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External benchmarking of trauma services in New South Wales: Risk-adjusted mortality after moderate to severe injury from 2012 to 2016

David Gomez[a,b,*], Pooria Sarrami[c,d], Hardeep Singh[c], Zsolt J. Balogh[c,e], Michael Dinh[c,f], Jeremy Hsu[b,c,g]

[a] Department of Surgery, Division of General Surgery, University of Toronto, ON, Canada
[b] Trauma Service, Westmead Hospital, Westmead, Sydney, NSW, Australia
[c] New South Wales Institute of Trauma and Injury Management, Sydney, NSW, Australia
[d] South Western Sydney Clinical School, University of New, South Wales, NSW, Australia
[e] Department of Traumatology, John Hunter Hospital, University of Newcastle, Newcastle, NSW, Australia
[f] Discipline of Emergency Medicine, The University of Sydney, Sydney, NSW, Australia
[g] Discipline of Surgery, Western Clinical School, Sydney Medical School, The University of Sydney, Sydney, NSW, Australia

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ABSTRACT

Background: Trauma centres and systems have been associated with improved morbidity and mortality after injury. However, variability in outcomes across centres within a given system have been demonstrated. Performance improvement initiatives, that utilize external benchmarking as the backbone, have demonstrated system-wide improvements in outcomes. This data driven approach has been lacking in Australia to date. Recent improvement in local data quality may provide the opportunity to engage in data driven performance improvement. Our objective was to generate risk-adjusted outcomes for the purpose of external benchmarking of trauma services in New South Wales (NSW) based on existing data standards.
Methods: Retrospective cohort study of the NSW Trauma Registry. We included adults (≥16 years), with an Injury Severity Score ≥12, that received definitive care at either Major Trauma Services (MTS) or Regional Trauma Services (RTS) between 2012-2016. Hierarchical logistic regression models were then used to generate risk-adjusted outcomes. Our outcome measure was in-hospital death. Demographics, vital signs, transfer status, survival risk ratios, and injury characteristics were included as fixed-effects. Median odds ratios (MOR) and centre-specific odds ratios with 95% confidence intervals were generated. Centre-level variables were explored as sources of variability in outcomes.
Results: 14,452 patients received definitive care at one of seven MTS (n = 12,547) or ten RTS (n = 1905). Unadjusted mortality was lower at MTS (9.4%) compared to RTS (11.2%). After adjusting for case-mix, the MOR was 1.33, suggesting that the odds of death was 1.33-fold greater if a patient was admitted to a randomly selected centre with worse as opposed to better risk-adjusted mortality. Definitive care at an MTS was associated with a 41% lower likelihood of death compared to definitive care at an RTS (OR 0.59 95%CI 0.35-0.97). Similar findings were present in the elderly and isolated severe brain injury subgroups.
Conclusions: The NSW trauma system exhibited variability in risk-adjusted outcomes that did not appear to be explained by case-mix. A better understanding of the drivers of the described variation in outcomes is crucial to design targeted locally-relevant quality improvement interventions.

Introduction

Trauma systems were established to ensure injured patients receive timely access to life saving interventions as well as ongoing care and rehabilitation. Integral parts of trauma systems include ambulance and medical retrieval protocols as well as the designation of specific hospitals as trauma centres. Trauma centres and trauma systems have been associated with improved morbidity and mortality after injury [1,2]. However, improved patient outcomes do not appear to be related entirely to better resources at trauma centres. The designation of specific hospital as

* Corresponding author at: St Michael's Hospital, 30 Bond Street, Donnelly Wing, Room 3-071, Toronto, ON, M4N 3M5, Canada.
E-mail address: GomezDA@smh.ca (D. Gomez).

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trauma centres leads to increased experience, improved interdisciplinary communication, development of standardized processes of care, and improved critical care delivery. Nonetheless, variability in outcomes across centres within a given trauma system have been repeatedly demonstrated [3–5].

Even within the same system, not all trauma centres are created equal. Based on a centre's geographic location, patient-mix across centres can vary to a great extent. A centre's proportion of patients with penetrating injuries, elderly patients with falls, or blunt multisystem injuries can lead to differing expertise, protocols of care, and culture. Understanding the strengths and weaknesses of different centres is instrumental in order to properly evaluate the variability in outcomes within a system.

Performance improvement initiatives are at the forefront of trauma system evaluation. These initiatives have evolved from comparing outcomes at the same institution over time (i.e. internal benchmarking) to comparing risk-adjusted outcomes across trauma centres (i.e. external benchmarking). Initiatives that utilize external benchmarking, as the backbone of system-wide performance improvement, have demonstrated system-wide reductions in morbidity and mortality [6,7]. External benchmarking allows for the identification of centres in which patients experience outcomes that are either above or below what would be expected after risk-adjustment. This allows for the identification and dissemination of resources and best practices that have been proven to be effective within the system. However, external benchmarking is highly dependent on valid, reliable, and standardized data.

