Journal of Pediatric Surgery 56 (2021) 512–519

Contents lists available at ScienceDirect

Journal of Pediatric Surgery

journal homepage: www.elsevier.com/locate/jpedsurg

Pediatric versus adult paradigms for management of adolescent injuries within a regional trauma system☆,☆☆,★

Natalie L. Yanchar [a,c,*], Lisette Lockyer [a], Chad G. Ball [b,c], Scott Assen [c]

[a] Alberta Children's Hospital Trauma Program, 28 Oki Drive NW, Calgary, Alberta, Canada, T3B6A8
[b] Foothills Medical Center Trauma Program, 1403 29 St NW, Calgary, Alberta, Canada, T2N2T9
[c] Department of Surgery, University of Calgary, 3333 Hospital Drive NW, Calgary, Alberta, Canada, T2N4N1

ARTICLE INFO

Article history:
Received 18 March 2020
Received in revised form 7 July 2020
Accepted 22 July 2020

Key words:
Trauma care
Adolescents
Pediatric trauma center
Triage
Outcomes

ABSTRACT

Background: We aimed to examine process and outcome indicators for adolescents with specific injury patterns managed in pediatric versus adult paradigms within the same trauma system.
Methods: Adolescents (15–17 years old) admitted to the region's adult trauma center (ATC) or pediatric trauma center (PTC) with an abdominal injury, femur fracture or traumatic brain injury (TBI) were reviewed retrospectively. Global and injury-specific process and outcome indicators were compared.
Results: Of 141 ATC and 69 PTC patients, injury patterns differed significantly with more TBI and abdominal injuries at the ATC and femur fractures at the PTC. Overall injury severity was greater at the ATC. Patients with solid organ injuries appeared more likely to undergo embolization or splenectomy at the ATC; however, higher injury grade and later time period were the only variables significantly associated with this. Computed tomography (CT) was used significantly more frequently at the ATC overall, most notable with panscanning and head CTs for major TBI. Time to operative management did not differ for patients with isolated femur fractures. Neuropsychological follow up after minor TBI was documented more often at the PTC than the ATC; there was no difference for those with more severe TBIs.
Conclusions: Management varies for adolescents between PTCs and ATCs with more exposure to radiation and less neuropsychological follow-up of less severe TBIs at the ATC. This presents distinct opportunities to identify best policies for triage and sharing of management practices within a single regional inclusive trauma system in order to optimize short and long-term outcomes for this population.
Type of study: Retrospective cohort.
Level of evidence: Level IV.

Management of major injury in adolescents presents challenges and perspectives conflict over whether they should be cared for in pediatric or adult trauma centers. Adolescents may have the physical size and physiology of young adults and mechanisms of injury are often more comparable to those seen in adults (e.g. driving) supporting treatment in adult trauma centers (ATCs). Conversely, their psychosocial and educational needs may be closer to those of children, resulting in benefits from services in pediatric centers.

Evidence suggests equal or better outcomes when injured adolescents are managed in PTCs. Rationale for this includes less surgical intervention on solid organ injuries (SOIs) and penetrating trauma, limiting exposure to ionizing radiation with CT scanning, lower thresholds for neurosurgical intervention for traumatic brain injuries (TBIs), stronger family and patient-centered care reflecting psychoeducational needs of the developing adolescent and cognizance of risk of posttraumatic stress disorders [1–10]. This is contrary to perceptions of greater trauma expertise and ready access to interventions at ATCs which may improve outcomes in that paradigm.

Striking a balance between the pediatric-like and adult-like needs of this unique population, care of major injuries may require a blend of ATC and PTC resources at both the prehospital and institutional levels within the same system. Although such a model may result in differences in severity of injury cases managed in either center, this and associated potential variations in outcomes require exploration. Using a common set of injury subtypes, we aim to compare severity of injury cases, processes in trauma care and outcomes of the adolescent trauma population managed at a PTC and ATC within a regional trauma system

☆ Conflicts of interest: There are no conflicts of interest with or supports from pharmaceutical and industry organizations for this research.
☆☆ Funding: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors
★ Ethics: This work was approved by the Research Ethics Board of the University of Calgary: REB-17-0356
* Corresponding author at: University of Calgary, Pediatric General Surgery, Alberta Children's Hospital, 28 Oki Drive NW, Calgary, AB, Canada, T3B 6A8. Tel.: +1 403 955 2850; fax: +1 403 955 7634.
E-mail address: natalie.yanchar@ahs.ca (N.L. Yanchar).

https://doi.org/10.1016/j.jpedsurg.2020.07.032
0022-3468/

using a blended model of adolescent trauma care. We hypothesize that although variations in injury severity will exist between the two paradigms, process and clinical outcomes will be comparable.

1. Methods

1.1. Study environment

The southern Alberta trauma system, centered on one Level I ATC and one Level I PTC [11], provides a blended model of care for injured adolescents. At both sites, trauma team response and emergent access to CT and surgical consultation are available 24 h a day, 7 days a week. Consistent in-house anesthesia, however, is present only at the ATC, allowing for emergent access to the operating room (OR) as needed while access is limited to within 60 min at the PTC during overnight hours, weekends and holidays. Similarly, interventional radiology, particularly for embolization of solid organ injuries, is available on an urgent basis around-the-clock at the ATC, but only within 1 h of request during evenings, weekends and holidays at the PTC. Adolescents (15–17 years old) with major injury are generally triaged to the ATC if being transferred from a rural hospital, and to the PTC if coming directly from the scene, most of these occurring in Calgary, the largest city in southern Alberta where the ATC and PTC reside. Some prehospital care-provider discretion also influences which site the patient may go to, depending (anecdotally) on perception of severity of injuries, concomitant intoxication, mechanism (assault) and apparent maturity of the patient. Around-the-clock access to the OR at the ATC as well perception of greater experience with surgical injuries also sways prehospital triage to the ATC for cases of penetrating injury and those with hemodynamic instability. In the emergency department (ED), decisions on need for imaging, transfusions and operative intervention are guided by the hemodynamic and clinical status of the patient, generally reflecting Advanced Trauma Life Support (ATLS) principles and predicated on the judgment of the trauma surgeon and/or emergency physician. Major trauma is assessed by a formal trauma team response at each center while more minor injuries are assessed by the emergency department physician with consultation to surgical services as needed. Acute in-hospital care follows protocols defined by each center's trauma program as do rehabilitation and follow-up, especially for patients with TBI. Those at the PTC receive a follow-up within 4–6 weeks through the center's Pediatric Brain Injury Clinic where they undergo assessment to ensure return to learn and play. Those admitted to the ATC, however, may either be transferred to the PTC for in-patient rehabilitation and subsequent Pediatric Brain Injury Clinic follow-up or they may follow the regional adult TBI trajectory and be referred to the region's Brain Injury Program which triages patients to services according to their needs [12].

