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Noninvasive Ventilation

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Noninvasive ventilation (NIV) is increasingly accepted as an alternative to endotracheal intubation (ETI) for the management of respiratory failure, both acute and chronic. While randomized controlled trials are generally lacking in the pediatric literature, progressively more research is addressing the implementation of NIV. Studies that focus on identifying predictors of NIV success or failure may help identify patients who will benefit from NIV.

— Ann M. Dietrich, MD, Editor

What Is Non-invasive Ventilation?

Definitions. NIV is a method of providing artificial respiratory support without placement of an endotracheal airway. In the literature, the terminology for NIV is broad and the terms noninvasive positive pressure ventilation (NPPV), noninvasive respiratory support (NRS), continuous positive airway pressure (CPAP), and bilevel positive airway pressure (BiPAP) are all common, despite the fact that their definitions may only overlap. In general, NIV refers to the application of both ventilatory and pressure support through the use of expiratory positive airway pressure (EPAP) and inspiratory positive airway pressure (IPAP). Oxygen and sometimes inhaled medications can also be delivered through the machine. Although it does not offer ventilatory support, CPAP is often mentioned and studied together with NIV, as they share patient interfaces, such as oronasal masks and nasal prongs, and are considered in similar clinical scenarios. BiPAP is the most accurate medical colloquialism for NIV; however, the term "BiPAP" itself is a trade name of a specific brand of portable ventilator and, therefore, should not be generalized to all forms of this modality.

NIV has been well studied in adult populations, particularly in the setting of acute respiratory failure (ARF) in patients with chronic obstructive pulmonary disease (COPD).[1] In pediatric populations, the literature on NIV is less abundant and what exists can be divided into two main categories: NIV application for acute respiratory failure and for chronic respiratory support. The latter has been better studied, especially in pediatric patients with neuromuscular disorders or upper airway abnormalities, and is gaining widespread acceptance as an in-home, chronic therapy.[2,3] This review, however, will focus on the application of NIV for pediatric patients in ARF.

Pathophysiology of Acute Respiratory Failure in Pediatrics

Compared to adults, newborns and infants have more compliant rib cages with relatively horizontal ribs, flatter diaphragms, and smaller diameter airways.[9] These physiologic principles are largely responsible for the differences between the presentation of an older child with a mild viral respiratory illness and an infant hospitalized for bronchiolitis. To facilitate passage through the birth

Executive Summary

- NIV is increasingly accepted as an alternative to endotracheal intubation (ETI) for the management of respiratory failure, both acute and chronic.
- Studies have shown that NIV is associated with lower rates of complications, such as infections and local injury, and shorter ICU stays and hospitalizations when compared to ETI.
- There is support in the literature for the use of NIV in asthma and bronchiolitis.
- Sepsis, abnormal RR for age, high IPAP, high EPAP, and high FiO_2 at initiation of therapy were all characteristics of patients who failed NIV.
- Most authors recommend starting with lower pressures that are gradually increased to produce relief of symptoms. This is in contrast to starting with higher pressure settings with the goal of rapid symptom relief, then titrating the pressure down to the lowest tolerated level.
- Worsening respiratory distress, increasing RR, increasing HR, reduced breath sounds, hypoxemia, and deteriorating mental or hemodynamic status despite NIV are generally accepted reasons to abandon NIV and initiate ET intubation.

canal, the rib cages of newborns contain relatively more cartilage. As they grow, the bones become progressively more ossified. In part due to the horizontal relationship of the ribs, infants are less efficient at the upward and outward movement of the chest wall and, therefore, expend more energy to overcome a relatively small amount of airway resistance.[10] Neonates are primarily nasal breathers, while infants are primarily mouth breathers.[11] Congestion of the upper airway in neonates can therefore lead to respiratory distress as the infant attempts to generate the inspiratory negative pressure needed to overcome resistance in their nasal airways. These factors together explain why they are more susceptible to acute respiratory distress and failure in the setting of mild viral illnesses.

Newborns and young infants exhibit a biphasic response in the setting of hypoxia. After 1-2 minutes of hyperventilation, immature brain centers develop hypoventilation when hypoxemia is sustained. Infants are therefore more likely to develop respiratory arrest in hypoxic states.[10] Bronchiolitis is a good condition to highlight how these physiologic differences change the clinical presentation in infants compared to adults and older children. In bronchiolitis, inflammation of the bronchioles causes a significant reduction in the radius of patent airway. As defined by Poiseuille's law, resistance down a tube is inversely proportional to the radius taken to the fourth power. Therefore, as the airway radius decreases, the resistance down the airway increases. First, poor ventilation occurs, and then air trapping is seen. Because the rib cage is so compliant, the infant must contract the intercostal and accessory muscles vigorously to expand the rib cage and overcome small airway resistance. This can lead to "tiring out" of the infant and one common reason for transfer to a pediatric intensive care unit (ICU) for intubation.

Older children have more respiratory reserve. As children grow, they accumulate more alveoli, their diaphragms become more domed, and their rib cages ossify and become less compliant.[9] Children also become taller and have more total lung capacity. Alveoli also continue to develop after birth. A neonate possesses around 24 million alveoli. By 8 years of age, this number has increased to 300 million, and by adulthood there are between 300 and 500 million alveoli.[9,12] Asthma is the most common medical diagnosis for hospitalized children in the United States.[13] In the setting of status asthmaticus, respiratory failure stems from inflammatory mediated bronchoconstriction and airway collapse, leading to dynamic hyperinflation.[14] As airway narrowing worsens in the acute episode, the work of breathing against airway resistance greatly increases during both inspiration and expiration and can lead to fatigue. In asthma, the application of IPAP decreases work of breathing by unloading the inspiratory muscles. EPAP, on the other hand, works to open narrowed airways and ameliorate airway collapse during expiration.

ARF can be broadly separated into hypoxemic respiratory failure and hypercarbic respiratory failure.[15] Hypoxemic respiratory failure is the more common form and is characterized by an arterial oxygen tension (PaO_2) lower than 60 mmHg with a low to normal arterial carbon dioxide tension ($PaCO_2$). Examples of hypoxemic respiratory failure include etiologies that affect the parenchyma such as pneumonia, pulmonary edema, acute lung injury (ALI), and acute respiratory distress syndrome (ARDS), as well as airway obstruction such as bronchiolitis and status asthmaticus.[16] Hypercapnic respiratory failure, on the other hand, is characterized by a $PaCO_2$ higher than 50 mmHg. Common etiologies include overdose, neuromuscular disease, chest wall abnormalities, and severe obstructive airway disease such as asthma and COPD. CPAP increases oxygenation and carbon dioxide (CO_2) washout by recruiting atelectatic lung, reducing work of breathing, and preventing apnea by stenting upper airways and chest wall, which is especially important

Table 1. Mechanisms of Action

- Decreases work of breathing
- Stents upper airways and chest wall
- Increases functional residual capacity
- Recruits collapsed alveoli
- Improves respiratory gas exchange

in former premature infants who may have components of bronchopulmonary dysplasia or laryngomalacia.[16] (*See Table 1.*) NPPV, on the other hand, allows for the benefits of CPAP with the additional benefit of better muscle unloading, alveolar recruitment, oxygenation, and CO_2 washout, in addition to being able to augment the rate of ventilation.[16]

Why Implement Noninvasive Ventilation?

