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Importance of the Mechanism of Injury in Trauma Radiology Decision-Making

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Take-home points

- Consideration of the mechanism of injury is a key factor in trauma radiology decision-making.
- The principles of energy transfer and deposition are used to predict likely injuries and ensure appropriate triage and management.
- Certain trauma patterns are associated with and can help predict specific injury patterns.
- It is important to consider the mechanism of injury, principles of energy transfer, and suspected injuries when selecting specific scan protocols and triaging patients with traumatic injuries.

Keywords: Trauma; Mechanism of injury; Energy transfer; Imaging protocols; Wounds and injuries

INTRODUCTION

Trauma is one of the most common causes of death in persons aged under 45 years [1]. Rapid recognition of seriously injured patients is the key to the successful management of trauma cases. Throughout the evaluation of trauma, the mechanism of injury and index of suspicion are key factors in trauma radiology decision-making. Information regarding the type of trauma (blunt or penetrating), mechanism, and direction of impact allows prediction of the expected type of injury [2]. Using multidetector computed tomography (MDCT), radiologists can efficiently recognize and diagnose life-threatening traumatic injuries, thereby guiding timely management and reducing mortality [1]. Because of its high sensitivity, MDCT is commonly used as a "screening" tool, particularly in low-mechanism injuries that are commonly seen in elderly patients [3]. Trauma surgeons and interventional radiologists take mechanism into consideration when treating patients, highlighting the importance of applying these principles prior to scanning patients.

A recent study by Parreira et al. [4] has found that analysis of the trauma mechanism enables accurate prediction of the possible injuries to investigate. This information can be used not only for streamlining investigations and reducing the number of diagnostic tests with negative results, but also for triaging patients to ensure the most appropriate treatment. Additionally, severe traumatic injuries are not always immediately identified in the primary survey. In such cases, a prompt diagnosis using MDCT has a significant impact on patient outcomes. In this article, the key principles of energy transfer, the mechanisms of injury, and their impact on decision-making are discussed.

Principles of Energy Transfer

Traumatic injury can result from any energy transfer; however, it most frequently occurs because of kinetic energy (KE) transfer. The law of conservation of energy states that energy cannot be created or destroyed but only changed

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from one form into another [5]. When two objects collide, energy is transferred between them, which is determined by the equation KE = ½ mass x $velocity^2$ [5]. Hence, velocity is an important determinant of energy transfer. Other forms of energy that can contribute to injury include chemical, electrical, nuclear, and thermal energy [5]. In trauma, motor vehicle collisions are frequently high-energy and inelastic, resulting in significant deformation and injury through energy transfer to the occupant(s) [5]. Thus, the mechanism of injury, including velocity, is helpful in predicting the severity of sustained injuries. Patients at the extremes of age require special consideration, as they have an increased risk of serious injuries despite relatively low-energy mechanisms, such as falls from a standing height [6].

While trauma clinicians, including surgeons and interventional radiologists, use the principles of energy deposition in their algorithms, few studies have identified the association between specific mechanisms of injury and the likelihood of a certain injury. This remains an area for future investigation.

Blunt Trauma

Blunt trauma accounts for most major traumatic injuries in Australia [7]. This type of trauma often occurs because of compression forces, rapid acceleration or deceleration forces, or a combination of these [5]. Compression injuries are caused by external compression against a fixed object, resulting in deformed hollow organs and increased intraluminal pressures, ultimately leading to rupture of the organ or tissue if the tensile strength is exceeded [8]. Acceleration and deceleration forces cause stretching and shearing at the interface between fixed and mobile structures, resulting in the disruption of organs, connective tissue, blood vessels, and nerves [8]. The most common causes of blunt trauma at the emergency department are motor vehicle accidents (MVAs) and falls (from a standing height or greater) [7].

Falls are a common cause of injury and many falls that necessitate hospitalization occur from relatively low heights [9]. Falls in elderly individuals often result in head injuries, vertebral and spinal cord injuries, and extremity fractures [9]. A large proportion of falls, even from seemingly low heights, result in multisystem injuries [9].

