Disparities in the Delivery of Pediatric Trauma Care

Mikael Petrosyan, MD, Yigit S. Guner, MD, Claudia N. Emami, MD, and Henri R. Ford, MD

Background: Trauma is the leading cause of morbidity and mortality in children. During the last few decades, trauma systems have evolved to improve the care of the injured with an ultimate goal of saving lives. As a result, pediatric trauma centers (PTC) have been established to optimize outcomes for injured children. We sought to determine whether injured children treated at PTC or adult trauma centers (ATC) with added qualifications to treat injured children receive better trauma care than those treated at other hospitals or trauma centers.

Methods: We reviewed more than 60 published studies on pediatric trauma outcomes. The studies included registry analysis: single and multihospital experience; abdominal, head and neck, and thoracic trauma; as well as functional outcomes.

Results: The data show that most injured children are not treated at PTC due to the geographically limited distribution of such specialized care, lack of pediatric surgeons, and other specialists. These limitations create persistent disparities in outcomes for injured children depending on where they are treated. Some of the larger database analyses suggest lower mortality rate, better outcome for nonoperative treatment of blunt abdominal injuries, and improved overall functional outcome for those children treated at PTC. However, others fail to demonstrate differences for children treated at ATC or ATC with added qualifications.

Conclusion: Although this analysis does not provide a definitive answer to the question as to which type of trauma center provides better care for injured pediatric patients, it identifies current gaps and disparities in the care of injured children that can be remedied through education and training.

Key Words: Pediatric trauma, Disparities in pediatric trauma, Pediatric trauma center.

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Trauma is the leading cause of death in children between the ages of 1 and 14 years in the United States.[1] Nearly 16,000,000 children visit emergency departments for injuries each year. Of those, 15,000 die and 20,000 develop permanent disabilities, most of which are the result of head injuries.[2,3] There are nearly 10 million pediatric injury-related primary care visits in the United States annually,[4] which make injury one of the principle reasons for health care expenditures for children between the ages of 5 and 14 years.[5] Indeed, injuries pose a serious economic burden on society. Data from the National Health Accounts show that in the year 2000 injury-related medical expenditures exceeded 117 billion dollars.[6] Furthermore, Finkelstein and coworkers[7] from the Centers for Disease Control and Prevention estimate that treatment of injuries sustained in the year 2000 will ultimately cost 406 billion dollars; this figure is based on an estimated 80.2 billion dollars in medical care costs and 326 billion dollars in productivity losses. Of that total, injuries among children ages 0 to 14 years account for 51 billion dollars.[8] These figures underscore the public health impact of pediatric trauma in contemporary American society. To that end, within the last three decades, pediatric trauma centers (PTC) were established to improve outcomes for injured children. However, there is controversy regarding whether PTC have made a significant impact on both the mortality and morbidity of pediatric trauma patients. In this report, we will review differences in outcomes for injured children treated in different trauma centers in the United States.

Pediatric Trauma Centers

PTC have evolved during the past three decades because of the recognition that injured children have unique characteristics and needs that are not easily addressed in adult trauma centers (ATC) because of the lack of experienced personnel and age-appropriate equipment to handle these patients. As a result, PTC emerged in the 1970s in Baltimore, Boston, Ann Arbor, Washington DC, and Brooklyn.[9–11] Indeed, the American College of Surgeons (ACS) Committee on Trauma notes that injured children have special needs that "may be optimally provided in the environment of a children's hospital with a demonstrated commitment to trauma care."[12] During the years, the number of PTC has grown significantly from 34 designated level I PTC in 1997 to the point where there are currently 65 level I and level II PTC verified by the ACS[13] throughout the United States and North America.[14] However, despite the significant increase in the number of PTC, only about 10% of injured children are treated at PTC, which suggests that even more PTC may be needed.[15–17] Because of the limited number of PTC, some ATC have sought added qualifications (ATC AQ) to treat injured children. However, despite the addition of these centers, a recent study by Segui-Gomez et al. reported that only 53% of injured children are treated in a trauma center, whether ATC or PTC. The remainder of the injured children are treated at centers without any trauma credentialing.[18] This phenomenon is due in part to the fact that most ATC and PTC are located in major