Benefits of Noninvasive Ventilation Compared to ET Intubation. NIV is increasingly considered as effective as and safer than ETI for managing ARF in pediatric populations. Studies have shown that NIV is associated with lower rates of complications, such as infections and local injury, and shorter ICU stays and hospitalizations when compared to ETI. This is important, as longer hospitalizations increase health care costs as well as opportunities for hospital-acquired infections and stress to families. Acute respiratory failure is the most common reason for admission to a pediatric ICU, accounting for about 20% of admissions.[17] Mechanical ventilation by ETI is required by 35% to 64% of pediatric ICU admissions.[17,18] Of those children who require intubation, many require only a short duration of treatment. In one study evaluating risk factors associated with prolonged intubation times, researchers found that less than 35% of pediatric patients requiring ventilation by ETI remained intubated for more than 12 hours, and less than 20% remained intubated for more than 24 hours.[18] Short-term ETI to bridge a period of ARF is therefore a common clinical situation seen in the pediatric ICU.

There are many well-known complications of ETI, including infection, vocal cord dysfunction, oropharyngeal injury, laryngeal injury, and the need for sedation.[16,19] Studies in adult populations have established that when compared to ETI, NIV is associated with shorter periods of ventilator assistance, shorter ICU stays, fewer infectious complications, and lower mortality both in the ICU setting and overall.[17,20] These studies in adults have especially looked at NIV used in the setting of acute exacerbations of COPD.[21] There is also evidence in adult populations that NIV can improve oxygenation and reduce the need for intubation in patients with hypoxemic ARF (such as ALI/ARDS) when instituted early.[17]

Literature on NIV for pediatric patients is less abundant, but increasingly in favor of NIV as an alternative to ETI for pediatric patients in ARF. What does exist is primarily from pediatric ICU literature and largely conducted in countries outside of the United States. One of the larger studies done in recent years was a prospective observational study that examined 278 children at a Malaysian university-based pediatric ICU being treated with NIV for a variety of conditions, including pneumonia, post-surgical respiratory support, upper airway obstruction, congestive heart failure, asthma, and bronchiolitis.[21] Of the 278 patients who received NIV in this study, 211 (75.9%) did not require any intubation. Additionally, pediatric ICU length of stay was reported to be statistically shorter for those who received NIV, especially the subgroup who never required intubation.

Many studies have examined disease-specific efficacy of NIV. Basnet et al showed in one randomized, controlled study that nine of 10 children admitted for treatment of status asthmaticus tolerated 24 hours of NIV without adverse effects and did not require any sedation.[22] Additionally, the NIV group had a more rapid and persistent improvement in clinical asthma score, less tachypnea, less tachycardia, lower supplemental oxygen requirement, and less need for adjunctive therapy.[22] Limitations of this study include small size. In a retrospective review of infants receiving mechanical ventilation for bronchiolitis, Lazner et al found that NIV was effective in 80% of infants receiving respiratory support for severe bronchiolitis.[23] Murase et al reported that at their institution, pediatric patients who received NIV following liver transplant had significantly lower rates of re-intubation and earlier discharge from the ICU.[24] They additionally found a benefit in decreasing atelectasis by applying NIV following extubation.

Complications of Noninvasive Ventilation

Poor patient interface, including improper fit and interface intolerance, is the root cause of the majority of NIV complications. Potential adverse effects include skin breakdown, inability to tolerate the interface, aspiration, and treatment failure leading to ETI. The location and types of local complications vary depending on the interface used. The most frequent complications reported in studies using oronasal masks are irritative dermatitis, mild erosion on the bridge of the nose, and irritative conjunctivitis.[19,25] Pressure sores are observed in 5.8% of children using the oronasal masks, and 7.2% develop a hospital-acquired pneumonia, although 75% of those who develop hospital-acquired pneumonia were previously intubated.[21] While in adult populations ineffective inspiratory efforts and double-triggering are the most common types of asynchrony leading to discomfort, in children auto-triggering is thought to be the primary cause of difficult patient-ventilator interaction.[16] Auto-triggering is defined as a cycle delivered by the ventilator in the absence of an inspiratory effort by the patient. Auto-triggering can

Table 2. Contraindications to NIV

- Hemodynamic instability
- Life-threatening hypoxemia
- Impaired mental status
- Uncooperative or agitated patient
- Poor mask fit
- Impaired cough
- Excessive oral secretions
- Upper airway obstruction
- Recent facial, upper gastrointestinal, or upper airway surgery
- Recent facial trauma
- Unrepaired congenital cyanotic heart disease
- Rapidly progressive neuromuscular weakness (i.e., Guillain-Barré)

be generated by cardiogenic oscillations (small variations in flow caused by heart beats) or leaks in the ventilator circuit, especially poor interface fit.

When to Use Noninvasive Ventilation

Selection of Candidates for Noninvasive Ventilation. While there are no consensus guidelines on selection criteria for NIV, many authors have suggested criteria for identifying patients who will benefit. Calderini et al suggest that NIV be initiated according to the presence of moderate to severe dyspnea, tachypnea, hypoxemia, and/or respiratory acidosis.[16] They also suggest that possible contraindications include life-threatening hypoxemia, upper airway obstruction, vomit, impaired cough, facial surgery, facial trauma, craniofacial abnormalities preventing a good mask interface, Glasgow Coma Scale (GCS) less than 10, hemodynamic instability, or congenital cyanotic heart disease that has not been corrected. NIV should also be avoided in severe ARF in the presence of clinical exhaustion, as these patients have a higher probability of failing NIV.[16] Institutional resources also factor greatly into the ability to initiate NIV, especially in the emergency department. (*See Table 2.*)

As NIV is becoming a more widely accepted and applied modality of treating ARF, research is lacking on how individual patients will respond to therapy. NIV failure is generally considered to be the cessation of therapy due to major complications, poor tolerance, and/or inability to stabilize the progression of respiratory failure requiring tracheal intubation.[25] One major concern in the literature is that implementation of NIV may delay definitive treatment. Payen et al conducted a retrospective cohort study to identify risk factors associated with longer durations of mechanical ventilation in pediatric ICU patients.[18] Among the possible risk factors evaluated, they found NIV failure was associated with a high risk of prolonged mechanical ventilation. While Payen et al did not demonstrate a causative relationship, their group does highlight that a better understanding of risk factors for NIV failure could be immensely useful in preventing a delay to ETI in those patients who will eventually require it. Sepsis, abnormal RR for age, high IPAP, high EPAP, and high FiO_2 at initiation of therapy were all characteristics of non-responders to NIV in another study.[21]

Identifying patients who will respond favorably to NIV is equally contentious in the literature. Evans et al identified oxygen requirement in the emergency department as the strongest single predictor of nasal prong CPAP requirement at their institution.[26] They also identified several other factors, including younger age at presentation, lower oxygen saturation, lower GCS, and younger gestational age. Muñoz-Bonet et al found young age and more severe underlying condition to be risk factors at their institution.[25] Cavari et al, in a retrospective study of NIV at their institution, separated patients with bronchiolitis and respiratory failure into "responders" (64%) and "non-responders" (36%) to NIV via nasal prong CPAP.[27] Their group failed to detect any physiologic or clinical markers to predict an individual patient's response to NIV, including demographics or disease severity.[27] Their group recommends that any infant in impending respiratory failure without other organ failure be given a trial with NIV. When evaluating NIV failures in their pediatric ICU, Lum et al also found no significant difference in demographics, sedation use, onset of NIV postoperatively, or prior ET intubation requirement.[21]