Motor Vehicle Accidents

MVAs are the most common traumatic mechanism of injury [5]. The severity of the resultant injury is directly proportional to speed, mechanism, and seatbelt compliance. MVAs can be categorized based on the direction of impact: frontal, right and left lateral, rear, and rotational impact, or rollover (Figs. 1-3). Although there are many variables to consider, injuries can be identified based on the specific mechanisms of an MVA. Prompt recognition and treatment of injuries can decrease morbidity, thus emergency radiologists and treating physicians should be aware of the injuries most likely to occur in combination with specific mechanisms [10].

Frontal impact collisions are the most common type of MVA based on the direction of impact, often resulting in head and neck, spinal, thoracic, pelvic, and lower limb injuries due to impact with the interior of the car [5]. The adoption of three-point seatbelts has significantly reduced MVA fatalities by preventing collisions with the dashboard and windshield and controlling the rate of deceleration [10]. The spectrum of seatbelt-related injuries can range from soft tissue contusions to visceral and unstable spinal injuries. Seatbelt syndrome is a term used to describe

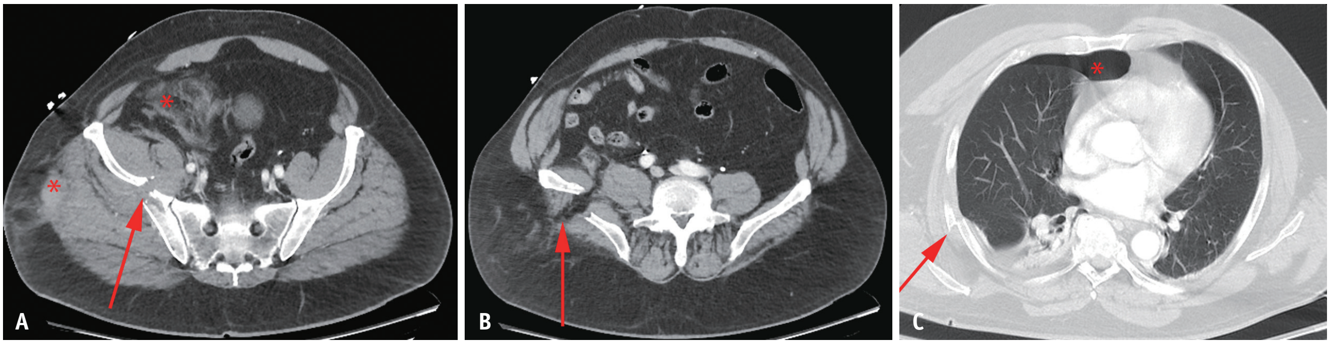

Fig. 1. Right lateral impact trauma. Contrast-enhanced axial scan (soft tissue and lung windows). **A:** Comminuted right iliac wing fracture (arrow) with an associated pelvic/gluteal hematoma (asterisks). **B:** Tear of the right iliacus muscle with herniating retroperitoneal fat (arrow). **C:** Lung windows demonstrating a displaced rib fracture (arrow) with a right pneumothorax (asterisk).

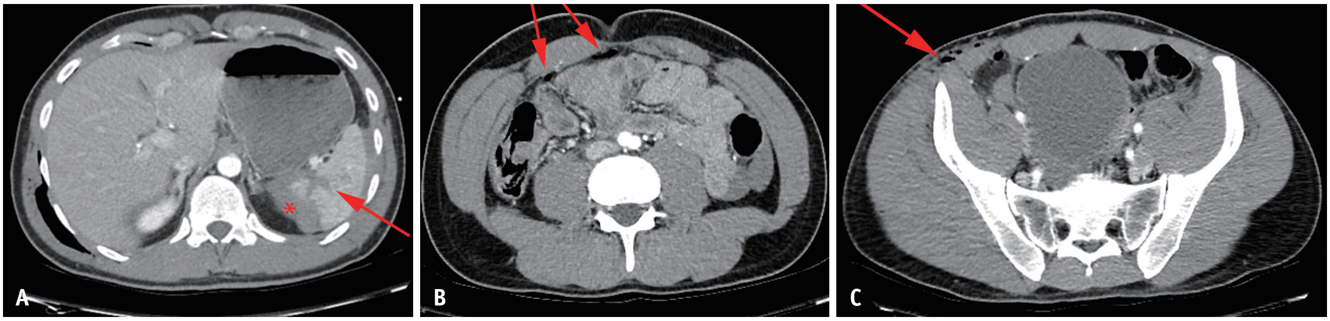

Fig. 2. Frontal impact trauma. Contrast-enhanced axial scans (soft tissue window). **A:** Splenic laceration with a large subcapsular hematoma (arrow) and hemoperitoneum (asterisk). **B:** Free intraperitoneal gas (arrows) and thickened small bowel loops in the left flank, with interloop fluid consistent with a small bowel injury. **C:** Skin abrasion anteriorly overlying the right pelvis iliac crest, known as the seatbelt sign (arrow).

