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Management of Major Trauma and the Role of Interventional Radiology

Dr. Ahmed Hussain Albaqshi
Dr. Huda Hamad G Almutairi
Dr. Hussain Abdullah Aljabran
Dr. Jafar Yassen Almomaten
Dr. Alharbi Amer Hamoud A
Dr. Hamad Faihan Almotairi
Dr. Alanazi Saqqar Abdulelah S

Abstract
This study aimed at exploring the management of major trauma and analyzing the role of interventional radiology for major trauma patients. As there are no prospective randomized controlled trials of interventional radiology in major trauma. Therefore, this review aims to summarize the evidence supporting the use of interventional radiological techniques in the management of major trauma. The study concluded that interventional radiology has become an essential part of the modern trauma unit. Roles in pelvic haemorrhage and aortic injury are now well established and have contributed to improving patient survival and reducing long-term morbidity.

Acknowledgment
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1.1 Introduction

Major trauma is the leading cause of death in people under the age of forty. Major trauma describes serious and often multiple injuries where there is a strong possibility of death or disability, and includes injuries to the head, neck, spine, chest, limbs, abdomen, pelvis and skin. Around 98 per cent of major trauma is caused by blunt force, and the most common mechanisms of injury are road accidents and falls. Major trauma can also be caused by assault, burns, blasts, crushes and self-inflicted injuries. Penetrating injuries, such as knife or gunshot wounds, account for only two per cent of major trauma (Trauma and Audit Research Network (2009).

Trauma is classified using an injury severity score (an anatomical scoring system, *see figure 1*) which retrospectively assigns a measure of severity ranging from zero to 75, with a score of 16 or greater signifying major trauma. Mortality increases with injury severity score, and a score of 75 signifies injuries which are unlikely to be survived as shown in table 1.

Table (1): Injury severity score group and mortality

Injury severity score	Percentage of major trauma patients	Percentage mortality of this injury severity score group
16-25	62.6	10.5
26-40	28.9	22.1
41-74	7.7	44.3
75	0.8	76.6

Source: Jordan statistics, Ministry of health, 2016

Major trauma describes multiple, serious injuries that could result in significant physical harm or loss of life. This includes serious head, chest, organ and bone injuries. People who suffer serious injury need high quality specialist care for the best chances of survival and recovery.

Region	Injury Description	AIS	Square Top Three
Head & Neck	Cerebral Contusion	3	9
Face	No Injury	0	
Chest	Flail Chest	4	16
Abdomen	Minor Contusion of Liver Complex Rupture Spleen	2 5	 25
Extremity	Fractured femur	3	
External	No Injury	0	
		Injury Severity Score:	50

AIS Score	Injury
1	Minor
2	Moderate
3	Serious
4	Severe
5	Critical
6	Unsurvivable

ISS	
1-8	Minor
9-15	Moderate
16-24	Serious
25-49	Severe
50-74	Critical
75	Maximum

Figure (1): Injury Severity Score; ISS

Major trauma is commonly defined using an Injury Severity Score (ISS) threshold of 15. Since this threshold was formulated, there have been significant developments in both the Abbreviated Injury Scale underlying the ISS, and trauma management techniques, both in the preventive and acute-care phases of trauma management (Palmer, 2007).

Interventional Radiology (*see figure 2*) is a medical sub-specialty of radiology, utilizing minimally invasive image guided procedures to diagnose and treat a host of diseases in nearly every organ system. These procedures involve the use of X-rays, CAT scans, or Ultrasound guidance to help the radiologist perform the appropriate procedure requested by your physician. These procedures have less risk, less pain and less recovery time compared to open surgery. Procedures commonly performed by the Interventional Radiology team include biopsies, draining of abscesses, ablations, kyphoplasty and vertebroplasty, angiography, venous access, biliary and renal drains, peripheral interventions and steroid injections (Wenzl & McDonald, 2002).