Many predictive factors have been suggested, including Pediatric Risk of Mortality III (PRISM III) score. PRISM III is a tool designed to assess risk factors contributing to mortality in pediatric ICUs.[28] Lum et al found that patients with higher PRISM II scores (a predecessor to PRISM III) were less likely to avoid intubation despite NIV therapy.[21] Additionally, using a multivariate analysis, they showed that a higher PRISM II score, sepsis, and a higher fraction of inspired oxygen (FiO_2) requirement at initiation of NIV were independent predictors of NIV failure. The two main causes of NIV failure in their study were worsening respiratory failure and septic shock. Muñoz-Bonet also found a higher PRISM III score, as well as requiring more hemodynamic support, were predictors of failure.[19]

When selecting patients for NIV, pediatric-specific risk factors should be taken into consideration in addition to those associated with NIV in adult populations. Patients with developmental or behavioral disorders, such as autism spectrum disorders or other developmental delays, may react poorly to the NIV interface, especially in conjunction with being in a new environment and acutely ill. This group may require significant sedation and ultimately may progress to ETI due to mask intolerance. Young children have a tendency to increase mouth breathing in the setting of nasal obstruction. This may induce air leaks and auto-triggering around nasal mask devices. Certain patient populations, such as those with cerebral palsy and former premature infants, may have intrinsic immaturity of their airway protective reflexes and be at high risk of aspiration with NIV. Lastly, gastroesophageal reflux is a physiologically normal process for infants from around 2 months to approximately 1 year of age.[29] Although rarely seen with the pressures used in NIV, barotrauma and air swallowing could theoretically worsen their gastroesophageal sphincter function and, thereby, their reflux.[30]

Some of the highest NIV failure rates are for patients with severe hypoxemic respiratory failure, especially ARDS. Muñoz-Bonet et al in a prospective non-controlled study searching for predictive factors of NIV failure found failure rates reach as high as 75% for pediatric patients with ARDS.[25] In their study, FiO_2 greater than 0.57 was associated with nearly 80% of NIV failures. Other studies have subsequently used this number as a cut off for intubation.[11] Muñoz-Bonet et al also commented on an association between failure and worsening radiographic imaging between 24 hours and 48-72 hours after initiation of therapy. Mean arterial pressure (MAP) greater than 11.5 cm H_2O also showed some predictive value, and was associated with nearly 90% of failures in their study. Patients in severe respiratory distress with high or rapidly increasing oxygen requirements may therefore be poor candidates for initiation of NIV.

Immunocompromised patients, such as those with immunodeficiency disorders, oncology patients, or those on immunosuppressive therapy, require special consideration. As a population, they are especially susceptible to ventilator-related infections and do poorly with mechanical ventilation. In adult populations, current evidence supports using NIV as a first-line approach for managing mild to moderate ARF in patients immunocompromised with cancer or HIV.[20] Bello et al reported that the risk of airway management complicated by infection with NIV to be less than that of ETI.[20]

A final consideration is provider familiarity and comfort with the modality. In a cross-sectional study evaluating the attitudes of pediatric critical care attending physicians concerning NIV, Fanning et al found that factors such as severe defects in oxygenation and ventilation, disease progression, and patient intolerability decrease the likelihood of a provider deciding to initiate NIV.[17] Age was not a factor in decision making. Providers were more comfortable initiating NIV for lower airway diseases, such as bronchiolitis or pneumonia, than with upper airway obstructions such as croup, with 27% of providers answering that they would avoid using NIV. The authors speculate that this stems from a provider belief that fighting the NIV interface reduces laminar flow in the upper airways and worsens respiratory distress. Overall, their qualitative study showed that the decision to initiate NIV has much to do with provider gestalt on the severity of respiratory distress and comfort with the modality.

Monitoring Response to NIV

Several groups have commented on objective measurements, such as vital signs or arterial blood gas findings, following implementation of NIV that may be useful in predicting a favorable response to therapy. Decrease in respiratory rate (RR) to age-appropriate limits and lack of need for increasing amount of sedation could be used to predict NIV success.[27] (*See Table 3.*) An increasing need for sedation may be a sign of asynchrony with the ventilator or discomfort with the interface and may serve as a marker of impending NIV failure. Lum et al measured RR, heart rate (HR), and FiO_2 at the start of therapy, then six hours and 24 hours following implementation.[21] They found that both RR and FiO_2 were significantly different at all three time points, while HR did not change significantly until the six-hour mark. All three metrics exhibited a downtrend toward age-adjusted norms in patients who tolerated therapy well. Bernet et al did not find improvement in blood gas to predict failure of NIV.[31]

Table 3. **Signs of Favorable Response to NIV (within 1-2 hours of application)**

- **Decreased respiratory rate to age-related normal ranges**
- **Decreased retractions and accessory muscle use**
- **Absence of paradoxical breathing**
- **Improved oxygenation on pulse oximetry and blood gases**
  - **— Improved pH**
  - **— Improved PaO_2/FiO_2**
  - **— Reduction in $PaCO_2$**
- **Improved lung volumes on chest radiographs**

How to Use Noninvasive Ventilation

Interfaces. Interfaces for delivering NIV to the pediatric patient come in a wide variety of shapes and sizes. The choice of a particular interface will depend on patient age, clinical presentation, presence of craniofacial abnormalities, and, most importantly for pediatric patients, tolerance of the device. Dead space is also a consideration, and many of the devices that are the best tolerated, such as a soft plastic helmet, may not be the ideal choice in the setting of hypercarbic respiratory failure. Proper fit is important for minimizing air leaks and thereby lowering the frequency of auto-triggering and improving patient comfort. There is little comparative data for different kinds of NIV interfaces.

Oronasal Mask. The most common interface is an oronasal mask that covers both the nose and the mouth. Properly fitted, it should extend from the bridge of the nose to just below the lower lip. While the oronasal mask allows for a tight fit and limits dead space, claustrophobia is commonly encountered. Pediatric populations often tolerate this modality poorly for this reason. When dealing with long-term therapy, the oronasal mask can cause breakdown of the skin around the nose as well as an irritative conjunctivitis. Many authors suggest having multiple sizes and models of masks available and to change masks from time to time to avoid local complications such as skin breakdown.[19] Infants are primarily mouth breathers, and for these patients a mask that covers the mouth is usually the best choice.

Nasal Cannula. Positive pressure delivery through nasal prongs is beneficial when little respiratory support is needed. They are generally easy to use and keep in place, but highly flow-resistive and problematic if nasal obstruction is part of the underlying ARF process, such as in bronchiolitis.

Nasal Mask. Nasal masks possess the advantage of being less anxiety-inducing for smaller children. A nasal mask should rest between the bridge of the nose to just above the upper lip. Nasal masks are generally easy to use and keep in place, but are associated with air leaks caused by mouth opening. Chin straps designed to keep the mouth closed have been made to address this issue. In general, the smaller the nasal mask, the better the fit and the less dead space.

Full Face Masks. Full face masks are infrequently used. They cover the entire face, including the eyes, and are made of a clear plastic. While they limit oral leaks and can reduce claustrophobia, they carry a relatively large amount of dead space compared to other interfaces, and patients may have difficulty eliminating CO_2. Craniofacial abnormalities may be of less concern with this interface.

