Libertas Academica
FREEDOM TO RESEARCH

Open Access: Full open access to this and thousands of other papers at http://www.la-press.com.

Clinical Medicine Insights: Trauma and Intensive Medicine

The Management of Pediatric Polytrauma: Review

H. Mevius[1], M. van Dijk[2–4], A. Numanoglu[2,3] and A.B. van As[2,3]

[1]Medical Student, Department of Pediatric Surgery, Erasmus MC-Sophia Children's Hospital, Rotterdam, The Netherlands. [2]Department of Paediatric Surgery, Red Cross War Memorial Children's Hospital, Cape Town, South Africa. [3]University of Cape Town, Cape Town, South Africa. [4]Department of Pediatric Surgery, Erasmus MC-Sophia Children's Hospital, Rotterdam, The Netherlands.

ABSTRACT: Polytrauma is a major cause of mortality and morbidity in both developed and developing countries. The primary goal of this review is to provide a comprehensive overview on current knowledge in the management of pediatric polytrauma patients (PPPs). A database review was conducted based on a search in the Embase, Medline OVID-SP, Web of Science, Cochrane central, and Pubmed databases. Only studies with "paediatric population" and "polytrauma" as criteria were included. A total of 3310 citations were retrieved. Of these, 3271 were excluded after screening, based on title and abstract. The full texts of 39 articles were assessed; further selection left 25 articles to be included in this review. The most crucial point in the management of PPPs is preparedness of the staff and an emergency room furnished with age-appropriate drugs and equipment combined with a systemic approach.

KEYWORDS: pediatric population, polytrauma, multiple injuries, current management, review

CITATION: Mevius et al. The Management of Pediatric Polytrauma: Review. *Clinical Medicine Insights: Trauma and Intensive Medicine* 2014:5 27–37 doi:10.4137/CMTIM.S12260.

RECEIVED: May 27, 2014. **RESUBMITTED:** August 24, 2014. **ACCEPTED FOR PUBLICATION:** September 29, 2014.

ACADEMIC EDITOR: Cyril Mauffrey, Editor in Chief

TYPE: Commentary

FUNDING: Authors disclose no funding sources.

COMPETING INTERESTS: Authors disclose no potential conflicts of interest.

COPYRIGHT: © the authors, publisher and licensee Libertas Academica Limited. This is an open-access article distributed under the terms of the Creative Commons CC-BY-NC 3.0 License.

CORRESPONDENCE: sebastian.vanas@uct.ac.za

Paper subject to independent expert blind peer review by minimum of two reviewers. All editorial decisions made by independent academic editor. Upon submission manuscript was subject to anti–plagiarism scanning. Prior to publication all authors have given signed confirmation of agreement to article publication and compliance with all applicable ethical and legal requirements, including the accuracy of author and contributor information, disclosure of competing interests and funding sources, compliance with ethical requirements relating to human and animal study participants, and compliance with any copyright requirements of third parties. This journal is a member of the Committee on Publication Ethics (COPE).
Provenance: the authors were invited to submit this paper.

Introduction

Polytrauma is a medical term that describes the condition of a patient subjected to multiple traumatic injuries and can be a life-threatening condition. These (life threatening) injuries typically affect two or more body regions and present a challenge for diagnosis and treatment.[1,2] However, there is no consensus yet about the term polytrauma in both literature and practice.[3] Polytrauma is a major cause of mortality and morbidity in both developed and developing countries. Despite its preventability, trauma remains the most common cause of death and disability in children.[2] In fact, all over the world, more than 700,000 children under the age of 15 years die each year due to accidental injury.[4] Leading causes of polytrauma are road traffic crashes, falls from heights, and bullet injuries.[2] Injuries to the head and the lower extremities are most frequently seen in pediatric polytrauma patients (PPPs). Traumatic injuries to the chest, abdomen, and head cause high mortality in children of all ages.[5]

At the emergency department, the psychological pressure of the staff dealing with young children, together with often suboptimal conditions for children in resuscitation areas, can negatively affect treatment of the PPP. In many cases, it is difficult or impossible to communicate with children in the emergency situation. In addition, polytrauma occurs less frequently in children than in adults and therefore most trauma staff lack experience with pediatric polytrauma treatment. Dedicated pediatric trauma centers are often not in close range, particularly in developing countries. Secondary referral to a dedicated pediatric trauma center can only take place after initial stabilization.[6]

The first hours following trauma—including the "golden hour"—are crucial for effective treatment and prevention of early death in PPPs. Unfortunately, numerous factors can delay the treatment in PPPs such as waiting for registration and availability of imaging techniques.[7] Furthermore, numbers of PPPs presenting to trauma centers have steadily increased in recent years.[8] The primary objective of this review is to provide an overview of the literature on management of PPPs. The secondary goal is to provide evidence-based guidelines concerning different aspects of this management worldwide.

Methods

A search was conducted on 28 January 2014 in the EMBASE, Medline OVID-SP, Web of Science, Cochrane central, and Pubmed databases using a search strategy of combinations of specific search terms such as "paediatric patient" and "polytrauma" or "multiple injuries." The search was limited to articles published in English and articles published between 1 January 2003 and the day of the search. The other filters that we applied during the search were studies in humans and pediatric population only, while conference papers were excluded.

Study selection and data extraction. During the screening algorithm, all available articles were evaluated for the occurrence of the keyword "polytrauma" and the presence of a subsequent definition such as "multiple injuries." The first filter was exclusion of case reports. The second filter was exclusion of articles based on title. The third filter was exclusion based on reading abstracts. The last filter was exclusion based on reading the full length of the remaining articles. Within this database query, the citations of the selected full-length articles were also analyzed.

Results

The search yielded a total of 3310 citations. Of these, 3271 were excluded. After reading the full text of the remaining potentially eligible 39 articles, 25 articles were included in this review.

General approach at the emergency department. Treatment of PPPs begins with the principles of Advanced Pediatric Life Support (APLS) and Advanced Trauma Life Support (ATLS).[8] ATLS has become the internationally recognized standard for management of serious injury in trauma patients.[4] Both the ATLS and subsequently developed courses such as APLS and the European Paediatric Life Support (EPLS) stimulate a systematic approach by a well organized team.[4]

The APLS and EPLS principles have to be frequently taught to all team members so that they will almost automatically react when PPPs present. Trauma team members need to understand the pediatric airway, control of hemorrhage, and principles of resuscitation. Only after successful stabilization of the child is it possible to assess the extent and degree of injury and determine treatment priorities. Centers that lack a regimented protocol are at risk of providing suboptimal care to PPPs.[9]

Preparation. Preparation is an essential component of the general approach. As soon as a PPP is expected, the trauma team is gathered for a briefing. This team should include a nominated leader, an experienced anesthetist, surgeons, and other emergency department and pediatric staff members. It is preferable that all team members are informed timely and do not leave until the PPP is fully stabilized.