1.2. Study design

We retrospectively reviewed cases of all adolescents (15–17 years old) admitted to the ATC or PTC between 01/01/2012 and 31/12/2016 with an intraabdominal injury (ICD10 codes S31.6, S35.0–S35.6, S36), and/or TBI (S06.0–S06.9), and/or femur fracture (S72). Patients were excluded if the mechanism of injury was not from an external source (e.g. slipped epiphysis). Injuries were considered "isolated" if there was no associated injury of either of the other two body systems considered in this study. Injuries of other body systems were not considered in the analysis. Justification of choice of these three body systems included: abdominal injuries with a focus on SOIs to evaluate differences in imaging and interventions; femur fractures with relatively uniform surgical needs that can reflect commitment to rapid surgical care and TBIs to evaluate for imaging and neurocognitive follow-up.

Data were obtained through electronic medical records, local data analytics and the Alberta Trauma Registry (ATR). The ISS is readily available from the ATR for all cases with an ISS ≥ 12; for this study, the ISSs of less severe cases were calculated by the ATR staff using the ICD-10 discharge diagnoses codes.

Process outcomes of interest included numbers of CT scans obtained in the ED and during admission (each of four body areas scanned counted as one event: head +/− cervical spine, chest, abdomen +/− pelvis, extremities); use of panscanning (head + chest + abdomen/pelvis scan); condition-specific length of stay (LOS) in the ED; condition-specific operative or radiologic interventions (spleen and liver SOIs were specifically addressed to reflect higher likelihood of requiring hemorrhage control); time to the OR for isolated femur fractures (from time of admission to the ED); blood product transfusion (any blood products within the ED or during admission); transfer between centers; and neurocognitive follow-up for TBIs (documented attendance at either a rehabilitation, traumatic brain injury or neurosurgery clinic). Missing data are described in the tables; effects on analysis are described in the text.

Clinical outcomes included mortality and in-hospital LOS. Evaluation of LOS was restricted to cases with isolated injuries in order to reduce the influence of other injuries on this outcome. Because of heterogeneity of cases, in-hospital complications were not collected; however, patient return to the ED within 30 days of discharge was evaluated as a measure of appropriateness of discharge. Analyses were stratified by injury severity where applicable: higher (>15) versus lower (<16) ISS. Spleen and liver SOIs were stratified by the CT organ grade: high (grades 4–5) versus low (grades 1–3). TBI cases were classified according to final clinical and CT diagnoses: concussions versus hemorrhagic lesions (contusions, intraparenchymal hemorrhage, subdural and epidural hematomas, subarachnoid hemorrhage) versus diffuse injury (diffuse axonal injury/diffuse anoxic injury); they were then stratified as major TBI (hemorrhagic lesions or diffuse injury) versus minor TBI (concussions).

1.3. Statistical analysis

Descriptive analyses included univariate comparisons using Student's T-Tests for numerical variables with normal distributions; data not normally distributed were compared using nonparametric methods (Kruskal–Wallis test). Proportions were compared using chi-squared or two-sided Fisher's Exact (for cell counts <5) tests. In cases where multiple variables were associated with the outcomes of interest, weighted logistic regression using propensity scoring was applied utilizing all variables reaching a p-value of <0.25 on univariate analyses. Variables of most interest (ATC versus PTC, high versus low ISS) were forced into the models regardless of univariate measures. Corresponding estimates and p-values are reported, with p-values <0.05 considered statistically significant.

All statistical analyses were performed using SAS statistical software, Version 9.4, Cary, NC, USA. The study was approved by the Research Ethics Board of the University of Calgary.

2. Results

One-hundred-forty-two and 68 patients meeting the inclusion criteria were admitted to the ATC and PTC, respectively (Table 1). Sex distribution was comparable but adolescents were, on average, older at the ATC (16.9 versus 16.1 years). Similar proportions were transferred from peripheral hospitals. Injury patterns differed significantly, with TBIs proportionally accounting for more cases at the ATC, femur fractures for more cases at the PTC and abdominal injuries (including liver and/or spleen SOIs) being equally distributed. Most injuries were isolated with regards to the three injury patterns under study (Fig. 1). The median ISS was significantly greater at the ATC with 2-fold more severely injured patients with ISS > 15 (Table 1). This pattern remained relatively consistent over the 5-year time period (Fig. 2).

CT scanning varied between the two centers (Table 2). For those cases with injuries isolated to one of the three body systems under study, this practice was significantly more frequent at the ATC for only

Table 1
Patient and injury characteristics.

		Pediatric trauma center	Adult trauma center	Significance of difference (p-value)
Count		68	142	
Mean age (years) +/− SD		16.1 +/− 0. 7	16.9 +/− 0.8	<0.0001
Male (%)		75.0%	71.8%	0.63
Admitted from peripheral hospital		35.3%	47.9%	0.085
Later era (2015–2016)		35.3%	45.1%	0.18
Total TBI (% of all injuries)		30 (44%)	90 (63%)	0.008
All TBI cases	Mild (concussion; no CT lesion) (%)	55.3	31.1	0.029
	Moderate (hemorrhagic lesion on CT[a]) (%)	43.3	55.6	0.25
	Severe (diffuse axonal/anoxic injury on CT) (%)	3.3	13.3	0.13
Total abdominal injuries (% of all injuries)		19 (28%)	47 (33%)	0.45
	Spleen and/or liver SOI (% of all injuries)	17.7%	28.9%	0.080
Total femur fractures (% of all injuries)		24 (35%)	24 (17%)	0.003
Median ISS (interquartile range)		9 (8.5–16)	16 (9–25)	0.0005
ISS > 15 (%)		30.9	62.0	<0.0001

TBI: traumatic brain injury, CT: computed tomography, ISS: injury severity score; SOI: solid organ injury; SD: standard deviation.
[a] Hemorrhagic lesion: intraparenchymal contusion/hemorrhage, subdural/epidural hematoma, subarachnoid bleed.

cases with TBI, regardless of the overall injury severity. Findings were more variable when considering TBI severity (Table 3). Patients with an isolated TBI and an identified hemorrhagic lesion on initial head CT underwent >1 head CT during their hospital admission more frequently at the ATC versus the PTC; the median (interquartile range) number of head CTs for this patient group was 1 (1–2) and 2 (2–3) at the two centers, respectively ($p = 0.004$). Conversely, 92% of patients with concussions underwent only 1 head CT with no difference seen between the 2 centers.

