The early management of gunshot wounds Part II: the abdomen, extremities and special situations

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The management of gunshot wounds of the abdomen and extremities is evolving with centres who treat large volumes of such injuries tending to the application of a policy of selective non-operative management. This article discusses the management of gunshot wounds to the abdomen and extremities and reviews the evidence supporting these changing practices. Special situations such as wounding by shotguns or air rifles are also examined as are the special considerations needed when dealing with the gunshot injured pregnant women or in a child.

\textbf{Key words:} gunshot wound; abdomen; extremity injury; pregnancy; paediatric trauma; nonoperative management

\section*{Introduction}

This article continues to describe the early management of gunshot wounds (GSWs). Injuries to the head, neck, and thorax have been described previously, as has the pathophysiology of gunshot injuries (Garner, 2005). Despite increasing United Kingdom gun crime (Porteous et al., 1997; Persad et al., 2005), the majority of published experience still arises from large centres in the United States and South Africa – their experiences with the increasing use of conservative management protocols require cautious appraisal in the UK. British clinicians must tailor their actions to both their experience in the management of such injuries and the availability of resources and investigations.

\section*{Abdominal GSWs}

The anterior boundaries of the abdomen are the trans-nipple line superiorly, the inguinal ligaments and pubic symphysis inferiorly and the anterior axillary lines laterally. Posteriorly it extends from the tips of the scapulae down to the gluteal folds and around to the posterior axillary lines – the flanks lie between, bounded above by the sixth intercostal space and below by the iliac crests. The intrabdominal viscera however may be injured without evidence of external transabdominal penetration as the missile may breach peritoneum via the buttocks and groins inferiorly and the diaphragm from above. Like thoracic GSWs, those involving the abdomen may present anywhere along the haemodynamic spectrum from absolute stability to complete collapse. Similarly, abdominal signs may vary between complete absence and frank peritonism. Accordingly the initial management of any gunshot injured patient must proceed along the standard ATLS lines of ‘ABCDE’ and an obvious abdominal wound must not distract from the basic assessment nor from the potential for co-existing, life threatening extra-abdominal injury that must be immediately addressed (American College of Surgeons, 1997).

Assessment of the abdomen forms part of the secondary survey and like in other forms of abdominal trauma seeks to address three broad questions. Have the abdominal contents been injured? Is a laparotomy required? If so, when should it occur? Until recently, having a GSW as the mechanism of injury reduced these questions by one third as laparotomy was mandatory for all abdominal gunshot victims – in many experienced...
centres however the necessity for mandatory laparotomy has now been questioned (Muckart et al., 1990; Demetriades et al., 1991) and a further question added – is a damage control approach necessary (Rotondo et al., 1993)? Cardiovascular collapse unresponsive to resuscitation with either abdominal signs or an abdominal GSW wound necessitates resuscitative laparotomy (with or without adjunctive thoracotomy) without delay or further investigation (Botha et al., 2002). In the absence of such complete collapse, the abdomen should be examined in its entirety including the back, flanks, gluteal region and the external genitalia. Note is made of any GSWs and pairing these may give an indication of likely trajectory although internal ricochets are frequent and potentially misleading. Evidence from the LA County trauma room suggests that wound track estimation has a 10% false positive rate for posterior GSWs (Velmahos and Degiannis, 1997) and only a 75.4% sensitivity in predicting an intraperitoneal injury requiring surgical repair in anterior gunshots (Demetriades et al., 1997). An odd number of GSW wounds suggests a retained bullet (Weistreich, 1986) with higher energy transfer.

The presence of tenderness and peritonism should be sought – auscultation contributes little, as bowel sounds may be present in the early post-injury period and the noisy resuscitation room limits accurate assessment. Digital rectal (and vaginal) examinations are mandatory and may reveal a perforating rectal injury – either from the primary gunshot or secondary to a ballistic pelvic fracture. Rectal examination may be augmented by gentle rigid sigmoidoscopy where rectal injury is suspected. Suspected urethral disruption requires investigation via urethrography following full stabilisation of the patient (Uehara and Eisner, 1986). The urinary bladder should be decompressed by catheterisation. If DRE is normal and there is no meatal blood then the urethral approach should be attempted. In the presence of suspected urogenital tract injury a single gentle attempt at urethral catheterisation is acceptable and if unsuccessful suprapubic catheterisation should be undertaken by an experienced operator, particularly in the presence of a pelvic fracture or haematoma. Ultrasound guidance as a means of closed suprapubic catheterisation has been reported (Aguilera and Choi, 2002), but experience in trauma is limited. Frank haematuria is indicative of urinary tract injury (Velmahos et al., 1997). Nasogastric intubation provides gastric decompression in the face of likely gastric atony thereby reducing aspiration risk – frank blood or coffee-ground aspirates suggest upper gastrointestinal injury.

Adjuncts to clinical examination
The abdomen may be further evaluated by a number of techniques, the choice of which will depend on local availability and expertise, the haemodynamic stability of the patient and the extent of abdominal signs. Despite the advent of selective nonoperative management (SNOM) for abdominal GSWs – abdominal penetration and hypotension resistant to resuscitation remains an indication for prompt laparotomy. The majority of these adjuncts are radiological. A plain chest radiograph as part of the standard trauma series, may disclose pneumoperitoneum or intrathoracic abdominal viscera indicative of diaphragmatic disruption. Plain abdominal radiographs are not part of the routine evaluation of the trauma patient as good quality portable films are difficult to obtain. If taken however, they may indicate free intraperitoneal air e.g., Rigler’s and the falciorm ligament signs (Levine et al., 1991), or air in the retroperitoneum from duodenal injury. If plain X-rays are taken then all potential entry and exit wounds should be marked – paperclips are ideal for this purpose (Brooks et al., 2002). An odd number of wounds and no bullet evident on torso imaging should prompt closer examination of the limbs and consideration of the rare ‘missile emboli’ scenario (Mattox et al., 1979) although neither eventuality is likely to alter the patient’s early management.