Over the past 10 years, the evaluation of trauma system performance in Australia has undergoing a rapid evolution. The Australian Trauma Quality Improvement Program (AusTQIP) has produced two reports to date with 25 trauma centres participating nation-wide [8]. It is a treasure trove of injury epidemiology data. However, no attempts at external benchmarking were carried out on the most recent report. At the state level, the New South Wales (NSW) Institute of Trauma and Injury Management (ITIM) produces yearly reports that provide extensive injury epidemiology data as well as unadjusted trauma centre outcomes. Only standardized mortality ratios based on injury severity score and age are currently provided [9]. External benchmarking efforts have been limited to date by issues with data quality, primarily missing vital sign data.

The NSW trauma registry was established by ITIM in 2002. However, it was not until 2006 when initial attempts at the creation of a single standardized data set were launched. By 2009 a comprehensive state-wide trauma registry had been developed. Standardized data dictionaries, minimum data sets, and the use of a single software platform to collect data has significantly improved data quality [10]. However, missingness of vital sign data remained a significant issue. These recent improvements in data quality provide the opportunity to generate sophisticated risk-adjusted outcomes.

Our objective was to generate risk-adjusted outcomes for the purpose of external benchmarking of trauma services based on locally existing data collection standards. Secondary objectives included the evaluation of data quality, as well as evaluation of overall and subgroup risk-adjusted mortality with the purpose of guiding future performance improvement initiatives.

Methods

Setting

The NSW trauma system is based on an inclusive system of hospitals designated to provide care based on injury severity, resources, and expertise. The system consists of seven Major Trauma Services (MTS), three Paediatric MTS (PTS), and ten Regional Trauma Services (RTS). MTS are equivalent to level I trauma centres as defined by the American College of Surgeons (ACS), and possess the depth of resources and personnel required to provide definitive care to severely injured patients [11]. MTS are regional resources and act as the cornerstone of the system. An RTS provides initial assessment, stabilization, and initiates transfer to MTS if required. Each RTS has a designated MTS for referral and support. RTS can provide definitive care to patients with minor to moderate injuries as well as definitive care to a limited number of severely injured patients in collaboration with the MTS. For the most part, an RTS is equivalent to a level III trauma centre as defined by the ACS.

State-wide prehospital triage criteria state that patients meeting major trauma criteria should be transported to the highest level Trauma Service located within a 60 min travel time from the scene, even if this means bypassing closer hospitals and/or an RTS [12].

Data sources

Data were derived from the NSW trauma registry which contains demographic, injury, and outcome data on patients admitted to a trauma service after major trauma. In the registry, major trauma is defined by an Injury Severity Score (ISS) $\geq$12, admission to an intensive care unit or death in hospital following injury [10]. The registry is compiled by the Institute of Trauma and Injury Management. Data was provided in a fully de-identified manner. This project was approved by the Hunter New England ethics and governance office. No external funding was required. All authors had full access to data, statistical reports, and tables, prior to drafting the manuscript.

Patient selection

We focused on adult patients ($\geq$16 years), with moderate to severe injuries (ISS$\geq$12), who received definitive care at either an MTS or RTS after mechanical injuries. Patients admitted after poisoning, suffocation, drowning, overexertion, environmental causes, and burns were excluded. Patients without signs of life on arrival (heart rate = 0, systolic blood pressure = 0 and Glasgow Coma Scale = 3) were also excluded [13]. Patients with isolated hip fractures are not included in our study population. Patients transferred from RTS to MTS were only analysed as MTS patients.

Data quality

The overall dataset as well as the study population derived after applying the inclusion and exclusion criteria was evaluated. Only the variables deemed relevant to mortality risk-adjustment were evaluated (i.e. demographic, vital signs, injury characteristics, outcome status) for completeness and out of range values. Changes in data quality over time were also assessed and were used to guide the study period for which risk-adjusted outcomes would be evaluated.

Risk-adjusted outcomes

The main outcome measure was in-hospital death. Given the nested structure of the data, hierarchical logistic regression models were used [14]. Patients were treated as the lower level units which were nested within each centre (higher level units). To adjust for possible differences in case-mix across centres, age, gender, mechanism, systolic blood pressure, heart rate, Glasgow Coma Scale, and transfer status were included in the model as fixed effects. Centres were included in the model as random effects. Survival risk ratios (SRR) based on Abbreviated Injury Scale (AIS) scores were calculated for each patient and included as a fixed effect. A SRR is defined as the number of patients who survived the AIS-coded injury divided by the total number of patients who sustained the same injury. It is a database-specific point estimate of survival which has been shown to further explain variance and offer better discrimination compared with other injury scoring systems [15]. A traditional worst-injury approach to calculating SRRs was used.