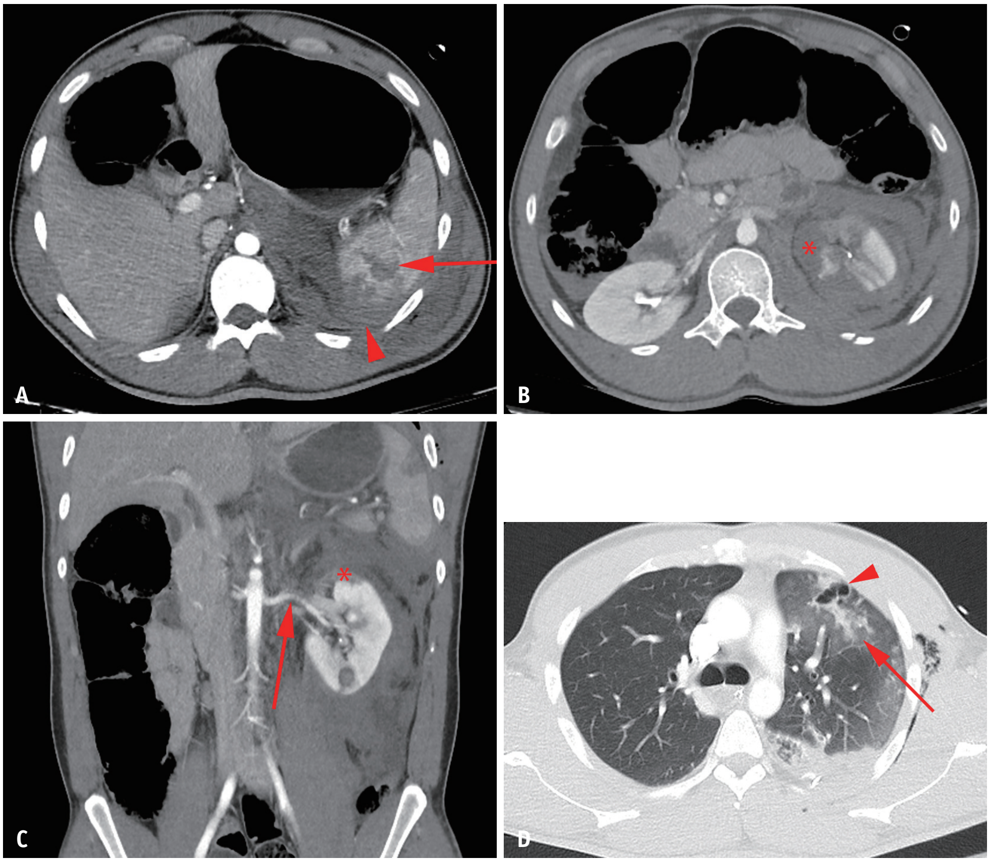

Fig. 3. Left lateral impact trauma. Contrast-enhanced axial scan (soft tissue and lung windows). **A:** High grade splenic injury (arrow) with a subcapsular hematoma (arrowhead). **B, C:** Left renal laceration (asterisks) with irregularity of the renal artery indicative of a vascular injury (arrow) and renal infarct. **D:** Lung windows demonstrating a left pulmonary contusion (arrow), pulmonary laceration (arrowhead), and small left hemothorax.

the combination of the seatbelt sign (contusion overlying the pelvis, anterior chest wall, and neck) and internal or visceral injuries [11]. Internal or visceral abdominal injuries are found in up to one-third of patients with a positive seatbelt sign, thus requiring close inspection when they are identified (Fig. 1) [12]. Other injuries commonly associated with the seatbelt sign include flexion-distraction spinal injuries at the cervicothoracic and thoracolumbar junctions, sternal and rib fractures, and pelvic ring injuries [5].

