INTRODUCTION

The care of the trauma patient is demanding and requires speed and efficiency. Evaluating patients who have sustained blunt abdominal trauma remains one of the most challenging and resource-intensive aspects of acute trauma care.[1]

Epidemiology

Trauma is a leading cause of morbidity and mortality in childhood, resulting in more than 1.5 million injuries, 500,000 hospital admissions, and 20,000 deaths per year.[2]

Approximately 80% of injuries are due to blunt force trauma. The abdomen is the second most common site of injury. The most common reported mechanism for abdominal injury is motor vehicle crashes, followed by automobile-versus-pedestrian injuries and falls.[3]

Abdominal trauma accounts for 8-10% of all trauma admissions to pediatric hospitals.[4] Blunt abdominal trauma is a frequent reason for emergency department admissions in children, and a significant cause of death in children older than 1 year.[5] Although injury to the abdomen accounts for only 10% of injuries in children with trauma, it is the most common unrecognized cause of fatal injuries. Therefore, a compulsive and systematic approach for identification and treatment is necessary.

Children are at greater risk than adults for intra-abdominal injuries after blunt trauma because of their immature musculoskeletal system. The overlying muscles and associated skeleton is much weaker than for adults, and therefore, less protective. In addition, children have a greater abdominal organ-to-body mass ratio. If a given force delivered to the abdomen is distributed over a smaller body surface area, increasing the likelihood of injury to the underlying structures.[6]

Causes

More than 80% of traumatic abdominal injuries in children result from blunt mechanisms; most commonly, they are related to motor vehicle accidents. Abdominal injuries may also result from falls or direct blows to the abdominal wall. In children, falls are the most common single mechanism of injury, although combined automobile-related injuries, including motor vehicle collisions and pedestrian injuries, are the most common cause of severe injury and death in children.[7] (Fig. 1)

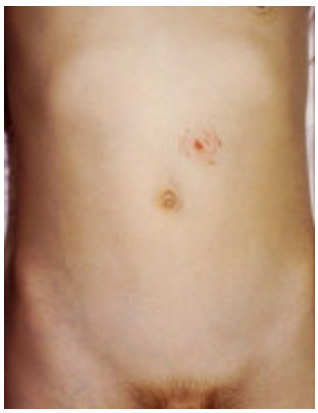


Fig. (1): Abdominal wall contusion in a handlebar injury in 10 years child.[7]

Risk factors

Several anatomic factors influence the child's susceptibility to and pattern of Intra-abdominal injuries (IAI). In particular, children are typically subjected to lower injury forces than adults. However, because of their smaller size, a given force is applied over a relatively larger area of the abdomen in children, increasing the likelihood of multi-organ injury. In addition, children have less abdominal wall muscle mass and fat than adults and a more compliant thoracic cage. These factors result in a less effectively protected liver and spleen, increasing the risk for significant organ injury compared to adults.[8]

Also, children have smaller blood vessels with enhanced vasoconstrictive response. Thus bleeding associated with solid organ injury usually stops spontaneously regardless of injury grade. As a result, most solid organs injury in children can be successfully managed non-operatively.[9]

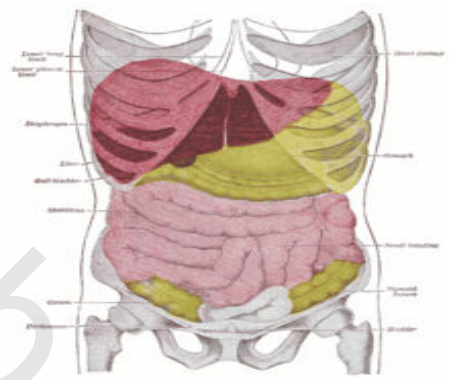
History

Since 1965, diagnostic peritoneal lavage (DPL) has been an integral diagnostic procedure in abdominal trauma. The DPL technique was developed because 45% of trauma patients had misleading physical exams resulting in treatment errors. The high sensitivity of DPL improved the ability of a surgeon to rapidly detect intra-peritoneal injury in trauma patients. However, not all injuries detected by DPL required surgical intervention. As a result, some patients received an unnecessary laparotomy. Also, the DPL procedure had procedural risks due to its invasiveness. Organs such as the bowel or bladder could be perforated by the DPL. In the 1970's and 80's, computed tomography (CT) was introduced to complement DPL and provides more specific information about organ injury. It is considered a sensitive and specific test for intra-abdominal trauma.[10]

Anatomy

A young child's abdomen is square and becomes more rectangular as the child matures. The abdominal wall of a child has thinner musculature than that of an adult, particularly during the first 2 years of life, providing less protection to underlying structures. The ribs are more flexible in the child, which makes them less likely to fracture. However, this increase in compliance makes them less effective at energy dissipation and, therefore, less effective at protecting the upper abdominal structures (e.g, spleen, liver).[11,12]

The solid organs are comparatively larger in the child than in the adult; therefore, more surface area is exposed, making the organ more at risk for injury. A lower fat content and more elastic attachment are typical of the intra-abdominal organs in children. These characteristics reduce the amount of energy absorption and may result in increased motility and vulnerability (e.g. kidneys). The child's spleen has a thicker capsule than that of the adult, yet it is among the most commonly injured solid organs in blunt abdominal trauma. In the young child, the intestine is not fully attached within the peritoneal cavity (especially the sigmoid and right colon), potentially making it more vulnerable to injury due to sudden deceleration and/or abdominal compression. The bladder extends to the level of the umbilicus at birth and therefore is more exposed to a direct impact to the lower abdomen. With age, the bladder descends to its retro-pubic position. The rapid growth of the spine during adolescence influences its anatomy and biomechanical properties, particularly in the lumbar area.[13] (Fig. 2)



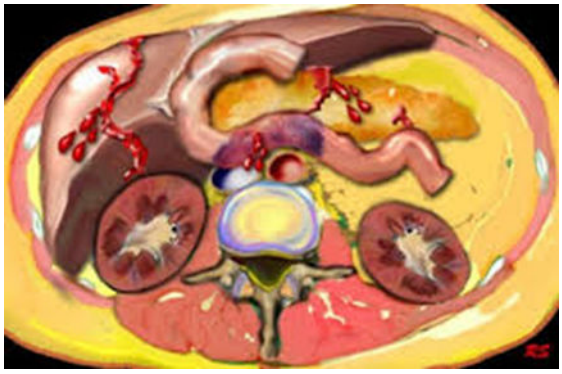


Fig. (2): The intra-abdominal organs.[14]

Pathophysiology

Intra-abdominal injuries secondary to blunt force are attributed to collisions between the injured person and the external environment and to acceleration or deceleration forces acting on the person's internal organs. Blunt force injuries to the abdomen can generally be explained by 3 mechanisms:

1) **The first mechanism is deceleration:** Rapid deceleration causes differential movement among adjacent structures. As a result, shear forces are created and cause hollow, solid, visceral organs and vascular pedicles to tear, especially at relatively fixed points of attachment. Classic deceleration injuries include hepatic tear along the ligamentumteres and intimal injuries to the renal arteries. As bowel loops travel from their mesenteric attachments, thrombosis and mesenteric tears, with resultant splanchnic vessel injuries, can result.

2) **The second mechanism is crushing:** Intra-abdominal contents are crushed between the anterior abdominal wall and the vertebral column or posterior thoracic cage. This produces a crushing effect, to which solid viscera (e.g. spleen, liver, and kidneys) are especially vulnerable.

3) **The third mechanism is external compression:** whether from direct blows or from external compression against a fixed object (e.g. lap belt, spinal column). External compressive forces result in a sudden and dramatic rise in intra-abdominal pressure and lead to rupture of a hollow viscous organ .The liver and spleen seem to be the most frequently injured organs, though reports vary. The small and large intestines are the next most frequently injured organs. Recent studies show an increased number of hepatic injuries, perhaps reflecting increased use of CT scanning and concomitant identification of more injuries.[15]

Abdominal injuries

1) Hepatic injuries

The liver is frequently injured after blunt trauma. Most hepatic injury occurs in the posterior segment of the right lobe. The principal types of liver injury are laceration, hematoma, and vascular injuries (Fig. 3). Lacerations appear as linear or branching low-attenuation areas. Lacerations are often associated with hematomas. Hepatic hematomas may be parenchymal, subcapsular, or parenchymal and subcapsular. Subcapsular hematomas

cause direct compression of underlying liver parenchyma, which allows differentiation from peritoneal fluid surrounding the liver. Vascular hepatic injury is rare in children. Partial hepatic devascularization can result from injury affecting the dual blood supply of the liver.