A significant difference was observed with panscanning which occurred 3.5 to 17-fold more frequently at the ATC for cases with high versus low ISS, respectively (Table 2). After adjusting for covariates, clinical variables remaining significantly associated with panscanning included presentation with a TBI (any severity), the requirement for transfusion of any blood products and an ISS of >15 (Table 4). Admission to the ATC was the only nonclinical variable also associated with this practice.

ED LOS did not vary significantly between the two centers among all cases or those with isolated femur fractures (Table 2). In-hospital LOS among all cases, however, was significantly longer at the ATC versus the PTC when examining all cases together or isolated femur fractures with low injury severity. Among those sustaining isolated TBIs, a significantly higher in-hospital LOS was observed in the ATC, regardless of severity (Table 3).

Regarding interventions for specific injuries, no significant differences were noted between the two center types. Eight percent of patients at the PTC with a hemorrhagic TBI underwent surgical intervention (ranging from insertion of an intraventricular drain to operative cranial decompression) similar to 19% at the ATC ($p = 0.67$) (Tables 2 & 3). Similarly, regardless of center, almost all underwent operative fixation for a femur fracture, with no difference seen when stratifying by overall injury severity. Time to the OR for isolated femur fractures appeared to be similar; however, almost half of cases were missing this data point (Table 2). Transfusion of blood products for abdominal injuries, including isolated spleen and liver injuries, was more frequently practiced at the ATC versus the PTC (31.9% versus 5.3%, $p = 0.02$), although statistical significance was lost when considering isolated spleen and liver injuries only (34.2% versus 8.3%, $p = 0.08$) (Table 2). Patients with spleen or liver solid organ injuries appeared to undergo intervention (5 underwent operative splenectomy; 10 underwent embolization) more frequently at the ATC versus the PTC (37.8% vs 0%, $p = 0.02$) (Fig. 3); however, this lost statistical significance when stratifying by injury severity (Table 2). There was also no association of undergoing such intervention in the presence (25.0%) versus absence of (26.7%) a concomitant major TBI (chi square, $p = 1.0$) or with older patients within the cohort (39% of 17 year olds versus 23% of 15–16 year olds, $p = 0.26$). Most notable is that after adjusting for covariates, organ grade (high grades of IV or V) and being injured in the latter half of the study period, but not the need for transfusion of blood products, were the only variables remaining positively associated with undergoing such an intervention (Table 5). No patients at either trauma center, with an isolated solid organ injury, regardless of grade, required admission to the intensive care unit. One patient at each site, each with a low grade SOI but major TBI, required critical care.

Over the study period, one patient was transferred from the PTC to the ATC for management of a spinal cord injury while 6 patients were transferred from the ATC to the PTC, primarily for ongoing neurocognitive rehabilitation. After discharge from hospital, neurocognitive follow up for TBI patients occurred significantly more often for adolescents managed at the PTC versus the ATC, although this reached statistical significance only with those with mild TBIs (concussions). This pattern persisted when categorizing patients by the initial hospital of management or recategorizing them after transfer between hospitals. No difference was found between the two sites of rates of mortality or unanticipated presentation to the ED/readmission within 30 days of discharge (Table 2).

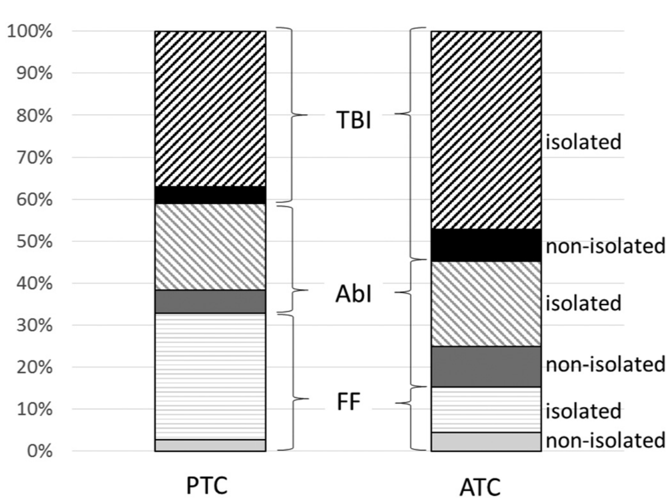

Fig. 1. Distribution of injuries: PTC versus ATC. TBI: traumatic brain injury, AbI: abdominal injury, FF: femur fracture. Hatched bars = isolated injuries; solid bars = nonisolated injuries (see text).

3. Discussion

Adolescence represents the transitional phase of growth and development between childhood and adulthood. Although defined by some as the age range of 10–19 years [13], it represents the phase of change of psychological, cognitive, social, sexual and emotional constructs

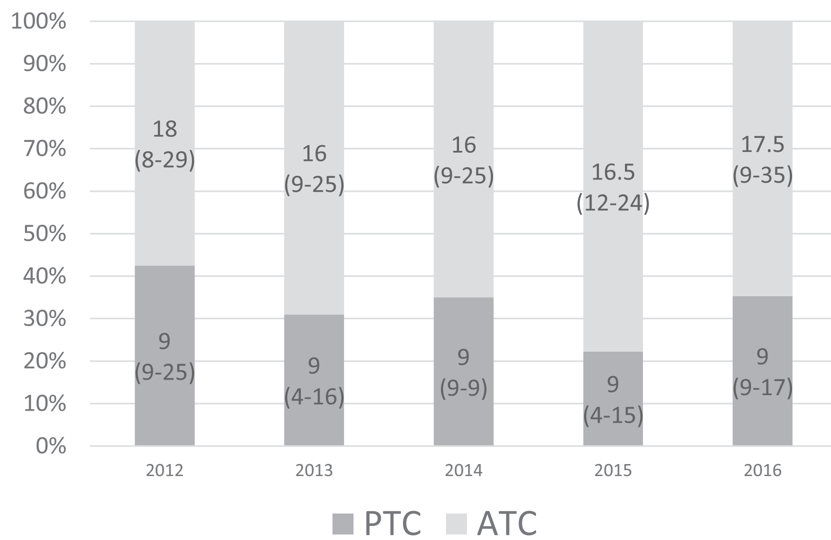

Fig. 2. Yearly distribution of admissions to regional trauma centers. Values within bars represent median ISS (interquartile range) of that year cohort.