Lateral impact collisions occur less commonly but pose a significantly higher risk of severe aortic injury [13], which is life-threatening and often fatal. This increased risk may be due to vehicular occupants being shifted within a limited cabin space, thus producing greater shearing forces in lateral impact than in frontal impact collisions (Figs. 2, 3) [13]. Additionally, unbelted occupants have a much higher risk of severe injury, owing to increased shearing forces and a greater number of potential contact and blunt injury causation points within the car [13].

Penetrating Trauma

Penetrating trauma encompasses a wide range of mechanisms that involve penetration of the skin and underlying tissues. These include ballistic (gunshot wounds) and non-ballistic trauma (knife or other puncture wounds) [14]. The extent of damage is determined by the characteristics of the wounding instrument, its velocity, and the characteristics of the tissue through which it passes [8]. Two important determinants are the amounts of subcutaneous and visceral fat in the trajectory of the penetrating instrument [15]. Most penetrating injuries also have a crush component, which involves disruption of the tissues in the path of the instrument [8]. A blunt penetrating instrument (for example, an axe) crushes a large area of tissue and requires a large force to penetrate tissue, resulting in mixed blunt and penetrating trauma [8].

Ballistic injuries are most commonly caused by bullets or spheres fired from a gun or by fragments discharged from explosives. The mechanisms of injury vary greatly depending on the missile characteristics and velocity [8]. A low-velocity missile crushes the tissue along its path to create a primary (permanent) cavity with approximately the same diameter as the projectile [8]. For a high-velocity missile, two pressure-related variations are present: shock waves and secondary cavities [8]. The secondary cavity may be 10–15 times the size of the primary cavity and may affect tissues as far as 10 cm from the primary cavity [8]. These pressure variations cause a cavitation effect, resulting in rapid compression and expansion of tissues, causing stretching and rupture of nearby tissues and blood vessels. High-velocity bullets tend to yaw and rotate once they enter tissue, resulting in a larger cavity. Depending on their individual characteristics, bullets may also fragment. As the fragments break off, the centrifugal force of a rotating bullet displaces the fragments in a radial distribution, creating additional cavities throughout the tissue [8].

The body parts affected by a gunshot wound are important in predicting injuries. More elastic tissues, such as those in the lungs, bowel, and skin, are usually less likely to be damaged than less-elastic tissues, such as those in the liver, spleen, kidney, brain, and heart. This difference is partly due to the formation of a secondary cavity, resulting in the crushing/pulping of soft, less elastic tissue [8].

Radiology Decision-Making

Imaging Protocol

Bedside imaging has an important role in the urgent management of patients with severe trauma. Chest radiography in patients with respiratory distress and pelvic radiography in patients with suspected pelvic fractures assist in initiating rapid stabilization procedures prior to computed tomography (CT) [16]. However, routine radiography and focused abdominal sonography in trauma (FAST) in stable patients should not delay transfer once a decision to perform CT has been made [17].

The standard protocol for CT in trauma usually involves an intravenous contrast-enhanced scan from the vertex to the pelvis, often in multiple phases. At the Alfred Health, Melbourne, Australia, we routinely perform split dual-bolus intravenous contrast-enhanced CT with single acquisition through the chest, abdomen, and pelvis to capture both the arterial and portal venous phases in patients with severe trauma. This CT protocol is commonly used for patients involved in MVAs, as this mechanism is associated with a high frequency of severe traumatic injuries to the chest, abdomen and pelvis [4]. The protocol is customized based on the specific mechanism and pattern of injury obtained from the clinical history (Table 1).

When head and neck trauma is suspected, non-contrast-enhanced CT of the brain and cervical spine is performed with the addition of CT angiography in select cases that meet the modified and expanded Denver criteria [18]. Blunt cerebrovascular injuries, particularly carotid artery injuries, often have a long latent period between the time of injury and the onset of symptoms; thus, the decision to initiate early imaging when indicated and administer appropriate treatment is essential in preventing neurological deficits [18].

The standard protocol is also modified in cases of motorcycle trauma. Motorcycles provide little protection, and incidents often result in severe lower-extremity injuries, such as complex or open tibial and femoral fractures [5]. Thus, the presentation of a motorcycle accident should prompt the radiologist and management team to consider extending the CT scan range to include the lower limbs to characterize fractures and detect vascular injury.

