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10.1 Introduction

Imaging is now at the forefront of trauma care. The days of a limited CT sometimes hours after injury have been replaced by rapid imaging involving plain film, ultrasound and CT. There is now increasing evidence pertaining to trauma imaging with a proven reduction in mortality with the use of rapid CT [1].

This chapter aims to describe the uses of imaging in ballistic trauma which have been learned from years of civilian and military trauma experience.

The first part of the chapter is focused on the injured patient. The second part will describe the imaging strategies that will be necessary in a mass casualty situation.

This chapter will focus on:

- Describing a trauma imaging algorithm
- The CT traumagram protocol
- The uses of different imaging modalities in trauma
- Injury patterns and examples

10.2 Trauma Imaging Algorithm

When an injured patient arrives in the ED having been subject to ballistic trauma the focus is on rapid assessment allowing rapid treatment. The role of imaging is to identify life or limb threatening injuries and identify sources of bleeding. In a modern ED there should be access to plain film, ultrasound and CT. Plain film and

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ultrasound should be available at the bedside and CT should be as close to ED as possible.

The initial assessment of the patient involves concurrent activity. A radiographer should be prepared for a plain chest and pelvic X ray whilst the primary survey is conducted, lines are inserted, bloods are taken and the patient is potentially intubated. A chest X-ray early in this period can help rule out potential impending fatal thoracic injury.

What happens next depends on the stability of the patient. If the patient is stable and a CT is nearby a CT traumagram should be considered as soon as possible. If the patient is very unstable and is going to the operating room, an ultrasound of the chest and abdomen can be performed. This will identify significant free fluid in the chest, abdomen or pelvis.

Ultrasound can be accurate at detecting pneumothorax, haemothorax and abdominal fluid but it is very operator dependent. The role of ultrasound in trauma will be discussed in detail further on.

It is the view of the authors that ultrasound should never delay the CT examination as long as CT is readily available and the patient is stable enough for the transfer. This has been incorporated into the latest NICE guidance for trauma [2]. This states that ultrasound should not be performed if imaging with CT is readily available.

The trauma imaging algorithm is presented as Fig. 10.1. It should be noted that the ultrasound scan does not change the patient pathway. In the authors' experience as well as providing prompt FAST assessment for the ED clinicians one of the main

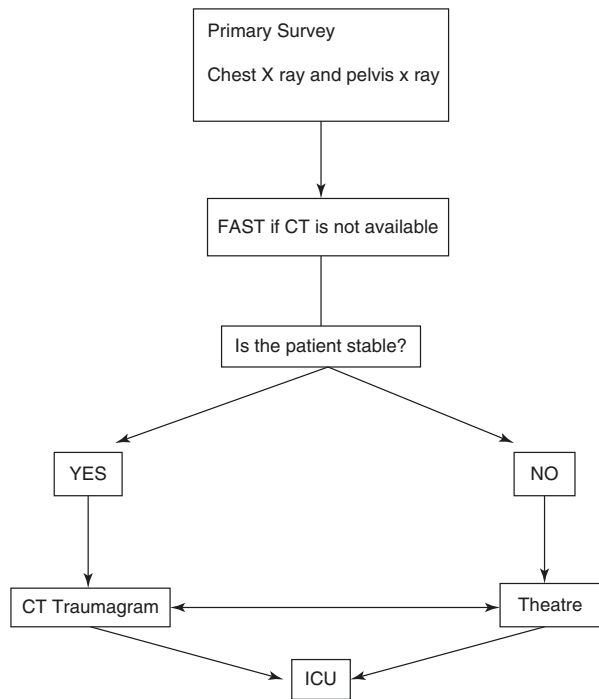


Fig. 10.1 Trauma algorithm. Note that the arrow between CT and theatre is a double arrow as some patients are scanned post or peri-operatively

benefits of performing ultrasound during the resuscitation phase is having a radiologist present in the ED to assist with further imaging and clinical decision making.

If a patient presents to a facility without CT then having a suitably experienced ultrasound operator is desirable. A radiologist or fully trained sonographer can image the abdominal viscera, the heart, the eyes and the pelvis. Sequential ultrasound can be of benefit looking for the progression of free fluid. Ultrasound of the optic nerve has been found to be accurate at detecting a raising intracranial pressure which could be lifesaving if a CT scan is not possible.

10.3 CT Traumagram

At the start of the Iraq war in 2003 CT imaging in trauma was essentially the same protocol as a staging scan for cancer. A non-contrast head scan was performed followed by an arterial phase scan of the chest. Then the patient was repositioned and a portal venous scan of the abdomen and pelvis was performed.