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From the Department of Surgery (M.P., C.N.E.), Keck School of Medicine, University of Southern California, Los Angeles, California; Department of Pediatric Surgery (M.P., Y.S.G., C.N.E.), Childrens Hospital Los Angeles, Keck School of Medicine, University of Southern California, Los Angeles, California; and Department of Surgery (Y.S.G.), University of California Davis Medical Center, Sacramento, California.
Address for reprints: Henri R. Ford, MD, Department of Surgery, Keck School of Medicine, University of Southern California, Children's Hospital of Los Angeles, 4650 Sunset Boulevard, Mailstop #72, Los Angeles, CA; email: hford@chla.usc.edu.

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metropolitan areas.[19] The question remains, however, whether PTC exert a significant impact on morbidity and mortality of injured children.

Densmore et al.,[16] using the KIDS inpatient database, demonstrated that pediatric trauma patients treated at children's hospitals have improved outcomes compared with those treated at adult hospitals. Of those treated at children's hospitals, 10.7% had significant reduction in mortality rates, length of stay, and total hospital costs.[16] Mortality rates were much lower at children's hospitals (0.9%) compared with that of adult hospitals (1.4%), even after adjusting for Injury Severity Score (ISS).[16] Moreover, mortality was lowest at children's hospitals for all injury types and for the youngest and most severely injured patients (age 0–10 years; ISS >15).[16] However, this study did not distinguish between outcomes of injured patients treated at ATC, ATC AQ, or PTC because trauma center designation was not available in the database. Consistent with these observations, several investigators have demonstrated higher mortality rates for injured children treated in rural areas without trauma centers, in contrast to improved survival and functional outcomes for those treated at PTC.[20–22] For instance, Potoka et al.[22] evaluated 13,351 injured children entered in the Pennsylvania Trauma Outcome Study (PTOS) database between 1993 and 1997. A majority of injured children in this study were treated at PTC or ATC AQ, with the preponderance of those younger than 10 years of age being admitted to PTC. Overall survival rates were superior at PTC and ATC AQ when compared with level I or level II ATC. The authors concluded that injured children treated at PTC or ATC AQ had better overall outcomes than those treated at ATC.[22] This study corroborates previous reports by Segui-Gomez et al.[18] who showed that injured children treated at PTC had a lower mortality rate than those treated elsewhere.

Osler et al.[15] used the National Pediatric Trauma Registry to evaluate survival rates. In this study, 53,113 pediatric trauma cases were identified from 53 centers (22 PTC and 31 ATC). The overall mortality rate was lower at PTC (1.81% of 32,554 children) than at ATC (3.8% of 18,368 children). However, after adjusting for ISS, Pediatric Trauma Score, mechanism of injury, age, sex, ACS verification, and clustering effect with a single logistic regression model, the odds of survival were not significantly different at PTC compared with ATC (OR 1.02; 95% CI 0.83–1.26; $p = 0.577$). Conversely, trauma centers that were verified by the ACS had substantially better survival rates than nonverified centers (OR 0.75; 95% CI 0.58–0.97; $p = 0.013$). In a parallel study, Bensard et al.[19] evaluated the probability of survival for injured children treated by adult surgeons at a single institution (ATC I). They showed no difference in survival for injured children compared with adults. Moreover, observed survival in children (98%) was similar to the Trauma and Injury Severity Score-predicted survival (Ps) (97.7%). Therefore, the authors concluded that treatment of injured children at an ATC I does not adversely affect outcome, consistent with the study by Osler et al.

Abdominal Trauma

Blunt abdominal trauma accounts for more than 90% of all pediatric injuries.[23] The spleen and liver are the most commonly injured organs during blunt force trauma.[23] Nonoperative management (NOM) of splenic injury was first described by Douglas and Simpson[24] from the Hospital for Sick Children in Toronto, Canada. Since then, the management of solid organ injuries has continued to evolve and has become primarily nonoperative.[25–28] In fact, splenectomy for trauma, which used to be common practice until the late 1970s, is now rarely performed. However, despite numerous studies describing the success of NOM of splenic injuries and the benefits of splenic preservation, actual practice patterns in children with splenic injuries vary widely based on the site of treatment. As a result, significant disparities in outcomes exist for children with splenic injuries.