Risk-adjusted outcomes were expressed as a centre-specific risk-adjusted odds ratio (OR) of death with 95% confidence intervals. Trauma centre odds ratios were derived from shrinkage estimates of random effects. A patient that receives care at a centre has a significantly lower than expected mortality if the upper limit of its 95% CI is <1. If the lower limit of the 95% CI is >1, the centre has a significantly higher odds of death compared to the overall average.

In order to quantify the variability in risk-adjusted mortality across centres, independent of patient factors, we calculated the median odds ratio (MOR). It is defined as the median value of the OR between the centre with the highest compared to the centre with the lowest likelihood of death [16]. It can be interpreted as the excess likelihood of in-patient mortality associated with the same patient receiving care at any centre with worse risk-adjusted mortality. The MOR always has a value of 1 or more because it compares a higher- with a lower-ranked centre.

An additional hierarchical model was generated in order to explore the centre characteristics that might contribute to risk-adjusted differences in outcomes. Centre-type (e.g. MTS vs. RTS) and patient volume (i.e. quartiles) were explored and included in the model as additional fixed effects.

Subgroup risk adjusted outcomes

Patients with moderate to severe injuries are quite heterogeneous and may pose distinct challenges which require different resources and expertise. For this reason, the overall cohort was divided into sub-groups for which specific risk-adjusted outcomes were generated: i) *polytrauma (i.e. severe multisystem blunt injuries)*: blunt mechanism of injury and AIS $\geq$ 3 in =>2 body regions; ii) *elderly patients*: $\geq$65 years with any mechanism; and iii) *isolated severe traumatic brain injury*: head AIS $\geq$ 3, Glasgow Coma Scale$\leq$9, and AIS $\leq$ 2 in all other body regions. Patient sub-groups were not mutually exclusive. The methodology mirrored that of the overall cohort. Patient subgroups were chosen based on clinical differences and not results of significance testing.

Statistical analysis

Medians and interquartile ranges were calculated for continuous variables, and absolute and relative frequencies were used to summarize discrete variables. Proportions were compared using the chi [2] test, medians were compared using non-parametric tests. We elected to use multiple imputation to address missing values for heart rate (7%), systolic blood pressure (7%) and GCS (8%) (Appendix A – statistical analysis). We believe this is a better approach than discarding patients with missing data or using a missing indicator given the low proportion of missing data as well as the relatively large sample size. In addition, this allows for the appropriate use of vital signs as continuous variables in the model [17,18].

Model performance and calibration was evaluated across all models using the C-statistic, the Hosmer Lemeshow test, and observed-versus-predicted outcome plots (Appendix A – statistical analysis). In all analyses, a 2-sided p <0.05 was considered significant. All data were analysed using SAS software (v. 9.4, SAS Institute, Cary, NC).

Results

Data quality

Prior to applying inclusion and exclusion criteria we identified 23,407 injured patients that received care at either an MTS (n = 17,895), RTS (n = 4456), or PTS (n = 1056). Non-vital sign variables were missing in <0.2% of patients. There were no out of range values. However, vital sign data was missing at much higher rates with differences in the proportion of missing data identified across centre-types (Table 1). The proportion of missing data significantly decreased over time, with vital sign data missing in 5% of patients in 2016. Given the high rate of missing vital sign data in 2011, we limited our subsequent analysis to patients that received care between January of 2012 and December of 2016. Furthermore, given that the motor component of the Glasgow Coma Scale was missing in over 10% of patients for the duration of the study period we elected to use the Glasgow Coma Scale instead.

Study population

After applying inclusion and exclusion criteria we identified 14,452 moderately to severely injured adult patients whom received definitive care at one of seven MTS (n = 12,547) or one of ten RTS (n = 1905) (Fig. 1). MTS volume ranged from 874 to 2689 while RTS volume ranged from 101 to 347 patients. On average, there was a 5% increase in the yearly number of patients. The proportion of patients that received definitive care at RTS did not change over time (p = 0.07).

Most patients were male (72%), mean age was 55 (SD 22.5), most were injured either after a fall (46%) or motor vehicle collision (43%), and the median ISS was 17 (IQR 14–25). Overall unadjusted in-hospital mortality was 10% (n = 1390). There were major differences in the volume and characteristics of patients that received definitive care at MTS compared to those at RTS.

There were differences in patient as well as injury characteristics when comparing those that received definitive care at RTS and MTS. Patients at RTS were older and less likely to be transferred from another hospital. Patients at RTS were less severely injured as evidenced by lower median injury severity scores. Over one third of patients at RTS [37%, n = 7060] had isolated severe chest injuries

Table 1
Proportion of missing data.