between childhood and adulthood [14]. Physiological and anatomical transitions also occur. Bone mass continues to increase during puberty reaching 90% not until age 18 in females and 20 in males [15]. Spleen morphology also changes, with children having a thicker and more elastic capsule, with a higher proportion of white pulp, which may help explain the greater comfort with and success of nonoperative management of splenic injuries in children relative to adults [4–6,16–19]. This is a continuous process so no discreet age cutoff can be determined for "peak" strength of the spleen, but higher thickness has been observed in cadaver specimens up to age 20 years [17]. Additionally, adolescents may be particularly vulnerable to opioid addiction and observations such as use of prescribed opioids by the 12th grade coupled with increased opioid prescribing practices by adult surgeons compared to pediatric surgeons, for comparable procedures, may

Table 2
Process and clinical outcome comparisons between pediatric and adult trauma centers, stratified by ISS.

	ISS < 16		Significance of Differences (p-value)	ISS > 15		Significance of differences (p-value)
	PTC (n = 47)	ATC (n = 54)		PTC (n = 21)	ATC (n = 88)	
CT scanning						
Total CT scans/patient: median (IQ range)	0 (0–1)	2 (1–3)	<0.001	1 (0–2)	4 (3–5)	<0.001
% undergoing panscan	2.1	35.2	<0.001	19.1	69.3	<0.001
% with isolated femur fracture undergoing a panscan	0	20.0	0.10	0	7.43	0.38
% with isolated TBI undergoing a panscan	6.7	53.9	0.0025	8.3	70.8	<0.0001
% with isolated abdominal injuries undergoing a panscan	0	12.5	0.51	20.0	43.8	0.61
Lengths of stay						
ED LOS (h): median (IQ range)	4.8 (2.9–10.2)	6.0 (4.1–8.4)	0.180	4.9 (3.5–7.8)	4.5 (2.9–6.6)	0.335
ED LOS (h): median (IQ range), isolated femur fractures	3.9 (1.9–6.8) (n = 21)	5.8 (4.1–8.1) (n = 10)	0.15	16.8 (16.8–16.8) (n = 1)	11.5 (4.7–14.1) (n = 7)	0.28
In-hospital LOS (days): median (IQ range)	2 (1–3)	3 (2–5)	0.0003	2 (2–5)	8 (4–28)	0.0003
In-hospital LOS (days): median (IQ range), isolated femur fractures	2 (2–3)	4.5 (3–11)	0.0062	9 (9–9)	8 (4–12)	0.51
Interventions						
Operative intervention for major TBI (%)	0	0	na	8.3	18.5	0.67
Operative intervention for femur fracture (%)	95.5	90.9	1.0	0	100	0.13
Hours to OR for isolated femur fracture	n = 12/20[a] 16.5 (4.0–18.0)	n = 5/10[a] 14.2 (12.2–16.5)	0.92	n = 0/1 -	n = 4/7 -	na
Transfusion blood products for any abdominal injury (%)	0	5.9	0.41	12.5	46.7	0.08
Transfusion blood products for spleen or liver SOI (%)	0	0	na	20	50	0.21
Intervention on spleen or liver SOI (%)	0	38.9	0.52	0	23.8	0.13
Clinical						
Return to ED within 30 d discharge (%)	8.5	1.9	0.18	4.8	9.2	1.00
In-hospital mortality (%)	0	0	na	4.8	6.8	1.00

PTS: pediatric trauma center, ATC: adult trauma center, ISS: Injury Severity Score, CT: computed tomography, IQ: interquartile, TBI: traumatic brain injury, ED: emergency department, LOS: length of stay, OR: operating room, na: not analyzed, SOII: Solid Organ Injury.
[a] Data available only for 12 of 20 cases undergoing operative fixation.

Table 3
Process and outcome comparisons between pediatric and adult trauma centers — isolated TBI cases only.

	Concussion			Hemorrhagic lesion			Diffuse lesions		
	PTC (n = 13)	ATC (n = 24)	p-value	PTC (n = 13)	ATC (n = 42)	p-value	PTC (n = 1)	ATC (n = 8)	p-value
Required neurosurgical intervention (%)	0	0	na	7.7	19.1	0.67	0	25	na
Underwent > 1 head CT (%)	7.7	8.3	1.0	38.5	86.5	0.018	0	100	na
In-hospital LOS (days), median (IQ range)	1 (1–1)	3 (2–5)	0.0015	2 (1–3)	9 (3–32)	0.0010	61	28 (13–67)	na
Attended TBI follow-up (%)	84.6	33.3	0.0029	100	73.8	0.097	100	71.4	na

PTS: pediatric trauma center, ATC: adult trauma center, CT: computed tomography, IQ: interquartile, TBI: traumatic brain injury, LOS: length of stay, na: not analyzed.

Table 4
Variables associated with panscan.

	Proportion of cases with panscan (total n = 210)		Estimate +/− std. error	
			Unadjusted	Adjusted[a]
Type of trauma center	ATC 56.3%	PTC 7.4%	−2.3 +/− 0.6 P < 0.0001	−2.4 +/− 0.3 p = <0.0001[b]
Clinical presentation of TBI (major or minor)	With any TBI 21.1%	No TBI 55.0%	−1.5 +/− 0.4 p = 0.0002	−1.5 +/− 0.3 P < 0.0001[b]
ISS	High (>15) 59.6%	Low (<16) 19.8%	1.1 +/− 0.4 p = 0.003	1.3 +/− 0.3 P < 0.0001[b]
Age	17 years 55.0%	15–16 years 31.5%	p = 0.91	ns
Year of admission	2015–2016 48.9%	2012–2014 34.4%	0.40 +/− 0.40 p = 0.22	0.8 +/− 0.3 p = 0.005[b]
Transfusion of blood products (any)	Yes 73.7	No 33.5	−1.1 +/− 0.5 p = 0.03	−2.1 +/− 0.5 P < 0.0001[b]

PTS: pediatric trauma center, ATC: adult trauma center, ISS: Injury Severity Score, TBI: traumatic brain injury, ns: not significant.
[a] Measure of model performance: null deviance 491 on 207 degrees of freedom; residual deviance 318 on 201 degrees of freedom; AIC:330.
[b] Statistically significant association.

further enhance this vulnerability [20,21]. Variability in timing of puberty, growth and development, especially in the context of psychological and psychoeducational constructs that are affected by traumatic injury events, defies establishment of a homogenous age cohort in this population.