Diagnostic peritoneal lavage
Diagnostic peritoneal lavage (DPL) was introduced in 1965 (Root et al., 1965) and despite its recent ‘obituary’ (Jansen and Logie, 2005) remains a useful technique by virtue of its speed and simplicity. It may be performed by open or closed methods (Box 1) and is highly sensitive for intraperitoneal injury. The standard criteria for a positive DPL are contamination with gastrointestinal content, bile or vegetable material, the presence of bacteria on gram

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staining of the lavage or lavage counts exceeding 100,000 red cells per mm$^3$ or 500 white cells per mm$^3$ (American College of Surgeons, 1997). In blunt abdominal trauma these criteria yield a sensitivity of 96.4%, a specificity of 99.1% and a positive predictive value of 96.5% (Gomez et al., 1987). Applying these cell count limits in penetrating trauma however gives unacceptably low sensitivity and specificity of 89% and 88%, respectively (Muckart and Macdonald, 1991). If the red cell threshold in penetrating trauma is reduced to between 5000 and 10,000 red cells/mm$^3$, a reduced false-negative rate of 5% may be achieved (Moore et al., 1980).

In the traditional context of mandatory laparotomy for abdominal GSWs and low-sensitivity ‘blunt’ lavage criteria, DPL was dismissed by many as unreliable in predicting the need for laparotomy (Thal et al., 1980). However, with the trend towards SNOM, DPL has been recently re-explored to examine its effectiveness in differentiating those stable patients who do or do not require laparotomy. In a prospective study of 44 haemodynamically stable patients with abdominal GSWs patients were investigated via DPL and then proceeded to laparotomy; DPL and laparotomy findings were correlated. DPL correctly identified the presence or absence of intra-abdominal injury in 40 patients (91%). At laparotomy, 32 patients (73%) were demonstrated to have sustained intra-abdominal injury, whilst 8 did not. This conferred a positive predictive value of 96.7% and negative predictive value of 78.6% for DPL (Kelemen et al., 1998).

In a larger series of 429 patients, DPL was demonstrated to have a sensitivity of 99% and specificity of 98% in predicting the need for laparotomy (Nagy et al., 1997), in patients with abdominal GSWs without peritonism, shock or with tangential wounds in which peritoneal penetration was uncertain. 144 such patients with positive DPL according to red cell criteria (>10,000 RBC/mm$^3$) had intra-abdominal injury at laparotomy. There were 6 false positive lavage results. Of 279 patients with negative DPL findings (lavage red cell counts less than 10,000 cells/mm$^3$), two patients deteriorated clinically and proceeded to laparotomy (false negative DPL findings). Seven further patients in the negative DPL group proceeded to laparotomy for other indications such as persistent tenderness, at which no intra-abdominal injury was demonstrated. The remaining 270 patients were managed expectantly without complication. In this study, the authors concluded that lowering the red cell threshold for a positive DPL to 10,000 per mm$^3$ did not translate into the anticipated shortfall in specificity. DPL in common with many other diagnostic modalities is poor at demonstrating retroperitoneal and diaphragmatic injury (Henneman et al., 1989). However, it remains a valuable tool, particularly in centres unsupported by CT facilities, and reports of its demise are premature.

**Focused abdominal sonography for trauma**

Focused Abdominal Sonography for Trauma (FAST) scanning is an abbreviated ultrasound survey intended to detect fluid within the peritoneum and pericardium of an injured patient (Scalea et al., 1999). The pericardium, right and left upper quadrants and pelvis are examined in turn for the presence of free fluid signifying either haemorrhage or visceral injury (Figure 1). FAST represents a rapid, noninvasive, nonionising radiation modality for the bedside assessment of abdominal trauma. It is designed to be performed by suitably trained nonradiologists and is not designed to evaluate the integrity of the abdominal viscera (Scalea et al., 1999). Experimentally it is difficult to detect less than 100 mLs of intraperitoneal fluid and only

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**Box 1 Techniques of DPL.**

**The Open Technique for DPL**
- Urinary catheter and nasogastric tube placement are mandatory prior to DPL.
- Aseptic preparation of the subumbilical midline with local anaesthetic infiltration
- Sharp dissection through skin, subcutaneous fat and linea alba to peritoneum.
- Open peritoneum between clips
- Infuse 1L of warmed saline (20 mL/Kg if used in children) via a sterile giving set directed into the pelvis
- Place the saline bag below the patient and collect the lavage return
- Send samples for laboratory analysis (microscopy, amylase, cell counts, and Gram Stain).

**The Seldinger technique for DPL**
- The preparation (Catheter, NGT, and asepsis) is identical to the open technique.
- The needle is introduced into the abdomen angled towards the pelvis and exchanged for a lavage tube over a guide wire using the Seldinger technique. Infusion of fluid and collection of samples is as for the open technique.
10% of a mixed group of radiologists and non-radiologists could detect volumes less than 400 mL with a mean threshold volume for detection of 619 mL (Branney et al., 1996). A small volume of free fluid in the pelvis of women of reproductive years is now regarded as a physiological normal finding (Sirlin et al., 2001). Appropriately trained surgeons have matched the competency of radiologists in this technique (McKenney et al., 1998). However, the sensitivity of FAST scanning is influenced both by operator (experience) and patient (obesity) factors (Boulanger et al., 1998). The majority of FAST studies reported have been for the assessment of blunt trauma in which sensitivity and specificity rates of 73–88% and 98–100% are claimed (Hoff et al., 2001). Studies of penetrating abdominal trauma are less common. A prospective study of 75 patients with penetrating abdominal trauma, both stabbings and GSWs, demonstrated a sensitivity of only 46% and specificity of 94% in the detection of intra-abdominal injury (Udobi et al., 2001). Boulanger et al. (2001) reported a similarly high specificity (98%), but only a marginally improved sensitivity of 67% in 72 apparently stable patients following penetrating abdominal injury.