	Missing data					
	Overall (n = 23,407)	MTS (n = 17,895)	RTS (n = 4456)	PTS (n = 1056)	2011 (n = 3518)	2016 (n = 4071)
GCS	2,979 (13)	2013 (11)	708 (16)	258 (24)	1052 (30)	222 (5)
mGCS	5,949 (25)	4314 (24)	1357 (30)	278 (26)	1669 (47)	504 (12)
Heart rate	2,569 (11)	1967 (11)	423 (9)	179 (17)	977 (28)	133 (5)
Systolic blood pressure	2,780 (12)	2003 (11)	470 (11)	307 (29)	1021 (29)	155 (4)

MTS: Major Trauma Service, RTS: Regional Trauma Service, PTS: Paediatric Trauma Service; GCS: Glasgow Coma Scale; mGCS: motor component of the Glasgow Coma Scale.

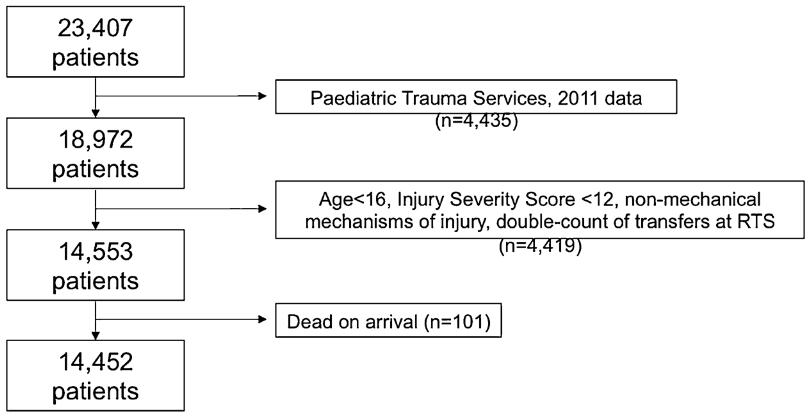

Fig. 1. Patient selection.

(AIS=>3 in the chest and AIS=<2 in all other body regions). However, 1 out of every 5 patients that received definitive care at RTS had an ISS ≥25 compared to 1 out of 3 at MTS. Finally, there was a lower proportion of patients who presented with a systolic blood pressure in the emergency department lower or equal to 90 mmHg at RTS compared to MTS (Table 2).

Overall risk-adjusted outcomes

Unadjusted in-hospital death was lower at MTS compared to RTS (Table 3). In addition, a greater degree of unadjusted variability in the range of in-hospital death was observed across RTS (6–20%) compared to MTS (7–12%). Given the observed univariate

Table 2
Patient characteristics across centre type.

	MTS (n = 12,547)	RTS (n = 1905)	*p* value
Age, mean (SD)	54.5 (22.6)	57.8 (21.9)	<0.001
Elderly (≥ 65 years)	4691 (37)	793 (42)	<0.001
Male gender	9,009 (72)	1387 (73)	0.36
Mechanism			<0.001
Fall	5,875 (47)	787 (41)	
Motor vehicle collision	5,270 (42)	914 (48)	
Other blunt	666 (5)	102 (5)	
Gunshot wound	82 (1)	7 (1)	
Stab wound	353 (3)	65 (3)	
Other	301 (2)	30 (2)	
Transfer from another hospital	3,134 (25)	384 (20)	<0.001
Injury Severity Score, median (IQR)	17 (16–25)	17 (14–22)	<0.001
Injury Severity Score 12–15	2967 (24)	651 (34)	
Injury Severity Score 16–24	5730 (46)	866 (45)	
Injury Severity Score 25–47	3601 (29)	372 (20)	
Injury Severity Score 48–75	249 (2)	16 (1)	
Severe injury by body region (AIS=>3)			
Head	6027 (48)	662 (35)	<0.001
Face	285 (2)	21 (1)	0.001
Neck	139 (1)	8 (1)	0.005
Chest	4654 (37)	919 (48)	<0.001
Abdomen	1024 (8)	205 (11)	<0.001
Spine	1867 (15)	174 (9)	<0.001
Upper extremity	216 (2)	24 (1)	0.14
Lower extremity	1,998 (16)	201 (11)	<0.001
Heart rate in emergency department			<0.001
0–60 bpm	1124 (9)	150 (8)	
61–90 bpm	6929 (55)	1129 (59)	
91–109 bpm	2809 (22)	401 (21)	
≥110 bpm	1,685 (13)	225 (12)	
Systolic blood pressure in emergency department			0.04
0–60 mmHg	120 (1)	17 (1)	
61–90 mmHg	573 (5)	65 (3)	
91–110 mmHg	1310 (10)	176 (9)	
≥110 mmHg	10,544 (84)	1647 (86)	
Glasgow Coma Scale in emergency department			<0.001
13–15	9455 (75)	1571 (82)	
10–12	829 (7)	146 (8)	
3–9	2253 (18)	188 (10)	

All data presented as n (%). MTS: Major Trauma Service; RTS: Regional Trauma Service; AIS: Abbreviated Injury Scale score.

differences in case-mix and variability in outcomes, risk-adjusted outcomes were evaluated.