The state of knowledge and published literature regarding optimal management of injured adolescents in PTCs versus ATCs are limited. However, for one injury pattern, as alluded to above, intraabdominal solid organ injuries undeniably undergo significantly less surgical and radiologic (embolization) intervention in PTCs than in ATCs, with equivalent transfusion rates, need for critical care, and mortality [7–9]. Even within the same trauma center, embolization has been shown to occur more frequently when management is led by adult versus pediatric care teams [5]. Intuitively, the presence of a concomitant TBI should also increase the likelihood of an intervention and/or transfusion to ensure optimal brain perfusion and prevent secondary neurologic injury, and may be used as reason why more intervention happen in an ATC, where the overall severity of injury presentation is often greater. We did not observe this, however, regardless of trauma center type. This was also the case when analyzing cases of blunt splenic injury in the National Trauma Database (aged ≥16 years), where the presence of a concomitant significant TBI was not associated with increase operative intervention, the authors hypothesizing that such patients may receive more focused interventions to prevent secondary brain injury such as increased used of blood products and more aggressive correction of coagulopathies [9].

In our study, however, although the descriptive and univariate analyses would suggest that adolescents with spleen or liver injuries

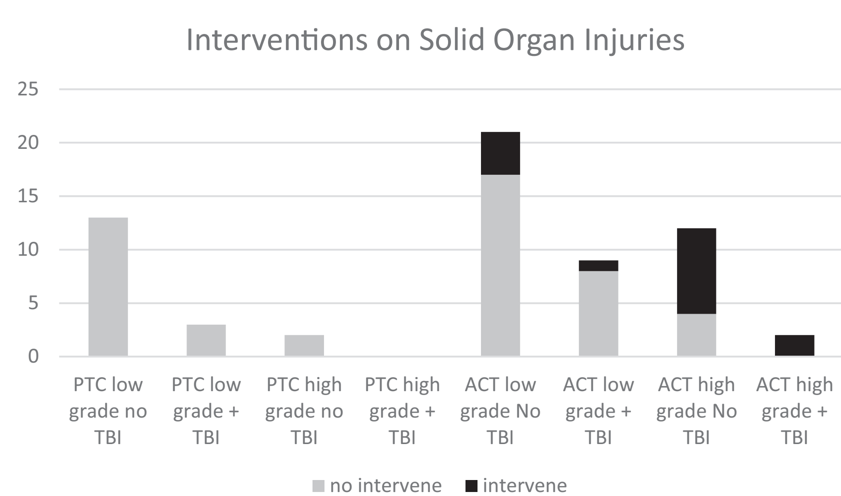

Fig. 3. Comparison of interventions on solid organ injuries relative to grade, trauma center type and concomitant TBI.

Table 5
Variables associated with interventions on liver/spleen solid organ injuries.

	Proportion of cases with intervention (total $n = 53$)		Estimate +/− std. error	
			Unadjusted	Adjusted[a]
Type of trauma center	ATC 34.5%	PTC 0%	p = 0.99	ns
Organ injury grade	IV–V 90.0%	I–III 11.6%	4.2 +/− 1.6 p = 0.009	4.1 +/− 1.4 p = 0.004[b]
ISS	High (>15) 36.4%	Low (<16) 0%	p = 0.93	ns
Transfusion of blood products	Yes 33.3%	No 23.7%	p = 0.48	ns
Sex	Male 35.0%	Female 0%	p = 0.99	ns
Year of admission	2015–2016 39.1%	2012–2014 16.7%	2.4 +/−1.2 p = 0.049	2.3 +/− 1.1 p = 0.030[b]

PTS: pediatric trauma center, ATC: adult trauma center, ISS: Injury Severity Score, ns: not significant.
[a] Measure of model performance: null deviance 91 on 52 degrees of freedom; residual deviance 25 on 47 degrees of freedom; AIC:36.6.
[b] Statistically significant association.

managed at the ATC were more likely to undergo an intervention, after controlling for covariates, only a higher organ grade and later time period within the study remained significantly associated with this. The inability to control for other important covariates such as hemodynamic status and the limitation of the relatively low number of these cases may call into question the true validity of our findings as differences in intervention rates between ATCs and PTCs have been seen in prior studies. The lack of significant difference in transfusion of blood products, however, might suggest that hemodynamic status did not differ between those at the ATC versus the PTC and that other drivers beyond CT grade, perhaps more prevailing in the later years, may influence this practice at an ATC. Indeed, previous studies have demonstrated less comfort with management of SOIs in children by those who predominantly manage adult trauma [22]. However, it is possible that observing no statistically significant difference is a true finding in our region, reflecting the increasing trend for nonoperative management for splenic injuries in adults that has been observed over the past decades.

The increased use of CT scanning in the ATC relative to the PTC is also consistent with previous studies. Although this only reached statistical significance with head CTs for more severely injured patients, adolescents managed at the ATC underwent at least twice as many CT scans (ED and in-patient combined) than those at the PTC. Sathya et al. also demonstrated similar findings utilizing data from the US Trauma Quality Improvement Program [10]. Comparing 19 PTCs versus 33 ATCs, injured adolescents (aged 13–18 years) seen primarily in the ED underwent 22% less CT scans overall in the PTCs, specifically 27% less head CTs, although this was not stratified on injury types. This is also consistent with the findings of Thurley et al. who demonstrated that the transition age range of adolescents is associated with an almost linear increase in CT scanning, increasing three-fold over the age range of 15 to 19 years [23]. Although that study was not limited to trauma alone, it demonstrates a change in culture of management of young patients as they transition to adulthood rather than a change in incidence of disease processes.

The practice of avoiding panscanning at the PTC likely reflects a higher cognizance of the long-term effects of radiation, creating a culture of more targeted imaging, especially in cases where clinical evidence suggests isolated body system injuries (e.g. isolated TBIs). Evidence-informed protocols to limit radiation exposure are also more likely to be present in a pediatric center. For example, several studies have shown that with the exception of an abnormal mediastinal silhouette on chest x-ray, a chest CT will not add any further value to inform management in injured children and adolescents, making routine panscans unnecessary in this patient population [24,25].