Figure (2): Interventional Radiology

Interventional radiologists (IRs) are ideally qualified to play an important role in the management of trauma patients. Aside from their specialized training in the delivery of trans catheter therapies, IRs receive broad-based multimodality imaging training, which renders them highly capable of correlating findings from preprocedural imaging studies to speed diagnosis and treatment of trauma patients in the emergency setting. However, an interventional practice must meet the following criteria to be an effective player in the team management of trauma patients:

1. A skilled IR who is available for consultation on urgent notice;
2. Availability of high-quality digital subtraction angiographic equipment, preferably with digital road mapping and/or fade-fluoroscopic capabilities;
3. Availability of skilled nursing and equipment needed for monitoring of critically ill patients; and
4. Ability to ready these resources within 30 to 60 minutes. Equally important, treatment of trauma patients requires efficient use of resources as well as cooperation and communication among a multidisciplinary team.

Patients need to be rapidly and accurately assessed to determine the nature of their injuries with treatments prioritized by injury severity. Angiography and trans catheter therapy can be time-consuming and may delay other important procedures, so it is critical that delays in interventional treatment are minimized (Zealley & Chakraverty, 2010).

Most preventable deaths from trauma are caused by unrecognized and therefore untreated haemorrhage, particularly in the abdomen. Haemorrhage causes early deaths, and the associated hypovolemic shock leads to secondary brain injury and contributes to late death from multi-organ failure (National Confidential Enquiry into Patient Outcome and Death, 2007).

Early management is focused on resuscitation and the diagnosis and treatment of life threatening bleeding to prevent the lethal metabolic disturbance triad of acidosis, hypothermia, and coagulopathy (Zacharias, Offner, Moore & Burch, 1999).

1.2 Problem Statement

Many aspects of immediate trauma care suffer from a lack of high quality prospective research. This review is based predominantly on evidence from retrospective cohort series and is subject to the limitations inherent in this type of level 2 research (Scottish Intercollegiate Guidelines Network, 2008).

There are no prospective randomized controlled trials of interventional radiology in major trauma. Although the volume of level 2 evidence is substantial and contains few contradictory findings, no robust level 1 evidence yet exists. This review aims to summarize the evidence supporting the use of interventional radiological techniques in the management of major trauma.

1.3 Study Background

Interventional radiology has become an essential part of the modern trauma unit. Its ability to treat patients with multiple, complex life threatening injuries in a fast and focused manner has become a lifesaving adjunct, and in some cases an alternative, to conventional surgery. Major trauma is defined as a situation where there are "serious and often multiple injuries where there is a strong possibility of death or disability". In Jordan alone there are at least 16,000 cases of major trauma a year leading to 3,600 deaths. In recent years there has been an increasing understanding of good practice within trauma care.

Death from trauma has been shown to follow a 'trimodal distribution'. This model describes three peaks to mortality following traumatic injury. The first peak occurs within seconds or minutes of injury and is often unpreventable. The second peak occurs within minutes to hours, these deaths are often related to uncontrolled haemorrhage and in many cases are preventable if recognised and treated promptly. The third peak relates to deaths in the days to weeks following the injury from sepsis and multi-organ failure. Again improved care can reduce the mortality and morbidity in this group. Prompt management is required to reduce death and prevent long term morbidity being inflicted within the second peak. The concept of the 'golden hour' has been introduced to highlight the importance of 'damage control' within this period. Through the widespread use of the ATLS (Advance Trauma Life Support) guidelines there has been an increasing understanding of the importance of the multidisciplinary trauma team performing diagnostic and therapeutic interventions simultaneously within this period. The importance of acting promptly to control haemorrhage and minimize metabolic insult is now known to not only reduce the second peak of deaths directly but also prevent the fatal cycle of acidosis, hypothermia and coagulopathy that can lead to multi-organ failure and the third peak of mortality and morbidity (Kortbeek, Al Turki, Ali, Antoine, Bouillon, Brasel, & Burton, 2008).