The team leader should allocate roles, primarily observe and coordinate the resuscitation. Equipment should be checked, although ideally routine checks should be in place to guarantee that the appropriate equipment is always ready for immediate utilization. A properly stocked resuscitation trolley, familiar to all personnel, should be available. Emergency drugs and infusion fluids should also be ready for use. The history provided by those at the site of the accident, the vital signs, and the treatment provided at the scene should inform the team about the mechanism of the accident and what injuries to anticipate. As children vary considerably in size and weight, care must be taken to administer the appropriate drug dosages, amount of fluids, and direct current shock voltage. A child's weight can easily be calculated using a formula based on age, providing an estimated weight in kilograms. However, this formula can underestimate the weight in modern childhood population because of increasing obesity and new formulas for different age groups have been suggested (see Fig. 1).[4]

Plasma levels of drugs depend on many other factors besides actual body mass, such as route of administration, body temperature, and pathophysiology. As most resuscitation drugs are hydrophilic, the lean body mass may be more important than the actual body mass. The Resuscitation Council (UK) and European Resuscitation Council courses therefore still use the standard formula. Alternatively, special tape—the Broselow tape—based on length and weight statistics can prevent dosing errors when lined up next to the child. The child's length corresponds with appropriate color-coded values on the tape for fluid volumes, drug doses, and materials such as tracheal tubes. These are stored in matching color-coded drawers of the resuscitation trolley. Adult values can be used when a child is longer than the tape itself. Unfortunately, utilization of the tape is limited by availability and costs and has also been reported to underestimate the weight of the current childhood population.[4]

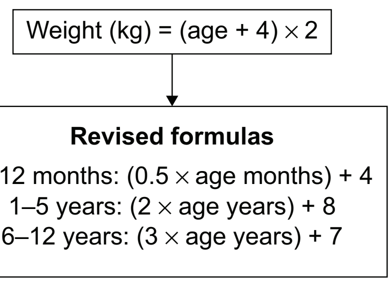

Figure 1. Formula to estimate weight in children.

Differences in anatomy of child versus adult. Cognizance of the particular physiological characteristics of children can contribute to improved management of pediatric trauma. Children have a relatively large tongue that easily obstructs the airway; the epiglottis is less stiff and may block the glottis, the location of the larynx is more cephalic with a narrow cricoid anteriorly, and the trachea has a short length. The normal estimated blood volume is 80 mL/kg or 7–8% of total body weight. Because of the large body surface to mass ratio, children are at a higher risk of dehydration following burns and hypothermia. The head of a child is relatively large, creating a higher center of gravity. This results in a greater risk of both accelerating and decelerating injury leading to increased incidence of cerebral concussion. The skeleton is more flexible and elastic, which leads to greater incidence of soft tissue injury without associated fractures.

Management of PPPs should be carried out in centers with a basic minimum infrastructure comprising a well-equipped emergency department, blood bank, intensive care with ventilator facilities, radiology services offering X-ray, ultrasound and computed tomography (CT) scan, and operating rooms. These should be all instantly available together with adequate communication facilities.[10]

Initial assessment—primary survey. The primary survey of the child entails a rapid, sequential evaluation to prioritize management of life-threatening issues.[4,9] This follows the "ABCDE" principle (airway, breathing, circulation, disability, and exposure), and frequent re-assessment is essential after each intervention.[4] Utilizing this easily recalled principle allows trauma team members to recognize specific injuries, such as airway obstruction, tension pneumothorax, pericardial tamponade, and hypovolemic shock, which are all potentially lethal. By following "ABCDE," injuries are ranked in order of severity. In this way, it is possible to treat the most life-threatening issues first.[9] In practice, the assessment through "ABCDE" is being done by several persons simultaneously according to the team approach in the emergency room.

Many trauma scoring systems are developed to assess PPPs. Specific pediatric trauma scores are not required. The Injury Severity Score is reproducible and useful in children with trauma and correlates well with mortality, morbidity, and hospitalization time after trauma.[11]

Airway and control of cervical spine. Airway management is first in order of priority starting with examination of its patency or potential obstruction.[10,12] Each PPP should be suspected of having cervical spine injury until proven otherwise. Immobilization of the spine is therefore obligatory; the spine should be kept in neutral and stable position by a trained person. The same person should pursue immobilization until a hard collar and immobilizing blocks (combined with chin and forehead tape) become available. An uncooperative child should not be immobilized actively, as more damage can be inflicted. Continuous manual immobilization is often better tolerated in these cases.

Airway assessment should adhere to the "look, listen, and feel" principle. Any potentially obstructing object has to be removed without causing any further harm. A blind finger sweep may never be carried out as the foreign object may be pushed deeper into the pharynx.[4] Another way of optimizing the impaired or obstructed airway of a child is performing the jaw thrust, a specific maneuver that, if properly performed, does not aggregate cervical spine injury.[4,12]

The neutral position by itself may already be sufficient to open infants' small and anterior airways. In young children, the "sniffing position" is required to achieve the same result. Observing the chest and abdominal movements is also part of the assessment. Wheezing, snoring, gargling, or no sound at all may all be detected by careful listening. Wheezing may indicate the presence of an object in the airway, snoring indicates that the tongue obstructs the airway, and gargling sounds may be because of all kinds of fluid. No sound at all can be either a good sign (normal breathing which indicates an open airway) or a very bad sign (possibly no breathing because of death). Listening also includes auscultation for breathing sounds. Lastly, exhaled air (against the cheek of the evaluator) may be perceived.

Each PPP requires high-flow oxygen, initially administered by a facial mask ideally connected to a rebreathing bag. If necessary and tolerated, airway deputies can be used, such as an oropharyngeal airway. This is inserted directly as it is located in position and a tongue depressor can assist in insertion.

A nasopharyngeal airway should be avoided when there are signs of an anterior basal skull fracture or facial injuries. Bag–valve–mask ventilation is started when there is inadequate breathing. If the airway is obstructed or likely to be compromised, a tracheal tube must be inserted rapidly and carefully. The appropriate size is estimated from a standard formula (shown in Fig. 2) or from measuring the diameter of the child's fifth finger. Tracheal tubes with and without cuff both can be used without complications in the hospital setting for all ages after the neonatal period. The insertion length in centimeters of insertion can be estimated with a standard formula (also shown in Fig. 2).