Recognition of the carcinogenic effects of ionizing radiation in children has been associated with a significant decrease in use of CT scanning in pediatrics over time in the past decade [26,27]. This, however, has not been the case in the adult population. Bellolio et al. demonstrated a consistent increase in ED visit CTs between 2003 and 2012 at a single institution, with rates of use in adults increasing between 5% and 34%, being highest in the older age strata [26]. Among patients <18 years of age, however, rates decreased by 41% over the same time period, demonstrating that management in the adult context does not reflect the concern of ionizing radiation seen in the pediatric context. This recognition is especially important for adolescents as recent studies have shown that the older pediatric age range appears to be an independent factor in experiencing higher effective doses of radiation from CTs, defined as the amount of radiation to which a person is exposed and the biological effects of that radiation on the exposed organs [28]. This may be somewhat a consequence of the larger doses required for larger body size, but, nonetheless, reflects an ultimately higher risk of CT-associated radiation in this older “pediatric” group.

This study has demonstrated that adolescents managed at the regional ATC were, in general, more severely injured than those at the PTC. This corresponds to the distribution of all adolescents entered into the ATR over the same time frame: 82% of those aged 15–17 years with an ISS of 12 or greater (all injury subtypes), or penetrating injury with any ISS, were managed at the ATC versus 18% at the PTC. This is in sharp contrast to the management pattern seen with injuries of any severity, where among the same age group, 63% were admitted to the PTC and only 37% to the ATC (ATR, personal communication, data not shown). From the perspective of an inclusive trauma system, this triage distribution may be appropriate. Volumes of major trauma at an ATC are significantly greater than at a PTC, allowing for more experience of personnel in acute management and may confer more readiness of emergent interventional resources such as angiography and access to the OR. Conversely, urgent surgical intervention may still be prioritized in both paradigms such as the comparable times to repair of isolated femur fractures between the two centers. As we demonstrated, ultimately, clinical outcomes varied little between the two trauma center types, suggesting that the system “is working”. This is comparable to recent studies including that by Rogers et al. demonstrating that within their regional trauma system, despite some variances in injury subtypes, penetrating trauma in their adolescent population had at least equivalent risk-adjusted outcomes when managed in a PTC versus an ATC [3].

From a resource perspective, it is of interest that overall length of stay for “isolated” injury patterns such as femur fracture or TBI appeared to be longer at the ATC versus the PTC, at both the lower and higher injury severity strata. It may be that “isolated” in this case means femur fracture without TBI or abdominal injury or TBI without femur or abdominal injury, and does not take into account other potential injuries that may have prolonged the patients' stay at the ATC. It may also be possible that those adolescents admitted to the PTC were more quickly connected with the in-house Pediatric Rehabilitation Program and Brain injury Clinic, creating a greater comfort in earlier discharge with outpatient follow-up versus those that may have had to be referred from the ATC and a more granular assessment of specific injury patterns is required to truly determine this.

Finally, we observed more complete neuropsychological follow-up of patients sustaining a TBI when managed at, or undergoing TBI rehabilitation at the PTC. This could be reflective of the perception that the adolescent brain is still a pediatric brain, and because of its ongoing development it requires close follow up in the event of injury. Although recent evidence demonstrates equivalent clinical short-term outcomes between those cared for in PTCs versus ATCs (mortality, overall complication rate and functional status at discharge), these studies tend to focus on early outcomes [29,30]. The significance of the findings in this study reflects that far less is known about more distal outcomes and how acute experiences in hospital may reflect later outcomes, especially with regards to educational, affective and behavioral outcomes. For example, adolescents have been found to be at high risk for posttraumatic depression, posttraumatic stress disorders (PTSD) and significant associated quality of life deficits up to 2 years after the traumatic event [31,32]. Associations between PTSD, acute events in hospital and mild TBI have been found and should be addressed in adolescents sustaining major injuries, especially if they have a concurrent TBI. Commitment to screening for and early intervention to address risks for transition from acute stress disorders to PTSD are more likely to occur in institutions committed to overall health care of children, youth and their families [33], leading to the potential of better psychological, educational and functional outcomes with management in a setting committed to care of adolescents. Additionally, parental reaction to the injury of their child, even as an adolescent, can lead to depressive or dysfunctional reactions which may be best approached with intervening at the family level, something that is more likely when managed in the pediatric versus adult paradigm [34].

Advantages of such follow-up have been demonstrated in recent studies. Undoubtedly, both children and adults with major TBI benefit from long-term follow-up in order to maximize outcomes despite long-term impairments as shown by several studies and we observed no significant difference in follow-up in this subgroup of patients in our study [35,36]. However, for those sustaining a minor TBI, follow-up was more consistent in the pediatric paradigm and it may be this population that requires specific consideration when managed in an adult setting where the value of this for children and adolescents may not be so readily recognized. For example, Renaud et al. recently performed a randomized controlled trial of older children (10–18 years) with mild TBI [37]. Those receiving individualized follow-up with psychoeducational assessments versus usual care of discharge pamphlet information demonstrated less fatigue, postconcussive symptoms, posttraumatic stress symptoms and better quality of life. Benefits of follow-up for mild TBI have also been shown in the adult population and truly should be considered for all ages within an inclusive trauma system [38].