Helmet. Transparent, soft plastic helmets are gaining more attention as a possible alternative to masks, especially in younger infants. Chidini et al found that CPAP delivered by a helmet was associated with a lower number of trial failures, less patient intolerance, longer tolerated application time, and reduced need for sedation in infants with ARF when compared with a mask.[11] In general, helmets tend to be well tolerated and associated with little air leakage and a lower risk of pressure sores. They also allow for speaking and coughing, which are of immense psychological and therapeutic value.[16] Craniofacial abnormalities become less of an issue with the helmets, as the interface is fit at the level of the shoulders and does not take into account the contours of the face. The main downsides to helmet-mediated NIV include CO_2 rebreathing, although this can be overcome by using a high-flow helmet system.[11,16] Ventilator settings are different with this interface, especially IPAP, to account for the compliance of the helmet itself. It is also better suited for application of CPAP alone and less well adapted to ventilation.

Initiating Noninvasive Ventilation

As a general rule, NIV settings are adequate when the work of breathing and respiratory rate have improved. Early initiation is especially important in patients with hypoxemic ARF, as discussed above.[17,19] When initiating NIV, it is important to consider interface fit and, if possible, have options at hand for interface types and sizes. Mild sedation may improve patient-ventilator synchrony, especially in infants.[27] As discussed above, good patient-ventilator synchrony is a positive predictor of NIV success.[27] Most authors recommend starting with lower pressures that are gradually increased to produce relief of symptoms. This is in contrast to starting with higher-pressure settings with the goal of rapid symptom relief, then titrating the pressure down to the lowest tolerated level. In this low-to-high approach, EPAP can be started at 5-8 cm H_2O and titrated to a maximum of 8-12 cm H_2O. IPAP can be started at 6-8 cm H_2O and titrated to a maximum of 20 cm H_2O. FiO_2 can be started at 0.4 and titrated up to 0.6 as needed.[21] IPAP should be adjusted and increased until optimal chest rise is seen and chest retractions are minimized. Once the patient is breathing comfortably, the IPAP can then be reduced in small increments (roughly 2 cm H_2O) until the normal range is met. Worsening respiratory distress, increasing RR, increasing HR, reduced breath sounds, hypoxemia, and deteriorating mental or hemodynamic status despite NIV are generally accepted reasons to abandon NIV and initiate ET intubation.

Nasal CPAP pressures 4-8 cm H_2O are generally safe.[16] Aerophagia and gastric distension are a concern with NIV, especially as the regurgitation of gastric contents can lead to aspiration. The risk of gastric distension increases with higher pressures. The need for gastric decompression is unlikely under 25 cm H_2O and, therefore, placement of a nasogastric tube for decompression is unnecessary in most cases.[19]

Summary

NIV is increasingly considered as effective as and safer than ETI for managing ARF in pediatric populations.

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Noninvasive Ventilation

Mechanisms of Action

- Decreases work of breathing
- Stents upper airways and chest wall
- Increases functional residual capacity
- Recruits collapsed alveoli
- Improves respiratory gas exchange

Contraindications to NIV

- Hemodynamic instability
- Life-threatening hypoxemia
- Impaired mental status
- Uncooperative or agitated patient
- Poor mask fit
- Impaired cough
- Excessive oral secretions
- Upper airway obstruction
- Recent facial, upper gastrointestinal, or upper airway surgery
- Recent facial trauma
- Unrepaired congenital cyanotic heart disease
- Rapidly progressive neuromuscular weakness (i.e., Guillain-Barré)

Signs of Favorable Response to NIV (within 1-2 hours of application)

- Decreased respiratory rate to age-related normal ranges
- Decreased retractions and accessory muscle use
- Absence of paradoxical breathing
- Improved oxygenation on pulse oximetry and blood gases
  - — Improved pH
  - — Improved PaO_2/FiO_2
  - — Reduction in $PaCO_2$
- Improved lung volumes on chest radiographs

Supplement to *Pediatric Emergency Medicine Reports*, November 2013: "Noninvasive Ventilation."
Authors: **Nathan Mick, MD, FACEP**, Associate Chief, Department of Emergency Medicine, Director, Pediatric Emergency Medicine, Maine Medical Center, Portland, ME; and **Katherine T. Liu, MD**, Maine Medical Center, Internal Medicine and Pediatrics Residency Program, Portland, ME.

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Trauma Reports

PRACTICAL, EVIDENCE-BASED REVIEWS IN TRAUMA CARE

Volume 14, Number 6 **Nov/Dec 2013**

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Blunt Abdominal Trauma in Pediatrics

Pediatric abdominal trauma is common, with delays in diagnosis and treatment resulting in an increased rate of complications. Advances in technology have made evaluation of intra-abdominal injuries increasingly less invasive, but clinical diagnosis and an appropriate level of suspicion are still the most important variables in management. The authors review common intra-abdominal injuries and the current standard for diagnostic evaluation and management.

— Ann M. Dietrich, MD, Editor

Introduction

Trauma is the number one cause of death in the pediatric age group.[1,2] Blunt trauma is much more common than penetrating trauma and can present a serious challenge to care providers.

Blunt abdominal trauma accounts for the large majority of abdominal injuries in the pediatric population. Blunt abdominal trauma far outnumbers penetrating abdominal trauma,[3] and the mechanisms of injury vary among the different age groups. Motor vehicle-related injuries, whether as vehicle occupants, bicyclists, or pedestrians, are the most common cause of pediatric blunt abdominal trauma.[4] Child abuse is the leading cause of homicide in infants and may occur secondary to blunt abdominal injury. Other mechanisms of blunt abdominal trauma include falls, sports, and recreation-related injuries.

There are specific injury mechanisms that should lead the practitioner to suspect the presence of intra-abdominal injury,[5] such as a handlebar injury (*see Figure 1*) to the upper abdomen and seat belt signs from a motor vehicle accident.

Management of intra-abdominal injury has undergone a major shift to non-operative management during the past decade. This shift to non-operative management has been possible due to the ability to accurately evaluate the abdomen and pelvis with computed tomography (CT) scan and ultrasound. Although most blunt injuries can be successfully managed non-operatively, the decision not to operate must be a thoughtful and rational decision. Early involvement of a surgeon experienced in the management of traumatic abdominal injuries in children is considered imperative.[7]

Pathophysiology

It must be remembered that children are not small adults. They have a unique anatomy, a different physiologic reserve, and a more pliant skeleton. As a result of unique anatomy and physiology, the injury patterns in children are different.[8]

Children's intra-abdominal organs are more closely situated to each other, and the likelihood of multiple organs being injured is higher in pediatric blunt abdominal trauma. There is also less protective adipose tissue, connective tissue, and muscle mass. This results in the force of the blow transmitting more energy to internal organs and increasing the chance of intra-abdominal injury.[9,10]

Executive Summary

- There are specific injury mechanisms that should lead the practitioner to suspect the presence of intra-abdominal injury, such as a handlebar injury to the upper abdomen and seat belt signs from a motor vehicle accident.
- It must be remembered that a negative FAST exam alone does not exclude hemoperitoneum or intra-abdominal injury, and repeated assessment is warranted to ascertain a change in the patient's clinical condition.
- Since most solid organ injuries do not require surgical intervention, a positive DPL has limited clinical significance in the management of solid organ injuries.
- One study shows that children with no evidence of abdominal wall trauma, no abdominal tenderness, a GCS greater than or equal to 14, no vomiting, no thoracic wall trauma, and normal breath sounds are at very low risk of an intra-abdominal injury and do not require CT scan to exclude injury.
- The spleen is the most commonly injured organ in pediatric abdominal trauma. Non-operative management has become standard practice.