Keller and Vane identified 817 children (aged younger than 19 years) in the National Pediatric Trauma Registry who sustained blunt abdominal injuries. Twenty-one percent of children managed by pediatric surgeons required operative intervention for splenic injuries compared with 52% of children managed by "adult" trauma surgeons. Moreover, this highly significant difference in operative rates remained even after controlling for ISS and age. Splenectomy rate was higher in children treated by nonpediatric surgeons (24% vs. 13%; $p < 0.05$).[29] A similar study by Stylianos et al.,[30] using state health department data sets from several states (New Jersey, California, Florida, and New York), identified 3,232 children with blunt splenic injuries. Interestingly, the rate of operation was significantly lower if they were treated at a trauma center (9.2%) compared with a center without any trauma credentialing (18.5%). In this study, the ISS-adjusted odds of splenectomy was 2.1 (95% CI 1.45–3.09) at a nontrauma center compared with a trauma center.[30] Davis et al.,[31] using Pennsylvania's 175 hospital in patient database, analyzed practice patterns in different centers. They identified 3,245 patients with blunt splenic injuries. The overall rate of splenectomy was 23.2%.[31] Compared with that of PTC, the relative risk (with 95% CI) for splenectomy was 4.4 (3.0–6.3) at ATC AQ, 6.2 (4.4–8.7) at ATC I, 6.3 (5.3–7.4) at ATCII, and 5 (4.2–5.9) at nontrauma centers.[31] The authors concluded that practice patterns vary significantly based on the trauma center designations.[31] Consistent with these observations, Potoka et al.[32] examined differences in the management of splenic injuries at PTC and ATC, using the PTOS registry. In their study, 15.1% of patients required splenectomy. However, the rate of splenectomy at PTC was <3%. Moreover, significantly more operations (splenectomy or splenorrhaphy) were performed for splenic injuries at ATC than at PTC despite similar mean Abbreviated Injury Scores (3.64–4.16). In fact, ATC were more likely to perform splenectomy for injured children than PTC and fewer splenectomies were performed per spleen injury at PTC. Mortality rate for splenic injuries was lower at PTC (5.8%) compared with ATC AQ (17%), ATCI (16.7%), or ATCII (8.9%). Similar results were demonstrated by Mooney et al.,[33] using the KIDS inpatient database, where the adjusted odds of undergoing splenectomy was 2.8 (95% CI 1.4–5.7) at adult hospitals compared with free-standing pediatric hospitals. Using an administrative dataset from New England, Mooney and Forbes[34] also showed that adult general surgeons were 3.1 times more likely to perform splenectomy compared with pediatric surgeons (95% CI 2.3–4.4), consistent with a previous study by Keller and Vane.[29] On the basis of these findings, the authors advocated for the distribution and implementation of guidelines for NOM of splenic injuries to all centers involved in the treatment of injured children.