A ‘positive’ FAST study is a strong predictor of injury and suggests the need for consideration of laparotomy if haemodynamically unstable or further imaging if available and the patient is sufficiently stable. However a ‘negative’ FAST study should be viewed in the context of the degree of clinical suspicion of serious intra-abdominal injury. Kirkpatrick et al., reported a sensitivity of 71.4% and specificity of 95.8% for the detection of intra-abdominal injury using hand-held ultrasound equipment in 38 patients (not further sub-divided) with penetrating trauma without shock, peritonism, or clear clinical evidence of peritoneal violation (Kirkpatrick et al., 2004). The authors concluded that the stable patient with a negative FAST should undergo alternative investigation such as CT scanning, as FAST is likely to exclude major injury mandating urgent surgery, providing confidence in proceeding to further investigation and observation. Diaphragmatic, hollow viscus, mesenteric, and retroperitoneal injuries have all remained undetected by FAST (Hoffman et al., 1992, Boulanger et al., 2001). Repeat FAST scanning after an initial negative scan has been demonstrated to increase the sensitivity for detection of intra-abdominal injury (Blackbourne et al., 2004). However, these observations relate to blunt trauma without a comparable study in penetrating injuries. Consequently, a time interval after which a second negative FAST scan may exclude injury sufficiently sensitively to permit discharge of the otherwise stable patient has yet to be defined.

Computed tomography

Initial use of CT in the evaluation of penetrating torso injury received criticism due to poor accuracy in the diagnosis of bowel injury (Marx et al., 1985; Rehm et al., 1989; Sherck and Oakes 1990). CT then found primary application in determining the need for laparotomy in stable patients with penetrating back and flank wounds either alone (Phillips et al., 1986) or in combination with other investigative modalities such as DPL (Himmelman et al., 1991). The emphasis in the early studies was upon stab

Figure 1 The position of the four FAST stations (A) Subxiphoid. The transducer is angled upward and slightly to the left shoulder to identify haemopericardium. If poor views are obtained, consider the transverse left intercostal position in 3rd or 4th interspace; (B) Right Upper Quadrant. Place the transducer in the final intercostal space in anterior axillary line with a slightly oblique posterior orientation to image the liver and right kidney. Fluid accumulates in Morrison’s Pouch between the two; (C) Left Upper Quadrant. Place the transducer far posteriorly in a low intercostal space (generally 2 spaces higher than on the right) and angle the probe anteriorly to visualise left kidney, spleen, and the space between the two where fluid accumulates. The left subdiaphragmatic space and lower thorax (for pleural effusion/haemothorax) may also be visualised and (D) Pelvic. The probe is placed transversely suprapubically to identify the bladder and then turned 90° to demonstrate fluid behind the bladder. If the bladder is empty, saline may be instilled via a urinary catheter to provide an acoustic window.
wounds (Phillips et al., 1986; Meyer et al., 1989) which have limited and more predictable wound tracks in comparison to bullet wounds. The application of CT-scanning as a single adjunct to clinical examination in abdominal gunshot wounding has evolved in tandem with scanning technology and refinement of image interpretation specific to abdominal injury. The development of helical CT scanners, and particularly multi-detector scanners, permits the faster acquisition of higher resolution images – and images may be obtained in a single breath hold, minimising motion artifact and reducing scan times (Figure 2). Rapid, precisely sequenced imaging allows vascular and organ contrast enhancement to be combined with a single IV contrast bolus (Novelline et al., 1999). ‘Triple contrast’ – intravenous, oral (or nasogastric), and rectal – is used to provide evidence of vascular, parenchymal, and gastrointestinal luminal injury. No formal comparison between the old and new technologies is available in the arena of abdominal trauma, although recent authors have acknowledged its impact (Butela et al., 2001). Although scan times are reduced, it remains inadvisable to subject the haemodynamically unstable patient to CT physically separated from the attending medical team – the CT scanner’s soubriquet of the ‘Donut of Death’ remains disastrously apt.

Múnera et al. (2004) prospectively evaluated the efficacy of triple contrast helical CT in the evaluation of stable patients with abdominal GSWs. Over a 19 month period 47 patients were recruited, with abdominal GSWs but without a clinical need for immediate laparotomy (peritonism, hypotension, evisceration, extra-abdominal injury requiring urgent surgical intervention). In 27 patients (57%) CT abnormalities were demonstrated, although only 9 proceeded to laparotomy, all of which were therapeutic for hollow viscus injury. An additional, nontherapeutic, laparotomy occurred in a patient with an extraperitoneal bullet trajectory on CT but persisting abdominal pain, tenderness, and pyrexia 6 hours after injury. No intra-abdominal injury was found at laparotomy. Fifteen patients had CT identified solid organ injuries successfully managed conservatively (12 liver injuries, 1 liver/right kidney and 2 spleen/left kidney). Twenty scans were reported as showing no intra-abdominal injury – one patient underwent laparotomy on clinical grounds as detailed above and one patient underwent laparotomy at the same time as exploration of an upper limb injury at which an undiagnosed caecal haematoma was repaired representing the sole false negative report – retrospective interpretation of the original CT suggested the presence of a small pericaecal haematoma. No complications were reported in the remaining 18 patients. In the use of triple contrast helical CT for predicting the need for laparotomy in gunshot injured patients, the authors reported a sensitivity of 96%, specificity of 95%, and a positive predictive value of 96%.