Proper positioning of the tube should be checked by looking at the thoracic wall movement and auscultating the chest

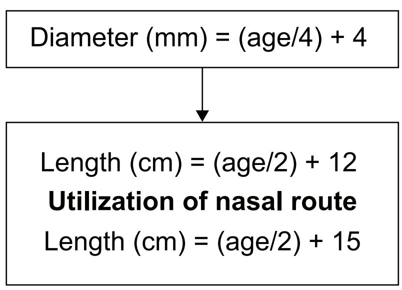

Figure 2. Formula to estimate endo-tracheal tube size in children.

for similar bilateral breathing sounds. A radiograph of the chest should always be performed to check the final position.[4]

Breathing and ventilation. Assessment of breathing and applicable interventions is second in order of priority once the airway is patent or secured. The effort, efficacy, and effect of breathing have to be evaluated, and it is necessary to look for signs of respiratory distress such as low respiratory rate (see Table 1), recession of the thoracic wall, and utilization of accessory muscles.[12]

Chest expansion and abdominal movement have to be observed. Life-threatening injuries requiring instant treatment include tension pneumothorax, open pneumothorax, massive hemothorax, flail chest, and cardiac tamponade.

Children have relatively more elastic tissue than adults. Rib fractures therefore indicate that substantial large forces were involved with a risk of severe internal damage. As decompensation can occur rapidly, extra care is required in those cases. Iatrogenic factors can also adversely affect breathing. Examples are aerophagia from resuscitation or excessive crying, both with resulting gastric distension. This in turn may cause diaphragmatic elevation and splinting resulting in impaired ventilation. After any clinical assessment of PPPs a radiograph of the chest is recommended.[4]

Circulation and hemorrhage control. After breathing has been assessed and controlled, the circulation is examined, first of all on hypovolemia. Any obvious external source of hemorrhage must be searched for. If hemorrhage is detected, an attempt should be made to stop the bleeding through direct digital compression over the wound or proximal to the point of bleeding.[12] Tourniquets might be used if appropriate.

Internal blood loss in areas such as the chest, abdomen, pelvis, and lower extremities should be considered.[4] Children possess a great physiological reserve, delaying manifest signs of hypovolemic shock. Children can compensate for hypovolemic shock through increased heart rate, systemic vascular resistance, and venous tone. Hypotension occurs only when children have lost approximately 30% or more of the blood volume and is then rapidly followed by complete cardiovascular failure.[4,12] Tachycardia is normally the initial and most trustworthy measurable reaction to hypovolemia in children, although it can also occur because of pain or anxiety. The most important indicators to detect hypovolemic shock include tachycardia; decreased level of consciousness that reflects poor cerebral perfusion; decreased pulse pressure; reduced skin perfusion resulting in cold peripheries and pale skin color; diminished urine output; delayed capillary refill; hypothermia; and eventually hypotension.[12] Decreased urine output and hypotension are both late signs of poor perfusion in children. Urine output of less than 1 mL/kg/hour in children or less than 2 mL/kg/hour in infants indicates a critical condition. Hypotension indicates decompensating shock and should be instantly and aggressively treated.[4,12]

The next priority is to establish vascular access and venous cannulation. Two large-bore intravenous (IV) cannulae should be inserted in the upper extremities. If cannulating a peripheral vein remains unsuccessful after three attempts or exceeding a period of 90 seconds, an intraosseous (IO) route has to be utilized. The preferred location for IO access is medially into the proximal tibia of an uninjured limb, 2–3 cm below the tibial tuberosity. An alternative IO location is the inferior one-third of the femur, 3 cm above the external condyle.[12]

Traditional IO needles utilize a screwing and pushing technique. The bone injection gun is easier to use, with similar success in accomplishing IO access, also in pre-hospital settings.[4] Aspiration of marrow indicates correct position of IO cannulation. If a percutaneous line subsequently is inserted, the IO line should be discontinued. If IO cannulation also fails, peripheral venous cutdown techniques can be resorted to. Options include a saphenous vein cutdown at the ankle (above the medial malleolus), a median cephalic vein cutdown on the elbow of an uninjured limb, or central venous cannulation utilizing femoral, subclavian, or internal jugular veins.

Once venous access is obtained, blood samples are taken to determine full blood count, grouping and cross-matching, urea, creatinine and electrolytes, prothrombin time, and amylase. Hereafter volume replacement therapy can be initiated depending on the weight of the child; initial fluids should comprise of warm isotonic crystalloids. Hypothermia may lead to harmful vasoconstriction, acidosis, and coagulopathy and should be prevented. The goal of resuscitation fluids is to achieve hemodynamic stability and to recover tissue perfusion rapidly.[12] It is currently recommended to administer 10 mL/kg while carefully monitoring the response. The recommended fluid type is 0.9% normal saline. If the child remains unstable after administration of 40 mL/kg, blood

Table 1. Normal vital signs for children in all ages.

AGE	RESPIRATORY RATE (BREATHS/MIN)	HEART RATE (BEATS/MIN)	SYSTOLIC BP (mmHg)	BLOOD VOLUME (ml/kg BODY WEIGHT)
Neonate	30–60	100–160	60–90	90
Infant	30–40	90–120	80–100	80
2–5 years	20–30	95–140	80–120	80
5–12 years	15–20	80–120	90–110	80
>12 years	12–15	60–100	100–120	70

products should be given. Surgical assessment is paramount at this stage. Blood and coagulation products (usually fresh frozen plasma and/or platelets) are given in a ratio of 1:1. In cases of ongoing bleeding, additional products may be administered such as fibrinogen and cryoprecipitate, titrated according to measurements of coagulation parameters.[4] During resuscitation, a urinary catheter is the only clinical measurement of tissue perfusion and is therefore reliable to assess resuscitation outcomes.[12]

Disability. A quick neurological assessment is needed to evaluate the level of consciousness, pupillary response, symmetry, and size. The level of consciousness can be rapidly examined through the easy mnemonic "AVPU"—"A" alert and oriented, "V" response to verbal stimulus, "P" response to painful stimulus, "U" unresponsive. It is important to observe the child's ability to follow simple commands and the quality and quickness of the reactions. The pupils have to be examined briefly for size, equality, and bilateral reactivity to light. The Glasgow Coma Scale (GCS) provides a more detailed neurological evaluation, especially after resuscitative attempts (see Table 2).[4] A GCS score of ≤8 indicates the need for intubation. Assessment should be repeated frequently to explore any changes that may emerge during resuscitation.[12] A history of head injury warrants instant neurological imaging and neurological surgical assessment. Secondary brain injury has to be prevented through optimization of oxygenation, cerebral perfusion, and therefore systemic perfusion. As altered mental status can possibly be the result of hypoxia or hypoperfusion, it is therefore of essential importance to reassess the "ABC." Mental status may also be affected by hypoglycemia, which should be treated immediately to prevent further damage. Furthermore, glucose should be checked in all PPPs.[4]

Exposure and environment. At this point, a complete physical examination should exclude other possible injuries in PPPs. Hypothermia should be prevented as it can cause vasoconstriction, acidosis, and coagulopathy, which impedes resuscitation. Because of their relatively large body surface area, children are more sensitive to heat loss. Therefore, they should be covered after each evaluation and the resuscitation area should be kept sufficiently warm.[4]

Secondary survey and management of specific injuries. The secondary survey is not performed until the child has been stabilized and life-threatening conditions have been covered. This entails a thorough evaluation to identify other present injuries and history from the PPP, paramedics, family members, and bystanders if possible. A systemic examination of the entire body is also required.