This protocol was slow as repositioning and different phases were time consuming. The contrast administration meant that arterial bleeding would be readily identified in the chest but not necessarily evident in the abdomen or pelvis.

With the advent of faster scanners with more slices and more advanced contrast injection systems a new protocol for trauma has evolved which has been used extensively in the military, both US and UK but has also been adopted in civilian trauma practice [3]. A non-contrast head scan is performed. This is then followed by a single scan from the base of skull to the pelvis, or the feet if there is lower limb trauma. This scan can be performed with a breath hold of 10–15 s. The key to this scan is the contrast timings. A dual phase scan is performed by injecting contrast at a slow rate for a number of seconds then the rate is increased just before the scan. This means that when the images are acquired the fast bolus of contrast is in the arterial system and the slow bolus of contrast is in the venous system. So for the same volume of contrast in less time the scan will identify arterial, portovenous and venous bleeding as well as enhancing the visceral organs to identify injury. This protocol is used to produce 3D vascular reconstructions to allow the surgeons to formulate plans rapidly pre-operatively when dealing with complex vascular injuries. An overview of this contrast protocol is shown in Fig. 10.2. This technique also reduces dose by avoiding repeat scans of anatomical areas to show the different phases of vascular enhancement.

This is a simple dual phase technique which is easy for less experienced radiographers to manage effectively and consistently. There was an initial learning experience for radiologists as the appearance of the spleen can appear heterogeneous on some studies. This should not be mistaken for visceral injury. Figure 10.3 demonstrates this appearance of the spleen.

A large multicentre study has recently looked at the timing of CT [4]. Injured patients (not just ballistic trauma) were split into conventional trauma imaging as described above or a CT before any plain film and before conventional trauma imaging. The findings showed no difference in hospital mortality.

	Head	Circle of willis to feet
Patient position	Head first	Head first
	Supine	Supine
Contrast	N/A	Omnipaque 300
Volume (mls)	90	50
Flow Rate (mls/sec)	1.6	3.5
Scan parameters		
Start location	Vertex	COW
End location	Base of skull	Pelvis/feet
Scan start delay (secs)	N/A	70
Scan type	Helical full	Helical full
Helical collimation	0.625	0.625
Scan FOV	Head	Large Body
Detector coverage (mm)	20	40
Rotation time (secs)	0.5	0.5
Pitch	0.531:1	1.375:1
Speed (mm/rotation)	10.62	55.00

Fig. 10.2 Contrast and scan parameters for a CT Traumagram

Kv	140	140
mA	300	80 - 610
Auto/Smart mA	No	Yes
Slice thickness (mm)	5	5
Recon algorithm	Soft	Standard
WW/WL	100/40	400/40
Additional recons		
Recon algorithm	Bone plus	Soft
	Bone plus	Standard
Thickness (mm)	1.25	1.25
	1.25	1.25
WW/WL	2000/500	100/40
	2000/500	400/40

CONTRAST VOLUMES AND RATES FOR PAEDIATRICS

Fig. 10.2 (continued)

Child Weight (Kg)	Contrast Volume	Venous Phase Volume	Venous Phase Rate	Arterial Phase Volume	Arterial Phase Rate
5	10	7	0.2	3	0.4
10	20	14	0.3	6	0.6
15	30	20	0.4	10	0.8
20	40	26	0.5	14	1.0
25	50	33	0.6	17	1.3
30	60	40	0.7	20	1.6
35	70	47	0.8	23	1.8
40	80	53	0.9	26	2.1
45	90	60	1.0	30	2.2
50	100	66	1.2	34	2.4
55	110	73	1.3	37	2.6
60	120	80	1.4	40	2.8
70	140	94	1.6	46	3.3

Fig. 10.2 (continued)

Fig. 10.3 A normal traumagram. Contrast is seen in the aorta and portal system with a slightly patchy enhancement pattern of the spleen