At CT, devascularized segments appear as low-attenuation areas that may be wedged shaped and may fail to show contrast enhancement (Fig. 4, 5). The liver is surrounded by a thin capsule that, in turn, is covered by peritoneal reflection of thin connective tissue. The presence of hemoperitoneum associated with hepatic injury principally relates to whether a laceration extends to the liver surface and whether the liver capsule remains intact at the site of injury. Hepatic injury is associated with hemoperitoneum in approximately two thirds of cases.[16]

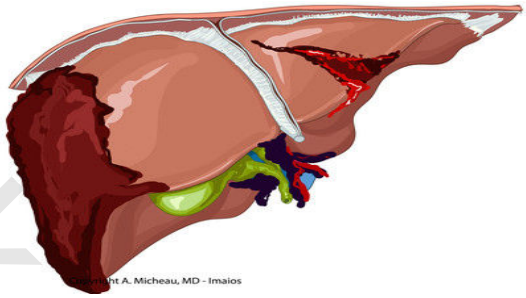


Fig. (3): hepatic injuries.[16]

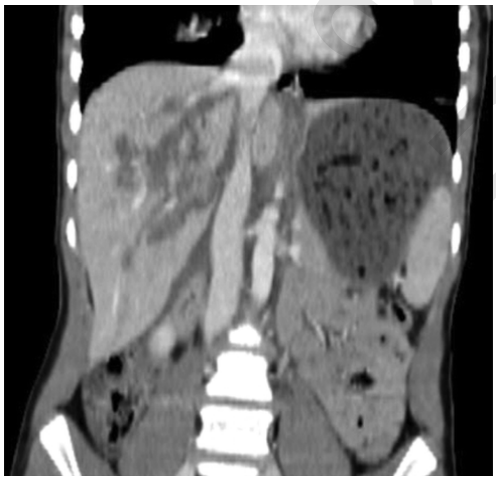


Fig. (4): Coronal reformation of contrast-enhanced CT scan through upper abdomen shows complex hepatic laceration.[17]

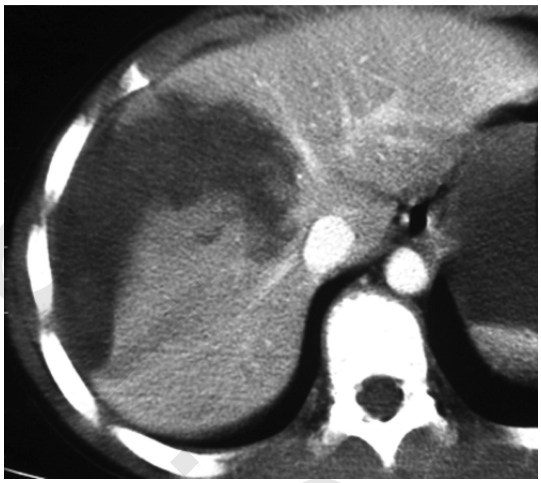


Fig. (5): Contrast-enhanced CT scan through upper abdomen shows laceration extending to periphery of liver with associated subcapsular hematoma.[17]

Hepatic injury may not be associated with intraperitoneal hemorrhage if the injury does not extend to the surface of the liver, if the hepatic capsule is not disrupted, or if there is extension to the liver surface in the bare area of the liver, which is devoid of peritoneal reflection. [17]

Most hepatic injuries can be successfully managed non-operatively regardless of the severity because bleeding typically stops spontaneously. In various reports, about 1% to 3% of children with hepatic injury required surgical hemostasis. [18]

2) Splenic injuries

Spleen is commonly damaged in blunt abdominal trauma and is the most commonly injured intra-abdominal organ in children. Splenic trauma is more common in children than in adults. A laceration of the spleen may be associated with hematoma. [19]

Trauma to the spleen can cause varying degrees of damage (Fig. 6), the major problem associated with internal bleeding. Mild splenic subcapsular hematomas are injuries in which bleeding is limited to small areas on and immediately around the spleen. Splenic contusions refer to bruising and bleeding on and around larger areas of the spleen.

Lacerations (tears) are the most common splenic trauma injuries (Fig. 7). Tears tend to occur on the areas between the three main blood vessels of the spleen. Because of the abundant blood supply, splenic trauma may cause serious internal bleeding. Most injuries to the spleen in children heal spontaneously. Severe trauma can cause the spleen or its blood vessels to rupture or fragment. Abdominal injuries including splenic trauma are the most common cause of preventable deaths in children. [20]

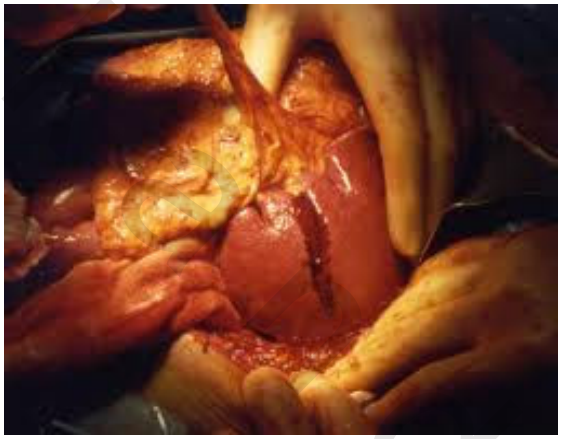


Fig. (6): Grade 2 splenic injury.[21]

The primary concern in any splenic trauma is internal hemorrhage, though the exact amount of hemorrhage may be small or large. Larger injuries bleed extensively, often causing hemorrhagic shock. A splenic hematoma sometimes ruptures, usually in the first few days, although rupture can occur from hours to even months after injury. [22]

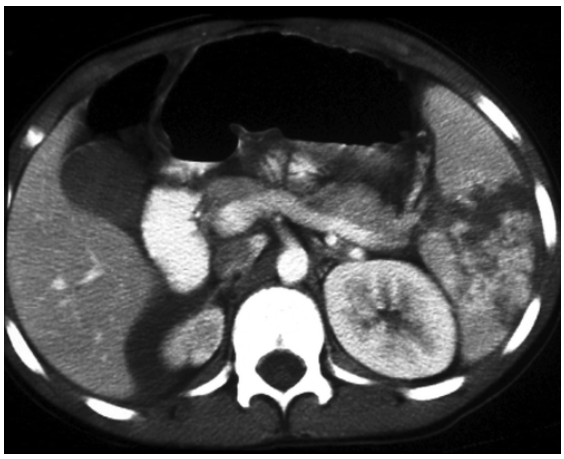


Fig. (7): Contrast-enhanced CT scans through upper abdomen showing shattered spleen. [19]

3) Renal injuries

The kidney is the third most frequently injured abdominal viscera in children. Renal parenchyma injury typically results from direct impact, whereas vascular and collecting system injuries usually result from deceleration. The most common renal injury is the parenchymal contusion. The contusion represents an organ bruise characterized by microscopic areas of hemorrhage and surrounding edema.

Renal lacerations appear as linear low-attenuation areas in the parenchyma. Deep lacerations may involve the renal collecting system (fig. 8). Renal injury may be complicated by peri-renal hematoma, which may be subcapsular or peri-nephric. These two types of hematomas can be differentiated on the basis of CT features. A subcapsular hematoma is limited in its extension by the renal capsule and will therefore exert greater mass effect on renal parenchyma (Fig. 9), whereas a perinephric hematoma is distributed throughout the perirenal space and typically shows less mass effect on renal parenchyma.