Several limitations of this study must be acknowledged. Firstly, the numbers are relatively small and preclude generalization of these results to other trauma systems, although anecdotally, triage of adolescent patients varies significantly across Canada, with different provinces and regions having different policies. Secondly, the retrospective nature of this study precludes the determination of nuances that may have led to the triage of a patient from one center versus the other in this study. More specifically, the overall increased injury severity of the cohort managed at the ATC suggests that other injuries (aside from femur fractures, abdominal injuries and TBIs) were likely, and would not have been accounted for when speaking of isolated injury patterns. This may also explain the longer overall lengths of stay of patients with isolated TBIs and femur fractures. On the contrary, we were unable to determine confounding that may lead to increased ISS values at the ATC, such as increased use of CT scanning which may pick up injuries that are not clinically obvious or relevant, yet would contribute arithmetically to the overall ISS (e.g. grade 1 splenic injuries). As follows, the use of ISS to discriminate major versus minor injury may also be a limitation as it is not pediatric-specific. Being based purely on anatomic injuries, the ISS does not account for physiologic derangements that may contribute to overall severity. As such, other scoring systems have been proposed and have shown perhaps better specificity to identify serious injury in all ages, but particularly in children, such as the weighted ISS or those that reflect need for critical care or operative resources [39–41]. These, however, have not generally been incorporated into large trauma registries such as ours. There is also a concern that scoring systems that reflect need for intervention [41] may bias severity in adult centers where interventions on pediatric injuries (e.g. splenic embolization) may be more likely to occur than in a pediatric setting, with equivalent severity of injury. The implications of this on a study population that is on the cusp of adulthood are not clear, but we feel unlikely to have affected the main conclusions of our study. Thirdly, review of cases admitted to the regional ATC or PTC precluded the ability to consistently identify patients who may have had tests or procedures, such as CT scanning, done prior to arrival at the trauma center, potentially leading to an underestimation of the total numbers of CTs performed. However, with triage policies favoring those cases from longer distances going to the ATC, and using the assumption that such patients are more likely to undergo CT scanning at their initial hospital prior to transfer, this would have unlikely changed the overall finding of more CTs performed at the ATC. Finally, missing data, especially with regards to time interval to surgical repair of femur fractures, lend caution to the interpretation of these results.

In conclusion, although clinical outcomes are relatively the same for adolescents managed within an adult or pediatric paradigm, we observed several differences, especially with use of ionizing radiation and neurocognitive follow-up after TBI. Unlike other published findings, we did not observe a significant association of trauma center type with interventions on liver and spleen SOIs, but this relatively consistent finding in the literature cannot be ignored. Findings from this study are not new in the literature: however, the variations in many aspects of care present distinct opportunities to identify best practices for management of adolescents sustaining major trauma. This study outlines several areas of management that may benefit from ongoing communication between the adult and pediatric centers and sharing of best practices reflective of the needs of this population within a single regional inclusive trauma system. Indeed, these concepts could be expanded to develop quality metrics of how (not necessarily where) this unique population is managed within an inclusive trauma system (e.g. rates of use of CT scanning, rates of appropriate versus inappropriate interventions on SOIs, comprehensiveness of neurocognitive follow-up after TBI). Ultimately, consideration of the psychosocial constructs that are unique to adolescence (school, social networking, etc.) should also be considered when optimizing their injury care. Undoubtedly, strict use of chronologic age to determine where an adolescent should be managed may not be in their best interest as both paradigms have potential benefits and disadvantages. Triage should always be to the center with the best access to needed resources. What may be more important is the sharing of best evidence-informed practices (such as limiting exposure to ionizing radiation, spleen conservation, criteria for admission to the intensive care unit) and guidelines (e.g. such as the ATOMAC guidelines for management of blunt splenic injury in children less than the age of 16 years) between adult and pediatric trauma centers within an inclusive trauma system, so that optimum short and long-term outcomes are ensured [42]. Undoubtedly, the results of this study raise more questions than provide answers, but clearly demonstrate the need for further work to ensure that this unique patient population is managed at the appropriate place to ensure efficient use of resources within an inclusive trauma system together with optimal short and long-term outcomes at all points of care.