NOM of hepatic injuries has also been increasingly successful. Such success is related, at least in part, to the availability of adjunctive procedures such as angiography, endoscopic retrograde cholangiopancreatography, and percutaneous drainage.[25,35–37] However, despite the success of NOM, disparities also exist in the treatment of hepatic injuries in children. Potoka et al.[32] also showed that PTC performed fewer surgical interventions per liver injury of similar severity (as defined by Abbreviated Injury Score) compared with ATC AQ, ATC I, or ATC II. Moreover, mortality rates for liver injury were significantly lower at PTC (9.1%) compared with ATC AQ (19.4%), ATC I (18.2%), and ATC II (32.3%).[32] In contrast, Klapheke et al.[38] did not demonstrate any differences in the need for surgical intervention when comparing adults with children. They evaluated all patients with blunt liver injuries admitted to an ATC and a PTC.[38] There were 389 liver injuries identified (pediatric = 90, adult = 299); 25% of adult injuries were greater than or equal to grade III, whereas 23% of pediatric injuries were grade III or higher.[38] Primary operative intervention rates were similar in both groups: 18% for adults and 16% for pediatric trauma patients.[38] Mortality rates were also similar: 7% for pediatric and 9% for adult patients.[38] The authors concluded that despite similar injury patterns, pediatric patients sustained fewer liver-related complications requiring less invasive procedures.[38] In another study, Sims et al.[39] examined whether adult and pediatric surgeons treated children differently. They compared 114 pediatric with 167 adult surgeons and gave them complex scenarios consisting of both splenic and liver injuries and asked for management options.[39] For all scenarios, they found adult surgeons more likely to operate or pursue interventional procedures or allow blood transfusions.[39] Overall, the above-mentioned studies underscore the fact that significant differences exist in the type of treatment injured children receive when managed at PTC compared with ATC.

The current success of NOM of pediatric blunt solid organ injuries is largely because of prompt clinical assessment and thoughtful observation. However, failure of NOM can have devastating consequences; thus, timely identification of predictors of failure of NOM is important. In a recent multi-institutional study, the failure rate for NOM was 5% during a 6-year period, with an overall mortality of 8%.[40] Failure rates for solid organ injuries were 3% for kidney, 3% for liver, 4% for spleen, and 18% for pancreas. Factors associated with increased failure rate included bicycle-related injuries, isolated pancreatic injuries, more than one solid organ injury, and isolated grade 5 solid organ injury. The median time to failure was 3 hours, with 38% failing by 2 hours, 59% by 4 hours, and 76% by 12 hours. Thus, continued surgical evaluation and thorough assessment during the entire hospital stay are of utmost importance to decrease morbidity and mortality in injured pediatric patients.

Head and Neck Injuries

Traumatic brain injury (TBI) is the most common cause of death and disability in children.[41,42] Approximately 75% of pediatric deaths from trauma are due to head injury.[41,43] Nearly half a million children younger than 14 years sustain TBI annually.[42] The incidence appears to be greatest in children younger than 12 months (14%) compared with children between 12 and 24 months of age (1%), and the most common mechanism of TBI in children younger than 24 months is child abuse.[44] Children with TBI exhibit different clinical signs than adults partly due to behavioral and emotional differences between pediatric and adult trauma victims. Moreover, it is difficult to follow the injured child clinically for evolution or progression of TBI. Therefore, the morbidity of TBI may indeed be higher in children whose injuries are not diagnosed in a timely fashion. Neuropsychological sequelae associated with pediatric TBI can influence key developmental processes, such as learning, social function, and emotional awareness.[45,46] Despite the implementation of guidelines to manage children with TBI that may positively influence overall outcome, disparity in outcomes between PTC and other trauma centers still exists.

Sherman et al.,[47] using the PTOS database analyzed 16,108 injured children. They measured "unexpectedness of survival," defined as actual survival (As) minus Ps, for injured children treated at various trauma centers in the state of Pennsylvania. According to this study, unexpected survival (As − Ps) in injured children was higher at ATC I (10.7%) and ATC AQ (11.8%) compared with PTC (6.2%). There was no significant difference in unexpected survival for both splenic and liver injuries. However, for head injuries, ATC AQ and ATC I had better unexpected survival than PTC (5.1 and 4.8 vs. 3.3), when adjusted for both age and ISS. Nonetheless, the overall As was still better at PTC in injured children with both ISS $\leq$16 and ISS $>$16, suggesting that Trauma and Injury Severity Score methodology to predict probability of survival in children may be imprecise.[47]