After adjusting for patient-level variables, the overall MOR was 1.33, suggesting that the odds of in-hospital death was 1.33-fold greater if the same patient was admitted to a randomly selected centre with worse risk-adjusted mortality as opposed to a centre with better risk-adjusted mortality. In addition, three centres were identified as having significantly lower risk-adjusted mortality compared to the overall average, all were MTS (Fig. 2).

Centre characteristics were then used to explore the variability in centre outcomes. After adjustment, definitive care at an MTS was associated with a 41% lower likelihood of in-hospital death compared to definitive care at an RTS (OR 0.59 95%CI 0.35-0.97). There was no association between centre volume quartile and risk adjusted outcomes.

Subgroup risk-adjusted outcomes

Similarly to the overall cohort, unadjusted in-hospital mortality was lower and time to death was longer across most patient subgroups when comparing MTS to RTS (Table 3). After adjusting for case-mix, definitive care at MTS was consistently associated with a lower likelihood of in-hospital death compared to RTS across the isolated severe brain injury and elderly subgroups (Fig. 3).

Discussion

The NSW Trauma system represents a complex system of designated trauma centres acting as hubs for rural and regional referral networks covering large areas. The generation of risk-adjusted outcomes for the purpose of external benchmarking of trauma services was considered an important step towards data-driven trauma system improvement.

This study has three main findings. First, current data collection standards across trauma services in NSW are of sufficient quality to produce risk-adjusted outcomes. Similar rates of missing data (<0.5%) were reported by the National Trauma Data Bank of the ACS, the largest repository of injured patient data [19]. In addition, data quality has improved over time with most vital sign variables reported in 2016 missing in <5% of patients. Improved data quality and the use of multiple imputation allowed the incorporation of heart rate, systolic blood pressure, and Glasgow Coma Scale as covariates in the risk-adjustment model which are considered essential in other trauma risk-adjustment strategies [20]. Previous attempts at evaluating the NSW trauma system have been limited by the lack of inclusion of vital sign variables in risk adjustment [21]. In addition, acknowledging the nested structure of the data as well as the local context of low volume centres through the use of hierarchical models, provides a more stable estimates that will not penalize low volume centres. Complete data coupled with valid risk-adjustment strategies are the foundations of a successful performance improvement initiative.

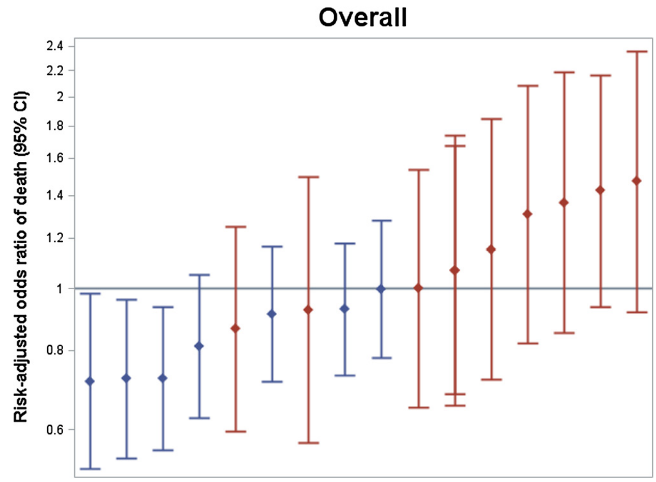

Fig. 2. Overall risk-adjusted outcomes across centre type.
Each diamond represents an individual centre's risk-adjusted odds ratio of in-hospital death with bars representing the 95% confidence interval. Centres in blue are Major Trauma Services while centres in red are Regional Trauma Services.

Table 3
Overall and subcohort unadjusted outcomes across centre type.

	MTS	RTS	*p* value
Overall			
Sample size	12,547	1905	
Unadjusted in-hospital mortality	1171 (9)	217 (11)	0.005
Time to death in days, median (IQR)	3 (1–8)	2 (1–4)	<0.001
Unadjusted centre in-hospital mortality, range in %	7–12%	6–20%	<0.001
Injury Severity Score > 15			
Sample size	9580	1254	
Unadjusted in-hospital mortality	1112 (12)	211 (17)	<0.001
Time to death in days, median (IQR)	2 (1–7)	2 (1–4)	<0.001
Unadjusted centre in-hospital mortality, range in %	7–14%	10–28%	<0.001
Polytrauma (blunt mechanism and AIS=>3 in at least two body regions)			
Sample size	2876	274	
Unadjusted in-hospital mortality	375 (13)	35 (13)	0.9
Time to death in days, median (IQR)	2 (1–7)	1 (1–3)	0.06
Unadjusted centre in-hospital mortality, range in %	9–15%	5–25%	0.26
Isolated severe head injury (head AIS=>3, AIS=<2 in all other body regions, and GCS =<9)			
Sample size	971	109	
Unadjusted in-hospital mortality	343 (35)	79 (72)	<0.001
Time to death in days, median (IQR)	1 (1–4)	1 (1–2)	0.11
Unadjusted centre in-hospital mortality, range in %	28–53%	33–100%	<0.001
Elderly injured (=>65 years)			
Sample size	4691	763	
Unadjusted in-hospital mortality	789 (17)	169 (21)	0.002
Time to death in days, median (IQR)	3 (1–8)	2 (1–5)	0.008
Unadjusted centre in-hospital mortality, range in %	13–21%	28–53%	<0.001