Firstly, the body surfaces are checked from head to toe, including front and back. The back side is inspected after a log roll.

Secondly, all body orifices (mouth, nose, ears, orbits, rectum, and genitals) must be checked for injuries.[4] Each clear sign of injury in the form of blood loss from any orifice should be specially recorded. The specific examination of the head contains a search for lacerations, hematomas, bleeding arising from the ears, nose, or throat and leakage of cerebrospinal fluid. Both eyes have to be evaluated carefully including the

Table 2. GCS for children and for infants and small (preverbal) children.

CHILDREN	SCORE	INFANTS AND SMALL CHILDREN	SCORE
Eye			
Spontaneous	4	Spontaneous	4
Voice	3	Voice	3
Pain	2	Pain	2
No response	1	No response	1
Motor			
Obeys verbal command	6	Spontaneous or obeys command	6
Localizes to pain	5	Localizes to pain or withdraws from touch	5
Withdraws from pain	4	Withdraws from pain	4
Abnormal flexion to pain	3	Abnormal flexion to pain	3
Abnormal extension to pain	2	Abnormal extension to pain	2
No response	1	No response	1
Verbal			
Orientated, appropriate	5	Smiles, tattles, fixes and follows	5
Confused	4	Irritated, cries but consolable	4
Unsuitable words	3	Continually irritated, cries to pain	3
Inconceivable sounds	2	Agitated, groans to pain, restless	2
No response	1	No response	1

pupils. Maxillofacial injuries are relatively rare in children and are easily missed. Evaluation of the neck entails a search for external signs of trauma.[10]

Thirdly, cavities of the body such as chest, abdomen, pelvis, and retro-peritoneum need to be assessed. The examination of the chest includes a search for clavicle and/or rib fractures.

Fourthly, the extremities have to be examined with respect to lacerations, joint dislocations, and fractures. In particular, instability of the pelvic bone should be excluded. Specific neurovascular examination of the limbs distal to fractured limb needs to be performed and documented.

Finally, a second detailed neurological assessment has to be completed to establish the status of the child based on the GCS. In addition, relevant imaging should be carried out in the secondary survey when necessary. For example, an X-ray of the cervical spine if there is suspected injury. Spinal cord injury is not always associated with visible abnormalities of the cervical spine on the X-ray though. All findings have to be documented, so as to inform other medical personnel. All members of the trauma team must remain fully informed while the assessment is still ongoing.[4,10] The ultimate goal of the secondary survey is to examine the overall effect of trauma on the child, as evaluated by the different specialists involved, organization of specific investigations, and planning of interventions in the correct order.[10]

Thorough assessment as sketched above cannot prevent late diagnosis of injuries in PPPs. Initially missed diagnoses include fractures of the upper extremities, pelvis, and spine but also visceral injuries. Cooperation of the patients themselves and their family members should be enlisted in the continuous search for such injuries; they should be prompted to communicate each preliminary undetected source of pain in the days and weeks following injury.[13]

Head injuries. Head injury is one of the most frequent issues in PPPs and the foremost cause of death.[10] It is also the commonest cause of long-term disability in PPPs.[13] Head injury, however, is not a uniform concept and it is therefore poorly classified in view of treatment. Severe traumatic brain injury can be caused by different pathologies including subdural hematomas, extradural hematomas, cerebral ischemia, cerebral hyperemia, vasospasm, focal hemorrhagic contusions, or diffuse axonal injury. There is a growing awareness of the role of secondary injury in determining outcome.[14] Secondary injury stands for everything that arises after primary injury and contributes to deterioration of brain damage. For example, an event related to primary injury such as brain swelling because of biochemical cascades, or hypotension or hypoxia when the brain is vulnerable.[15] In PPPs with traumatic brain injury, a minimum of 40 mmHg cerebral perfusion pressure may be considered.[16]

The rehabilitation of surviving patients requires appropriate management.[13] The GCS is applied to assess the best motor, verbal, and eye responses. The best motor response is most directly related with the long-term outcome. A GCS score of <8 implies that the child is most at risk of developing life-threatening intracranial hypertension and should be electively ventilated. GCS assessment should take place regularly, and pupil size, reaction to light, and pulse rate should be monitored. Signs of an intracranial injury include asymmetric clinical signs like pupillary constriction, dilatation, or neurological signs of lateralization.[10]

Acute management often includes elevation of the head of the bed, fluid restriction, and fracture stabilization. Fracture stabilization with a temporary splint or ultimate fixation is essential to minimize possible rises in intracranial pressure after brain injury.[13]

Altered consciousness or any of the above-mentioned signs are indications for a CT scan as quickly as possible.

Key points in management of PPPs

1. The most important point is preparedness of the staff and an emergency room furnished with age-appropriate drugs and equipment.
2. Non-indicated aggressive volume replacement might raise themortalityrate in PPPs.
3. Trauma teams should exercise caution with blood transfusion in PPPs; massive transfusion is currently unusual in children, has a bad prognosis and can usually be avoided.
4. Total body scanning is ideal in the clinical setting, it allows imaging andresuscitation simultaneously in the emergency room.
5. Only very few absolute indications for (immediate) surgical interventions in PPPs exist; most injuries can be safely managed with conservative management.

Figure 3. Key points in management of paediatric polytrauma patients.

Indication for surgery is generally the presence of a mass lesion or a depressed skull fracture. Diffuse cerebral edema is often found, caused by trauma and secondary hypoxia, hypotension, hypercarbia, increased intracranial tension, and seizures. Treatment of raised intracranial pressure involves oxygen therapy, anticonvulsants, supportive therapy of an unconscious patient, and monitored ventilation retaining the value of PCO2 between 25–30 mmHg in the initial 48 hours after primary injury.[10,16] Mannitol is frequently used in the treatment of raised intracranial pressure in PPPs with traumatic brain injury.[16]

Decompressive craniectomy to reduce intracranial pressure is a new option for patients who are not responding adequately to medical interventions to reduce intracranial pressure early. The procedure involves removal of a large bone flap from the cranium and extending the dura with a graft to enlarge the intracranial volume available for swelling of the brain. This procedure significantly reduces intracranial pressure and improves oxygenation of the brain.[15]

The use of corticosteroids in PPPs with severe traumatic brain injury is not recommended to enhance outcome or reduce the intracranial pressure.[16]

Neurological injuries. Current evidence-based guidelines on the management of neurological injuries recommend an exhaustive clinical examination and two plain radiographic images of the cervical spine during initial treatment of PPPs.[17] CT is recommended only for patients that demand more diagnostic assurance or when suspected injuries require more investigation. Magnetic resonance imaging (MRI) is recommended in neurologic abnormalities or in suspected soft tissue injuries.[8]