Renal collecting system injury is typically managed nonoperatively, particularly if the leak is confined to the perirenal space.[23]

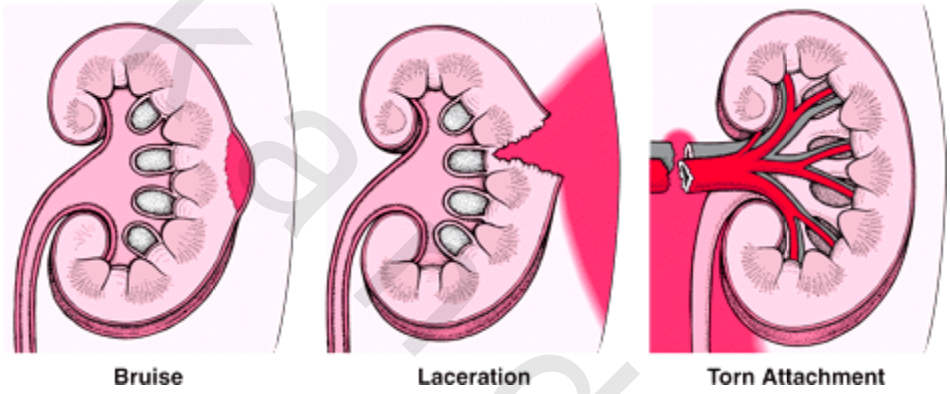


Fig. (8): The types of kidney injuries (bruises: areas of hemorrhage and surrounding edema, laceration: tear in the parenchyma, torn attachment: devascularization of the kidney).[24]

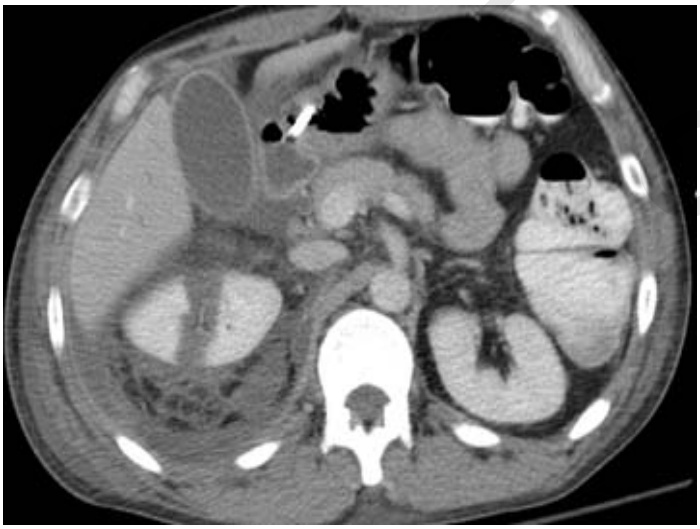


Fig. (9): Contrast enhanced CT scan through kidneys shows show a right upper pole renal laceration.[23]

4) Pancreatic injuries

Pancreatic trauma in children is relatively uncommon, but carries high morbidity and mortality rates when diagnosis is delayed. Preoperative diagnosis of pancreatic lesion might be difficult, especially in the case of isolated injury.[25]

Pancreatic traumas account for approximately 3-5% of blunt abdominal injuries. In cases of isolated pancreatic injuries failure to recognize injury to the Wirsung duct is the main cause of morbidity and mortality. Spiral CT with contrast medium is the standard investigation in hemodynamically stable traumatized patients, with a sensitivity of approximately 90%. However, at least initially, the extent of the pancreatic damage is not proportional to the severity of the clinical and instrumental picture. The patients need to be continuously and carefully monitored.[26]

5) Bowel injuries

Bowel injury is uncommon after blunt trauma in children. Injury can result in a partial-thickness injury that results in intramural hematoma or a full-thickness injury that results in bowel rupture. Associated mesenteric injury is often present. Most injuries are noted in children who have been involved in motor vehicle crashes and who display lap-belt ecchymosis.[25] Bowel rupture most commonly occurs in the mid to distal small intestine. The most common site is the jejunum.[28] (Fig. 10)

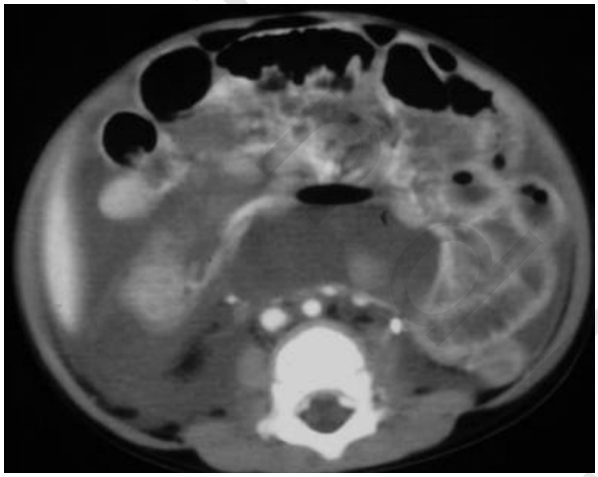


Fig. (10): Contrast-enhanced CT scan through upper abdomen shows bowel rupture with extra-luminal air. [28]

6) Bladder injuries

Bladder injury is also uncommon in children. Bladder rupture can be intra-peritoneal or extra-peritoneal. Combined injuries may occur. Extra-peritoneal bladder rupture occurs more frequently than intra-peritoneal rupture in children. Intra-peritoneal rupture typically results from shearing of the distended bladder by a lap belt, whereas extra-peritoneal rupture often results from laceration by a bone spicule from a pelvic fracture. The most common pelvic injuries associated with extra-peritoneal bladder rupture are obturator ring fractures, pubic symphysis diastasis, sacral fractures, and sacroiliac joint diastasis. Extra-peritoneal bladder rupture is typically managed non-surgically, whereas an intra-peritoneal rupture requires immediate surgical repair. [29]

Management of a child with trauma

A favorable outcome from any trauma depends upon rapid diagnosis and treatment of potentially life-threatening injuries. The management of pediatric trauma patients follows the paradigm of Advanced Trauma Life Support (ATLS) course of the American College of Surgeons. [30]

According to the ATLS, patient assessment is divided into

1) Primary survey

The first and key part of the assessment of patients presenting with trauma is called the primary survey. During this time, life-threatening injuries are identified and simultaneously resuscitation is begun. A simple mnemonic, ABCDE, is used as a memory aid for the order in which problems should be addressed:

a) Airway maintenance with cervical spine protection: The first stage of the primary survey is to assess the airway. If the patient is able to talk, the airway is likely to be clear. If the patient is unconscious, he/she may not be able to maintain his/her own airway. The airway can be opened using a jaw thrust (Fig.12). Airway adjuncts may be required. If the airway is blocked (e.g. by blood or vomit), the fluid must be cleaned out of the patient's mouth by the help of suctioning instruments. In case of obstruction, insertion of an endotracheal tube or supraglottic devices should be done.

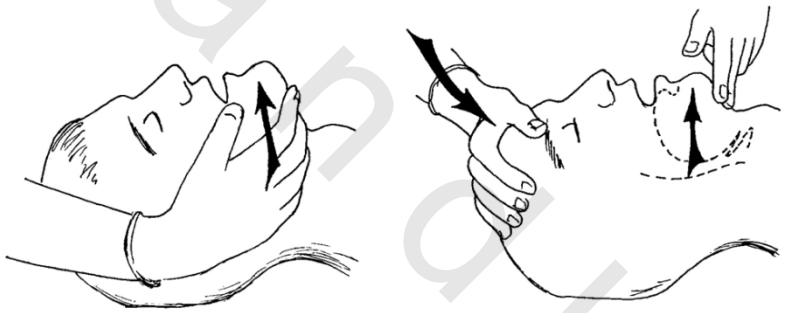


Fig. (11): (left) Jaw thrust maneuver, (right) Chin lift maneuver. [31]

b) Breathing and ventilation: The chest must be examined by inspection, palpation, percussion and auscultation. Subcutaneous emphysema and tracheal deviation must be identified if present. The aim is to identify and manage six life threatening thoracic conditions as airway obstruction, tension pneumothorax, massive haemothorax, open pneumothorax, flail chest segment with pulmonary contusion and cardiac tamponade. Flail chest, penetrating injuries and bruising can be recognized by inspection.

c) Circulation with hemorrhage control: Hemorrhage is the predominant cause of preventable post-injury deaths. Hypovolemic shock is caused by significant blood loss. Two large-bore intravenous lines are established and crystalloid solution may be given. If the person does not respond to this, type-specific blood, or O-negative if this is not available, should be given. External bleeding is controlled by direct pressure. Occult blood loss may be into the chest, abdomen, and pelvis or from the long bones.