All data presented as n (%) unless otherwise specified. MTS: Major Trauma Service; RTS: Regional Trauma Service; IQR: interquartile range.

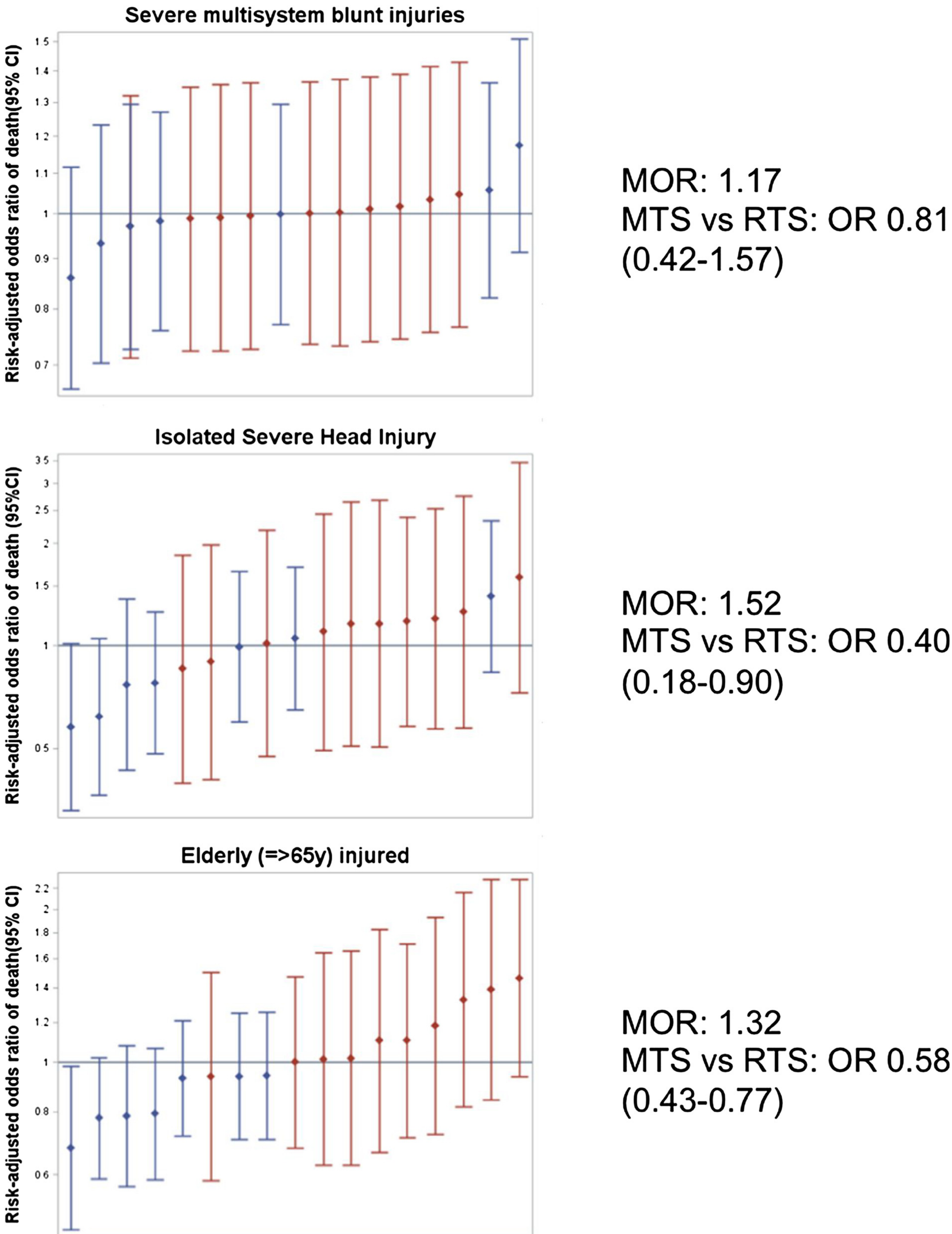

Fig. 3. Subcohort risk-adjusted outcomes across centre type.
Each diamond represents an individual centre's risk-adjusted odds ratio of in-hospital death with bars representing the 95% confidence interval. Centres in blue are Major Trauma Services (MTS) while centres in red are Regional Trauma Services (RTS). MOR: Median Odds Ratio.