As children have a very flexible cervical spine, they are susceptible to deceleration injuries since joint capsules and horizontal facet joints can be shifted more easily. Younger PPPs are more vulnerable to sustaining injury between the occiput and the third cervical segment, while lower cervical and thoracolumbar injuries are more common in older PPPs.[10]

Because of the flexible spine, spinal cord injury in PPPs can present without radiographic abnormalities (SCIWORA). In these cases, the long-term outcome depends on the neurological status on admission to the emergency department.[8] To examine cervical spine injury in PPPs, the antero-posterior, lateral, and odontoid radiographic views are used.[10]

Treatment of spinal cord injury is mainly supportive. In rare cases, however, such as displacement of a segment, which entails instability, surgical fixation is required.[10]

It seems that the management of acute spinal fractures in adult patients with polytrauma has become more proactive over the years. This approach is called spine damage-control (SDC), and it is defined as an immediate posterior fixation of unstable thoracic and lumbar fractures, which is performed within 24 hours after primary injury. Still, more research is needed regarding the ideal timing of spine fracture fixations in both adults and children presenting with polytrauma.[18]

Thoracic injuries. Isolated thoracic injuries are associated with a mortality rate of 5%, which increases to 25% if concurrent head and abdominal injuries are present in PPPs.[19] Screening for thoracic injuries entails inspection of the trachea position, symmetry in movements of the chest, palpation of fractures and subcutaneous emphysema, and auscultation for the location and quality of the breathing sounds.[9]

Pulmonary contusion remains the most prevalent pediatric thoracic trauma.[10,13] Lung parenchyma is subjected to disruption and hemorrhage with edema caused by direct trauma to the chest and compression of the chest wall.[10] In about 90% of the children, this diagnosis can generally be made based on a screening chest X-ray, half of which will demonstrate rib fractures or other findings such as pneumothorax or hemothorax. A CT scan may assist in recognizing previously missed pulmonary contusions.[13]

Rib fractures are uncommon in PPPs and are usually of little consequence.[10] However, they often are more suggestive of severe chest injuries such as long contusion or laceration, pneumothorax, hemothorax, mediastinal trauma, and cardiac and/or great vessel injuries.[13] Multiple rib fractures are also associated with serious injury elsewhere in the body, including the brain, spine, abdomen, pelvis, and limbs.[13] Flail chest can occur when there are more than three fractured ribs in two or more places.[9]

Pneumothorax is not uncommon in PPPs.[10] It may be either an "ordinary" or "tension" pneumothorax. An ordinary pneumothorax can be seen in asymptomatic pediatric patients and may be initially noted on a CT scan. Tension pneumothorax requires immediate thoracic drainage.[13] In most cases, drainage for several days is sufficient. If the pneumothorax persists, bronchial injury should be suspected, and this is a clear indication for a CT scan and if necessary followed by a surgical intervention.[10]

Hemothorax is common in PPPs but is usually transient and self-limiting. Nevertheless, it requires drainage of the blood through a chest tube to improve breathing. This will prevent delayed "fibrothorax" and it stops active hemorrhage.[10] A surgical intervention is indicated in approximately 5% of all cases, although the indications for surgery remain controversial.[19]

Airway injuries rarely occur in PPPs, but are lethal in one-third of the children.[19] They are usually caused by penetrating or blunt trauma and occur at the lower trachea or the upper bronchus. These injuries might cause a "tension" pneumothorax or subcutaneous emphysema.[13] Persistent air leaks and failure of the lungs to expand after placing a thoracic tube enhance suspicion of tracheobronchial injury. Immediate bronchoscopy should be performed prior to definitive repair.[13]

Cardiac and/or great vessel injury is common in either penetrating or blunt trauma.[9]

On suspicion of great vessel injury, upper limb pulses must be examined. Injury may even occur later with chronic ischemic changes of the upper limb.[10]

An X-ray and a focused ultrasound examination for trauma of the chest allow finding of early evidence of mediastinal injury and cardiac tamponade.[9] In addition, echocardiography must be carried out in stable PPPs to exclude underlying cardiac injury.

Pericardiocentesis is considered an emergency treatment in the case of cardiac tamponade, but is of little use in diagnosing or managing cardiac injury or tamponade.[9]

Abdominal injuries. Abdominal trauma can generally be divided into penetrating and blunt injury. In most cases of penetrating injury, exploration of the abdomen will be necessary. In blunt trauma bruises, contusions, abrasions, pelvic or rib fractures, distension of the abdomen, and pain are important signs.[10] The most affected organs are the liver and spleen, kidneys, pancreas, and hollow viscera.[15]

Abdominal wall ecchymosis may indicate severe visceral or spine injury. Most children have no underlying medical conditions and have excellent physiological reserves. Therefore, they often remain clinically stable in the initial stages of polytrauma. Abdominal visceral injuries may often not be recognized until CT scans are performed.[13] CT has several advantages over ultrasound; it is more objective and less operator-dependent and is superior in diagnosing pathology.[10,13] CT scanning of the abdomen is of less value in neurologically intact children without significant abdominal findings and in those for whom surgery has already been indicated given the clinical findings.[9]

Initial management is conservative in most cases, unless there is a clear sign of hollow viscus perforation with characteristics of peritonitis and pneumoperitoneum.[10] An explorative laparotomy is only performed on strong suspicion of hollow viscus perforation and when CT scan of the abdomen cannot be performed. Most solid organ injuries heal naturally and blood in the peritoneal cavity is not an absolute indication for a laparotomy.[9] Therefore, the current approach for most blunt (solid) injuries is non-operative.[15]

A persistent conservative approach may be ill-advised in patients with life-threatening hemodynamic instability.[15] The abdomen should be reassessed regularly for resolution of abdominal signs and return of bowel activity.[10] In the presence of peritonitis or significant sustained hemorrhage, a laparotomy is indeed indicated.[15] Conservative management of solid organ injuries includes bed rest, blood transfusion, and supportive care.

