Mortality Among Injured Children Treated at Different Trauma Center Types

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IMPORTANCE Trauma is the leading cause of death among US children. Whether pediatric trauma centers (PTCs), mixed trauma centers (MTCs), or adult trauma centers (ATCs) offer a survival benefit compared with one another when treating injured children is controversial. Ascertaining the optimal care environment will better inform quality improvement initiatives and accreditation standards.

OBJECTIVE To evaluate the association between type of trauma center (PTC, MTC, or ATC) and in-hospital mortality among young children (5 years and younger), older children (aged 6-11 years), and adolescents (aged 12-18 years).

DESIGN, SETTING, AND PARTICIPANTS In this retrospective cohort study, injured children aged 18 years or younger who were hospitalized in the United States from January 1, 2010, to December 31, 2013, were observed for the duration of their admission until discharge or death. We included patients with an Abbreviated Injury Score of 2 or greater in at least 1 body region. Random-intercept multilevel regression was used to evaluate the association between center type and in-hospital mortality after adjusting for confounders. Stratified analyses in young children, older children, and adolescents were performed. We conducted secondary analyses limited to patients with severe injuries (Injury Severity Score ≥25). Both analyses were performed between January 1 and August 31, 2014. Data were derived from 252 US level I and II trauma centers voluntarily participating in the American College of Surgeons adult or pediatric Trauma Quality Improvement Program.

MAIN OUTCOME AND MEASURE In-hospital mortality.

RESULTS We identified 175,585 injured children. Crude mortality rates were 2.3% for children treated at ATCs, 1.8% for children treated at MTCs, and 0.6% for children treated at PTCs. After adjustment, children had higher odds of dying when treated at ATCs (odds ratio [OR], 1.57; 95% CI, 1.15-2.14) and MTCs (OR, 1.45; 95% CI, 1.05-2.01) compared with those treated at PTCs. In stratified analyses, young children had higher odds of death when treated at ATCs vs PTCs (OR, 1.78; 95% CI, 1.05-3.40), but there was no association between center type and mortality among older children (OR, 1.17; 95% CI, 0.65-2.11) and adolescents (OR, 1.23; 95% CI, 0.82-1.85). Results were similar in analyses of severely injured children: those treated at ATCs (OR, 1.75; 95% CI, 1.25-2.44) and MTCs (OR, 1.62; 95% CI, 1.15-2.29) had higher odds of death when compared with those treated at PTCs.

CONCLUSIONS AND RELEVANCE Injured children treated at ATCs and MTCs had higher in-hospital mortality compared with those treated at PTCs. This association was most evident in younger children and remained significant in severely injured children. Quality improvement initiatives geared toward ATCs and MTCs are required to provide optimal care to injured children.

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Trauma is the leading cause of death and disability for children in the United States. Every year, approximately 10 million children are treated for an injury and more than 9000 children die in the United States alone. Furthermore, pediatric trauma results in a substantial burden on the US economy, with a staggering estimated annual cost of more than $200 billion.

Pediatric hospitals have unique expertise in providing care to pediatric patients. This expertise addresses the unique disease states, physiological characteristics, and social needs of children. Similarly, specialized trauma care for children is available at designated pediatric trauma centers (PTCs). However, the number and geographic distribution of these centers require that either adult trauma centers (ATCs) or ATCs with added pediatric qualifications (mixed trauma centers [MTCs]) provide care to most injured children.

The precise optimal care environment offering a survival advantage to severely injured children is not clear. On one hand, PTCs provide children with specialized pediatric trauma care. However, ATCs may have higher patient volumes than PTCs, which could translate into improved outcomes. Some studies have shown lower mortality rates among children treated at PTCs or MTCs compared with those treated at ATCs alone, while other studies have shown no difference. One study showed lower mortality rates among severely injured children treated at ATCs. Many of these studies, however, are hampered by significant methodologic limitations, including insufficient injury severity risk adjustment and small sample sizes at the patient or center level.