Second, unadjusted mortality after moderate to severe injury in NSW is in-line with other mature trauma systems [22–25]. However, after risk-adjustment, we identified a median 33% increased odds of death if the same patient received care at a centre with worse risk-adjusted outcomes (MOR 1.33). In other words, to a moderate extent, a patient's likelihood of death was associated with the centre at which definitive care was received. It suggests a moderate degree of heterogeneity between centres that was unexplained by patient factors. However, the type of centre at which patients received definitive care was associated with their outcomes. Definitive care at MTS was associated with a 41% lower likelihood of death compared to RTS, even after taking into account case-mix and centre-volume. This finding implies that even though there is variability in outcomes within the MTS group as well as within the RTS group as evident in the caterpillar plot, definitive care at an MTS overall is associated with a lower likelihood of death compared to an RTS.

Third, care at an MTS, as in the overall cohort, was consistently associated with a lower likelihood of death across the isolated severe brain injury and elderly subgroups. Although a degree of variation would be expected given the range in facilities involved, the degree of variability in risk-adjusted outcomes identified may also be an indication of unwarranted variation due to resourcing, clinical practice, and models of care.

These findings assist with ongoing Australia-wide efforts to benchmark trauma system performance and improve the care of severely injured patients [8]. It is important to note that external benchmarking is only the backbone of what should be a multipronged approach at performance improvement. Risk-adjusted outcomes must be analysed within the larger context of associated variations in structures and processes of care across centres. A better understanding of the drivers of the described variation in outcomes is crucial to design targeted locally-relevant quality improvement interventions. The obvious next step would be an attempt towards delineating the underlying causes of this variation. Efforts towards the collection of consensus derived process indicators as well as the establishment of a clinical quality registry comprising patient reported outcomes and experience measures are currently underway at the state level. This data driven approach has improved system-wide outcomes in the National Surgical Quality Improvement Program of the ACS [6] and in the Michigan trauma collaborative [7].

Some limitations must be taken into account when interpreting our results. Patient factors that may influence outcomes and were not captured in our risk-adjustment, include but are not limited to prolonged discovery and transport times that are common in rural and remote locations. The incorporation of vital signs and a transfer flag into our risk-adjustment model should limit the impact in our results. Pre-existing conditions that may influence the likelihood of death after injury, as well as pre-existing medical directives to withhold care, are not captured. The absence of these variables may negatively impact centres with a higher proportion of elderly patients. In addition, patients may have been deemed non-salvageable and thus remained at RTS instead of undergoing transfer to MTS. The trauma registry does not capture this information. As a sensitivity analysis, we repeated the analysis in the overall cohort after excluding patients with severe isolated brain injury in order to limit the impact of non-salvageable brain injured patients deemed not fit for transfer from RTS to MTS. The MOR of the overall cohort decreased from 1.33 to 1.16 suggesting that not all variability across centres is secondary to patients with isolated severe brain injury. No centre was identified as having lower or higher than expected risk-adjusted mortality, a finding that must be interpreted with caution as sample size decreased by over 1000 patients. However, definitive care at a MTS was still associated with a 33% lower adjusted likelihood of death compared to care at a RTS [OR 0.67 (95%CI 0.50-0.91)] after excluding patients with severe isolated brain injury.

Conclusion

There was variability in risk-adjusted outcomes across the NSW trauma system exhibited. Possible target for future study and targeted interventions are the subgroups of patients with isolated severe brain injuries and the elderly injured where significant variability in outcomes was identified. The ongoing evaluation of trauma system performance, as well as targeted interventions derived from such analyses, are instrumental in the delivery of high-quality care for injured patients.

Conflicts of interest

The authors have no financial or personal conflicts of interest to disclose.

MTS vs. RTS: Risk-adjusted odds ratio of death with 95% confidence intervals.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.injury.2018.09.037.