References

[1] McLaughlin KA, Koenen KC, Hill ED, et al. Trauma exposure and posttraumatic stress disorder in a national sample of adolescents. J Am Acad Child Adolesc Psychiatry. 2013;52(8):815 30.e14.
[2] Renaud MI, van de Port IG, Catsman-Berrevoets CE, et al. The Brains Ahead! intervention for children and adolescents with mild traumatic brain injury and their caregivers: rationale and description of the treatment protocol. Clin Rehabil. 2018; 32(11):1440–8.
[3] Rogers FB, Horst MA, Morgan ME, et al. A comparison of adolescent penetrating trauma patients managed at pediatric versus adult trauma centers in a mature trauma system. J Trauma Acute Care Surg. 2020;88(6):725–33.
[4] McDonald LA, Yanchar NL. Management of pediatric splenic injuries in Canada. J Pediatr Surg. 2012;47(3):473–6.
[5] O'Connor SC, Doud AN, Sieren LM, Miller PR, Zeller KA.. The spleen not taken: differences in management and outcomes of blunt splenic injuries in teenagers cared for by adult and pediatric trauma teams in a single institution. J Trauma Acute Care Surg. 2017;83(3):368–72.
[6] Safavi A, Skarsgard ED, Rhee P, et al. Trauma center variation in the management of pediatric patients with blunt abdominal solid organ injury: a national trauma data bank analysis. J Pediatr Surg. 2016;51(3):499–502.
[7] Lippert SJ, Hartin CW, Ozgediz DE, et al. Splenic conservation: variation between pediatric and adult trauma centers. J Surg Res. 2013;182(1):17–20.
[8] Matsushima K, Kulaylat AN, Won EJ, et al. Variation in the management of adolescent patients with blunt abdominal solid organ injury between adult versus pediatric trauma centers: an analysis of a statewide trauma database. J Surg Res. 2013;183 (2):808–13.
[9] Dhillon NK, Barmparas G, Thomsen GM, et al. Nonoperative management of blunt splenic trauma in patients with traumatic brain injury: feasibility and outcomes. World J Surg. 2018;42(8):2404–11.
[10] Sathya C, Alali AS, Wales PW, et al. Computed tomography rates and estimated radiation-associated cancer risk among injured children treated at different trauma center types. Injury. 2019;50(1):142–8.
[11] Trauma Association of Canada. Trauma system accreditation guidelines. https://www.traumacanada.org/wp-content/uploads/2019/05/Accreditation_Guidelines_2011.pdf; 2011. [Accessed 30 October 2019].
[12] Services AH. Calgary brain injury program. https://www.albertahealthservices.ca/services/cbip.aspx; 2019. [Accessed 27 June 2019].
[13] Organization WH. Coming of age: adolescent health. https://www.who.int/health-topics/adolescents/coming-of-age-adolescent-health. [Accessed 27 June 2019].
[14] Allen BWH. Stages of adolescence 2019. https://www.healthychildren.org/english/ages-stages/teen/pages/stages-of-adolescence.aspx. [Accessed 27 June 2019].
[15] Diseases NIoAaMaS. Osteoporosis: peak bone mass in women. https://www.bones.nih.gov/health-info/bone/osteoporosis/bone-mass; 2018. [Accessed 27 June 2019].
[16] Cheung HT, Nadakavukaren MJ. Age-dependent changes in the cellularity and ultrastructure of the spleen of Fischer F344 rats. Mech Ageing Dev. 1983;22(1):23–33.
[17] Shumi MS, Khalil M, Sultana SZ, et al. Variations of thickness of splenic capsule of different age and sex in Bangladeshi cadaver. Mymensingh Med J. 2016;25(1):7–11.
[18] Rodrigues CJ, Sacchetti JC, Rodrigues AJ. Age-related changes in the elastic fiber network of the human splenic capsule. Lymphology. 1999;32(2):64–9.
[19] Himamoni D, Das TK, Talukdar KL. Age related histological changes of human spleen. IJHRMLP. 2016;3(1):59–61.
[20] Miech R, Johnston L, O'Malley PM, et al. Prescription opioids in adolescence and future opioid misuse. Pediatrics. 2015;136(5):e1169–77.
[21] Freedman-Weiss MR, Chiu AS, Solomon DG, et al. Opioid prescribing habits of general versus pediatric surgeons after uncomplicated laparoscopic appendectomy. J Surg Res. 2019;235:404–9.
[22] Li D, Yanchar N. Management of pediatric blunt splenic injuries in Canada — practices and opinions. J Pediatr Surg. 2009;44(5):997–1004.
[23] Thurley P, Crookdake J, Norwood M, et al. Demand for CT scans increases during transition from paediatric to adult care: an observational study from 2009 to 2015. Br J Radiol. 2018;91(1083):2017.
[24] Holscher CM, Faulk LW, Moore EE, et al. Chest computed tomography imaging for blunt pediatric trauma: not worth the radiation risk. J Surg Res. 2013;184 (1):352–7.
[25] Golden J, Isani M, Bowling J, et al. Limiting chest computed tomography in the evaluation of pediatric thoracic trauma. J Trauma Acute Care Surg. 2016;81 (2):271–7.
[26] Bellolio MF, Bellew SD, Sangaralingham LR, et al. Access to primary care and computed tomography use in the emergency department. BMC Health Serv Res. 2018;18(1):154.
[27] Lodwick DL, Cooper JN, Lawrence AE, et al. Factors affecting emergency department computed tomography use in children. J Surg Res. 2019;241: 294–301.
[28] Cooper JN, Lodwick DL, Adler B, et al. Patient characteristics associated with differences in radiation exposure from pediatric abdomen-pelvis CT scans: a quantile regression analysis. Comput Biol Med. 2017;85:7–12.
[29] Gross BW, Edavettal MM, Cook AD, et al. Big children or little adults? A statewide analysis of adolescent isolated severe traumatic brain injury outcomes at pediatric versus adult trauma centers. J Trauma Acute Care Surg. 2017;82(2):368–73. https://doi.org/10.1097/TA.0000000000001291.
[30] Ovalle F, Xu L, Pearson WS, et al. Outcomes of pediatric severe traumatic brain injury patients treated in adult trauma centers with and without added qualifications in pediatrics — United States, 2009. Inj Epidemiol. 2014;1(1):15.
[31] Holbrook TL, Hoyt DB, Coimbra R, et al. Long-term posttraumatic stress disorder persists after major trauma in adolescents: new data on risk factors and functional outcome. J Trauma. 2005;58(4):764–9 [discussion 9-71].
[32] Han PP, Holbrook TL, Sise MJ, et al. Postinjury depression is a serious complication in adolescents after major trauma: injury severity and injury-event factors predict depression and long-term quality of life deficits. J Trauma. 2011;70(4):923–30.
[33] Brown RC, Nugent NR, Hawn SE, et al. Predicting the transition from acute stress disorder to posttraumatic stress disorder in children with severe injuries. J Pediatr Health Care. 2016;30(6):558–68. https://doi.org/10.1016/j.pedhc.2015.11.015.
[34] Wade SL, Cassedy AE, McNally KA, et al. A randomized comparative effectiveness trial of family-problem-solving treatment for adolescent brain injury: parent outcomes from the Coping with Head Injury through Problem Solving (CHIPS) study. J Head Trauma Rehabil. 2019;34(6):E1–9.
[35] Neumane S, Câmara-Costa H, Francillette L, et al. Functional outcome after severe childhood traumatic brain injury: results of the TGE prospective longitudinal study. Ann Phys Rehabil Med. 2020. https://doi.org/10.1016/j.rehab.2020.01.008 In press.
[36] Stålnacke BM, Saveman BI, Stenberg M. Long-term follow-up of disability, cognitive, and emotional impairments after severe traumatic brain injury. Behav Neurol. 2019; 2019:1–7. https://doi.org/10.1155/2019/9216931.
[37] Renaud MI, van de Port IGL, Catsman-Berrevoets CE, et al. Effectiveness of the Brains Ahead! intervention: 6 months results of a randomized controlled trial in school-aged children with mild traumatic brain injury. J Head Trauma Rehabil. 2020. https://doi.org/10.1097/HTR.0000000000000584 In press.
[38] Yousefzadeh-Chabok S, Kapourchali FR, Ramezani S. Determinants of long-term health-related quality of life in adult patients with mild traumatic brain injury. Eur J Trauma Emerg Surg. 2019. https://doi.org/10.1007/s00068-019-01252-9 In press.
[39] Shi J, Shen J, Caupp S, et al. A new weighted injury severity scoring system: better predictive power for pediatric trauma mortality. J Trauma Acute Care Surg. 2018 Aug;85(2):334–40.
[40] Snyder CW, Ciesla DJ, Tepas JJ, et al. Two novel resource-based metrics to quantify pediatric trauma severity based on probability of requiring critical care and anesthesia services. J Trauma Acute Care Surg. 2020. https://doi.org/10.1097/TA.0000000000002607 In press.
[41] Roden-Foreman JW, Rapier NR, Foreman ML, et al. Rethinking the definition of major trauma: the need for trauma intervention outperforms Injury Severity Score and Revised Trauma Score in 38 adult and pediatric trauma centers. J Trauma Acute Care Surg. 2019;87(3):658–65.
[42] Notrica DM, Eubanks JM, Tuggle DW, et al. Nonoperative management of blunt liver and spleen injury in children: evaluation of the ATOMAC guideline using GRADE. J Trauma Acute Care Surg. 2015;79(4):683–93.