Similar efficacy with respect to CT identification of intra-abdominal injury has been reported in mixed studies of ‘all-cause’ penetrating abdominal trauma. A prospective study using triple contrast helical CT as the single diagnostic adjunct in 104 patients with penetrating torso injuries (54 GSW and 50 stab wounds), yielded a sensitivity of 100% (19 patients) and specificity 96% for predicting the need for laparotomy in otherwise haemodynamically stable patients (Shanmuganathan et al., 2001). In an extension of the study to 200 patients (86 GSW and 111 stab wounds), the authors reported separately the accuracy of CT for discerning peritoneal violation (97% sensitivity and 98% specificity) and their subsequent laparotomy findings (Shanmuganathan et al., 2004). On the basis of CT diagnosed potential injury, 38 patients proceeded to laparotomy, with therapeutic intervention required in 87%, 8% had a nontherapeutic laparotomy, and 5% were negative.
CT diagnosis of bowel injury has been refined. Oral contrast leak is highly specific for full thickness bowel wall injury. Free intraperitoneal fluid in penetrating trauma may result from solid organ injury or be introduced from a bleeding wound track. Similarly, free intraperitoneal air may result from penetrating wounding processes. Bowel wall thickening may result from the shocked state due to extra-abdominal injury (Butela et al., 2001). However, numerous other CT appearances – particularly in combination and in relation to a suspected wound track – are recognised as signifying bowel or mesenteric injury, including mural thickening with adjacent mesenteric contusion or haematoma and mesenteric vascular contrast leak (Shanmuganathan et al., 2001).

CT scanning of the haemodynamically stable patient allows solid organ injuries amenable to nonoperative management to be identified. Injuries to the solid organs have been classified by the American Association for the Surgery of Trauma (AAST) – injury grading increases with increasing size of subcapsular haematoma, level of parenchymal injury, or vascular pedicle damage. Low-grade injuries are generally amenable to conservative management whilst the high grade injuries demand operative intervention – the intervening injuries may potentially undergo conservative management, but with a low threshold for intervention.

**Laparoscopy**

The principal function of laparoscopy to date is to exclude diaphragmatic injury in the stable patient (Smith, 2002). It also has value in excluding peritoneal violation in tangential wounds. In contrast to rupture provoked by blunt injury, penetrating diaphragmatic injury is less frequently associated with visceral herniation in the acute phase (McQuay and Britt, 2003) and the sensitivity of CT is impaired in the absence of visceral herniation. Diagnosis and repair is necessary due to its association with intra-abdominal injury and to avoid future morbidity. In this context, laparoscopy has been demonstrated to be an effective diagnostic tool (Ivatury et al., 1993). However, there is little evidence to support its use in the exclusion of bowel injury. Similarly, the identification of an injury requiring repair should generally provoke conversion to a complete investigative laparotomy and open repair. Any surgeon intending to laparoscope a patient with penetrating thoracoabdominal injuries and a possible occult diaphragmatic injury must be mindful of the possibility of precipitating a tension pneumothorax as the peritoneum is insufflated and be prepared for immediate chest drain insertion.

A novel technique of ‘awake laparoscopy’ in trauma has recently been described with the intention of assessing equivocal penetrating abdominal wounds for peritoneal violation (Weinberg et al., 2007). The study cohort comprised patients with anterior stab wounds (mid to anterior axillary lines, 13 patients) and anterior tangential GSWs (2 patients). All were haemodynamically stable at presentation, alert, nonperitonitic and without indication for other urgent surgery. The stab wound patients were initially assessed via local wound exploration proceeding to laparoscopy if a breach in the anterior fascia was demonstrated. Patients with additional, clear peritoneal breach at exploration proceeded to laparotomy. Consent, stable, tangential gunshot wounded patients proceeded to laparoscopy. ‘Local anaesthetic’ comprised an analgesic/sedative combination of morphine and midazolam and at laparoscopy, insufflation pressures were minimised (7–10 mm Hg) and a 5 mm periumbilical port used for access. The procedure took place within the emergency department. If laparoscopic inspection demonstrated peritoneal intrusion, the patient proceeded to laparotomy in the operating theatre; if no such violation was noted local wound care was administered and the patient discharged after the effects of the sedative medication had dissipated. Of 15 patients undergoing ‘awake laparoscopy’, peritoneal penetration was identified in four patients, of which two had positive laparotomy findings, necessitating a gastric and diaphragmatic repair in one patient and repair of the diaphragm and liver laceration in the other. The 10 negative laparoscopies included both gunshot injured patients and were discharged from the emergency department after local wound care. A patient with an equivocal laparoscopy was observed without incident for 16 hours and discharged. No further complications were reported. This limited study demonstrates how the role of laparoscopy may be further expanded in the assessment of gunshot wounded patients and selection for formal laparotomy.
Selective nonoperative management
The early management of abdominal GSW has evolved beyond the policy of mandatory laparotomy in centres with high caseloads of such trauma and the treatment algorithm now includes the potential for SNOM. Mandatory laparotomy was based on the high incidence of peritoneal penetration of gunshots with the almost universal findings of intrabdominal visceral injury and the unreliability of physical examination in determining intraperitoneal. Moore et al., reported 121 patients who underwent mandatory laparotomy for abdominal GWSs, including those in whom peritoneal signs were absent, over a three year period (Moore et al., 1980). Tangential wounds which were clearly superficial to the abdominal fascia were excluded but observed for a 24-hour period. Ninety-two percent of patients had significant intraperitoneal injury including 26 patients in whom abdominal signs were absent at presentation. A similar retrospective study (Lowe et al., 1977) reported significant intra-abdominal injury in 98% of 362 abdominal GSW received by a trauma unit in Chicago. A positive laparotomy occurred in 41.5% of patients in which no sign of intra-abdominal injury other than the presence of the missile track was observed at presentation. As the success of SNOM of abdominal stab wounds accumulated, attention focussed on the rate of nontherapeutic laparotomy after abdominal GSW and its attendant morbidity and financial costs. Renz and Feliciano (1995) described a 41.3% morbidity rate following nontherapeutic trauma surgery in 254 patients with abdominal trauma (98% due to penetrating injury), whilst Morrison et al. (1996) reported a 43% rate of short term complications such as cellulitis, pneumonia, and prolonged ileus in those who underwent either a negative or nontherapeutic laparotomy but had extra-abdominal injuries – the rate fell to 20% if there were no additional injuries. Long term complications, especially adhesive small bowel obstruction however appear rare (Weigelt and Kingman, 1988; Morrison et al., 1996). In addition, the assertion of retrospective studies that clinical assessment is a poor predictor of such injury has been questioned with Demetriades et al. (1997) describing the initial physical examination as being 97.1% sensitive for the need for therapeutic laparotomy after abdominal shooting – this however comes from the busiest trauma room in the world!