It is clear that whilst both surgical and Interventional Radiology(IR) care is essential in any trauma unit neither can claim the ability to treat all traumatic injuries with superiority. An understanding must then be gained of the applications of both and seen within the context of the patient's global clinical pathway. At a basic level the benefits of interventional care may be seen as the ability to control haemorrhage from deep structures inaccessible to the surgeon or where surgery would necessitate disruption of blood clot and damage to adjacent structures. The benefits of surgery, especially with damage control packing techniques can be haemostasis of diffuse or superficial bleeding and surgical treatment can be definitive. Some type of injury may be difficult to treat definitively through interventional procedures alone without significant risk of devascularisation of adjacent healthy tissues (Hanssen & Spangehl, 2004).

Imaging plays a key role in the triage of patients following major trauma. In any institution unstable patients undergo a FAST scan (Focused Abdominal Sonography in Trauma) either in the ambulance, helicopter or on their arrival to A&E. A number of clinicians now across a range of specialties other than radiology (including accident and emergency and trauma surgery) are trained to perform FAST scans. Once in the resuscitation department all patients undergo chest and pelvic radiographs as part of the primary survey. If the patient is stable they are transferred to CT which is located within the emergency department. A non-contrast head and cervical spine and single post contrast chest, abdomen and pelvis images are acquired. CT allows the identification of vascular and visceral injury, active bleeding, haematoma and neurological injury. Once these findings are known the most appropriate direction for management can be followed. The most commonly sustained injuries are fractures of the pelvis and extremities (80%), head trauma (60%), thoracic trauma (25-50%), abdominal trauma (12-40%) and spinal trauma (6-10%) (Ranatunga & Renfrew, 2012).

1.4 Role of interventional radiology in haemorrhage control in the trauma setting

The role of CT in the trauma setting is multifaceted. There is not only the diagnostic aspect of the study but it is integral to treatment planning and triage. The findings on CT can be used to classify the types of bleeding seen, which can be considered in a number of ways:

- Visceral bleeding(kidney, spleen, liver); distal or proximal.
- Peripheral end artery or vessel with significant collateral flow.
- Active arterial bleed – seen as active contrast extravasation on CT.
- Retroperitoneal/pelvic – multiple arteries involved.
- Hematoma without site of bleeding.
- False aneurysm.
- Fistula.

There are a number of advantages of endovascular treatments in comparison with surgery. There is less distortion of the anatomy by haematoma when viewed fluoroscopically, especially in the pelvis and solid viscera. Endovascular techniques are able to reach areas which are difficult for open surgical access, for example the retroperitoneum. IR techniques produce a smaller physiological insult, which is significant in patients with multiple injuries and multiple medical co-morbidities. Endovascular techniques do have their disadvantages. Definitive treatment is not always possible, although this is not always the aim in trauma care. Some newer treatment options, such as aortic stent grafts for traumatic aortic injuries, are unproven in their durability. Trans catheter embolization has been used all over the body in various settings. In the trauma setting, the aim of embolization is to avoid surgery or to obtain haemodynamic stability, to allow surgery to be undertaken safely. Trans catheter embolic agents used can be permanent or temporary. One needs a good knowledge of embolic agents and of the vascular anatomy. Coils are the most common embolic agent used. Trans catheter embolization can reduce complications of pseudo aneurysms and AV fistulas. In a case of pelvic trauma where there was significant blood loss from the internal iliac artery in a haemodynamically unstable patient, an aortic occlusion balloon can be a very rapid and effective way of temporarily achieving haemostasis. Especially useful at sites which are inaccessible to pressure such as the aorta and vessels within the thoracic cage.2 Balloon must be inflated proximal to the bleeding site (see figure 3).