Hypovolemic shock was classified according to ATLS into 4 Grades as shown in table 1

Table (1): Classification of Hemorrhagic Shock in PEDIATRIC Trauma Patients Based on Systemic Signs. [32]

System	Class I Very mild hemorrhage	Class II Mild Hemorrhage	Class III Moderate Hemorrhage	Class IV Severe Hemorrhage
Amount of blood loss	(<15% blood volume loss) 39% blood volume loss)	(15%-25% blood volume loss) (26%-39% blood volume loss)	(26%-39% blood volume loss)	(≥40% blood volume loss)
Cardiovascular	Heart rate normal or mildly increased	Tachycardia	Significant tachycardia	Severe tachycardia
Pulse	Normal pulses	Peripheral Pulses may be diminished	Thready peripheral pulses	Thready central pulses
ABP	Normal/Increased BP	Might be decreased	Decreased	Decreased
Respiratory	Rate normal	Tachypnea	Moderate tachypnea	Severe tachypnea
Central Nervous	Slightly anxious	Irritable, confused, Combative	Irritable or lethargic, diminished pain response	Lethargic / coma
Skin	Warm, pink,	Cool extremities, mottling	Cool extremities, mottling, or pallor	Cold extremities, pallor, or cyanosis
Kidneys	Normal urine output	Oliguria, increased specific gravity	Oliguria, increased BUN (<0.5 ml/Kg/ hour)	Anuria

d) Disability/Neurologic assessment: During the primary survey a basic neurological assessment is made, known by the mnemonic AVPU (alert, verbal stimuli response, painful stimuli response, or unresponsive). A more detailed and rapid neurological evaluation is performed at the end of the primary survey. This establishes the patient's level of consciousness, pupil size and reaction, lateralizing signs, and spinal cord injury level. The Glasgow Coma Scale is a quick method to determine the level of consciousness, and is predictive of patient outcome. An altered level of consciousness indicates the need for immediate reevaluation of the patient's oxygenation, ventilation, and perfusion status. Hypoglycemia and drugs, including alcohol, may influence the level of consciousness. If these are excluded, changes in the level of consciousness should be considered to be due to traumatic brain injury until proven otherwise.

Table (2): Total Glasgow Coma Score (GCS Score) ranging from 3-15.

Eye opening	Verbal response	Motor response
Spontaneous 4	Oriented 5	obeys commands 6
to speech 3	Confused 4	Localizes pain 5
to pain 2	inappropriate words 3	Withdraws 4
None 1	incomprehensible sounds 2	abnormal flexion 3
	None 1	Abnormal extension 2
		None 1

For children under 5, the verbal response criteria are adjusted as follows. [33]

Table (3): Modified in GCS in children < 5 Years. [33]

Score	2 to 5 Years	0 to 23 Months
5	Appropriate words or phrases	Smiles or coos appropriately
4	Inappropriate words	Cries and consolable
3	Persistent cries and/or screams	Persistent inappropriate crying &/or screaming
2	Grunts	Grunts or is agitated or restless
1	No response	No response

e) Exposure and environmental control: The patient should be completely undressed, usually by cutting off all what he wear. It is important to cover the patient with warm blankets to prevent hypothermia in the emergency department. Intravenous fluids should be warmed and a warm environment maintained. Patient privacy should be maintained.[34,35]

2) Secondary survey

When the primary survey is completed, resuscitation efforts are well established, and the vital signs are normalizing, the secondary survey can begin. The secondary survey is a head-to-toe evaluation of the trauma patient, including a complete history and physical examination, including the reassessment of all vital signs. Each region of the body must be fully examined. X-rays indicated by examination are obtained. If at any time during the secondary survey the patient deteriorates, another primary survey is carried out as a potential life threat may be present. The person should be removed from the hard spine board and placed on a firm mattress as soon as reasonably feasible as the spine board can rapidly cause skin breakdown and pain while a firm mattress provides equivalent stability for potential spinal fractures. [36]

Sample history

Before going on, be certain to obtain the SAMPLE history before the opportunity is lost.

S Signs and symptoms
A Allergies
M Medications
P Past history, pregnancy
L Last meal
E Events, environment. [37]

Abdominal examination

The initial clinical assessment of patients with blunt abdominal trauma is often difficult and notably inaccurate. The most reliable signs and symptoms in alert patients are pain, tenderness, gastrointestinal hemorrhage, hypovolemia, evidence of peritoneal irritation. However, large amounts of blood can accumulate in the peritoneal and pelvic cavities without any significant or early changes in the physical examination findings. Bradycardia may indicate the presence of free intra-peritoneal blood. On physical examination, the following injury patterns predict the potential for intra-abdominal trauma:

1) Lap belt marks: Correlate with small intestine rupture.
2) Steering wheel–shaped contusions.
3) Ecchymosis involving the flanks (Grey Turner sign) or the umbilicus (Cullen sign): Indicates retroperitoneal hemorrhage, but is usually delayed for several hours to days
4) Abdominal distention.
5) Auscultation of bowel sounds in the thorax: May indicate a diaphragmatic injury.
6) Abdominal bruit: May indicate underlying vascular disease or traumatic arterio-venous fistula.
7) Local or generalized tenderness, guarding, rigidity, or rebound tenderness: Suggests peritoneal injury.
8) Fullness and doughy consistency on palpation: May indicate intra-abdominal hemorrhage.
9) Crepitation or instability of the lower thoracic cage: Indicates the potential for splenic or hepatic injuries.[38,39]

The initial clinical assessment of patients with blunt abdominal trauma is often difficult and notably inaccurate. Associated injuries often cause tenderness and spasms in the abdominal wall and make diagnosis difficult. Lower rib fractures, pelvic fractures, and abdominal wall contusions may mimic the signs of peritonitis. So, clinical evaluation alone has an accuracy rate of only 65% for detecting the presence or absence of intra-peritoneal blood. [40]

In general, accuracy increases if the patient is reevaluated repeatedly and at frequent intervals. However, repeated examinations may not be feasible in patients who need general anesthesia and surgery for other injuries. The greatest compromise of the physical examination occurs in the setting of neurologic dysfunction, which may be caused by head injury or substance abuse. The abdominal examination must be systematic by inspection, palpation and auscultation:

1- Inspection: The abdomen and the back are inspected for abrasions or ecchymosis. Particular attention should be paid to injury patterns that predict the potential for intra-abdominal trauma (e.g. lap belt abrasions, steering wheel–shaped contusions). In most studies, lap belt marks have been correlated with rupture of the small intestine and an

increased incidence of other intra-abdominal injuries. Ecchymosis involving the flanks (Grey Turner sign) or the umbilicus (Cullen sign) indicates retroperitoneal hemorrhage, but this is usually delayed for several hours to days. Visual inspection for abdominal distention, which may be due to pneumoperitoneum, abdominal collection, or gastric dilatation secondary to assisted ventilation or swallowing of air, or ileus produced by peritoneal irritation, is important.

2- **Palpation and percussion:** Palpation may reveal local or generalized tenderness, guarding, rigidity, or rebound tenderness, which suggests peritoneal injury. Such signs appearing soon after an injury suggest leakage of intestinal content. Peritonitis due to intra-abdominal hemorrhage may take several hours to develop. Fullness and doughy consistency on palpation may indicate intra-abdominal hemorrhage. Crepitation or instability of the lower thoracic cage indicates the potential for splenic or hepatic injuries associated with lower rib injuries. Tenderness on percussion constitutes a peritoneal sign. Tenderness mandates further evaluation and probably surgical consultation.

3- **Auscultation:** Auscultation of bowel sounds in the thorax may indicate the presence of a diaphragmatic injury. Abdominal bruit may indicate underlying vascular disease or traumatic arterio-venous fistula.

4- **Rectal pelvic examinations:** A rectal examination should be done to search for evidence of bony penetration resulting from a pelvic fracture, and the stool should be evaluated for gross or occult blood. The evaluation of rectal tone is important for determining the patient's neurologic status, and palpation of a high-riding prostate suggests urethral injury.