Also, it is plausible that the benefits of one center type compared with another differ by patient age. For example, there is no reason to believe that the unique expertise available to care for an infant benefits an adult-sized adolescent. Heterogeneity in the type and quality of care across different pediatric age groups may account for the variable findings observed in previous studies.

We evaluated the association between care environment and in-hospital mortality among pediatric trauma patients. We hypothesized that the association between trauma center type and mortality differs across clinically relevant age strata. The purpose of identifying strengths and opportunities for improvement is not to redirect pediatric patients from one type of center to another; rather, it defines areas where trauma centers might need quality improvement to provide the highest level of care for children of all ages.

Methods

Study Design

This retrospective cohort study was designed to evaluate the association between trauma center type and in-hospital mortality among injured children of different age strata. The study was approved by the Sunnybrook Health Sciences Centre Research Ethics Board. Because this study was conducted using deidentified data, our ethics approval did not require informed patient or parental consent.

Data Sources and Participating Centers

Data were derived from 252 US trauma centers participating in the American College of Surgeons (ACS) adult or pediatric Trauma Quality Improvement Program (TQIP). The TQIP is a voluntary performance improvement program that was created to provide level I and II trauma centers with feedback on risk-adjusted outcomes for quality-improvement purposes. Trauma Quality Improvement Program data are extracted from the National Trauma Databank. Several variables are recorded, including patient demographics, injury characteristics, physiological data, complications, and outcomes. Extensive training of data abstractors and external validation checks are required by participating TQIP centers as a mechanism to improve data quality. Live training of TQIP registrars began in 2010, followed by formal training and on-site validation in 2012. As centers joined the TQIP at different times during our study period, we analyzed 4 years of data for all centers in this study regardless of when participation began.

Study Cohort

We identified patients aged 18 years or younger who were hospitalized at a TQIP trauma center between January 1, 2010, and December 31, 2013. We included patients with either blunt or penetrating trauma with an Abbreviated Injury Score (AIS) of 2 or greater in any body region. We excluded patients with superficial injuries, those who were transferred to another hospital or home directly from the emergency department, and those who were dead on arrival.

Trauma Center Classification

Our exposure was definitive care at a PTC, MTC, or ATC. We defined an ATC as any center having adult ACS verification or adult state designation and no pediatric qualifications. Pediatric trauma centers were defined as any center having exclusively either pediatric ACS verification or pediatric state designation. Mixed trauma centers were defined as any center having both adult and pediatric ACS verifications or state designations.

Outcomes and Covariates

The primary outcome was in-hospital death, which included patients who died in the emergency department or during their hospital admission. As case mix varied significantly across centers, we used multivariable regression to adjust for differences in mortality risk. The main effect in the model was trauma center type, with patient and injury characteristics considered as potential confounders. Clinically significant founders were included in the model a priori, and founders of uncertain significance were retained if they led to a ±10% change in the estimate of the exposure-outcome association.

Patient characteristics considered for inclusion into our model were age, sex, comorbidities, transfer status (direct from accident scene vs transfer to trauma center from other facility), and insurance type (commercial vs noncommercial). Injury characteristics considered were age-adjusted hypertension, initial motor Glasgow Coma Scale score (mGCS), injury mechanism (eg, motor vehicle collision, motorcycle, fall, pedestrian, other blunt trauma, firearm, cut and pierce), and the presence of severe injury (AIS ≥3) in any body region. In...
addition, we included an International Classification of Diseases, Ninth Revision (ICD-9)–derived injury severity score (ISS) based on survival risk ratios, 21-24 defined as the number of patients who survive a given ICD-9–coded injury divided by the total number of patients who sustain the injury. 25 Consistent with other reports, we used the survival risk ratio from the single worst injury for each patient, given its superiority compared with other risk adjustment methods. 21-24

We also considered the possibility that trauma center volume (number of injured pediatric patients per annum with AIS ≥2 in at least 1 body region) might account for observed mortality differences between center types. Prior studies have shown a strong association between trauma center volume and outcomes such as mortality. 26 To further explore how trauma center volume influenced the association between center type and mortality, we performed additional regression analyses with volume (quartiles) as a hospital-level covariate.