Table 1. Summary of Trauma Mechanisms, Injury Patterns and Recommended Imaging Protocols

Mechanism	Major Energy Transfer	Pattern of Injury	Recommended Scan Area	CT Protocol
Motor vehicle accident	Blunt force; frontal impact, left/right lateral impact, rear impact, rotational impact, rollover	Multisystem with severity dependent on speed and specific mechanism	Whole body	Brain/C-Spine: non contrast with or without angiogram if suspected BCVI Chest/Abdomen/Pelvis: Dual bolus (arterial and delayed phases) Limbs: angiogram if comminuted fractures or open wound
Falls	Blunt force	Headstrike associated with intracranial haemorrhage, cervical spine injury Spinal, rib and limb fractures Deep organ injury/ lacerations possible if high energy	Whole body or targeted depending on severity and clinical assessment	Brain/C-Spine: non contrast Chest/Abdomen/Pelvis: contrast or non-contrast if poor renal function and low index of suspicion
Penetrating	Ballistic/non-ballistic, crush injury, cavitation and shock wave	Localised to affected body part	Appropriate to restrict scan range to affected body system/part	Contrast enhanced (arterial and delayed phases) to assess for active bleeding and organ injury

CT = computed tomography, BCVI = blunt cerebrovascular injuries

Considerations in Radiation-Sensitive Populations

Whole-body CT in trauma cases is usually associated with significant doses of radiation; therefore, special considerations must be given when imaging radiation-sensitive populations, such as pediatric and pregnant patients.

Children are more sensitive to radiation than adults, as their tissues are still developing and maturing [19]. They also have longer remaining lifetimes, during which potential stochastic tissue effects associated with radiation exposure may arise and manifest. The aim in pediatric imaging is to perform the most appropriate test the first time, in line with the principle of “as low as reasonably achievable” [20]. The risk of developing radiation-induced cancer may be several times higher in children than in adults; thus, the benefit should outweigh this risk when deciding whether an individual child should undergo imaging [21]. If CT is the imaging method of choice, appropriate dose reduction techniques should be implemented. In the case of pediatric head trauma, the Royal Australian and New Zealand College of Radiologists recommends the use of clinical decision rules to determine pretest risk and evaluate the need for CT [19].

In pregnant patients who experience low-energy trauma in which there is no cause for concern for the mother but there is for the fetus, ultrasound assessment is preferred. However, in cases of severe trauma, CT remains the investigation modality of choice. The risks due to radiation during pregnancy are small compared with the risks due to missing or delaying the detection of life-threatening traumatic injury. Moreover, fetal survival does not usually occur without maternal survival [22].

Treatment Considerations

The mechanism of injury in trauma, as described above, is vital information for clinicians during initial and subsequent assessments, as well as during diagnostic and treatment decision-making. This is particularly important in cases where damage control within the golden hour may require decisions with little information other than vital signs and the mechanism of injury [23]. For example, in assessing patients with a splenic injury, interventional radiologists who understand the association between energy deposition and injury grade are able to recognize the increased risk of rebleeding or delayed rupture associated with high-energy and high-grade splenic injuries [24,25]. Consequently, this information may help determine the need for embolization instead of conservative management, thereby affecting future splenic immune function [26].

CONCLUSION

Traumatic injuries are a common cause of mortality. Early diagnosis and damage-control treatment are important aspects of the assessment of patients with these traumatic injuries. The mechanism of injury is integral to early decision-making, as the principles of energy transfer allow the risk stratification of patients and assessment of the burden of injury. The mechanism of injury also drives the differences in injury identification and management of patients after blunt or penetrating injury. By developing an understanding of the principles and mechanisms associated with trauma, radiologists can more efficiently recognize and diagnose severe traumatic injuries, resulting in earlier intervention and morbidity reduction. Further translational data are required to relate basic concepts in physics and physiology with the occurrence of injuries, thus highlighting the important role of mechanisms of injury in the development of imaging and treatment guidelines for major trauma.

Conflicts of Interest

The authors have no potential conflicts of interest to disclose.

Author Contributions

Conceptualization: all authors. Methodology: all authors. Project administration: all authors. Supervision: Dinesh Varma, Warren Clements. Writing—original draft: all authors. Writing—review & editing: all authors.

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