The genitals and perineum should be examined for soft tissue injuries, bleeding, and hematoma. Blood at the urethral meatus is suggestive of urethral trauma .Pelvic instability indicates the potential for lower urinary tract injury, as well as pelvic and retroperitoneal hematoma and necessitates avoidance of repeated examination, which may increase blood loss. Open pelvic fractures are associated with a mortality rate exceeding 50%.A nasogastric tube should be placed routinely (in the absence of contraindications, e.g., basilar skull fracture) to decompress the stomach and to assess for the presence of blood. If the patient has evidence of a maxillofacial injury, an orogastric tube is preferred. As the assessment continues, a Foley's catheter is placed and a sample of urine is sent for analysis for microscopic hematuria. If injury to the urethra or bladder is suggested because of an associated pelvic fracture, then a retrograde urethrogram is performed before catheterization. With respect to the primary and secondary surveys, pediatric patients are assessed and treated at least initially as adults. However, there are obvious anatomic and clinical differences between children and adults that must be kept in mind, including the following:

1) A pediatric patient's physiologic response to injury is different.
2) Effective communication with a child is not always possible.
3) Physical examination findings become more important in children.
4) A pediatric patient's blood volume is smaller, predisposing to rapid exsanguinations.
5) Technical procedures in pediatric patients tend to be more time consuming and challenging.
6) A child's relatively large body surface area contributes to rapid heat loss.
7) Perhaps the most significant difference between pediatric and adult blunt trauma is that, for the most part, pediatric patients can be resuscitated and treated non-operatively. Some pediatric surgeons often transfuse up to 40 mL/kg of blood products in an effort to stabilize a pediatric patient. Obviously, if this fails and the child continues to be unstable, laparotomy is indicated.[41]

Diagnosis of intra-abdominal injuries

The diagnostic evaluation of a child with IAI begins with a complete understanding of the mechanism of injury. The circumstances of the traumatic event, including the magnitude and directionality of the force(s) applied to the body, should be determined as accurately as possible. The child with blunt trauma to the abdomen may require either emergent or selective laparotomy, depending on hemodynamic stability and response to resuscitation. Most patients, though, remain hemodynamically stable. For these patients, diagnostic tests (laboratory evaluation and radiographic studies) combined with the history and physical examination become important in diagnosing IAI.

Laboratory evaluation of the child at risk for intra-abdominal injuries

The utility of specific laboratory studies for the diagnosis of IAI is somewhat controversial. Nonetheless, a decrease in the hemoglobin level or hematocrit will raise the suspicion of intra-abdominal bleeding if no other obvious source of bleeding exists. However, in the acute setting before intravascular equilibration has occurred after administration of intravenous fluids (IV), there may not be a significant decrease in hemoglobin or hematocrit despite significant intra-abdominal bleeding. A number of authors have reported the association of abnormal laboratory values and IAI. [42]

Imaging of intra-abdominal injuries

Includes focused abdominal sonography for trauma patient (FAST), computed tomography (CT) with or without contrast and x-ray of the abdomen.

1) FAST

Ultrasound physics

Ultrasound is sound with frequency greater than 20,000 cycles per second or 20 kHz. Audible sound sensed by the human ear is in the range of 20Hz to 20 kHz. Creating an ultrasound image is done in three steps - producing a sound wave, receiving echoes, and interpreting those echoes. Ultrasound waves are produced by a transducer. A transducer is a device that takes power from one source and converts the energy into another form e.g. electricity into sound waves. The sound waves begin with the mechanical movement (oscillations) of a crystal that has been excited by electrical pulses, this is called the piezoelectric effect.

The sound waves are emitted from the crystal similar to sound waves being emitted from a loud speaker. The frequencies emitted are in the range of (2- 15MHz) and are unable to be heard by the human ear. Several crystals are arranged together to form a transducer. It is from the transducer that sound waves propagate through tissue to be reflected and returned as echoes back to the transducer. Sound is produced using Piezoelectricity (Fig. 12 &13) Precise electrical pulses from the ultrasound machine make the transducer create sound waves at the desired frequency.

The sound is focused either by the shape of the transducer (Curved, Linear, and Sector) or a set of control pulses from the ultrasound machine. This focusing produces the desired shaped sound wave from the face of the transducer. The wave travels into the body and comes into focus at a desired depth. On the face of the transducer a rubber material enables the sound to be transmitted efficiently into the body. This rubber coating is

required for impedance matching and allows good energy transfer from transducer to patient a vice versa.

To help with the transmission of sound waves a water based gel is placed between the patient's skin and the probe. The gel establishes good acoustic contact with the body, since air is a very good acoustic reflector. The image is formed by the reverse of the process used to create the sound waves. The returning echoes to the transducer are converted by the crystals into electrical signals and are then processed to form the image. To form the image ultrasound machine needs to determine the direction of the echo, how strong the echo was and how long it took the echo to be received from when the sound was transmitted. Once the ultrasound scanner determines these three things, it can locate which pixel in the image to light up and to what intensity. When a sound wave encounters a material with a different density (acoustic impedance), part of the sound wave is reflected back to the transducer and is detected as an echo.

The time it takes for the echo to travel back to the transducer is measured and used to calculate the depth of the tissue interface causing the echo. The greater the difference between acoustic impedances, the larger the echo is. Highly reflective interfaces give rise to a strong echo which is represented on the screen as a bright spot, whilst the opposite is true of weak reflective interfaces. Areas without acoustic interfaces such as the lumen of vessels and other cavities containing liquid (blood, bile, ascites or urine) give no reflection and no spot on the screen i.e. a black space on the monitor.

If the waves hit gases or solids the density difference is so great that most of the acoustic energy is reflected and it becomes impossible to see deeper. The speed of sound differs in different materials, and depends on the acoustical impedance of the material. However, the ultrasound scanner assumes that the acoustic velocity is constant at 1540 m/s. An effect of this assumption is that in a real body with non-uniform tissues, the beam becomes de-focused and image resolution is reduced.

The formula for the velocity of sound is (velocity = frequency x wavelength). The frequencies used for medical imaging are generally in the range of 2 to 15 MHz. Higher frequencies have a smaller wavelength (as can be seen from the formula for velocity of sound), and can be used to make images with smaller details. However, the attenuation of the sound wave is increased at higher frequencies, so in order to have better penetration of deeper tissues, a lower frequency 3-5 MHz is used. Seeing deep structures in the body with ultrasound is very difficult as some acoustic energy is lost every time an echo is formed, but most of it is lost from acoustic absorption. [43]

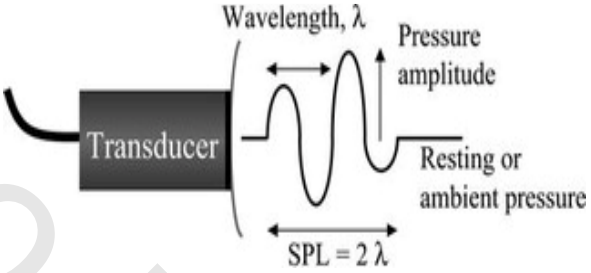


Fig. (12): Electrical pulses from the ultrasound machine make the transducer create sound waves at the desired frequency.[43]

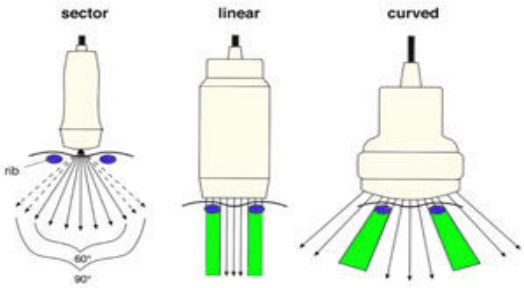


Fig. (13): Types of scanners which are used in abdominal sonography.[43]

Emergency ultrasound is the medical use of ultrasound technology for the bedside diagnostic evaluation of emergency medical conditions and diagnoses, resuscitation of the acutely ill, critically ill or injured patient. Emergency ultrasound examinations are performed and interpreted by emergency physicians or those under the supervision of emergency physicians in the setting of the Emergency Department (ED). [44]

History

Ultrasound in the evaluation of abdominal trauma has evolved over the past30 years. The use of ultrasound for abdominal trauma was described initially by Kristensen and colleagues in 1971. In 1976, Ascher and colleagues first reported the accuracy of ultrasound in Radiology, with 80% sensitivity for the detection of splenic injury. In 1990 reported a sensitivity of 89%, a specificity of 100%, and an accuracy of 98%.