The skeleton of a child is not completely calcified, which allows it to be more pliable. The consequence is that a child's skeleton absorbs less energy from the trauma, and underlying organs may be injured even in the absence of bony injury. Alternatively, when there are bony injuries, this suggests that a great amount of force was applied, and the suspicion of intra-abdominal injury should be high.

Initial Management

The initial evaluation of any trauma patient is vital to a successful outcome. Every trauma patient, including pediatric patients of all ages, must be initially managed according to the principles of Advanced Trauma Life Support (ATLS).[11]

A primary survey needs to be completed without delay to identify immediately life-threatening injuries.[12] The primary survey consists of an assessment of the airway to ensure that it is open to allow the travel of air into and out of the lungs without any hindrance.[13]

Vital signs in children vary according to age group, and the practitioner should be familiar with the range of normal vital signs in children. (*See Table 1.*)

Hypoxia is the most common cause of cardiac arrest in children, and bradycardia in children is a sign of hypoxia. Any child who cannot maintain his or her own airway, including those with severe head injury, significant hypovolemia, or in whom an operation is likely necessary, must be intubated.[15]

Spontaneous, effortless breathing should occur. A quick way to assess airway patency is to engage the patient in a conversation, and if patient is able to speak without difficulty, then the airway is likely intact. If there are clear breath sounds with easy flow of air, you can move on to checking for circulation.

Circulation is evaluated to ensure that there is no life-threatening bleeding. External bleeding is easily detected and controlled with manual compression. Internal bleeding may be more difficult to detect, but close attention to the patient's vital signs and physical appearance can help in detecting occult bleeding. A child who is exhibiting signs of hypovolemia should alert the practitioner to the possibility of internal injuries and the need for resuscitation, as well as an investigation to find the source of bleeding.[16]

Finally, the primary survey should be completed with a quick neurologic examination, including Glasgow Coma Scale (GCS), and the patient must be disrobed from head to toe to allow for a complete and unhindered examination. Cover the child with warm blankets to prevent hypothermia once a thorough examination is complete.[17]

Adjuncts to the primary survey may include a chest X-ray, a pelvic X-ray, and the Focused Abdominal Sonography for Trauma (FAST) exam.

Figure 1. Handlebar Injury[6]

Chest X-ray

The chest X-ray in pediatric trauma is a valuable tool to identify conditions such as rib fractures, pneumothorax, hemothorax, and the rare aortic injury. It also serves as a screening tool to determine which patients need further imaging with a CT of the chest. A completely normal chest X-ray is associated with a reduced risk of having a significant

Table 1. Vital Functions[14]

Age	Weight (kg)	Heart Rate (beats/min)	Blood Pressure (mmHg)	Respiratory Rate (breaths/min)	Urinary Output (mL/kg/hr)
0-12 months	0-10	< 160	> 60	< 60	2.0
1-2 years	10-14	< 150	> 70	< 40	1.5
3-5 years	14-18	< 140	> 75	< 35	1.0
6-12 years	18-36	< 120	> 80	< 30	1.0
> 13 years	36-70	< 100	> 90	< 30	0.5

thoracic injury and may allow the practitioner to safely avoid a CT of the chest.[18]

Routine pelvic X-rays in pediatric trauma patients are not necessary. A screening tool from the University of Michigan level 1 pediatric trauma center accurately predicts the absence of a pelvic fracture.[19] (*See Table 2.*)

FAST Exam

The FAST exam has added a method to quickly evaluate a patient with possible abdominal injuries in the trauma bay. While FAST does not replace a CT scan in the evaluation of abdominal trauma, it can aid in the decision to perform a CT scan or go to the operating room.

A positive FAST in a hemodynamically unstable patient who is not responding to resuscitation is an indication to go to the operating room. A positive FAST in a hemodynamically stable patient should spur further evaluation with a CT scan.

A negative FAST exam in combination with a benign physical exam and normal levels of ALT/AST, amylase, and lipase can decrease the likelihood of a CT scan being necessary.[21,22] However, it must be remembered that a negative FAST exam alone does not exclude hemoperitoneum or intra-abdominal injury,[23] and repeated assessment is warranted to assess for a change in the patient's clinical condition.

Secondary Survey

A secondary survey follows the primary survey once the practitioner is confident there is no immediate life-threatening injury and the patient's vital signs are normal or responding appropriately to resuscitation.[24]

The secondary survey consists of a complete medical history, including medications, surgical history, last meal, and allergies. Additional tests in the secondary survey may include further radiographic imaging, such as a CT scan or additional X-rays and lab work.

In the evaluation of blunt abdominal trauma, a CBC, CMP, hepatic function panel, amylase, and lipase should be sent. Laboratory studies are sent to assist in the evaluation of the patient with blunt abdominal trauma based on organ system. Serial laboratory values are generally more helpful than any single value, but ALT and AST values greater than 250 U/L warrant further evaluation.

CT SCAN

CT scanning is the imaging study of choice for blunt abdominal trauma in children, but there is a downside to CT scans.[25] Although CT is able to identify and evaluate intra-abdominal organ injury with great accuracy,[26] children should not be unnecessarily or reflexively exposed to the radiation from a CT scan.[27]

Hemodynamically unstable patients do not belong in the CT scan under any circumstances. A trauma patient who is hemodynamically unstable belongs in the operating room if he or she is not responding to resuscitation.

While CT scans are being increasingly used to assess for traumatic injuries,[28] there is concern for the eventual development of malignancy related to the radiation exposure from even one CT scan. One study shows that children with no evidence of abdominal wall trauma, no abdominal tenderness, a GCS greater than or equal to 14, no vomiting, no thoracic wall trauma, and normal breath sounds are at very low risk of an intra-abdominal injury and do not require CT scan to exclude injury.[29]

CT is beneficial when assessment must be made of an intubated trauma patient.[30] Use of oral contrast is not indicated in a trauma setting. It leads to a delay in diagnosis and is a potential aspiration risk.

Diagnostic Peritoneal Lavage

Diagnostic peritoneal lavage (DPL) is rarely indicated in evaluation of pediatric trauma and, if performed, must be done by a surgeon. It has been largely replaced by the FAST exam. Because most solid organ injuries do not require surgical intervention, a positive DPL has limited clinical significance in the management of solid organ injuries.[31] DPL does have the highest sensitivity in detection of bowel injury. The presence of bile, food particles, and amylase activity can be used to diagnose small bowel perforation.