10.4 Use of Imaging Modalities in Trauma

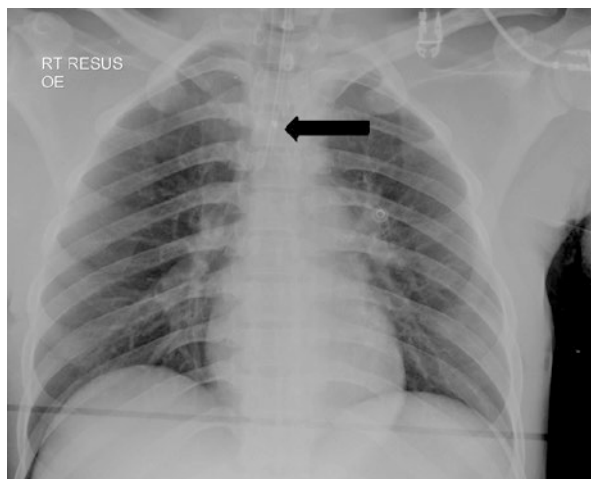
10.4.1 Plain Film in the ED

Plain film of the chest is an essential part of the initial assessment. To rule out or in a large haemothorax or pneumothorax can lead to a life saving procedure before further assessment with CT or an urgent theatre transfer. Digital radiography (DR) X ray equipment can produce an almost instant image on a screen at the bedside (Fig. 10.4). ED staff can then assess the chest image for gross pathology without having to wait for a formal report. In an established ED the X ray equipment can be ceiling mounted to allow positioning at different resuscitation bays. In a field setting mobile DR equipment is now more lightweight with new versions having a battery power source allowing them to be carried in a backpack. The plain film is also useful in ED for tube and line positioning prior to moving the patient but with the advent of novel devices such as sternal buttons and intraosseous needles clinicians need to be aware of the appearances of these new devices to avoid misinterpretation of a sternal button for a ballistic fragment (Fig. 10.5).



Fig. 10.4 A mobile digital X ray

Fig. 10.5 Portable digital chest radiograph demonstrates an IO device in the sternum (*black arrow*)



What is more controversial is the need for a pelvic film. In major trauma it has long been part of the ED X ray series. It could be argued that if a patient is imminently going to have a CT scan the pelvic X ray is futile. There is no level 1 evidence to support either argument. In ballistic trauma a pelvic X ray should not slow the time to CT. In the event of ballistic injury pelvic instability is unlikely however the patient may arrive with a pelvic binder in situ. At this point clinical assessment is warranted and imaging following binder loosening or removal is recommended. This does not need to be a plain film but may be by CT if this is already planned or fluoroscopy.

10.4.1.1 Ultrasound in Trauma

Ultrasound is a versatile, mobile modality that has the advantage of not producing ionising radiation. In a trauma setting ultrasound can be used to assess for pneumothorax, haemothorax, cardiac activity, haemopericardium, visceral abdominal injury, IVC filling and free fluid. The disadvantage of ultrasound is that the results are heavily operator dependent. Only practitioners that are properly trained and regularly use ultrasound as part of their regular practice should perform ultrasound in a trauma setting.

The commonly used algorithm for ultrasound in trauma is the Focused Assessment Sonography in Trauma or FAST. This describes a four part assessment of the heart and pericardium, the right and left sides of the abdomen and the pelvis. The principle of FAST is detection of free fluid.

An unpublished audit by one of the authors compared FAST with operative findings or CT findings. One hundred and sixty seven patients were scanned that went on to CT or laparotomy. There were 24 true positives, one false positive, 154 true negatives and eight false negatives. This resulted in sensitivity of 95.3%, specificity of 99.4, and 94.7% accuracy for the detection of free fluid.

FAST need not be used if there is rapid access to CT. This is part of the latest trauma guidance from the National Institute for Clinical Excellence [2]. However in a remote setting without CT ultrasound may be the only imaging modality which is portable and can image the viscera. However ultrasound should be performed by trained, competent operators who regularly perform ultrasound whilst recognising there is suboptimal sensitivity even in experienced operator's hands [5].

Ultrasound has a reasonable accuracy for detecting pneumothorax by detecting the lack of moving pleura beneath the chest wall [6]. If CT is not available this could be used to detect a small pneumothorax not seen on the CXR. If CT is available and the patient is stable CT will be more accurate at detecting pneumothoraces.

10.4.1.2 Orbital Ultrasound

Ultrasound of the orbit is easy to do and more importantly easy to learn. Studies have proven that non sonographers can learn the technique very quickly [7]. There are two main uses for performing orbital ultrasound: foreign body detection and assessing rising intracranial pressure.