### Statistical Analysis

Categorical variables were summarized as counts and continuous variables were presented as means (if normally distributed) or as medians (if nonnormally distributed). Random-intercept multilevel regression was used to evaluate the association between trauma center type and in-hospital death after adjusting for potential confounders. Results were reported as adjusted odds ratios (ORs) and 95% CIs. As patients cared for in the same center were not independent, we accounted for clustering (correlation) within centers using hierarchical modeling. 27 Model discrimination was estimated using the C statistic and calibration was evaluated using observed vs predicted plots. The variance inflation factor was used to check for multicollinearity within the model. 28 Data for age-adjusted hypotension, mGCS, and insurance type were missing for fewer than 5% of patients, and no trauma center had more than 10% missing data for the entire study period. Rather than delete rec-

### Table 1. Patient Characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value*</th>
<th>ATC (n = 62 119)</th>
<th>MTC (n = 61 766)</th>
<th>PTC (n = 51 700)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, mean (SD), y</td>
<td>12.4 (5.8)</td>
<td>10.1 (5.9)</td>
<td>8.0 (5.1)</td>
<td></td>
</tr>
<tr>
<td>Age category, y</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤5</td>
<td>10 818 (17.4)</td>
<td>17 771 (28.8)</td>
<td>19 551 (37.8)</td>
<td></td>
</tr>
<tr>
<td>6-12</td>
<td>11 388 (18.3)</td>
<td>16 866 (27.3)</td>
<td>19 140 (37.0)</td>
<td></td>
</tr>
<tr>
<td>13-18</td>
<td>39 913 (64.3)</td>
<td>27 129 (43.9)</td>
<td>13 009 (25.2)</td>
<td></td>
</tr>
<tr>
<td>Male sex</td>
<td>42 470 (68.4)</td>
<td>41 022 (66.4)</td>
<td>33 406 (64.6)</td>
<td></td>
</tr>
<tr>
<td>Transfer patient</td>
<td>20 386 (32.8)</td>
<td>26 875 (43.5)</td>
<td>25 944 (50.2)</td>
<td></td>
</tr>
<tr>
<td>Injury mechanism</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Motor vehicle collision</td>
<td>15 662 (25.2)</td>
<td>12 649 (20.5)</td>
<td>4871 (9.4)</td>
<td></td>
</tr>
<tr>
<td>Motorcycle</td>
<td>1302 (2.1)</td>
<td>875 (1.4)</td>
<td>233 (0.5)</td>
<td></td>
</tr>
<tr>
<td>Fall</td>
<td>18 716 (30.1)</td>
<td>24 284 (39.3)</td>
<td>28 504 (55.1)</td>
<td></td>
</tr>
<tr>
<td>Pedestrian</td>
<td>14 539 (23.4)</td>
<td>14 651 (23.7)</td>
<td>13 009 (25.3)</td>
<td></td>
</tr>
<tr>
<td>Other blunt trauma</td>
<td>6157 (9.9)</td>
<td>6079 (9.8)</td>
<td>3747 (7.3)</td>
<td></td>
</tr>
<tr>
<td>Firearm</td>
<td>4054 (6.5)</td>
<td>1990 (3.2)</td>
<td>568 (1.1)</td>
<td></td>
</tr>
<tr>
<td>Cut and pierce</td>
<td>1689 (2.7)</td>
<td>1238 (2.0)</td>
<td>693 (1.3)</td>
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<tr>
<td>Injury Severity Score</td>
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<td></td>
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<td>4-8</td>
<td>26 091 (42.0)</td>
<td>26 627 (43.1)</td>
<td>26 445 (51.2)</td>
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</tr>
<tr>
<td>9-15</td>
<td>20 431 (32.9)</td>
<td>20 008 (32.4)</td>
<td>17 119 (33.3)</td>
<td></td>
</tr>
<tr>
<td>16-24</td>
<td>9640 (15.5)</td>
<td>9908 (16.0)</td>
<td>5887 (11.4)</td>
<td></td>
</tr>
<tr>
<td>≥25</td>
<td>5957 (9.6)</td>
<td>5223 (8.5)</td>
<td>2169 (4.2)</td>
<td></td>
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<tr>
<td>Age-adjusted hypotension</td>
<td>2038 (3.3)</td>
<td>2493 (4.0)</td>
<td>1993 (3.9)</td>
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<tr>
<td>Motor Glasgow Coma Scale score</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-2</td>
<td>4084 (6.6)</td>
<td>3709 (6.0)</td>
<td>1305 (2.5)</td>
<td></td>
</tr>
<tr>
<td>3-4</td>
<td>1158 (1.9)</td>
<td>872 (1.4)</td>
<td>609 (1.2)</td>
<td></td>
</tr>
<tr>
<td>5-6</td>
<td>54 148 (87.2)</td>
<td>54 419 (88.1)</td>
<td>46 507 (90.0)</td>
<td></td>
</tr>
<tr>
<td>Severe injury</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head</td>
<td>13 457 (21.7)</td>
<td>14 660 (23.7)</td>
<td>9672 (18.7)</td>
<td></td>
</tr>
<tr>
<td>Chest</td>
<td>10 251 (16.5)</td>
<td>8481 (13.7)</td>
<td>2881 (5.6)</td>
<td></td>
</tr>
<tr>
<td>Abdomen</td>
<td>4573 (7.4)</td>
<td>4064 (6.6)</td>
<td>2296 (4.4)</td>
<td></td>
</tr>
<tr>
<td>Upper extremities</td>
<td>2942 (4.7)</td>
<td>2836 (4.6)</td>
<td>4689 (9.1)</td>
<td></td>
</tr>
<tr>
<td>Lower extremities</td>
<td>8816 (14.2)</td>
<td>8853 (14.3)</td>
<td>6374 (12.3)</td>
<td></td>
</tr>
<tr>
<td>Spine</td>
<td>2230 (3.6)</td>
<td>1711 (2.8)</td>
<td>707 (1.4)</td>
<td></td>
</tr>
<tr>
<td>Commercial insurance type</td>
<td>28 967 (46.6)</td>
<td>29 020 (47.0)</td>
<td>24 343 (47.1)</td>
<td></td>
</tr>
<tr>
<td>Mortality</td>
<td>1451 (2.3)</td>
<td>1118 (1.8)</td>
<td>323 (0.6)</td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: ATC, adult trauma center; MTC, mixed trauma center; PTC, pediatric trauma center.