Rare injuries that may have a delayed presentation comprise injury to the duodenum or pancreas, mesenteric injuries resulting in bowel ischemia, transaction of bile duct, and pelvi-ureteric junction. When suspected, specific investigations include upper gastrointestinal contrast study, isotopic scan for bile duct or ureteric injury, and CT/MRI scans with contrast to detect, for example, pancreatic injury.[10]

Vascular injuries. Impaired perfusion to the extremities of a child with fractures or dislocations must be managed by a multidisciplinary team including pediatric trauma, vascular, and orthopedic surgeons. In the case of a limb-threatening vascular injury, physical examination, Doppler, and angiography are advised since vasospasm is relatively more common in children than in adults.[20] Temporary reduction and stabilization of pediatric fractures has to be performed along with definitive vascular recovery to ease optimal rehabilitation.[8]

Abdominal vascular injury is rather uncommon in PPPs, but half of these injuries are lethal.[21] This diagnosis should be considered if a PPP has a continuous need for volume replacement after resuscitation.[13]

Genitourinary injuries. Genitourinary injuries occur more often in males and most frequently occur at the level of the bulbourethra.[13,22] Most renal injuries in PPPs are secondary to blunt trauma and often associated with liver or spleen injuries.[10,13] Urine examination for hematuria, ultrasonography, and subsequent isotope renography help to confirm these injuries. IV pyelography can be used in selected cases. Medical management should take into account issues such as persistent hemorrhage, associated extrarenal injury, condition of the contralateral kidney, and the psychological status of the PPP. Bed rest is generally curative. Isolated renal injury alone is rarely an indication for urgent exploration.

Genitourinary injuries are frequently seen in combination with anterior pelvic injuries.[13] Pelvic injury is commonly associated with fractures, urethral and bladder injury. These types of injuries should therefore always be suspected and confirmed by a contrast study with a retrograde urethrogram and stress cystogram.[10] Extreme care is required during placement of a urinary catheter in a PPP with an anterior pelvic fracture since greater harm can be caused at the site of the injury. Preoperative imaging techniques are frequently of limited value in PPPs demanding surgical reconstruction.[13] The most basic surgical intervention in genitourinary injuries is a supra-pubic urinary diversion. Definitive treatment of urethral injuries should take place in a specialized unit.[10]

Musculoskeletal injuries. Musculoskeletal injuries are frequent in PPPs. The limbs should be evaluated for soft tissue injuries, bone fractures as well as nerve and vascular injury. Hemorrhage in an affected limb should be handled by compression bandages and elevation of the limb. Artery clamping to control hemorrhage should not be performed in the emergency room without an involved specialist because of high risk of nerve damage.[10]

Appropriate diagnosis is the first priority in the initial management, followed by pain reduction and stabilization of potential fractures. After initial resuscitation, a detailed assessment of the limbs is necessary to establish the need for surgical intervention. An absent pulse with ischemic signs is an indication for an angiography and exploration.[10]

Most PPPs will survive their injuries; musculoskeletal injuries need to be managed in an aggressive way in order to obtain the best possible function and independence after recovery from trauma.[8]

Non-musculoskeletal injuries. The bony skeleton in children is more flexible than in adults, and PPPs are therefore less likely to develop severe bone injuries caused by highly energetic trauma. Instead, energy is often transferred to other organ systems in the vicinity and children are at a greater risk of multiple organ injury.[8]

Orthopedic injuries. Orthopedic surgery has become more essential in the management of PPPs, since almost 63% of PPPs present with one or more fractures.[23]

Orthopedic injuries should be viewed within the context of the overall status of the PPP. Usually these injuries do not require immediate treatment, however, unless there are associated vascular injuries, compartment syndromes, and open fractures.[13] Open fractures are found in about 10% of the PPPs with extremity fractures, and almost half of the PPPs with open fractures have supplementary skeletal or other system injuries.[1,13] Crucial in treatment of open fractures is initiating IV antibiotics, initiated as early as possible.[13]

Early surgical fixation of fractures is advocated to facilitate nursing care, comfort, and early mobilization of the PPP.[13]

Discussion

Radiation exposure. PPPs often are hemodynamically unstable at the moment of presentation. Imaging techniques are important since clinical examination may be unreliable.[7] Injuries are often not manifest on initial clinical examination, and it is often impossible to ascertain a reliable history when children have head injuries, are intubated, or are pre-verbal. In addition, verbal children are often unable to provide a reliable history.[24]

Approximately 30% of children with severe trauma die because of inadequate initial assessment.[22] To prevent these deaths, proper evaluation, initiation of critical care measurements, and early radiographic imaging are essential.[7] The use of multi-slice CT has increased in trauma imaging. This imaging technique is an efficient diagnostic tool but carries risks, especially in the pediatric population.

Exposure to radiation in children appears to have an accumulative effect and lifetime radiation risks per unit effective dose are likely to be substantially higher in comparison with adults. Growing tissues in children are more sensitive to radiation exposure than fully mature tissues in adults. Several options are described to reduce radiation exposure, such as ultrasound and MRI instead of CT.[24]

The cornerstone of all radiographic imaging protocols is therefore limiting of ionization radiation to the lowest possible value, while maximizing the detection of injuries.[25]

The Statscan, a total body digital imaging tool that can be used in the resuscitation room, has brought a significant change in pediatric trauma care.[15,26] PPPs need no longer to be transferred to a distant radiology department, allowing imaging and resuscitation simultaneously. The Statscan has a complementary imaging role in the clinical setting of polytrauma, while standard radiography continues to be the modality of choice for trauma imaging.[25]

Blood transfusion. Hemorrhage remains the major cause of all preventable deaths in trauma patients of all ages.[27–31] Conserving a normal blood pressure even after loss of 25–30% blood volume does not prevent this, particularly when brain injury occurs simultaneously. Damage control resuscitation intends to enhance outcome in trauma by alleviating the "lethal triad" consisting of hypothermia, coagulopathy, and acidosis, which frequently entails hemorrhage. Apart from packed red blood cells (PRBCs), balanced resuscitation with fresh frozen plasma (FFP) and platelets is indicated to decrease coagulopathy.[27–36] Multifactorial coagulopathy, present in more than half of all traumatized children requiring massive transfusion, is strongly associated with increased mortality. Massive transfusion is defined as the transfusion of the equivalent of the total blood volume of a patient within 24 hours. It is suggested that appliance of massive transfusion protocols (MTPs) would be advantageous in pediatric trauma, yet protocol development is challenging. Besides, there are transfusion difficulties unique to children, such as increased predisposition to hyperkalemia secondary to administration of blood products. Centers familiar with MTP development for pediatric trauma did not reach the same level of success as in adults. Massive transfusion is rarely required in children. It has been firmly demonstrated that traumatic brain injury, rather than exsanguination, is the primary cause of death.[37]

It is important to determine whether the quantity of volume replaced will have implications in PPPs, for example in children with hemorrhage. The decision for enhanced volume replacement therapy must be made on a case-by-case basis. Increased preclinical volume replacement and equivalent extended rescue times are responsible for a higher mortality rate after trauma, which may be because of deterioration of the coagulation system.[38] In critically injured children with hemorrhagic shock, non-indicated aggressive volume replacement treatment has an adverse impact on the clinical course and may lead to higher mortality.[38]