In ballistic trauma patients can be subjected to small fragments of ammunition, dirt, clothing or even biological tissue from other casualties. The eye is very sensitive to foreign body ingress and sight can be threatened with even small fragments. Assessing the eye involves acuity and visual fields but some departments cannot proceed to a slit lamp assessment. Ultrasound can detect small foreign bodies, lens dislocation, retinal haemorrhage and retinal detachment. Figure 10.6

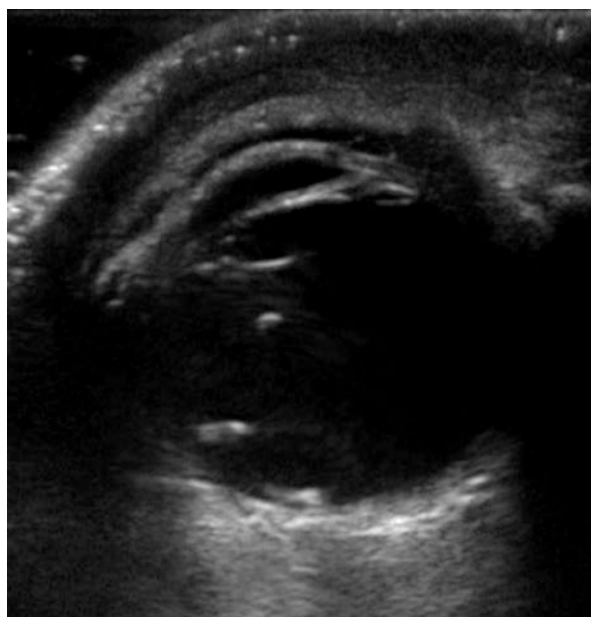


Fig. 10.6 Orbital ultrasound demonstrated multiple foreign bodies in the posterior chamber

Fig. 10.7 Optic nerve measurement



shows orbital ultrasound demonstrating multiple foreign bodies in the posterior chamber. A study performed during a military deployment with high numbers of eye injuries found ultrasound to be more sensitive than CT at detecting foreign bodies [8].

Ultrasound of the orbit can readily see the optic nerve (Fig. 10.7). The nerve is covered in all three meningeal layers and is a direct link to the CSF. Any raised intracranial pressure can result in the diameter of the optic nerve increasing [9]. Studies have shown the measurement of the nerve has good inter and intra-observer variability [10]. There is also a normal range for the size of a normal optic nerve from 4 to 5.9 mm [10]. The main utility of this test is in a setting where access to a neurosurgeon or intracranial pressure monitoring is limited.

10.4.2 The Role of MRI in Ballistic Trauma

MRI has a very limited role in trauma imaging. The nature of ballistic injuries often results in metallic fragments being deposited in the patient. An MRI would either rip the fragment out of the patient or heat it up to make the scan unbearable for the patient.

If there are no retained metal fragments MRI is principally used for imaging the brain and spine. If a spinal cord injury is suspected MRI is more sensitive than CT for assessing the cord and nerve roots.

10.5 Injury Patterns and Examples

10.5.1 Junctional Injuries

The neck, axilla and groin are known as the junctional zones. These are very difficult areas to assess clinically and more difficult to operate on especially to control haemorrhage. CT has proven very useful at detecting life and limb threatening injuries to these areas. Accurate diagnosis often with triplanar reconstruction can help the surgeon plan an approach and plan surgery. See Figs. 10.8 and 10.9.

Fig. 10.8 A metallic fragment has resulted in a carotid pseudoaneurysm (confluence of *green* and *red* lines)

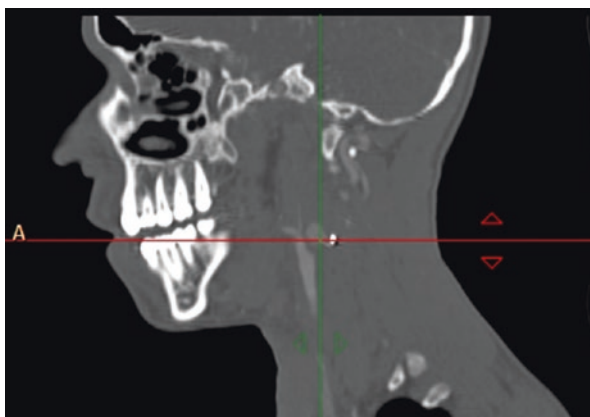


Fig. 10.9 Groin injury. A metallic fragment is just superficial to the uninjured external iliac vessels (*arrow*)



10.5.2 Foreign Bodies

Foreign bodies and the tract they have taken can be an important part of imaging ballistic injuries. The appearance of the IO device has already been described. In blast injuries the foreign body may be part of the patient's own anatomy or clothing (Fig. 10.10). Other organic or non-organic matter can be blown into the patient.

10.5.3 When Not to Operate

One of the most important decisions in trauma management is when not to operate. Will the procedure be more harmful to the patient than a period of observation? CT heavily influences this decision by being able to rule out active extravasation. The dual phase traumagram has improved the ability to detect arterial and venous haemorrhage.

If a trauma CT has ruled out active extravasation then either serial ultrasound or repeat CT can detect any increase in the amount of free fluid or haemorrhage.