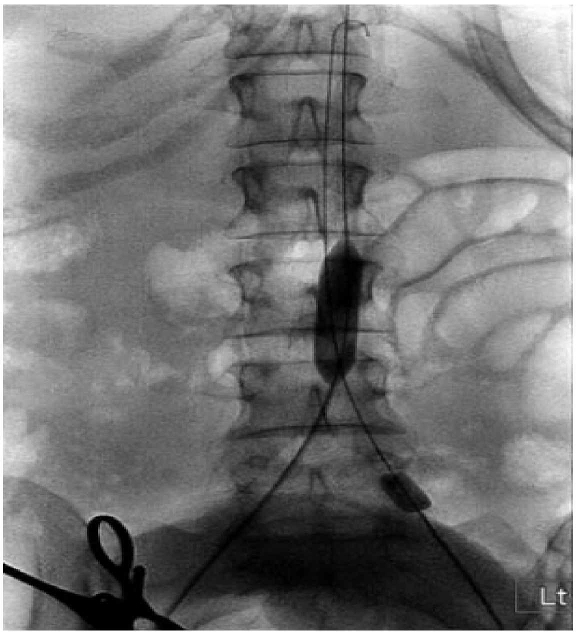

Figure (3): Use of an aortic and left iliac artery occlusion balloon to obtain haemostasis while a definitive procedure can be performed in a more controlled and physiological stable environment.

Alternatively in the setting of pelvic fractures, which can have a mortality risk of up to 25% depending on the severity of the injury and the associated injuries.7,8 Bleeding can occur from three sites, arteries, sheared veins and fractured bone surfaces. Initial management is with pelvic binders, to obtain stability. CT often will not demonstrate a bleeding source within the pelvis but will demonstrate pelvic haematoma (figure 4).

Figure (4): CT of the pelvis demonstrating multiple pelvic fractures and haematoma. Angiogram following bilateral internal iliac artery embolization to bring the vessel to slow flow; you can see flow in the internal iliac artery with reflux into the external

If the patient is haemodynamically unstable in the setting of pelvic fractures, then non-selective embolization of both the internal iliac arteries with gel foam can be lifesaving (figure 5).

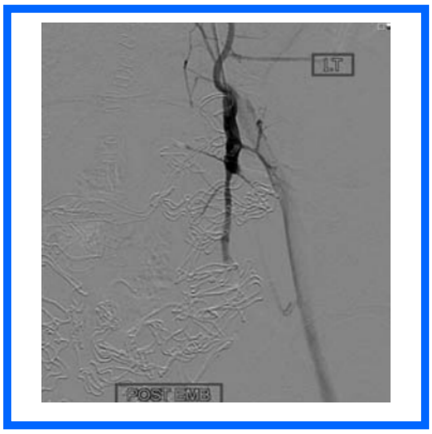

Figure (5): CT of the pelvis demonstrating multiple pelvic fractures and haematoma. Angiogram following bilateral internal iliac artery embolization to bring the vessel to slow flow; you can see flow in the internal iliac artery with reflux into the external

In relation to abdominal injuries, the spleen is the most frequently injured solid organ. There is now emerging data for organ salvage instead of removal. Splenic embolization for isolated splenic injuries where there is active contrast extravasation can reduce the splenectomy rate by 20% without reducing overall survival (Zealley & Chakraverty, 2010).

Splenic artery embolization for type 3 and 4 injuries often allows the patient to be treated as a type 1 or 2 injury allowing for the preservation of splenic function (see figure 6), without the short and long term complications of splenectomy. Splenic embolization with either coils or a plug should be performed as proximal as possible in the vessel but distal to the main pancreatic branch. This is to allow a reduction in arterial pressure without ischemia (Madoff, Denys & Wallace, 2005).

Figure (6): Traumatic splenic injury. CT demonstrating splenic laceration. Angiogram of the spleen showing the two fracture fragments. The splenic artery was emblazed using a nitinol plug to reduce flow and prevent ischemia.

1.5 Pelvic trauma

In the context of major trauma the presence of a pelvic fracture (see figure 7) confers a greater risk of mortality. The presence of a pelvic fracture is an indicator of severe trauma. Indeed, 90% of patients with a pelvic fracture suffer a concurrent injury (Suzuki, Smith & Moore, 2009).