*Data are presented as number (percentage) of patients unless otherwise indicated.

The one continuous variable (age) was normally distributed; hence, the mean (SD) was presented.

Values are missing for motor Glasgow Coma Scale score and do not total the patient cohort numbers for each center type.

Abbreviated Injury Score ≥3.
In secondary analyses, we examined the association between center type and mortality in a cohort of children who were at highest risk of adverse outcomes (ISS ≥25). All analyses were repeated in this cohort. We performed additional analyses evaluating the association between center type and mortality in select children who arrived direct from the accident scene and were injured in motor vehicle collisions, a more homogeneous population in which confounding was less of a concern. By doing so, the likelihood of unmeasured differences among injured children triaged to one center type compared with another was reduced, thereby improving the validity of our comparison.

### Age-Stratified Analyses

To evaluate whether the effect of trauma center environment on mortality differed across age strata, we developed separate multilevel regression models to examine the association in young children (5 years or younger), older children (aged 6-11 years), and adolescents (aged 12-18 years). Stratum-specific ORs were generated within each age group to determine how the magnitude of the effect of center type on mortality differed. All statistical analyses were performed using SAS, version 9.3 (SAS Inc.). All tests were 2 sided, with \( P < 0.05 \) considered statistically significant.

### Results

From January 1 through August 31, 2014, we identified 175,585 injured children admitted to 252 trauma centers across the United States. Overall in-hospital mortality in the study cohort was 1.6% (n = 2892). Patient and hospital characteristics are presented in Table 1 and Table 2. Overall, 35.4% of patients received definitive care at ATCs, 35.2% at MTCs, and 29.4% at PTCs. Relative to children treated at PTCs, children treated at ATCs and MTCs were older, were more severely injured, had higher rates of penetrating injury, and had lower mGCS scores. At the hospital level, PTCs were more likely to be level I trauma centers, be university teaching, and have higher pediatric patient volumes.