The effect of training and experience and reported that surgeons with extensive ultrasound experience could diagnose intra-abdominal fluid with a sensitivity of 96% and an accuracy of 99%. Interest and experience with ultrasound for trauma grew steadily around the world among surgeons and emergency physicians during the early 1990s. During this period, ultrasound technology was improving with regard to price, portability, and resolution, allowing its use during resuscitation.

At the same time, in the United States, there was continuing reliance on DPL and CT and much less interest in sonography for abdominal trauma. This all changed when emergency physicians and surgeons in the United States began to publish their experience with ultrasound.

The term Focused Assessment with Sonography for Trauma (FAST) was coined by Rozycki et al.[45] in 1996 and has persisted as the accepted tool for the trauma ultrasound evaluation. The basic four-view examination (perihepatic, perisplenic, pelvic, and pericardiac views) has become the foundation of the FAST examination. The rapid, noninvasive, and practical nature of ultrasound for bedside evaluation of critically injured patients has changed the evaluation of blunt abdominal trauma.[44] As in adult patients, emergency ultrasound in children can be life-saving, time-saving, increase procedural efficiency and maximize patient safety.[45]

Focused abdominal sonography for trauma (FAST) has become part of the initial trauma resuscitation and evaluation, replacing diagnostic peritoneal lavage. It can be done in 3 to 5 minutes, is noninvasive, portable, can be performed during the resuscitation, and does not offer a radiation dose. By the late 1990s, it was part of the initial resuscitation at 79% of all adult level I trauma centers.[46]

It is a rapid, four-view ultrasound examination carried out during the primary survey that assesses for haemoperitoneum and haemopericardium. Extended FAST (EFAST) adds assessment for haemothorax, pneumothorax and intravascular filling to the FAST examination.[47]

Children are ideal subjects for ultrasound compared to adults as their body water content is higher and their body fat level is lower, contributing to better image quality.[48]

Technique

In the supine patient, the hepatorenal space is the most dependent area and the least obstructed for fluid flow. Fluid in the abdomen can move freely up the right pericolic gutter into this space. The left pericolic gutter is higher and the phreno-cocolic ligament blocks the flow; consequently, fluid tends to flow to the right pericolic area. On the right, fluid flows into Morison's pouch, the potential space in the hepatorenal recess. On the left, fluid flows preferentially into the subphrenic area and not into the splenorenal area, which is important because the subphrenic area may be difficult to visualize due to bowel gas and splenic flexure gas. Given these anatomic relationships, the FAST examination has evolved into three to five intraperitoneal views and one cardiac view (Fig. 16). These views include:

1) Subxiphoid or parasternal view to detect pericardial fluid;
2) Right upper quadrant view to assess the hepatorenal interface (Morison's pouch) and right chest;
3) The right paracolic gutter;
4) Left upper quadrant view to assess the splenorenal interface and left chest;
5) The left paracolic gutter; and
6) Longitudinal and transverse pelvis views to look for free fluid adjacent to the bladder. Although the bladder is not a peritoneal organ, a full bladder greatly enhances the detection of free fluid for the pelvis view by giving readily identifiable landmarks and providing an acoustic window. The focus of the FAST examination is the detection of free fluid; however, during the procedure, specific organs occasionally may be visualized, providing potential injury localization.[49]

There are two basic types of probe used in emergency and critical care ultrasound:

1) Linear: higher frequencies (5–13 MHz), provides better resolution and less penetration, ideal for imaging superficial structures and in ultrasound-guided procedures. (Fig. 14)
2) Curvilinear array: low frequencies ranging between 1 and 8 MHz, greater penetration, but less resolution. These probes are most often used in abdominal and pelvic applications. They are also useful in certain musculoskeletal evaluations or procedures when deeper anatomy needs to be imaged or in obese patients. (Fig. 15).[50]

Fig. (14): Linear array probe.[50]

Fig. (15): Curvilinear array probe.[50]

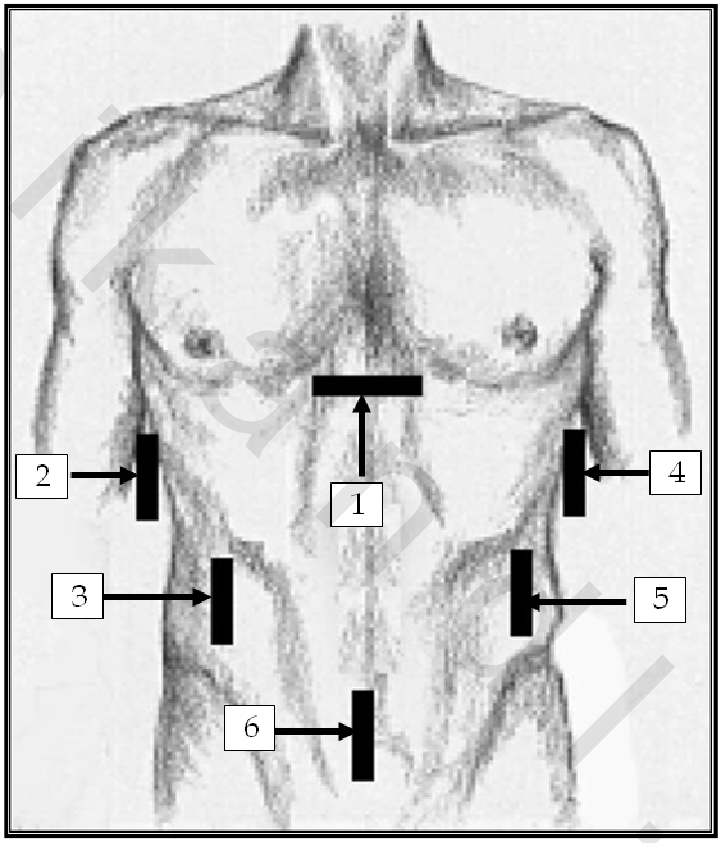


Fig. (16): FAST examination views.[48]

1. Subxiphoid view.
2. Right upper quadrant view.
3. The right paracolic view.
4. Left upper quadrant view.
5. The left paracolic gutter.
6. Longitudinal and transverse pelvis views.[48]

Advantages

It has a unique role in assisting the clinician in the trauma setting. Ultrasound is portable, can be immediately accessed, does not have to interrupt resuscitation, is safe, repeatable and gives dynamic information that yields a diverse range of diagnostic information and can guide procedures. Also, ultrasound is now frequently used in the pre-hospital setting, in disaster situations, during patient retrieval and in the hospital setting from the emergency department through to operating theatres, intensive care units and the wards. It is used by pre-hospital medical staff, emergency physicians, trauma surgeons, anaesthetists, radiologists and sonographers. In major trauma and the critically ill patient, ultrasound is used to assist in identifying immediate life threats, in directing and prioritizing interventions and in guiding resuscitation. In regional trauma, ultrasound can give diagnostic information about a vast range of pathologies including individual organ, musculoskeletal, soft-tissue and vascular injuries. Finally, ultrasound can also be used as a guide to interventional procedures, ranging from vascular access and nerve blocks to foreign-body removal.[51]

Role of FAST in blunt trauma

1- Unstable patients with potential thoraco-abdominal injury

These patients are too unwell for transfer to CT. Laparotomy is indicated if FAST is positive (i.e., free intra-abdominal fluid). Immediate therapy directed towards haemothorax or pericardial effusion if either of these are detected. Negative or equivocal FAST should prompt rapid search for other potential causes of hypotension, a repeat FAST and if uncertainty still remains a DPL.

2- Stable patients with high clinical suspicion of thoraco-abdominal injury

Highly significant mechanism, abdominal pain, abdominal wall bruising, macroscopic hematuria, unexplained transient hypotension, equivocal or unreliable physical examination (intoxication or distracting injury), CT represents the diagnostic modality of choice. Contrast-enhanced comprehensive ultrasound may come to represent an alternative modality particularly in those in whom iodinated contrast (allergy) or radiation (pregnancy) makes CT a far less attractive option. Positive FAST will prioritize and expedite other imaging, and if the patient deteriorates prior to CT, immediate directed intervention can be delivered.