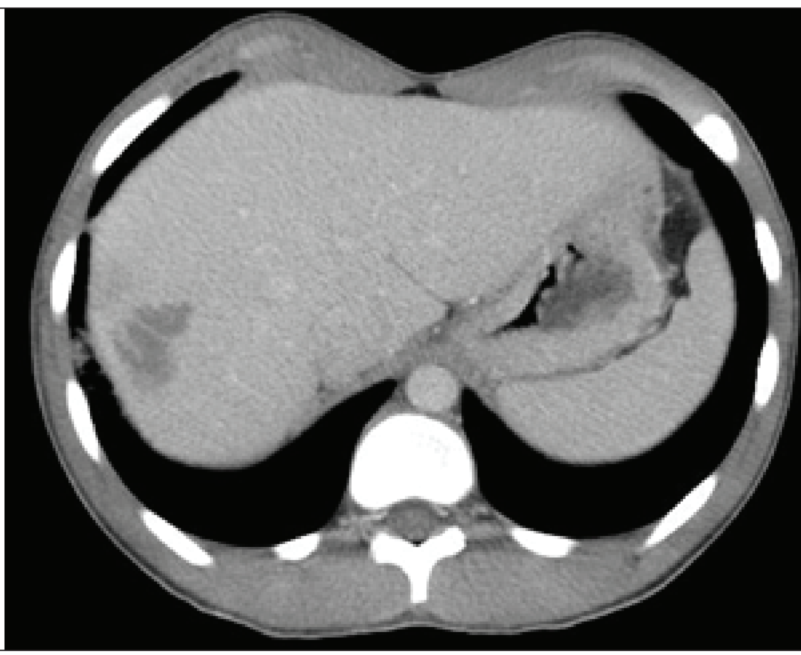
Diagnostic Laparoscopy

Diagnostic laparoscopy can be both diagnostic and therapeutic in

Table 2. Risk Factors Predictive of Pelvic Fracture[20]

High-risk Clinical Findings
• GCS < 14
• Positive urinalysis
• Pelvic tenderness
• Pelvic laceration
• Pelvic abrasion
• Abdominal pain/tenderness
• Femur fracture
High-risk Mechanism of Injury
• Unrestrained motor vehicle crash
• Motor vehicle crash with ejection
• Motor vehicle crash rollover
• Pedestrian struck by motor vehicle
• Bicyclist struck by motor vehicle

Figure 2. Liver Laceration with Blush



cases of bowel injury.[32] Some trauma surgeons contend that a diagnostic laparoscopy is appropriate in the scenario of suspicion for a bowel injury instead of DPL because of the lower morbidity associated with diagnostic laparoscopy. It is also the test of choice for suspected diaphragmatic injury, although this is rare in pediatric trauma patients.

Resuscitation

The goal of initial resuscitation is to normalize vital signs and to maintain perfusion of vital organs.[33] One pitfall to be aware of in pediatric trauma patients is that they are able to maintain a normal blood pressure despite significant volume loss. The initial physiologic response to blood loss will be tachycardia. Hypotension in children indicates a significant hypovolemia. (*See Table 3.*)

The initial bolus of intravenous fluid should be 20 mL/kg of a crystalloid solution, such as normal saline or lactated Ringers. If there is no response, a second bolus should be given. If hemodynamic instability remains, a third bolus of 20 mL/kg of a crystalloid solution can be given, but at this point there should be a consideration for using packed red blood cells.[35,36] Transfusion protocols vary and are dependent on institution-based protocols.

Continuous monitoring of the patient response to the fluid boluses is imperative. Patients are characterized as either responders, non-responders, or transient responders.

Responders will have improved vital signs, a clearer mental status, return of normal skin color, increased perfusion of the extremities as indicated by peripheral pulses, and increased warmth of the skin.

Non-responders are those patients whose hemodynamic status does not respond to crystalloid or blood products. These patients must receive ongoing resuscitation and be taken to the operating room for control of hemorrhage.[37]

Hemodynamic instability should not delay surgical intervention because ongoing hypotension that is unresponsive to resuscitation increases mortality and morbidity. Prompt control of injuries is necessary.

Transient responders show preliminary improvement of their hemodynamic status, but the status worsens again over time. This likely indicates ongoing bleeding and requires ongoing resuscitation and consideration of surgical intervention. It is also possible that additional resuscitation will stabilize a patient and avoid the need for an operation.

Liver Injury

The liver accounts for nearly one-third of injured organs in pediatric blunt abdominal trauma, and

Table 3. Physiologic Response to Blood Loss[34]

System	< 30% blood loss	30-45% blood loss	> 45% blood loss
Cardiovascular	Increased heart rate, weak thready peripheral pulses, normal blood pressure (80-90 + 2 × age in years), normal pulse pressure	Markedly increased heart rate, thready central pulses, absent peripheral pulses, low normal systolic blood pressures (70-80 + 2 × age in years), narrowed pulse pressure	Tachycardia followed by bradycardia, very weak or absent central pulses, absent peripheral pulses, hypotension (< 70 + 2 × age in years), narrowed pulse pressure (or undetectable diastolic blood pressure)
Central nervous system	Anxious, irritable, confused	Lethargic, dulled response to pain	Comatose
Skin	Cool, mottled, prolonged capillary refill	Cyanotic, markedly increased capillary refill	Pale and cold
Urine output	Low to very low	Minimal	None

most injuries are managed non-operatively as long as the patient remains hemodynamically stable and does not have other injuries (i.e., a bowel injury) that require operative intervention.

Liver injury should be suspected in patients with trauma to the right upper quadrant and those complaining of right upper quadrant pain. Severe liver trauma can cause significant internal bleeding that may need operative intervention. Patients with suspected liver injury who are unstable and not responding to resuscitation need to go to the operating room. These injuries have a high mortality, even with surgical intervention.

An active blush on CT scan may be successfully managed by embolization, but there is still debate over the safety of angioembolization in children.[38] (*See Figure 2.*)

Non-operative management according to APSA guidelines have been successful in guiding care. They suggest bed rest equal to the grade of the injury plus one day, but protocols vary by institution. There are data to suggest an accelerated protocol of one night of bed rest for grade I and II injuries, and two nights for grade III or higher can be used without harm.[39]

Figure 3. Splenic Injury

Splenic Injury

The spleen is the most commonly injured organ in pediatric abdominal trauma. Non-operative management has become standard practice and achieves a high success rate.[40] Splenic preservation should be achieved whenever possible to avoid post-splenectomy infection, which has a high mortality rate, and splenectomy has been shown to increase risk of infection and death.[41,42]

Splenic injury should be suspected in children with direct trauma to the left side, associated rib fractures, and left upper quadrant tenderness. CT

Table 4. Spleen Injury Scale (1994 Revision)[49]

Grade*	Injury Type	Description of Injury
I	Hematoma	Subcapsular, < 10% surface area
	Laceration	Capsular tear, < 1 cm parenchymal depth
II	Hematoma	Subcapsular, 10%-50% surface area Intraparenchymal, < 5 cm in diameter
	Laceration	Capsular tear, 1-3 cm parenchymal depth that does not involve a trabecular vessel
III	Hematoma	Subcapsular, > 50% surface area or expanding; ruptured subcapsular or parenchymal hematoma; intraparenchymal hematoma > 5 cm or expanding
	Laceration	> 3 cm parenchymal depth or involving trabecular vessels
IV	Laceration	Laceration involving segmental or hilar vessels producing major devascularization (> 25% of spleen)
V	Laceration	Completely shattered spleen
	Vascular	Hilar vascular injury with devascularized spleen

*Advance one grade for multiple injuries up to grade III.

scan is the standard imaging study to diagnose and grade a splenic injury. (*See Figure 3.*) CT also guides management of injuries, and a finding of blush on CT scan seems to increase the rate of operation and correlate with hemodynamic instability.[43] However, even most of the patients with blush still can be managed successfully with non-operative management.[44,45]

Splenic angioembolization (SAE) can be used when the CT scan suggests ongoing bleeding, as long as the patient is hemodynamically stable. (*See Figure 4.*)

The decision to operate on a patient with a splenic injury is best based on hemodynamic stability, ongoing blood loss, and responsiveness to non-operative methods rather than grade of injury.