References

[1] MacKenzie E.J., Rivara FP, Jurkovich GJ, Nathens AB, Frey KP, Egleston BL, et al. A national evaluation of the effect of trauma-center care on mortality. N Engl J Med 2006;354(4):366–78.
[2] Utter GH, Maier RV, Rivara FP, Mock CN, Jurkovich GJ, Nathens AB. Inclusive trauma systems: do they improve triage or outcomes of the severely injured? J Trauma 2006;60(3)529–35 discussion 35-37.
[3] Curtis K, Chong S, Mitchell R, Newcombe M, Black D, Langcake M. Outcomes of severely injured adult trauma patients in an Australian health service: does trauma center level make a difference? World J Surg 2011;35(10):2332–40.
[4] Shafi S, Nathens AB, Parks J, Cryer HM, Fildes JJ, Gentilello LM. Trauma quality improvement using risk-adjusted outcomes. J Trauma 2008;64(3)599–604 discussion -6.
[5] Cudnik MT, Sayre MR, Hiestand B, Steinberg SM. Are all trauma centers created equally? A statewide analysis. Acad Emerg Med 2010;17(7):701–8.
[6] Hall BL, Hamilton BH, Richards K, Bilimoria KY, Cohen ME, Ko CY. Does surgical quality improve in the American College of Surgeons National Surgical Quality Improvement Program: an evaluation of all participating hospitals. Ann Surg 2009;250(3):363–76.
[7] Hemmila MR, Jakubus JL, Cain-Nielsen AH, Kepros JP, Vander Kolk WE, Wahl WL, et al. The Michigan Trauma Quality Improvement Program: results from a collaborative quality initiative. J Trauma Acute Care Surg 2017;82(5):867–76.
[8] Alfred Health. Caring for the severely injured in Australia: inagural report of the australian trauma registry 2010 to 2012. Melbourne, Victoria: Alfred Health; 2014.
[9] NSW Institute of Trauma and Injury Management. Major trauma in NSW 2015. Sydney, NSW: Agency for Clinical Innovation; 2016.
[10] NSW Institute of Trauma and Injury Management. NSW ITIM trauma dictionary. NSW Agency for Clinical Innovation; 2017.
[11] Committee on Trauma American College of Surgeons. Resources for optimal care of the injured patient. Chicago, IL: American College of Surgeons; 2014.
[12] Ambulance Services New South Wales. Protocol T1: pre-hospital management of major trauma. 2015.
[13] Byrne JP, Xiong W, Gomez D, Mason S, Karanicolas P, Rizoli S, et al. Redefining "dead on arrival": identifying the unsalvageable patient for the purpose of performance improvement. J Trauma Acute Care Surg 2015;79(5):850–7.
[14] Austin PC, Tu JV, Alter DA. Comparing hierarchical modeling with traditional logistic regression analysis among patients hospitalized with acute myocardial infarction: should we be analyzing cardiovascular outcomes data differently? Am Heart J 2003;145(1):27–35.
[15] Kilgo PD, Osler TM, Meredith W. The worst injury predicts mortality outcome the best: rethinking the role of multiple injuries in trauma outcome scoring. J Trauma 2003;55(4)599–606 discussion -7.
[16] Merlo J, Chaix B, Ohlsson H, Beckman A, Johnell K, Hjerpe P, et al. A brief conceptual tutorial of multilevel analysis in social epidemiology: using measures of clustering in multilevel logistic regression to investigate contextual phenomena. J Epidemiol Commun Health 2006;60(4):290–7.
[17] Sterne JA, White IR, Carlin JB, Spratt M, Royston P, Kenward MG, et al. Multiple imputation for missing data in epidemiological and clinical research: potential and pitfalls. BMJ 2009;338:b2393.
[18] van der Heijden GJ, Donders AR, Stijnen T, Moons KG. Imputation of missing values is superior to complete case analysis and the missing-indicator method in multivariable diagnostic research: a clinical example. J Clin Epidemiol 2006;59(10):1102–9.
[19] American College of Surgeons Committe on Trauma. NTDB annual report 2016. Chicago, IL: Chang MC, ed.; 2016.
[20] Newgard CD, Fildes JJ, Wu L, Hemmila MR, Burd RS, Neal M, et al. Methodology and analytic rationale for the american college of surgeons trauma quality improvement program. J Am Coll Surg 2013;216(1):147–57.

[21] Curtis K, Mitchell R, Chong S, Balogh Z, Reed D, Clark P, et al. Injury trends and mortality in adult patients with major trauma in New South Wales. Med J Aust 2012;197(4):233–7.
[22] Gomez D, Alali AS, Haas B, Xiong W, Tien H, Nathens AB. Temporal trends and differences in mortality at trauma centres across Ontario from 2005 to 2011: a retrospective cohort study. CMAJ Open 2014;2(3):E176–82.
[23] Moore L, Stelfox HT, Evans D, Hameed SM, Yanchar NL, Simons R, et al. Trends in injury outcomes across canadian trauma systems. JAMA Surg 2017;152(2):168–74.
[24] Gerdin M, Roy N, Dharap S, Kumar V, Khajanchi M, Tomson G, et al. Early hospital mortality among adult trauma patients significantly declined between 1998-2011: three single-centre cohorts from Mumbai. India. PLoS One. 2014;9(3)e90064.
[25] Cameron PA, Gabbe BJ, Cooper DJ, Walker T, Judson R, McNeil J. A statewide system of trauma care in Victoria: effect on patient survival. Med J Aust 2008;189(10):546–50.