In the presence of a pelvic fracture retroperitoneal haemorrhage should be assumed to be present. Haemorrhage associated with pelvic fractures occurs from three sources: arterial disruption, venous shearing and bleeding from bone surfaces. A multidisciplinary team approach is key to reducing morbidity and mortality in this group with neither interventional radiology or surgery being able to treat all three forms of haemorrhage effectively. Surgical control of arterial pelvic bleeding is difficult and it is here that interventional radiology has a key role to play through angiography and embolization. Control of venous and bone surface blood loss remains the domain of the surgical team with packing enabling effective tamponade of venous bleeding and external fixation of the opposing fractured bone surfaces controlling superficial ooze.

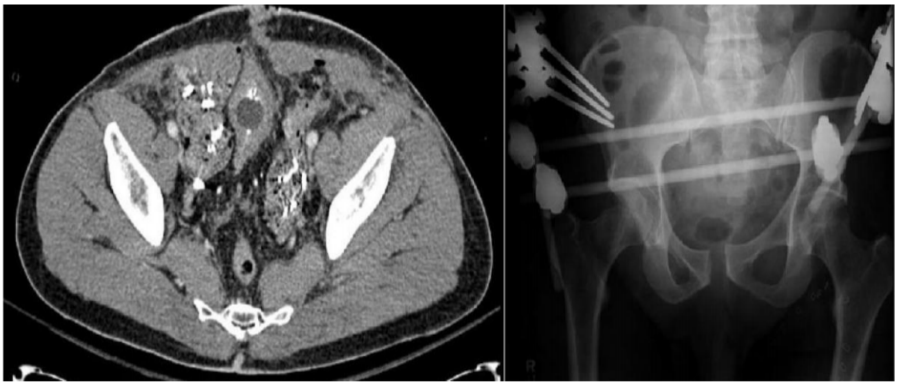

Figure (7): CT and pelvic radiograph from the same patient, a cyclist hit by van at 70mph. CT demonstrates the appearances of surgical packing within the pelvis and the radiograph shows an external fixation device insitu.

Although protocols exist for the management of patients with pelvic fractures it must be acknowledged that no two patterns of injury are the same and for each patient treatment must be based on their haemodynamic status and the presence and severity of any concurrent injury. Pelvic fractures generate retroperitoneal haemorrhage so with a solitary pelvic fracture a patient would be expected to be negative for intraperitoneal fluid on FAST scan. If intraperitoneal fluid is seen on FAST and the patient is unstable this suggests concurrent intraperitoneal injury and the patient should be taken to theatre for damage control laparotomy (Stawicki, 2017).

If laparotomy is negative or the patient remains haemodynamically unstable then the patient moves to the interventional suite for pelvic angiography and embolization, at which time angiography of other sites of haemorrhage may also be treated. Gaining all possible information on the nature and severity of a patient's injuries is clearly essential in cases such as these. In many cases it is possible and appropriate to perform CT prior to departure from the accident and emergency department even in patients traditionally considered unstable. Not only does CT allow an assessment of the source of haemorrhage it also allows the nature and order of surgical and IR management to be planned, so reducing the time of procedures in both theatre and angiography (Hagiwara, Sakaki, Goto, Takenega, Fukushima, Matuda & Shimazaki, 2001).

1.6 Aortic disruption

Whilst penetrating injuries to the aorta can occur at any location blunt aortic injuries are typically seen at the aortic isthmus, or more rarely at the level of the diaphragm. In conventional anatomy the aortic isthmus lies between the root of the left subclavian artery and the origin of the third intercostal artery. The relative mobility of the aorta at the isthmus, at the site of the attachment of the ligamentum arteriosum, and possible compression against the adjacent vertebral column are thought to combine with a raised high intraluminal pressure to inflict damage at this site on sudden deceleration (Hopkins, Peden & Gandhi, 2009).