The selective approach to operative management of abdominal GSW is based upon repeated clinical assessment and supported by noninvasive imaging techniques, in a similar fashion to the techniques introduced for abdominal stab wounds (Shaftan et al., 1960; Nance et al., 1974). Much of the work on SNOM of abdominal GSW has come from Demetriades and his colleagues in the LA County Trauma room. A prospective study of 309 patients with GSW to the anterior abdomen collected over 16 months (Demetriades et al., 1997) illustrates many of the key features of a SNOM regime. All patients were assessed by the chief trauma resident who decided the probability of violation of the peritoneal cavity based upon entry and exit wounds. Basic resuscitation and plain chest and abdominal radiographs were undertaken in sufficiently stable patients. Haemodynamic instability, peritonism, spinal cord, or head injury precluding meaningful abdominal examination or extra-abdominal injury requiring surgery mandated urgent laparotomy. Patients requiring minimal resuscitation and with abdominal tenderness in the immediate vicinity of the wound sites only were admitted to a surgical assessment unit and observed. The observed cohort received serial abdominal examination, assessment of vital signs and monitoring of haematocrit. Additionally, urinalysis, contrast abdominal CT scans or intravenous pyelography were obtained. In cases of emerging peritonism, haemodynamic instability, or radiographic evidence of injury requiring intervention, patients proceeded to surgery; otherwise they were transferred to a general surgical ward after 24 hours and discharged between 24 and 48 hours following admission unless receiving attention to extra-abdominal injuries. One hundred and eighty-five patients (59.9%) proceeded to immediate laparotomy of which 90% were therapeutic. One hundred and six patients were observed – clinical decline requiring delayed laparotomy occurred in 14, but only 5 were therapeutic. All interventions within the protocol occurred within 24 hours. The complication rate following negative and nontherapeutic laparotomies was 27.6%, with mean discharge at 6.4 days compared to 3.3 days for those undergoing successful SNOM. The authors subsequently reported a retrospective analysis of 1856 patients accrued over 8 years, 38% of which were managed successfully by SNOM (Velmahos et al., 2001). Eighty patients

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selected for SNOM subsequently needed surgery, a quarter of which were nontherapeutic. Five patients suffered complications related to the delay in surgery caused by initial SNOM (intra-abdominal abscesses, sepsis, prolonged ileus, and ARDS) but all survived. The authors calculate that SNOM of abdominal GSWs reduced the unnecessary laparotomy rate from 47 to 14%, saved over 3500 hospital bed days and $9 million. Similar data has emerged from South Africa (Muckart et al., 1990).

**GSWs to the Back and Flank**
The thick musculature of the back and the vertebrae confer a degree of protection against peritoneal violation by a penetrating missile, consuming its kinetic energy. Haematuria suggests possible urinary tract injury and some form of contrast radiology is indicated. This may be a simple one-shot intravenous pyleogram or the kidneys may be imaged by any subsequent CT scan as long as intravenous contrast is used. The evidence has now also accrued to support SNOM of GSW to the back. Demetriades et al. (1988), whilst still in Johannesburg, reported 230 patients with penetrating back trauma of whom 190 were successfully managed nonoperatively, although the vast majority of these were stab wounds rather than GSW. In reporting their 8-year experience from LA County, Velmahos et al. (2001) differentiated between anterior and posterior gunshots. Twice as many posterior GSWs were managed conservatively as anterior ones and the proportion of those SNOM patients subsequently requiring intervention were similar. Unstable patients proceeded directly to laparotomy whilst the stable subgroup were subject to at least 24 hours of close clinical assessment. Triple contrast CT is highly sensitive in demonstrating sub-clinical injury (Shanmuganathan et al., 2004) and is now used routinely in the assessment of the stable GSW (anterior or posterior) patient selected for nonoperative management (Burns et al., 1994; Velmahos et al., 2001).

**Thoraco-abdominal wounds**
The thoraco-abdominal region is roughly distributed between the nipples superiorly, the costal margins inferiorly and mid axillary lines posteriorly and wounding in this region raises the suspicion of a two cavity injury with the ‘intra-thoracic’ abdominal viscera at risk. Specifically, the liver, biliary tree, aorto-caval structures, and the diaphragm are vulnerable as well as the lung and intra-thoracic vasculature. Standard ATLS approaches mandate primary tube decompression of pneumothoraces during the primary survey. In the face of continuing haemodynamic instability, without evidence of obvious exsanguinating chest injury, urgent laparotomy is indicated which may subsequently be extended into thoracotomy if necessary (Botha et al., 2002). Laparoscopy is a useful adjunct to assessment of diaphragmatic integrity and potential trans-thoracic injury.

