[2] and high percentages of missing data. Additionally, it cannot be applied for variables that are difficult to measure such as physiologic data. However, it seems to us as an effective method, especially when missing data mechanisms do not meet the conditions for statistical simulation such as multiple imputation, provided that the medical records are complete and the data are accurate.

We also agree with the vital importance of data quality assurance in the context of an international trauma registry. Establishing minimal international requirements for collecting comparable injury data worldwide is the key to learning more about disparities in injury outcomes and the structures and processes of injury care that explain those disparities. An international trauma database would provide an ideal context for establishing data quality standards for trauma registries. Complete and accurate international injury data have the potential to significantly advance knowledge on optimal strategies for primary, secondary, and particularly tertiary injury prevention. This work is part of the research agenda of the International Injury Care Improvement Initiative, a global effort of more than 60 collaborators, harnessing national capabilities in injury control from 30 countries in pursuit of a mission to reduce the burden of injuries.

References

1. Porgo TV, Moore L, Tardif PA. Evidence of data quality in trauma registries: a systematic review. *J Trauma Acute Care Surg*. 2016;80(4):648-658.
2. Ordoñez CA, Herrera-Escobar JP, Parra MW, et al. Computed tomography in hemodynamically unstable severely injured blunt and penetrating trauma patients. *J Trauma Acute Care Surg*. 2016;80(4):597-603.