Road traffic accidents account for 80% of these injuries with 70-90% of patients dying at the scene of injury5,6. Of those that do survive to receive medical care 90% will have an associated injury requiring major surgery, a fact that reflects the ferocity of trauma required to inflict aortic injury6 .

Traditional diagnosis of thoracic aortic injury was challenging. Much weight was placed on widening of the mediastinum on chest radiographs but this has been shown to be a highly non-specific sign, especially in the resus supine film. Often patients have no clinical signs and with a historical mortality of 30% within 6 hours of injury in those reaching hospital outcome for many of these patients has previously been bleak (Felker, Pang, Adams, Cleland, Cotter, Dickstein & Khan, 2010).

The evolution of CT, with ever improving image speed, resolution and multiplanar reformat abilities has revolutionized the diagnosis of aortic injury. CT carries a 99.7% accuracy in the identification of traumatic aortic injury and some believe it even to be superior to angiography. Once an aortic injury has been diagnosed developments in resuscitation and medical management have reduced the pre-operative rate of progression and rupture (Hoffer, 2008).

Endovascular repair has been shown in non-randomized studies to carry not only a survival advantage but also reduce major complications, blood loss and intensive care stay . Rapid quick intervention has the added benefit of being able to quickly reinstate high perfusion pressures in the presence of concurrent brain injury (see figure 8).

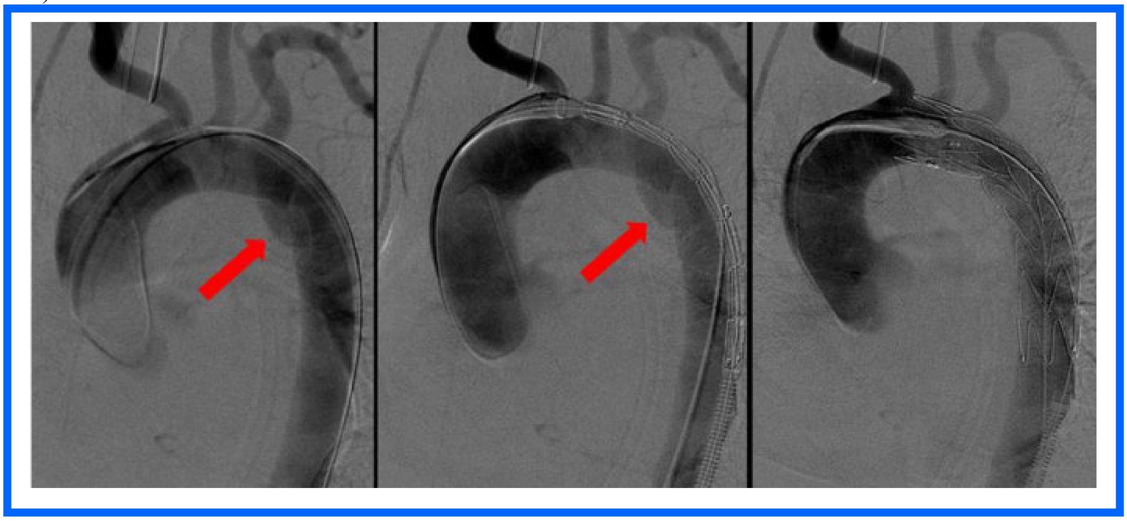

Figure (8): Serial images from the endovascular repair of the 45 year old man whose CT is above. The site of injury is indicated by arrows