3- Stable patients with low clinical suspicion of thoraco-abdominal injury

Admission with serial negative FAST examinations in conjunction with monitoring and normal serial clinical examinations for at least 8 hours is advisable. At this point, if a patients remain well, has normal urinalysis and consistently normal haemoglobin levels, they may be safely discharged with advice to return if concerning symptoms develop. (Fig.17).[52]

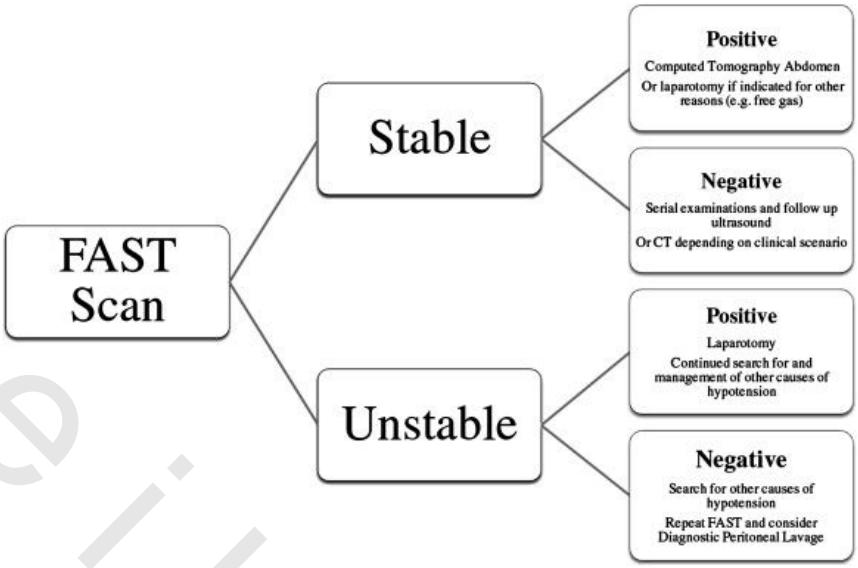


Fig. (17): FAST-oriented algorithm.[52]

All patients suffering blunt abdominal trauma have a FAST scan and further investigation and management then depends on their hemodynamic status and results of investigations.

Findings in FAST

Abdominal ultrasound searching for free fluid as a marker of intra-abdominal injury and searching for individual organ injury with or without free fluid found the sensitivity of ultrasound at detecting any intra-abdominal injury to be 82%.[53]

The volume required to be readily detected on a FAST scan is in the range of 200–620 ml. Several scoring systems exist to quantify fluid, but have not been extensively used or validated. There are several scoring systems that have attempted to quantify the amount of free fluid in the abdomen, because the use of terms such as a trace, small, moderate or large amounts are not thought to be clinically useful and show considerable inter-observer variability.[54] (Fig. 18&19)

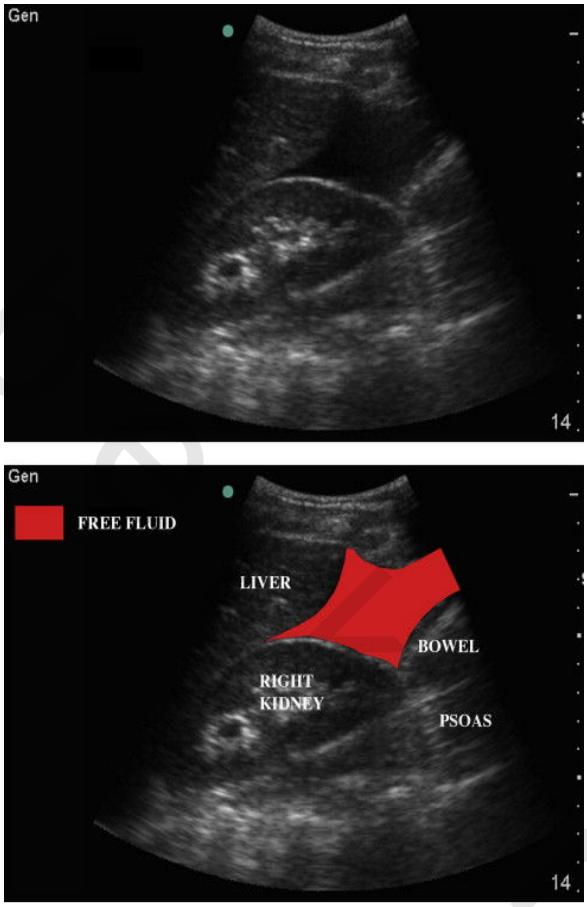


Fig. (18): Positive FAST scan showing free fluid anterior to the right kidney.(54)

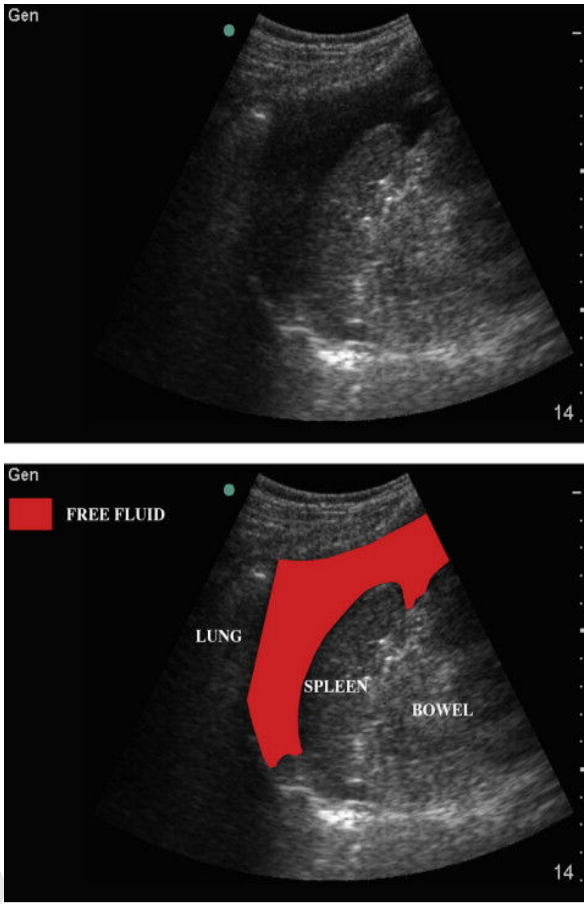


Fig. (19): Positive FAST scan showing free fluid around the spleen.(54)

The most important factor in determining the need for emergent laparotomy in the context of abdominal trauma is the hemodynamic status of the child, judged in large part by heart rate and blood pressure, both of which are age-specific. Cardiac contractility is relatively fixed in healthy infants and children, thus the response to hypovolemia in these patients is an increase in heart rate to maintain cardiac output.

Pulse is therefore the most important early indicator of hypovolemic shock in pediatric trauma patients. The compensatory tachycardic response to hypovolemia enables the pediatric patient to maintain blood pressure until significant volume loss (N45% of blood volume) has occurred. Blood pressure alone is therefore an inadequate measure of volume status or a resuscitation end point in children.

Hypotension is a late indicator of hemodynamic instability that suggests a child is near the point of complete decompensation. The goal of fluid resuscitation is to maintain adequate organ and cerebral perfusion. Advanced Trauma Life Support protocol guides fluid resuscitation, and in an injured child, the lack of a response to volume resuscitation should suggest the presence of severe hemorrhage (intra-abdominal or otherwise) and the need for urgent operative intervention. Detection of IAI requires analysis of the mechanism of injury, physical examination, and diagnostic testing.(55)

2) Computed tomography (CT)

CT is the imaging method of choice in the evaluation of abdominal and pelvic injuries after blunt trauma in hemodynamically stable children. Unstable patients need to be stabilized before CT or to proceed directly to surgery.[56]

The role of Computed Tomography (CT) in the evaluation of injured children includes establishing the presence or absence of visceral and bone injury, identifying injury requiring close monitoring and operative intervention, detecting active hemorrhage, and estimating associated blood loss. The use of CT as the primary screening technique in the assessment of injured children, along with improvements in supportive care, has played a critical role in the success of non-operative management of solid organ injuries.