**Embolisation of solid organ injury**
Embolisation permits ‘nonoperative’ management of vascular injury in selected cases—a technique initially practiced in blunt abdominal trauma (Sclafani et al., 1995). Nonselective angiography delineates the vasculature of the abdomen. Points of concern are then isolated selectively and bleeding may be arrested using metallic or gelatin based coils or gelatin sponges introduced via the vascular catheter. In an early study specific to penetrating abdominal trauma, 40 patients underwent angiographic investigation (Velmahos et al., 1999), 33 with gunshot wound injury, and 7 with stab injury. A sub-group of six patients were selected for nonoperative management at initial presentation. The remainder proceeded to angiography in the post operative phase to address bleeding not adequately controlled (or identified) surgically. In the first group, angiography proceeded in three patients with haematuria following flank injuries, two patients with CT diagnosed hepatic injury and right upper quadrant wounds, and one patient with a bleeding buttck wound. In two of the three patients with suspected renal injuries, renal artery branch bleeding was identified and controlled via embolisation. In the third patient no renovascular injury was identified. In the liver-injured patients, one patient was managed successfully angiographically, with the second proceeding to surgery to oversew a deep laceration after failed embolisation. Angiographic studies in the patient with the buttck wound did not yield a bleeding point and he died subsequent to a laparotomy which also failed to identify a source...
of haemorrhage. This report identifies the three major roles of angiographic embolisation in trauma: at presentation in the ‘nonoperative’ case, after failed surgical control of haemorrhage and to address later causes of haemorrhage – particularly pseudoaneurysms and delayed bleeding. A later, larger report of mixed-cause abdominal trauma (97 patients with blunt injury, 40 with penetrating injury already reported) from the same unit (Velmahos et al., 2000) identified two further selected indications: in stable patients with injuries known to be associated with major haemorrhage (e.g., pelvic fractures) and in stable patients with additional injuries precluding meaningful clinical surveillance such as liver injury in the head-injured patient. Therapeutic angiography may also be undertaken after the vascular injury has been identified by contrast CT scanning (Demetriades et al., 2006) and in the damage control scenario, usually post-operatively (Johnson et al., 2002). Major complications have been reported in up to 27% of splenic (Ekeh et al., 2005) and 58% of hepatic (Mohr et al., 2003) interventions, including target organ necrosis and abscess and contrast induced renal insufficiency.

**Damage control laparotomy**

A small subset of abdominal gunshot victims will necessitate Damage Control Laparotomy (DCL), the aim of which is to provide temporary surgical control of intra-abdominal haemorrhage and contamination in those for whom lengthy definitive surgery would significantly increase mortality. In such patients, the ‘bloody lethal’ triad of acidosis, coagulopathy, and hypothermia combine synergistically – the longer surgery continues the worse the outcome. In cold, acidic patients who have been resuscitated with large volumes of crystalloid, thought should be given at an early (pre-surgical) stage about the potential need for a damage control strategy. It is a technique that trades mortality for morbidity, the rates of which may reach 40% to achieve a 50% survival rate (Shapiro et al., 2000). The details of the DCL process are beyond the scope of this article but are reviewed elsewhere (Hoey and Schwab, 2002).

**Summary**

The management of abdominal GSWs relies on physical examination and adjunctive investigations to determine intraperitoneal violation and the likely intra-abdominal injuries. Haemodynamically unstable patients or those with peritonitis undergo urgent laparotomy which may need to be of the ‘damage control type’. The investigations used will depend on local availability and expertise and the haemodynamic stability of the patient. Approximately one third of abdominal GSW patients may be managed conservatively with low failure rates, drastically reducing the cost of their management. It requires frequent re-examination of the abdomen and should be approached with caution in units with minimal experience of penetrating missile trauma. Computed tomography is the single most useful investigation in managing these patients. In the UK, laparotomy for all abdominal GSWs remains a permissible approach.

**Gunshot injuries to extremities**

GSWs to the extremities presents the potential for four types of injury: vascular, neurological, bony, and soft tissue damage, all of which may contribute to the subsequent morbidity, although mortality from such trauma is less common. Between 1993 and 1998 extremity injury accounted for 71.8% of unintentional and 45.8% of intentional nonfatal firearm wounds in the USA (Gotsch et al., 2001). Death largely results from uncontrollable haemorrhage from the junctional zones (axillae and groins) and proximal limb injury (Dorlac et al., 2005).

**Vascular injury**

Assessment begins with the vascular supply to the limb. Recognition of the presence of ‘hard’ and ‘soft’ signs of vascular injury is essential (Table 1) and continues in the face of ongoing resuscitation and direct compression of external haemorrhage. The limbs must be inspected, to assess colour, the presence of wounds or fractures, deformity, swelling, and bruising. Palpation permits skin temperature, tenderness, and capillary refill to be assessed. Distal pulses should be sought and this may be augmented by a Doppler probe if pulses are palpable. A peripheral pulse may persist even in the face of significant arterial injury, particularly where collateral circulatory systems are present (Gelberman et al., 1980). Gross sensation and
movement should be assessed in the conscious patient – parasthæsia or weakness may indicate arterial injury (American College of Surgeons, 1997). Blind application of vascular clamps should be avoided as it risks damage to adjacent structures and so may exacerbate distal ischaemia (Berlatsky et al., 1998). Splinting of injured limbs serves to stabilise fractures and ameliorate vascular and soft tissue injury in a grossly malaligned limb; joint dislocation with associated vascular compromise requires immediate skilled reduction (American College of Surgeons, 1997); however, repeated attempts to restore a limb to its anatomical position may precipitate further injury. After a single failed attempt, the limb should be splinted and urgent surgical review organised.