Crude mortality rates were 2.3% for children treated at ATCs, 1.8% for children treated at MTCs, and 0.6% for children treated at PTCs. When compared with children treated at PTCs, the crude OR of death for children treated at ATCs was 4.31 (95% CI, 3.31-5.62) and was 3.29 (95% CI, 2.47-4.37) for those treated at MTCs (Figure 1).

### Adjusted Analyses

After adjustment, injured children had higher odds of death when treated at ATCs (OR, 1.57; 95% CI, 1.15-2.14) and MTCs (OR, 1.45; 95% CI, 1.05-2.01) compared with children treated at PTCs (Figure 1). All of the following were associated with higher odds of death: presence of hypotension; lower mGCS scores; motor vehicle collision, pedestrian, and firearm injury mechanism; and severe head, chest, and abdominal injuries (Table 3). In contrast, having been transferred from another facility or having commercial insurance were associated with lower odds of death (Table 3). The regression model had excellent discrimination (C statistic, 0.96).

In secondary analyses, results were similar (Figure 2). Severely injured children treated at ATCs (OR, 1.75; 95% CI, 1.25-
2.44) and MTCs (OR, 1.62; 95% CI, 1.15-2.29) had higher odds of death when compared with those treated at PTCs. Children who were injured in motor vehicle collisions and those brought directly from the scene of the accident also had higher odds of death when treated at ATCs (OR, 1.64; 95% CI, 1.09-2.77) and MTCs (OR, 1.65; 95% CI, 1.05-2.82) vs those treated at PTCs.

**Age-Stratified Analyses**

In stratified analyses (Figure 1), younger children had higher odds of death when treated at ATCs compared with those treated at PTCs (OR, 1.78; 95% CI, 1.05-3.40), but no significant difference in the odds of death was seen in the same age group among those treated at MTCs vs PTCs (OR, 1.52; 95% CI, 0.92-2.52). There was no association between trauma center type and mortality among older children (OR, 1.23; 95% CI, 0.82-1.85) and adolescents (OR, 1.17; 95% CI, 0.76-1.79).

In the secondary analyses of severely injured children, younger children had higher odds of death when treated at both ATCs and MTCs vs PTCs (Figure 2). Similar to our primary analyses, no significant association between trauma center type and mortality in older children or adolescents was observed (Figure 2).

**Discussion**

In a large US population of injured children, we found that children treated at ATCs and MTCs have higher odds of death than those treated at PTCs. The findings were robust after case-mix adjustment and on additional analyses in more homogeneous cohorts of children. We found that the effect of trauma center type on in-hospital mortality was most apparent in younger children; compared with older children and adolescents, younger children had higher odds of death when treated at ATCs vs PTCs. In our secondary analyses of severely injured children, younger children had higher odds of death when treated at both ATCs and MTCs vs PTCs.
PTCs, whereas there was no such association in other age groups. Center volume attenuated the strength of the association between trauma center type and mortality in all children; however, the direction of the observed effect remained consistent. Furthermore, volume had no influence on the association in severely injured children. As such, the association between trauma center type and mortality is not entirely explained by center volume and remained evident even after accounting for differences in volume.