1.7 Splenic laceration

Traditional surgical management of traumatic splenic injury has been based on laparotomy and splenectomy. In recent years there has been an increasing move towards splenic conservation rather than removal. This is desirable as patients post splenectomy not only have an increased rate of post-operative wound infection but also an ongoing risk of developing overwhelming sepsis. Surgical techniques and non-operative management, including splenic artery embolization, have made splenic conservation an increasingly viable treatment option. Treatment options available in traumatic splenic injury now include; traditional laparotomy and splenectomy, splenic salvage surgery, angiographic embolization and observational management. The key to optimizing outcome is appropriate patient selection for each group. CT is crucial in making this assessment and should be performed in all stable patients. Grading systems do exist for splenic injury, most notably the AAST injury scale but this offers no advantage in predicting outcome or indicating the most appropriate management option. The presence of haemorrhage, pseudo aneurysms or AV fistulae on CT are all predictors that observational management alone is likely to fail. In these cases interventional or surgical management is appropriate. No clear guidance is available as to which patients are more appropriately treated by either specialty but it has been suggested that age of patient, their haemodynamic status and the severity of the splenic injury should guide this decision (van der Vlies, van Delden, Punt, Ponsen, Reekers & Goslings, 2010).

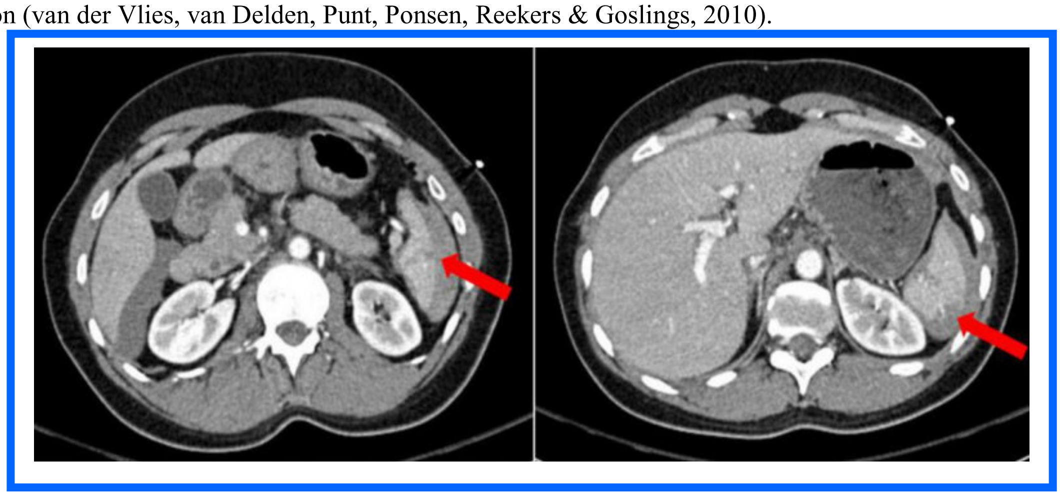

Figure (9): 44 year old female driver hit by lorry causing the car to roll. On admission to the resuscitation department see was haemodynamically unstable with a pelvic fracture on initial radiographs and free fluid on FAST. CT demonstrates multiple splenic lacerations.

1.8 Hepatic injuries

The care of hepatic injury has also undergone radical change in recent years with an increasing number of patients being treated conservatively. Triage as always is based on clinical condition, haemodynamic state and

CT findings. In unstable patients with active hepatic bleeding FAST scan can be expected to be positive and therefore the patient will proceed immediately to damage control laparotomy with or without a pre-operative CT. Surgical techniques have moved away from resection and repair and now focus on debridement and packing. This liver sparing surgery may be followed by angiography and embolization, especially in the presence of active arterial bleeding or if surgical control has been unsuccessful. The use of arterial embolization is effective in 83% of cases. Injury may be demonstrated as contrast extravasation, the presence of a false aneurysm, abrupt arterial truncation or the presence of fistulae on hepatic angiogram. Once the site of injury has been illustrated it is then desirable to perform sub selective catheterization. This though can be time consuming and carries the risk of arterial dissection. Coils are most commonly used for hepatic embolization due to the concern that gel foam risks vessel recanalization and therefore repeat / delayed haemorrhage (Bouras, Truant & Pruvot, 2010).