The rapid evaluation of injured children with CT has also resulted in improved triage and has contributed to reduced morbidity and mortality. CT primarily guides non-operative decisions such as the duration of hospitalization, intensity of care, and length of activity restriction. Solid organ injury grading at CT has been shown to be useful for estimating the time course of healing. However, follow-up imaging is probably not necessary in asymptomatic children for several reasons. First, no injury progression or complication is noted in most solid viscus injuries. Second, clinical management is rarely altered on the basis of follow up imaging.[57]

CT scans are obtained from the lower chest to the symphysis pubis. Gastric distention should be relieved because artifacts may arise from air–fluid interfaces. Sedation is rarely required before CT because advances in CT technology have greatly reduced scanning times. However, excessive patient motion will result in image degradation. Therefore, in select instances, a short-acting sedative may be necessary to obtain diagnostic images. The use of IV contrast material by rapid bolus injection is essential to maximize opacification of solid viscera and ensure adequate injury detection. We administer 2 mL/kg with a maximum amount of 120 mL. IV contrast material is necessary because solid viscus laceration or hematoma may be relatively isodense to unenhanced or poorly enhanced solid viscera. In addition, the use of IV contrast material allows the detection of active hemorrhage. Scanning of the pelvis should be delayed by several minutes after IV contrast injection to optimize bladder distention by IV contrast material. If a renal parenchymal injury is noted at initial scanning, delayed scanning through the kidneys is also helpful in the detection of renal collecting system injury.

There is controversy regarding the use of oral contrast material after blunt trauma. Potential advantages to the use of oral contrast material include, first, enhanced detection of small intramural or mesenteric hematomas; second, improved delineation of the pancreas from surrounding bowel; and, third, detection of oral contrast extravasation as a sign of bowel rupture. Potential disadvantages include time constraints and decreased bowel motility in injured children, which limits the ability to opacify much beyond the proximal small bowel; creation of artifacts from air–contrast interfaces in the stomach; and the possibility of vomiting with resultant aspiration. If oral contrast material is used, dilute (2%) water-soluble contrast material should be administered at least 30 minutes before scanning.[58]

Haemoperitoneum and the detection of active hemorrhage

CT has high sensitivity and specificity for the detection of blood in the peritoneal cavity. Haemoperitoneum starts near the site of injury and spreads along the expected anatomic pathways. When the patient is in a supine position, blood from the liver collects in Morison's pouch and passes down the right paracolic gutter to the pelvis. From the spleen, blood passes via the phrenocolic ligament to the left paracolic gutter and the pelvis (Fig. 20).

Blood from a splenic injury also goes to the right upper quadrant. The 'sentinel clot' sign indicates adjacent, focal higher attenuation clotted blood as a marker for the organ that is the cause of haemorrhage (Fig. 21). A large amount of blood may collect in the pelvis without much haemoperitoneum seen in the upper abdomen. Active haemorrhage can appear as a region of extravasated contrast material and is indicated on a CT scan by an area of high attenuation, with values ranging from 85 to 350 Hounsfield units (HU).[59]

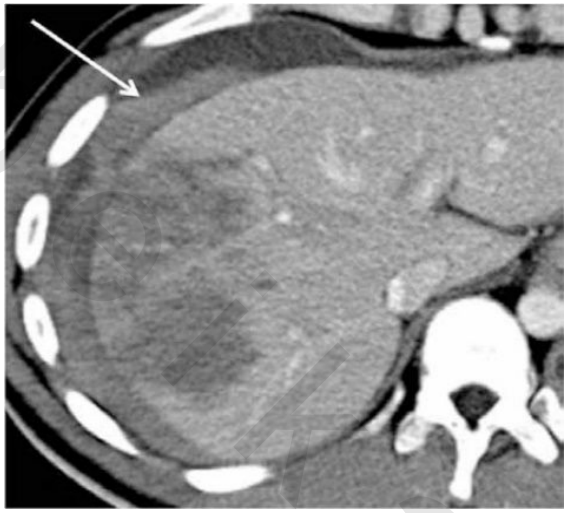


Fig. (20): Coronal section of CT abdomen with I.V contrast showing hepatic injury. These arrows demonstrate the possible pathway of blood.[59]

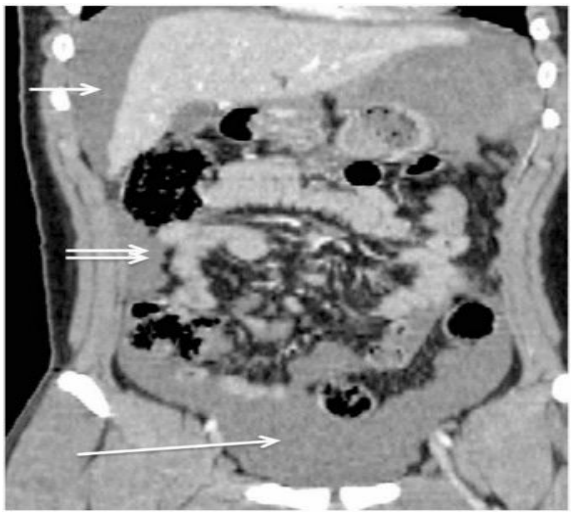


Fig. (21): Sagittal section of CT abdomen with I.V contrast showing haemoperitoneum from liver injury The 'sentinel clot' sign is seen as a high-attenuation collection adjacent to the liver surface (arrow).[59]

Impact of CT on clinical decision making

The decision for operative intervention in the small percentage of children who require surgical hemostasis is primarily made based on clinical criteria and not on CT findings. Therefore, CT primarily guides non operative decisions such as the duration of hospitalization, intensity of care, and length of activity restriction. The American Pediatric Surgical Association Trauma Committee has defined consensus guidelines for resource utilization in hemodynamically stable children with isolated hepatic or splenic injury based on CT grading.

These guidelines include ICU stay, length of hospital stay, and physical activity restriction. A study of 138 consecutive children studied by CT after blunt trauma showed that CT findings changed the diagnoses after initial clinical assessment in 84% and management plans in 44%, decreasing the intensity of care in 38% and increasing the intensity of care in 6%.[60]

CT Dose reduction strategies

CT provides the largest single source of radiation exposure in diagnostic imaging. In addition, the use of CT in children has increased dramatically in recent years. It is estimated that more than 4 million CT examinations are currently performed on children in the United States per year. CT accounts for approximately 5–10% of the total imaging procedures and

40–70% of the imaging dose. Children are at greater risk than adults from a given dose of radiation; they are inherently more radiosensitive and they have more remaining years of life during which a radiation-induced cancer could develop. Therefore, we must consider all possible means by which to reduce the administered CT dose. The most important dose reduction strategy is to reduce utilization.

This can be achieved by, first, eliminating unnecessary examinations; second, ensuring availability of outside examinations; and, third, decreasing or eliminating follow-up CT examinations. When CT is necessary, the ALARA (as low as reasonably achievable) principles should be followed rigorously. These principles include limiting the use of multiphase examinations, collimating the examination to the area of interest, and adjusting the technique for the patient size. The use of automatic exposure control available on the latest generation of CT scanners is helpful in optimizing dose reduction. The judicious use of CT and adherence to ALARA principles are therefore essential to minimize the population risk.[61,62]

3) X-ray abdomen

Pneumoperitoneum is often demonstrated on an erect chest X-ray as free gas under the diaphragm. On occasions, a small pneumoperitoneum can be easily missed due to technical factors such as inadequate time for the gas to migrate to the subphrenic region when the patient is positioned from the supine to the erect position. On the other hand, in some rare situations, subphrenic fat may be mistaken for a small pneumoperitoneum (fig. 22). However, for patients who cannot be placed in the sitting or upright position, like patients suffering from shock or severe abdominal pain, this investigation is not possible. Under this circumstance, one would usually resort to a left lateral decubitus horizontal beam abdominal X-ray, or other imaging modalities.[63-66]

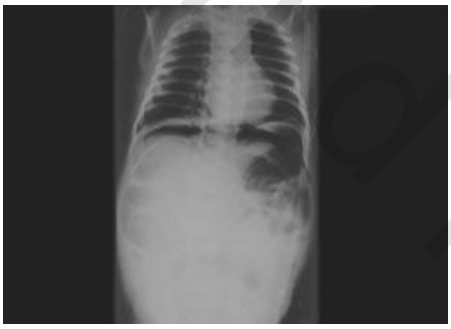


Fig. (22): Plain erect x-ray abdomen showing pneumoperitoneum.