Quality indicators for pediatric trauma evaluation. Accumulating evidence suggests that many PPPs do not receive optimal treatments and strategies.[39,40] Treatment options and outcome of common injuries vary significantly per region. There is no widely accepted evidence for best practice and outcomes of PPPs and management may be enhanced with better translation of the best research evidence in practice. Quality indicators (QIs) are performance measures that can compare actual care against ideal care. The majority of QIs were designed initially for adults and were subsequently applied for children. Based on the best available evidence, deficiencies were demonstrated in quality of care measured with QIs as primary outcome in as many as half of all pediatric trauma patients. Death rates were estimated to be preventable in 6% to 32% of all cases. Most of QIs concerned processes and outcomes of acute care, while no direct indicators were identified. Quality-of-care problems in pediatric trauma care create an imperative to measure the quality of trauma care and to ensure that the measurements used are relevant and valid.[41]

Pain control in PPPs. Pain control is an important component of all trauma care. Pharmacological treatment should be titrated to the response of the child combined with the level of consciousness. The drug of choice is morphine at 0.1–0.2 mg/kg. The dose should be lowered when the child develops decreased consciousness. Intranasal diamorphine has also been used when there is no immediate venous access available. Entonox inhalation therapy can be used but is contraindicated in young age and in cases of pneumothorax or basal skull fracture.[4]

Training for personnel. The Intercollegiate Committee for Standards for Children and Young People in Emergency Care Settings in the UK considers an appropriate training as a condition for all relevant staff in centers that deliver care to PPPs. Since the incidence of major trauma in children is relatively low, it is important to keep skills of staff in the team tightened with regular simulator or dummy scenario training sessions in individual departments. Worldwide, trauma teams should use common definitions and purposes to provide consistent and best possible care.[4] Unfortunately, it seemed in the past that clinical practice guidelines had limited effect on changing behavior in physicians. Several reasons can be responsible for this, such as lack of awareness, lack of agreement, lack of self-efficacy, lack of outcome expectancy, inertness in previous practice, or external barriers. Focusing on these reasons may be more direct in improving adherence, instead of searching for predisposing factors for poor adherence, what could possibly be too broad in assisting selection of possible solutions.[42]

Providing team training that focuses on avoiding errors of neglect, instead of focusing on general performance, might also be a solution to improve adherence to ATLS guidelines during pediatric resuscitation.[43]

Parental presence. The presence of parents during resuscitation may alleviate their child's anxiety.[4] A contributory reason for their presence is to witness all the possible efforts made, creating an increased level of acceptance if management fortunately appears to be unsuccessful.[4] Parental presence may also encourage professional behavior of the trauma personnel. A dedicated member of the staff should remain on the side of the parents all the time in order to explain the entire process in an empathetic manner. This may ensure that parents do not interfere with the resuscitation or distract the trauma team.

Conclusion

The management of PPPs remains associated with clinical problems worldwide, mainly because of unfamiliarity with emergency care for children and substandard emergency room equipment. For instance, preclinical volume replacement treatment in critically injured children is frequently used but is associated with a range of often unknown risks and should therefore be carefully considered.[39]

However, this review shows that a systemic approach and adequate preparation will facilitate care for most patients and often without heroic surgery. Improvements in the quality of care of PPPs can be expected from the following recommendations.

Firstly, more pediatric-specific indicators (QIs) have to be developed. Secondly, standardized definitions should be established for QIs. Clinicians, researchers, and all others involved in trauma care have to communicate and report uniformly by using the same definitions.[41] A crucial issue continues to be the lack of consensus worldwide about the term polytrauma.[44] To improve communication and resource allocation it is necessary to define an objective definition of polytrauma.[3] Establishment of a universally accepted definition for polytrauma is also important to serve as a basis for future research.[45] Thirdly, indicators that cover the entire spectrum of trauma care have to be developed. Improving trauma care demands an understanding of the entire spectrum of trauma care, including care after hospitalization and secondary injury prevention. Fourthly, indicator measurement features have to be developed. And lastly, QIs should also comprise patient and family perceptions of the quality of trauma care into their definitions.[41]

Current clinical practice guidelines should include a specific section about polytrauma in the pediatric population. This section should take into account various age groups in children, as there are considerable differences in treatment.

Furthermore, more research is needed regarding identifying factors that negatively influence adherence to pediatric trauma guidelines, from the perspective of the professional, patients, organization, and characteristics of the guidelines. Based on these found influencing factors, proper solutions may be offered in the future to improve adherence.[46]

Author Contributions

Conceived the concepts: ABvA. Analyzed the data: HM. Wrote the first draft of the manuscript: HM. Contributed to the writing of the manuscript: HM, MvD, ABvA. Agree with manuscript results and conclusions: AN. Jointly developed the structure and arguments for the paper: HM, MvD, ABvA. Made critical revisions and approved final version: HM, MvD, ABvA. All authors reviewed and approved of the final manuscript.

REFERENCES

1. Schalamon J, Bismarck SV, Schober PH, Hollwarth ME. Multiple trauma in pediatric patients. *Pediatr Surg Int*. 2003;19(6):417–423.
2. Puri P, Goel S, Gupta AK, Verma P. Management of polytrauma patients in emergency department: an experience of a tertiary care health institution of northern India. *World J Emerg Med*. 2013;4(1):15–19.
3. Butcher NE, Enninghorst N, Sisak K, Balogh ZJ. The definition of polytrauma: variable interrater versus intrarater agreement—a prospective international study among trauma surgeons. *J Trauma Acute Care Surg*. 2013;74(3):884–889.
4. Cleugh FM, Maconochie IK. Management of the multiply injured child. *Paediatr Child Health*. 2012;23(5):194–199.