Although the foregoing findings suggest that results or outcomes were comparable in adult and PTC, this study did not address functional outcome after head injury in the pediatric population, which can influence overall long-term outcomes. Potoka et al.[32] demonstrated disparities between ATC and PTC in the treatment of TBI. Using the PTOS registry, they showed that mortality rates were lower for children with an initial Glasgow Coma Score $<$8 if they were treated at PTC (21%) or ATC AQ (20.5%), when compared with ATC I (31%) or ATC II (27.5%).[32] Similar observations were made after neurosurgical procedures, where the mortality rates were 13.5% and 15.7% for PTC and ATC AQ, respectively, when compared with 18% and 24% for ATC I and ATC II, respectively.[32]

Children who sustain nonaccidental TBI represent an important subset for which PTC or ATC AQ could significantly impact overall outcome, because of the potential adverse effects of delay in diagnosis and treatment on morbidity and mortality, as well as prevention of future abuse. Jenny et al.[48] reported that the mean time of diagnosis of nonaccidental TBI is 7 days in children treated at PTC. They noted that 15 of 173 children were reinjured and five children died in this group.[48] The authors further speculated that four of five deaths in this group may have been prevented by timely diagnosis.[48] Although similar data are not available for children treated at ATC, one can speculate that outcome for nonaccidental TBI is unlikely to be any better because of the challenges involved in making the diagnosis in younger infants. Furthermore, ATC may also lack the social support available in a pediatric hospital for cases of child maltreatment.

The evaluation of cervical spine injuries is another area where disparities may exist between ATC compared with PTC. However, this category is rather difficult to study as the incidence of cervical spine injuries in pediatric patients is extremely low (~1%) and many PTC are actively developing specific guidelines or protocols to manage potential cervical spine injuries.[49] Considerable debate exists regarding the optimal approach for clearing the cervical spine in conscious children younger than 5 years because of the difficulties involved in performing an adequate physical examination and the rather subtle signs of injury in these young children. There is a paucity of data in the literature supporting the routine use of computed tomography (CT) or magnetic resonance imaging as screening tools in pediatric patients. One recent study by Estrada and coworkers[50] identified 103 patients younger than 3 years who were treated for blunt trauma at PTC during a 5-year period. All patients underwent clinical examination; only 49 patients (48%) had radiographic imaging of their cervical spine. Two patients had an abnormal clinical examination and underwent an additional cervical CT scan, which failed to reveal any clinically significant abnormality. There was no statistically significant difference in the diagnosis of cervical spine injury between patients who underwent clinical examination alone and those who also had a CT scan of the cervical spine. Thus, the authors concluded that routine CT scanning of the cervical spine in children 3 years of age or younger who sustain blunt force trauma but have a normal clinical examination is an ineffective tool for detecting cervical spine injury.

Overall, the clearance of the cervical spine should be performed in a systematic manner with strategies aimed at decreasing the need for radiation exposure. To that end, Viccellio et al.[52] showed that the use of National Emergency X-Radiography Utilization Study[51] guidelines can reduce the use of spine imaging in children by 20%. The major concern regarding the routine use of CT scanning of the cervical spine in children is the potential for cancer due to excessive radiation exposure.[53] Estimated lifetime cancer mortality risks attributable to the radiation exposure from a CT in a 1-year old are 0.18% (abdominal) and 0.07% (head); an order of magnitude higher than for adults. In the United States, of approximately 600,000 abdominal and head CT examinations performed annually in children younger than 15 years, it is estimated that 500 of these individuals may ultimately die from cancer attributable to the CT radiation.[54]

Less common than head injuries, but an important cause of significant morbidity and mortality among injured children, are neck injuries. These injuries can be life-threatening because of associated laryngotracheal disruption. The true incidence of blunt pediatric neck injuries is unknown. This is attributed to the fact that a number of patients die at the scene.[55] A study from the Children's Hospital of Pittsburgh identified a total of 23 neck injuries during a 5-year period, which represented only 0.5% of all trauma admissions.[56] There were 9 blunt and 14 penetrating neck injuries. Treatment of all patients with blunt neck injury included direct laryngoscopy, bronchoscopy (DL & B), and esophagoscopy. At the time of presentation, the most common symptom in patients who sustained blunt neck injury was hoarseness followed by subcutaneous emphysema. Seven patients underwent neck exploration and successful repair of the laryngotracheal injuries. There were two deaths; one of these patients had laryngeal transection, which was not recognized at the time of DL & B. The other death resulted from associated tracheobronchial disruption secondary to massive blunt chest trauma. In contrast, none of the patients with penetrating neck injuries had any evidence of airway compromise. They were more likely to be treated nonoperatively, to have a shorter stay in the hospital and intensive care unit, and to have a lower ISS. There were no deaths in this group. The authors concluded that all patients with blunt neck trauma should undergo emergent and meticulous DL & B. Visualization of laryngotracheal disruption mandates immediate neck exploration and primary repair. Future studies will be needed to evaluate outcomes in pediatric patients with neck injuries treated at different trauma centers.