Previous studies evaluating the association between trauma center type and mortality have produced conflicting results. Many studies have shown higher mortality rates among injured children treated at ATCs and MTCs vs PTCs. These studies used a variety of methods of injury severity risk adjustment, including ISS, Trauma and Injury Severity Score (TRISS), and ICD-9-derived Injury Severity Score (ICISS). However, studies using these same methods of risk adjustment have demonstrated no difference in mortality between trauma center types. One study used TRISS methods and demonstrated higher survival among injured children treated at ATCs and MTCs vs PTCs. More recent state-specific studies have used instrumental variable analyses, but results again have been conflicting. One Florida state-specific study showed that injured children had higher mortality within centers, in addition to controlling for the majority of confounders. As our main method of injury severity risk adjustment, we used the single worst injury based on the injury scoring systems and has been validated in the pediatric population as highly predictive of mortality. Using these techniques, we adjusted for differences in case mix among injured children triaged to one center vs another, improving the validity of our comparison. To ensure our results were robust, we also performed secondary analyses in children with severe injuries. In addition, we performed stratified analyses to evaluate how the association between center type and mortality varied across age groups, something reported in few other studies. Last, we explored trauma center volume within the context of the association between center type and mortality. We elected not to adjust for other hospital-level factors, as the goal of this study was to evaluate outcomes that were related to structure and processes of care after adjusting for patient case mix. Since all center-level variables work through differences in structure and process, adjusting for these variables leaves no potential to offset outcome, assuming that case mixes are similar. We did, however, explore patient volume given a prior demonstrated association between trauma center volume and mortality.

There are limitations that should be considered when interpreting our findings. We used a voluntary trauma registry of only level I and II trauma centers, which may introduce selection bias. Hence, we acknowledge that our results are only generalizable to the type of trauma centers and patients studied herein. In addition, among transferred patients, we have no data on where patients received care before transfer or where patients were transferred to once they left the hospital. To address this issue, we included interfacility transfer status as a covariate, excluded patients who were transferred out of only level I and II trauma centers, which may introduce selection bias. Hence, we acknowledge that our results are only generalizable to the type of trauma centers and patients studied herein. In addition, among transferred patients, we have no data on where patients received care before transfer or where patients were transferred to once they left the hospital. To address this issue, we included interfacility transfer status as a covariate, excluded patients who were transferred out of only level I and II trauma centers, which may introduce selection bias. Hence, we acknowledge that our results are only generalizable to the type of trauma centers and patients studied herein. In addition, among transferred patients, we have no data on where patients received care before transfer or where patients were transferred to once they left the hospital. To address this issue, we included interfacility transfer status as a covariate, excluded patients who were transferred out
mortality outcomes exist between different trauma center types, quality improvement initiatives can focus on determining what processes of care are responsible for this gap. Once identified, beneficial processes can be highlighted and adopted without changes to established triage patterns. Our study also demonstrates a consistent gradient effect for children treated at ATCs, MTCs, and PTCs, with a survival benefit for children treated at MTCs vs those treated at ATCs. Determining the causal pathways that confer a survival benefit to injured children treated at MTCs may also provide valuable information into what pediatric qualifications can be added to ATCs.

**Conclusions**

Future studies examining which processes of care result in lower mortality at PTCs and in some cases, MTCs, should be undertaken to give ATCs the ability to provide high-level care to all injured children. Further research incorporating prehospital, posthospital, and geographical data are also warranted. By identifying areas for improvement, additional resources can be targeted where needed. Changes in the accreditation process may also be required to ensure that trauma centers adopt all relevant practices.
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Author Contributions: Dr Sathya and Nathens had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. Study concept and design: Sathya, Alali, Scales, Karanicolas, Burd, Nathens. Acquisition, analysis, or interpretation of data: Sathya, Alali, Wales, Scales, Karanicolas, Nance, Xiong, Nathens. Drafting of the manuscript: Sathya, Alali, Nathens. Critical revision of the manuscript for important intellectual content: All authors. Statistical analysis: Sathya, Alali, Xiong. Obtained funding: Sathya, Nathens. Administrative, technical, or material support: Sathya, Nathens. Study supervision: Wales, Scales, Karanicolas, Nance, Nathens.

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Disclaimer: Although the American College of Surgeons oversees the dataset used, the authors of this study are solely responsible for the study design, analysis, and conclusions presented here.

Previous Presentation: Preliminary results pertaining to this study were presented at the Scientific Session of the Annual Meeting of the American College of Surgeons Committee on Trauma, March 20, 2014, Chicago, Illinois; and at the Canadian Association of Pediatric Surgeons meeting, September 18, 2014; Montreal, Quebec, Canada.

REFERENCES