Two case studies are detailed below (Figs. 10.11 and 10.12) where the CT findings together with the stability of the patient resulted in a decision being made not to intervene. Both patients were observed and neither required an operative procedure.

10.5.4 Pregnancy

The benefits and risks of CT and the associated high dose of ionising radiation with CT must be carefully considered in pregnant patients. Reducing the risks to the foetus by selective CT imaging or adjusting CT technique should be considered [11]. In ballistic trauma more harm will come to mother and child if CT is avoided or delayed particularly if the life of the mother is at risk.

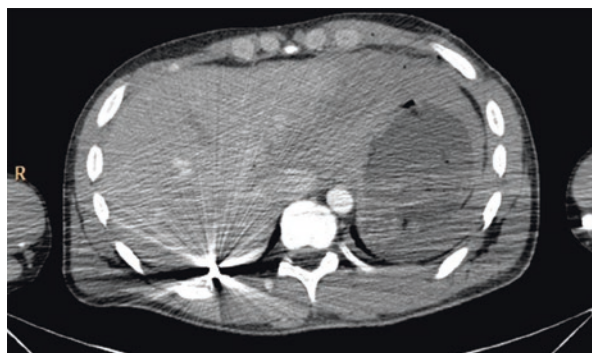


Fig. 10.10 A postoperative CT traumagram demonstrates the patient's talus in the peri-lumbar region

Fig. 10.11 Demonstrates a pregnant patient and foetus after ballistic abdominal injury. There is a small amount of fluid surrounding the liver but no active haemorrhage. No operative intervention was necessary and the patient discharged after a period of observation



Fig. 10.12 Demonstrates a metallic fragment in the posterior liver with a tract along the left lobe. No active haemorrhage was seen and no intervention was carried out due to the risk of bleeding if any tamponade was relieved



10.5.5 Paediatrics

Children's anatomy, their proportions and the relative elasticity of tissues, particularly in bone, differ from that of adults and for this reason must be considered separately. The NICE and RCR guidance for imaging children after trauma states that CT should be avoided unless there is serious injury especially of the chest as children rarely suffer from chest trauma [12]. However in ballistic trauma CT should be used to delineate injuries as there is no real alternative. What should be borne in mind is how much of the body to image. Consideration should be given for restricting the coverage of the traumagram on a case by case basis.

10.6 Imaging Multiple Casualties

A mass casualty scenario is defined by a number of casualties that overwhelm the accepting medical facility. In a small hospital this may be as low as two or three injured patients. The following is aimed at a situation involving many injured patients such as a Marauding Terrorist Firearms Attacks as seen in recent years in Mumbai and Paris. Considering how your department will function prior to such an event is the first step in being able to cope effectively with the situation [13].

Any large trauma centre should have a well rehearsed plan for such a situation. This should involve multiple agencies as well as all relevant departments within the hospital. Such a plan should be regularly rehearsed with table top and moulaged scenarios [13].

In the event of a major incident it is essential that each department such as ED, surgery, radiology and intensive care has a senior clinician who will coordinate personnel and equipment without being directly involved in clinical care. In radiology, inpatient and outpatient scanners may need to be emptied to accept casualties. Radiographers need to be briefed ideally before the first patient arrives. Reporting radiologists need to be stood up or, if the event is out of hours, called in to assist. A mixture of consultants and senior trainees should be used [13].

As the patients arrive a form of triage will be performed in the ED. FAST has a crucial role in this scenario to rapidly assess multiple patients for free fluid which adds objectivity and confidence to the triage. A radiology presence in the ED is essential for good communication. The senior clinicians coordinating the response should establish a priority list of patients for theatre or CT but this priority list will be fluid depending on the changing clinical conditions of patients. Good communication between these clinicians is essential to ensure priorities continue to be addressed. It is very easy in a busy stressful situation for staff to confuse patients even when using pseudonyms. Training and rehearsal in small teams will help avoid confusion, help develop local policies and build a team ethos which has benefits in day-to-day practice.

As patients are scanned rapid provisional reports should be given to the team looking after the patient with a full report issued as soon as possible. The coordinating radiologist should be aware of the findings. It may become apparent that CT

results mean that a patient moves up or down the list for theatre. The coordinating radiologist should also maintain good communications with their ED, surgical and ITU colleagues. Only when every patient has been scanned and reported should personnel be stood down.

A hot debrief followed by a lessons learnt process is also vital for the development of a good service.

Occasionally an incident will be so large that patients may go to different facilities. It may also be possible for regional reporting with neighbouring hospitals on the same PACS assisting each other reporting trauma scans [13].

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