Thoracic Trauma

Compared with adults, thoracic trauma is less common in children, with an estimated incidence of 4% to 6%.[57] Thoracic injury patterns are different in children, when compared with adults. The predominant mechanism responsible for thoracic injury in children is blunt trauma.[58,59] Anatomic differences in young children, such as the presence of a narrow trachea, which makes them more prone to obstruction by blood and debris, may exacerbate the morbidity of significant thoracic injury in this population. Indeed, control of the pediatric airway can be more challenging and right main stem intubations are more common in children, when compared with adults. In fact, DiRusso et al.[60] recently demonstrated that field intubations in children do not improve survival but increase complication rates. There are insufficient data comparing outcomes for children with thoracic injuries treated at PTC versus ATC. Peterson et al.[61] evaluated 2,415 patients from a single ATC I who sustained blunt or penetrating thoracic trauma during an 8-year period. Seventy-nine patients were 12 years of age or younger (children), 137 were between 13 and 17 years of age (adolescent), and the remaining were adults (1,857). More children sustained blunt thoracic trauma (81%) compared with that of the other age groups; the rate of thoracotomy after blunt thoracic trauma was unrelated to age. However, penetrating thoracic trauma was more common in adolescents (58%) and the rate of thoracotomy was higher in adolescents compared with the other age groups. The authors concluded that children are more susceptible to blunt thoracic injuries, and thus, they advocated the use of a specific algorithm for the adolescent population.

Aortic or great vessel injuries in the pediatric population are extremely rare.[62] They are typically caused by blunt trauma.[58,63,64] Endovascular stent grafting is a new alternative to open aortic repair in injured children.[65] The long-term outcome with this type of a repair is not yet known in adults or children. It is currently provided as a bridge for children who are otherwise too unstable to undergo open operative repair.[65,66] However, most of the experience with these types of emerging techniques may be available primarily at ATC as the need for such procedures is rare in free-standing children's hospitals.

CONCLUSION

Pediatric trauma remains the most common cause of mortality and morbidity in children. Despite the establishment of ATC and PTC to reduce injury-related mortality and morbidity, to date, disparities in pediatric trauma care persist. The limited number of PTC, pediatric surgeons, and specialists may be responsible for some of the ongoing differences. Review of the literature indicates that the question of whether injured children treated at PTC have a better outcome than those treated at ATC still remains unanswered. Some of the larger database analyses suggest lower mortality rate, better outcome for nonoperative treatment of blunt abdominal injuries, and improved overall functional outcome for those children treated at PTC. However, others fail to demonstrate differences for children treated at ATC or ATC AQ. Nevertheless, from the aforementioned studies, several important observations can be safely made: a majority of injured children are not treated at PTC; injured children treated at accredited trauma centers do better than those treated at nonaccredited trauma centers; and children treated at PTC or ATC AQ have improved overall outcome. Appropriate triage systems are needed to ensure that severely injured children are treated in PTC. However, because of the limited number of PTC not all injured children can be treated in PTC. Perhaps, PTC should develop integrated pediatric trauma systems as well as provide education to surgeons practicing at ATC on the different strategies in pediatric care. ATC treating the injured children need to appreciate the child's unique anatomic, physiological, and immunologic differences and incorporate them into appropriate treatment protocols. Most importantly, all institutions that use, train, or educate individuals committed to the care of children must work together to develop injury prevention strategies.

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