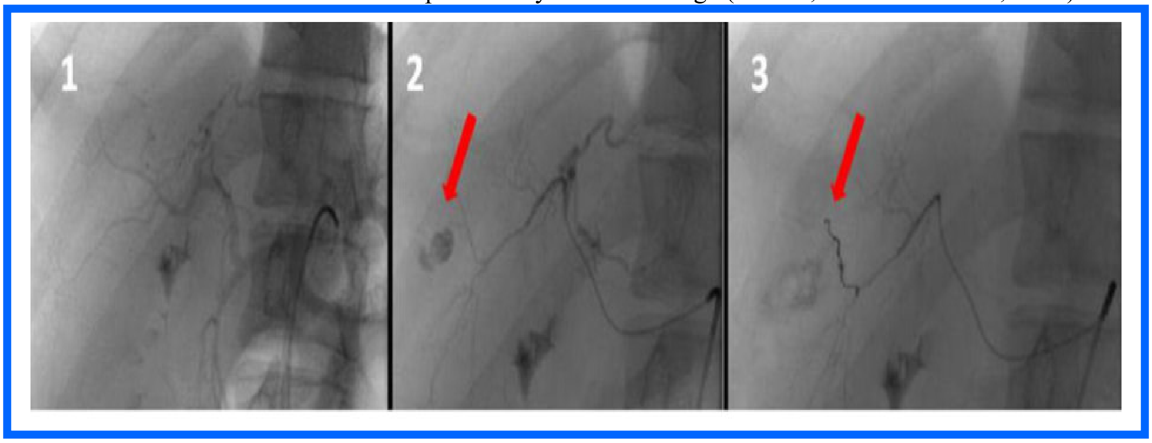

Figure (10): Serial images from the stab victim whose CT is shown above. 1 - Initial hepatic angiogram does not illustrate the site of bleeding. 2 - Selective angiography demonstrates contrast blush at the site of injury. 3 - Post coil embolization and cessation of haemorrhage

1.9 Renal injuries

The majority of renal injuries can be treated by conservative management alone. Indications for intervention or surgery are persistent haemorrhage and haemodynamic instability, haematuria or progressively deteriorating renal function. An expanding retroperitoneal haematoma may be seen on laparotomy and in the presence of haematuria this suggests renal haemorrhage. Optimal CT assessment is with triple phase CT (arterial, nephrographic and urographic phases) but as with injuries to other organ systems CT in major trauma is aimed at global assessment identifying all life threatening injuries in a timely manner and therefore a tradeoff is taken by single phase imaging or nephrographic and delayed phases alone.

As well as active contrast extravasation, false aneurysms, arteriovenous fistulae and arterio-calyceal fistulas may be indications for intervention. In a stable patient with unilateral injury and a normal contralateral kidney the decision may be taken not to treat surgically even in the presence of a main renal artery injury (Holden, 2008).

Intervention can allow organ preservation with some degree of function and is therefore an attractive alternative to nephrectomy or organ sacrifice. Flush aortogram is performed to assess for central renal vascular injury followed by selective renal catheterization as peripheral injuries may be underestimated on the aortogram. Coil embolization is most often used. Injuries to the renal pedicle are generally considered an indication for surgical management rather than intervention but there has been increasing interest in treating even high grade injuries by embolization initially to gain haemodynamic control. Once haemorrhage has been controlled and the patient is stabilized they can then progress to nephrectomy at a later date. Injuries to the central collecting system will also necessitate operative management (see figure 11).

Figure (11): Fall from 50ft admitted haemodynamically unstable and seen to have pelvic fracture on initial radiographs. CT demonstrates avulsion of the right main renal artery (red arrows) with active extravasation of contrast (yellow arrows). Note the devascularised right kidney

Conclusion

Interventional radiology has become an essential part of the modern trauma unit. Roles in pelvic haemorrhage and aortic injury are now well established and have contributed to improving patient survival and reducing long-term morbidity. An understanding of the role and potential of interventional radiology and its relationship to surgical and medical care within the trauma setting is essential if techniques and departments are to continue to thrive.

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