Formerly, any clinical evidence of arterial injury mandated surgical exploration to exclude or address vascular trauma (Burnett et al., 1976) – the morbidity associated with negative exploration was accepted in comparison to that due to missed injuries. With the development of techniques of diagnostic contrast arteriography, routine exploration was reserved for cases in which hard signs of vascular injury were present. Hard signs of vascular injury signify an imminently threatened limb. Warm ischaemic times in excess of six hours – measured from the time of injury not presentation – are poorly tolerated, with onset of irreversible soft tissue necrosis (Earnshaw, 2006). Immediate surgical exploration and revascularisation was and still is required, with or without on-table angiography (Bartlett, 2003). Pre-operative angiography in a threatened limb is time-consuming and should be avoided (Earnshaw, 2006). A ‘completion’ angiography may be necessary to assess the success of repair (van Marle, 2006).

Following the demise of mandatory exploration, diagnostic angiography (DA) was used routinely in all cases of suspected vascular injury in which there was insufficient clinical evidence for immediate exploration, with a reduction in negative exploration rate (Geuder et al., 1985). Supporters of mandatory DA cited its value in detecting clinically ‘occult’ vascular injuries such as pseudoaneurysm or intimal flaps, reported in up to 19% of penetrating injury in proximity to a major vascular structure but without hard signs (King et al., 1991). However, follow-up studies of such injuries pointed towards the safety of nonoperative management, with only a minority requiring eventual surgical treatment. A prospective study of 46 ‘occult’ injuries followed via arteriography (39 injuries) or physical examination (7 injuries) over a mean of 3.1 months (range 3 days to 27 months) demonstrated that 89% of the injuries receiving follow-up did not evolve to an extent requiring surgical intervention. Complete resolution occurred in 63% of cases. Pseudoaneurysm accounted for the five cases requiring eventual intervention (Frykberg et al., 1991). The same group has published similar supportive data with mean follow-up of 5.4 years (Dennis et al., 1998).

The identification of a set of patients with the potential for nonoperative management marked a change in the management of penetrating vascular injuries. The criteria for SNOM were further refined, in particular the investigation of ‘proximity’ injuries was further examined. A series of 157 patients with such injury due to penetrating trauma were prospectively subjected to arteriography, with the diagnosis of 17 injuries (10.8%), of which only one required surgical intervention (0.6%) (Weaver et al., 1990).

Clinical assessment of the injured limb in the presence of ‘soft’ signs of vascular injury following penetrating trauma may now be augmented by noninvasive imaging. Physical examination may be combined with measurement of the Doppler

**Table 1** ‘Hard’ and ‘Soft’ signs of vascular injury

<table>
<thead>
<tr>
<th>Hard signs</th>
<th>Soft signs</th>
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<tbody>
<tr>
<td>Visible pulsatile haemorrhage</td>
<td>Wounds in proximity to major vascular structures</td>
</tr>
<tr>
<td>Expansile haematomas</td>
<td>Small nonexpansile haematomas</td>
</tr>
<tr>
<td>Bruit or thrill detected over vessel</td>
<td>Stable neurological deficit</td>
</tr>
<tr>
<td>‘The 6 Ps’: Signs of vascular occlusion or extremity under-perfusion - not global hypoperfusion:</td>
<td></td>
</tr>
<tr>
<td>• Pallor</td>
<td>History of haemorrhage at the scene</td>
</tr>
<tr>
<td>• Pulselessness</td>
<td></td>
</tr>
<tr>
<td>• Paraesthesia</td>
<td></td>
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<tr>
<td>• Paralysis</td>
<td></td>
</tr>
<tr>
<td>• Pain</td>
<td></td>
</tr>
<tr>
<td>• ‘Perishingly’ cold limb (poikilothermia)</td>
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Pressure Index (DPI) to screen for occult vascular injuries subsequently requiring arteriography. The DPI compares the ankle/brachial or brachial/brachial systolic pressures between injured and uninjured limbs. A DPI less than 1.0 in the absence of hard signs of vascular injury has been validated as a predictor of occult penetrating vascular injury that must proceed to arteriography, with 86% sensitivity (Schwartz et al., 1993). This combination of DPI and physical examination can facilitate early discharge (Conrad et al., 2002). Experience with 102 extremity GSW without vascular compromise on physical examination, normal DPI measurements, and without the requirement for surgery for co-existing injuries were discharged without further intervention. No missed injuries were reported, although long term follow up is poor in this population.

CT arteriography is being developed as an additional, noninvasive tool that may supplant the need for catheter-arteriography in the evaluation of potential arterial extremity trauma with equivocal clinical findings. A recent examination of this method reported the outcome of 139 patients (76 GSW, 19 stab wounds 44 fractures or dislocations) that would otherwise have proceeded to catheter arteriography (Soto et al., 2001). The sensitivity and specificity of CT angiography in the diagnosis of arterial injury was reported at 95.1% and 98.7%. The study was limited to proximal injuries of a single anatomic segment, owing to the poor CT vascular resolution of the distal arterial supply and limitation of the length of vascular anatomy that may be evaluated with a single contrast bolus. Additionally, injuries in the vicinity of retained metallic fragments were excluded owing to the image artifact produced. This technique is likely to evolve to produce global injury assessment using a single helical CT scan. Experience with Magnetic resonance (MR) angiography in trauma is limited with an early case series of 11 GSW and 1 stab wound to the extremities declaring diagnostic equivalence to conventional angiography (Yaquinto et al., 1992). However, the area remains under explored but is unlikely to be widely embraced in view of the relative inaccessibility and expense of MR scanning and the technical problems associated with retained metallic bodies.