Observation with bed rest, serial physical examinations, and frequent hematocrit checks for management of splenic laceration according to APSA guidelines have been shown to be effective.[46,47] Stylianos proposes that only grade IV injuries or above (*see Table 4*) should be observed in the intensive care unit (ICU) for one day, and that no follow-up imaging is indicated. Activity restriction should be based on grade of injury.[48]

Injury to the Intestine

Detection of bowel injury poses a challenge to the clinician. Bowel injury is not always evident at initial presentation and may have a delayed presentation secondary to perforation. Mesenteric tears can cause associated bowel to become ischemic and present with perforation even days after the initial trauma. (*See Figure 5.*)

Intestinal injury should be considered with any patient who has suffered trauma to the abdomen, has any abdominal tenderness, or has visible abdominal wall ecchymosis. In particular, a seat belt sign should raise a clinician's suspicion for a bowel injury.[50] CT findings of extraluminal air, free intraperitoneal fluid, bowel wall thickening, bowel wall enhancement, bowel dilatation, and fat stranding should raise the clinician's suspicion of a bowel injury and perforation. Although CT scan is very useful in diagnosing injuries, the findings on CT scan must be interpreted in the clinical context. Serial clinical examination is the gold standard for diagnosis of intestinal injury.[51]

Rapid deceleration, as in the case of a restrained passenger in a motor vehicle crash, can cause injury to the bowel near a point of fixation (i.e., ligament of Treitz, terminal ileum, and rectosigmoid region).

Initial and subsequent serial abdominal exams are more critical to the diagnosis of bowel injury than any imaging modality.[52] If there is a perforation, early or late, an awake patient will have abdominal pain and signs of peritonitis due to the contents of the bowel irritating the peritoneum.

If a bowel injury is suspected, surgical consultation is mandatory.

Duodenal Injury

Duodenal injury is a specific type of injury to the intestines with unique characteristics. Due to the location of the duodenum in the protected retroperitoneum, duodenal injury is rare. Additionally, duodenal injuries may be associated with other injuries that can distract the clinician from making the diagnosis. There are reports that isolated duodenal injury is highly associated with child abuse.[53] Therefore, the clinician's suspicion of child abuse should rise when presented with a patient with isolated duodenal injury, as well as a history of trauma that does not correlate with the injuries.

Diagnosis of duodenal injury is difficult, but when suspicion for a duodenal injury exists, early CT scan with oral contrast will help make the diagnosis.[54] Duodenal injuries can be categorized into different grades based on size of hematoma or perforation/laceration.

A duodenal hematoma is managed non-operatively, and perforation is managed with an operation.[55] Non-operative management of hematoma is bowel rest with no oral intake and total parenteral nutrition. Resolution of the hematoma normally requires 1-3 weeks of observation and nutrition provided with TPN.

There are multiple operative managements of duodenal lacerations, and surgical consultation must be obtained in cases of duodenal perforation. All surgical treatments include drainage of the area. A variety of methods exist to bypass and repair the injury.[56] However, each institution has a low number of experiences with operative duodenal injuries per year, and a definite best method of repair is not established.

Pancreatic Injury

Pancreatic injuries are rare in pediatric blunt abdominal trauma, with an estimated range from 3% to 12%. Detecting this rare injury requires a high degree of suspicion based on the mechanism of injury and early CT scan (*see Figure 6*) to prevent a delay in diagnosis and subsequent complications, such as infection.[57]

Pancreatic injury occurs most commonly from force applied to the abdomen that results in compression of the abdomen against the vertebra and crushes the pancreas in between two structures, such as a classic handlebar injury to the mid upper abdomen. The signs and symptoms are vague, which often leads to a delay in diagnosis.

The initial serum amylase may be normal, even with complete transection of the duct. A CT scan with IV contrast and serial measurements of amylase are helpful in making the diagnosis. If injury is still suspected, ERCP can provide early evaluation and the possibility of intervention with pancreatic injuries.

Treatment of pancreatic injury is not well defined, secondary to the rarity of this injury. Proponents of non-operative management point to safe management of pancreatic injury with no morbidity.[58,59] The development of pseudocysts is

Figure 4. Angioembolization of Grade V Splenic Laceration

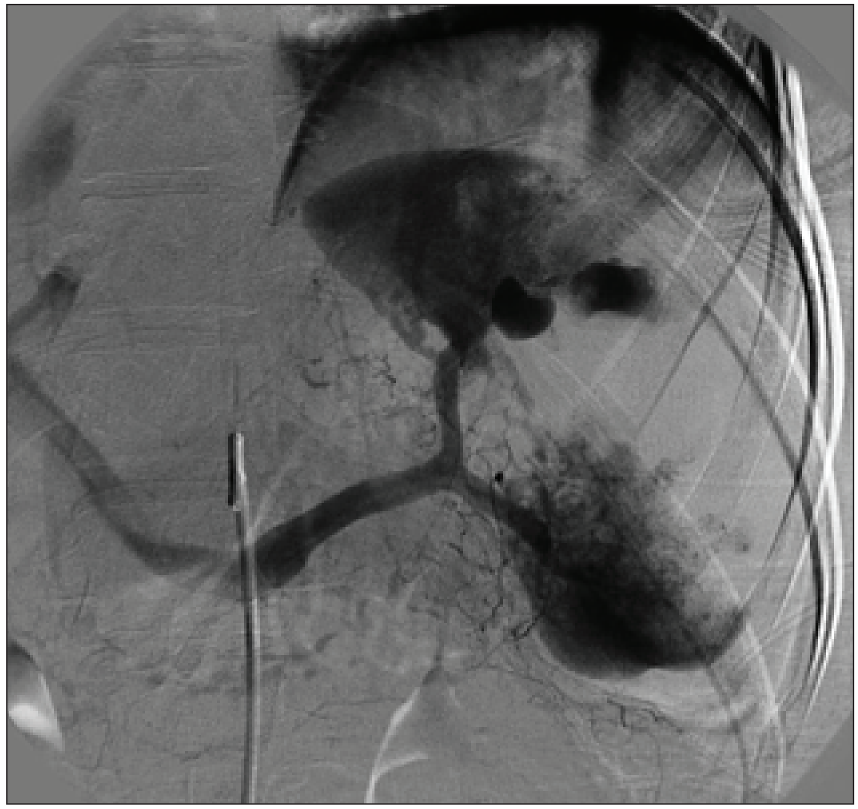
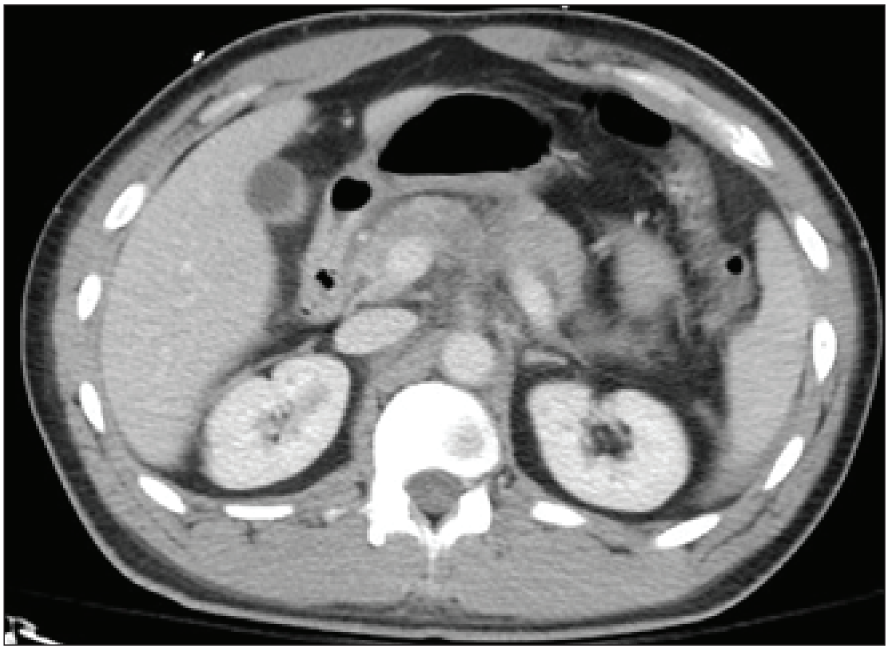


Figure 5. Bowel Injury Found on CT: Dilated Bowel with Surrounding Induration

Figure 6. Pancreatic Injury



expected in this patient population and can be managed with percutaneous drainage.[60] Proponents of early intervention quote a higher rate of TPN dependency and an increase in complications with non-operative management.[61]

Higher-grade pancreatic injuries can be managed with ERCP. Laparoscopic pancreatectomies of the distal pancreas, when indicated, are possible.