5. Meier R, Krettek C, Grimme K, et al. The multiply injured child. *Clin Orthop*. 2005;432:127–131.
6. Weinberg A, Marzi I. Pediatric polytrauma: always a strong challenge. *Eur J Trauma Emerg Surg*. 2010;36(4):297–298.
7. Zuidgeest J, Jonkheijm A, van Dijk M, van As AB. Is the golden hour optimally used in South Africa for children presenting with polytrauma? *S Afr Med J*. 2013;103(3):166–167.
8. Pandya NK, Upasani VV, Kulkarni VA. The pediatric polytrauma patient: current concepts. *J Am Acad Orthop Surg*. 2013;21(3):170–179.
9. Khilnani P. Management of a child with multiple trauma. *Indian J Crit Care Med*. 2004;8(2):78–84.
10. Chowdhary SK, Menon P, Rao KLN. Management of multiple injuries in children. *Indian J Pract Pediatr*. 2004;6(2):175–182.
11. Wesson DE, Spence LJ, Williams JI, Armstrong PF. Injury scoring systems in children. *Can J Surg*. 1987;30(6):398–400.
12. Abantanga FA, Jackson S, Upperman JS. Initial assessment and resuscitation of the trauma patient. In: Ameh EA, Bickler SW, Lakhoo K, Nwomeh BC, Poenaru D, eds. *Paediatric Surgery: A Comprehensive Text for Africa*. Vol 1. Seattle: Global HELP Organization; 2011:172–179.
13. Kay RM, Skaggs DL. Pediatric polytrauma management. *J Pediatr Orthop*. 2006;26(2):268–277.
14. Figaji AA. Targeted treatment of severe head injury. *Contin Med Educ*. 2010;28(3): 104–107.
15. Sebastian van As AB. Paediatric trauma care. Review. *Afr J Paediatr Surg*. 2010;7(3):129–133.
16. Kochanek PM, Carney N, Adelson PD, et al. Guidelines for the acute medical management of severe traumatic brain injury in infants, children, and adolescents—second edition. *Pediatr Crit Care Med*. 2012;13(suppl 1):S1–S82.
17. Chung S, Mikrogianakis A, Wales PW, et al. Trauma association of Canada Pediatric Subcommittee National Pediatric Cervical Spine Evaluation Pathway: consensus guidelines. *J Trauma*. 2011;70(4):873–884.
18. Stahel PF, VanderHeiden T, Flierl MA, et al. The impact of a standardized "spine damage-control" protocol for unstable thoracic and lumbar spine fractures in severely injured patients: a prospective cohort study. *J Trauma Acute Care Surg*. 2013;74(2):590–596.
19. Bliss D, Silen M. Pediatric thoracic trauma. *Crit Care Med*. 2002;30(11 suppl): S409–S415.
20. Shah SR, Wearden PD, Gaines BA. Pediatric peripheral vascular injuries: a review of our experience. *J Surg Res*. 2009;153(1):162–166.
21. Fayiga YJ, Valentine RJ, Myers SI, Chervu A, Rossi PJ, Clagett GP. Blunt pediatric vascular trauma: analysis of forty-one consecutive patients undergoing operative intervention. *J Vasc Surg*. 1994;20(3):419–424; discussion 424–425.
22. Samuels M, Wieteska S. *Advanced Paediatric Life Support: The Practical Approach*. 5th ed. Chichester: Wiley-Blackwell; 2011.
23. Loder RT. Pediatric polytrauma: orthopaedic care and hospital course. *J Orthop Trauma*. 1987;1(1):48–54.
24. Tepper B, Brice JH, Hobgood CD. Evaluation of radiation exposure to pediatric trauma patients. *J Emerg Med*. 2013;44(3):646–652.
25. Pitcher RD, Wilde JCH, Douglas TS, van As AB. The use of the Statscan digital X-ray unit in paediatric polytrauma. *Pediatr Radiol*. 2009;39(5):433–437.
26. Pitcher RD, van As AB, Sanders V, et al. A pilot study evaluating the "STATSCAN" digital X-ray machine in paediatric polytrauma. *Emerg Radiol*. 2008;15(1):35–42.
27. Pickett PM, Tripi PA. Massive transfusion protocol in pediatric trauma. *Int Anesthesiol Clin*. 2011;49(2 Spring):62–67.
28. Hess JR, Holcomb JB, Hoyt DB. Damage control resuscitation: the need for specific blood products to treat the coagulopathy of trauma. *Transfusion*. 2006;46(5): 685–686.
29. Shaz BH, Dente CJ, Harris RS, MacLeod JB, Hillyer CD. Transfusion management of trauma patients. *Anesth Analg*. 2009;108(6):1760–1768.
30. Demetriades D, Murray J, Charalambides K, et al. Trauma fatalities: time and location of hospital deaths. *J Am Coll Surg*. 2004;198(1):20–26.
31. Kauvar DS, Lefering R, Wade CE. Impact of hemorrhage on trauma outcome: an overview of epidemiology, clinical presentations, and therapeutic considerations. *J Trauma*. 2006;60(6 suppl):S3–S11.
32. Kashuk JL, Moore EE, Johnson JL, et al. Postinjury life threatening coagulopathy: is 1:1 fresh frozen plasma: packed red blood cells the answer? *J Trauma*. 2008;65(2):261–270; discussion 270–271.
33. Cushing M, Shaz BH. Blood transfusion in trauma patients: unresolved questions. *Minerva Anestesiol*. 2011;77(3):349–359.
34. Duchesne JC, Holcomb JB. Damage control resuscitation: addressing trauma-induced coagulopathy. *Br J Hosp Med (Lond)*. 2009;70(1):22–25.
35. Borgman MA, Spinella PC, Perkins JG, et al. The ratio of blood products transfused affects mortality in patients receiving massive transfusions at a combat support hospital. *J Trauma*. 2007;63(4):805–813.
36. Gonzalez EA, Moore FA, Holcomb JB, et al. Fresh frozen plasma should be given earlier to patients requiring massive transfusion. *J Trauma*. 2007;62(1):112–119.
37. Nosanov L, Inaba K, Okoye O, et al. The impact of blood product ratios in massively transfused pediatric trauma patients. *Am J Surg*. 2013;206(5):655–660.
38. Hussmann B, Lefering R, Kauther MD, Ruchholtz S, Moldzio P, Lendemans S. Influence of prehospital volume replacement on outcome in polytraumatized children. *Crit Care*. 2012;16(5):R201.
39. Borse NN, Gilchrist J, Dellinger AM, Rudd RA, Ballesteros MF, Sleet DA. Unintentional childhood injuries in the United States: key findings from the CDC childhood injury report. *J Safety Res*. 2009;40(1):71–74.
40. Stylianos S, Egorova N, Guice KS, Arons RR, Oldham KT. Variation in treatment of pediatric spleen injury at trauma centers versus nontrauma centers: a call for dissemination of American Pediatric Surgical Association benchmarks and guidelines. *J Am Coll Surg*. 2006;202(2):247–251.
41. Stelfox HT, Bobranska-Artiuch B, Nathens A, Straus SE. A systematic review of quality indicators for evaluating pediatric trauma care. *Crit Care Med*. 2010;38(4): 1187–1196.
42. Cabana MD, Rand CS, Powe NR, et al. Why don't physicians follow clinical practice guidelines? A framework for improvement. *JAMA*. 1999;282(15): 1458–1465.
43. Carter EA, Waterhouse LJ, Kovler ML, Fritzeen J, Burd RS. Adherence to ATLS primary and secondary surveys during pediatric trauma resuscitation. *Resuscitation*. 2013;84(1):66–71.
44. Butcher N, Balogh ZJ. AIS $>$ 2 in at least two body regions: a potential new anatomical definition of polytrauma. *Injury*. 2012;43(2):196–199.
45. Butcher N, Balogh ZJ. The definition of polytrauma: the need for international consensus. *Injury*. 2009;40(suppl 4):S12–S22.
46. Ebben RH, Vloet LC, Verhofstad MH, Meijer S, Mintjes-de Groot JA, van Achterberg T. Adherence to guidelines and protocols in the prehospital and emergency care setting: a systematic review. *Scand J Trauma Resusc Emerg Med*. 2013;21:9.