Renal Trauma

The majority of cases of renal injury result from motor vehicle crashes, falls, and sports-related trauma.[63] Like the other solid organ injuries from blunt abdominal trauma, renal injuries in a hemodynamically stable patient can be managed non-operatively.[64]

Renal injury should be suspected in patients with gross hematuria or microscopic hematuria with associated hypotension. Other findings associated with renal trauma include flank tenderness, a flank or abdominal mass, and ecchymosis of the flank.

In a hemodynamically stable patient, a CT scan with IV contrast should be obtained to grade the injury. Management should be based on the grade of the injury. Grade 1 to 3 injuries can be almost universally managed non-operatively. Grade 4 or 5 injuries can be selectively managed non-operatively if the patient is hemodynamically stable and has no associated abdominal injuries that require surgery.[65,66]

As long as the patient remains hemodynamically stable, bed rest and observation are indicated. If there is an active bleed seen on CT scan and the patient is hemodynamically stable, angiographic embolization can be used. Surgical intervention should be undertaken for hemodynamic instability or persistent blood loss requiring ongoing transfusions.[67]

If the patient is unstable, the operating room is the safest place. Prior to performing a nephrectomy on the injured kidney, the surgical team should ensure that the patient has two kidneys.

Aortic Injury

Blunt abdominal trauma causing abdominal aortic injury is exceedingly rare in the pediatric population. Since 1966, there have been only 17 reports in the literature of pediatric trauma patients with aortic injury from blunt trauma.[68]

Chance fractures associated with seat belts from motor vehicle crashes are a common mechanism.[69] Other mechanisms include child abuse, horseback riding, and handlebar injuries from bicycle crashes.

The symptoms of abdominal aortic injury include nonspecific complaints of abdominal and back pain, as well as specific findings such as loss of distal pulses, pulsatile abdominal mass, abdominal bruit, and paraplegia.[70]

Diagnosis can be made with a CT scan, and treatment normally includes open operative repair. Endovascular techniques have been reported for thoracic aortic injuries in children, but disadvantages, such as stent migration as the patient grows, must be considered.

Child Abuse

Abdominal trauma is the second leading cause of abusive trauma mortality.[71] The true incidence of abusive abdominal trauma is difficult to determine, but child abuse should be considered when a child presents with abdominal trauma and a discordant story. Risk factors include poverty, male gender, young age, previous unexplained or repetitive injuries, an adult male other than the father in the home, and children with physical and developmental delays.[72]

While any organ may be injured from abuse, the liver and the bowel are the most common, and injuries to multiple organs are not uncommon. Toddlers aged 2 to 4 years of age are the most likely to suffer abusive injuries, but infants and older children, including adolescents, are at risk, too.

A high level of suspicion should be maintained in children whose history and pattern of injuries do not correlate. Social work consults and referral to child protective services for investigation should be considered in suspected cases.

Summary

Adherence to the principles of ATLS is imperative in managing pediatric trauma effectively. A delay in diagnosis and treatment leads to an increased rate of complications. Advances in technology have made evaluation of intra-abdominal injuries increasingly less invasive, but clinical acumen and a high degree of suspicion is still the most important aspect of management.

The majority of blunt abdominal injuries to solid organs can be managed non-operatively, but surgical consultation should be obtained prior to committing this course of treatment. Serial examination and re-evaluation is mandatory while treating any injury non-operatively. Hollow organ injuries, such as bowel injuries, require operative intervention and should not be treated non-operatively.

The care of pediatric patients with blunt abdominal trauma can be challenging. Adhering to the principles of trauma resuscitation according the ATLS will help clinicians to recognize injuries early and lead to proper treatment. Transfer to institutions well versed in the care of pediatric patients should be considered, especially for those with multisystem trauma.[73]

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CNE/CME Objectives

Upon completing this program, the participants will be able to:

- discuss conditions that should increase suspicion for traumatic injuries;
- describe the various modalities used to identify different traumatic conditions;
- cite methods of quickly stabilizing and managing patients; and
- identify possible complications that may occur with traumatic injuries.

CNE/CME Instructions

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CME/CNE Questions

1. Blunt trauma can be caused by which of the following?
   A. motor vehicle crashes
   B. bicycle accidents
   C. child abuse
   D. sports injuries
   E. all of the above

2. The initial management of a pediatric trauma should be guided by the principles of:
   A. Advanced Trauma Life Support
   B. patient comfort
   C. parental concerns
   D. individual hospital protocol

3. Which of the following is the most common cause of cardiac arrest in children?
   A. blunt thoracic trauma
   B. hypoxia
   C. severe head injury
   D. blunt abdominal trauma

4. Which of the following factors is/are predictive of pelvic fracture?
   A. pelvic tenderness
   B. motor vehicle crash with ejection
   C. abdominal tenderness
   D. positive urinalysis
   E. all of the above

5. Which of the following is true of the FAST exam?
   A. It replaces the need for a CT scan.
   B. It can help in deciding if a patient needs further evaluation with a CT scan.
   C. It definitively excludes intra-abdominal injury.
   D. It should not be repeated if a patient's condition worsens.

6. The goal of the initial resuscitation is:
   A. to normalize vital signs and maintain perfusion of vital organs
   B. to normalize laboratory values
   C. to prevent fluid overload
   D. to allow a hemodynamically unstable patient to go to CT scan

7. Which of the following is true of patients with a grade 3 splenic injury?
   A. They must be taken to the operating room immediately, even if hemodynamically stable.
   B. They should be placed on bed rest and undergo continuous hemodynamic monitoring and serial CBC monitoring.
   C. They may be safely discharged home.
   D. They must be monitored with serial CT scans.

8. Which of the following is true regarding pancreatic injury in children?
   A. It is extremely common.
   B. It can be easily diagnosed with a single amylase level.
   C. CT scan with IV contrast and serial measurement of amylase are helpful in making the diagnosis.
   D. ERCP is not able to provide either evaluation or intervention of pancreatic injuries.

9. Risk factors for child abuse include which of the following?
   A. poverty
   B. male gender
   C. young age
   D. adult male in the home other than the child's father
   E. all of the above

10. In evaluating pediatric patients with suspected blunt abdominal trauma, which of the following is true?
    A. CT scans should be used liberally without concern for sequelae.
    B. CT scan is the study of choice to detect solid organ injury.
    C. Ultrasound can definitively exclude intra-abdominal injury.
    D. Physical exam has no role in evaluating the patient.

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