Venous injury is rarely of major significance in the emergency department and can usually be controlled by direct pressure. If the wounds are surgically explored major venous injury should be repaired to save subsequent venous insufficiency problems (Timberlake and Kerstein, 1995), but ligation is appropriate for more minor vessels. Limb ischaemia and subsequent reperfusion, particularly in the presence of fractures and soft tissue injury predisposes to the development of compartment syndrome. Relieving fasciotomies are required if they have not been achieved in the process of soft tissue debridement. The presence of a penetrating wound is insufficient for compartmental decompression; particularly at risk are injuries to the proximal third of the forearm (Moed and Fakhouri, 1991) and lower limb (Ernst and Kaufer, 1971).

Nerve injury
Nerve injury is the major determinant of disability subsequent to gunshot extremity injury, with greatest functional impairment resulting from more proximal injuries (Hardin et al., 1985). Injury across the spectrum of contusion and neuropraxia to transection and nerve destruction may occur. Gross evidence of peripheral nerve damage should be sought in the initial assessment of the injured limb. This may be difficult in the multiply injured, uncooperative or obtunded patient. However, an early assessment will provide a baseline against which repeat examinations may be compared (American College of Surgeons, 1997). Nerve injury may occur primarily, or as a secondary effect of ischaemia, fracture, or compression due to injury related limb swelling or immobilisation in a cast. Power in major muscle groups, and the presence or absence of sensation and asymmetry of each between limbs should be objectively recorded, in addition to any potential limitation by pain. The location of injury will indicate which nerve structures require focus, according to their proximity to the injury (American College of Surgeons, 1997). Repeated examinations will demonstrate declining nerve function, pointing towards ongoing compression injury. Unless a clearly divided nerve is seen within the wound, it is rarely possible to define the class of nerve injury (neuropraxia, axonotmesis, or neurotmesis) present in the acute phase, (Omer, 1974). This may only be defined in the weeks following injury, via electrophysiological measurement, guiding decisions to
proceed to delayed repair (Oberle et al., 1997). Although heavily dependent upon neural function, additional injuries will influence the degree of functional recovery obtained in the limb (Omer, 1974).

The optimal timing of nerve repair has not been defined (Bartlett, 2003). Delayed repair in GSWs receives support from studies demonstrating progressive return of function in the majority of cases. In an early series of 513 upper limb nerve injuries due to GSWs, spontaneous recovery occurred in 69% of wounds distal to the elbow, with recovery in 90% of isolated and multiple injuries occurring within 6 and 7 months, respectively (Omer, 1974). However, early repair prior to retraction reduces grafting distances and avoids dissection through mature scar tissue (Magalon et al., 1988). Primary nerve repair by an experienced surgeon may then be considered, particularly if wound exploration is mandated by the presence of an associated fracture or vascular injury. A pragmatic immediate approach is to mark the transacted nerve endings with a nonabsorbable suture, permitting ease of identification at later planned repair.

**Soft tissue management**

GSWs produce soft tissue injury according to the interplay between tissue type and energy transfer with weapon and ammunition type and the aerodynamic properties of the projectile important contributory factors. Management of soft tissue injury is based upon the initial assessment and debridement of devitalised and contaminated tissue, anti-bacterial prophylaxis, and later, staged reconstruction (Bartlett, 2003). GSW assessment requires the clinician to ‘treat the wound, not the weapon’ (Lindsey, 1980). An important early distinction is required between high and low energy transfer wounds (Table 2), which will dictate the course of early management.

High energy transfer injuries present with extensive soft tissue injury contributed to by a wide zone of temporary cavitation. Additionally, comminuted fractures, neurovascular injury, and significant contamination may be anticipated. Such wounds require surgical exploration to assess the extent of injury and debride nonviable tissue. Wound exploration requires excision of the skin wounds, the wound track and sufficiently large incisions to permit inspection of adjacent devitalised tissue (Mendelson, 1991). Generous irrigation assists in reducing contamination with debris and bacteria. High flow irrigation offers increased initial local decontamination but a propensity to contribute to tissue damage is subject to ongoing debate in the literature (Anglen, 2001). Devitalised tissue, including bone fragments and contaminated tissue resistant to lavage should be excised. Wadding may be present in shotgun wounds produced at close range and must be removed. Fascia should be debrided where appropriate and the incisions lengthened to allow inspection of deeper structures and compartmental

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Typical characteristics of high and low energy transfer wounds</th>
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<tbody>
<tr>
<td><strong>Low energy transfer wounds</strong></td>
<td><strong>High energy transfer wounds</strong></td>
</tr>
<tr>
<td>Minimal limb swelling.</td>
<td>Marked limb swelling.</td>
</tr>
<tr>
<td>Minimal soft tissue disruption confined to immediate vicinity of wound track.</td>
<td>Marked soft tissue disruption beyond wound track ('zones of cavitation').</td>
</tr>
<tr>
<td>Minimal muscle devitalisation.</td>
<td>Marked muscle devitalisation extending beyond wound track.</td>
</tr>
<tr>
<td>Minimal contamination with external debris.</td>
<td>Highly contaminated with external debris.</td>
</tr>
<tr>
<td>Simple fracture or minimal fracture comminution.</td>
<td>Highly comminuted fracture with devitalised bone fragments. Possible bone loss from exit wound.</td>
</tr>
<tr>
<td>Minimal vascular or nerve injury unless in path of bullet. Small exit wound comparable to entrance wound with intact or minimally deformed bullet.</td>
<td>Vascular and nerve injury beyond wound track due to cavitation. Large irregular exit wound (if present), with significant bullet fragmentation or deformity (if retained). Retained bullet implies transfer of all missile energy to tissue.</td>
</tr>
<tr>
<td>Path through low density/high elasticity organs (e.g., lung).</td>
<td>Path through high density/low elasticity organs (e.g., liver). Shotgun injury at range &lt;12m.</td>
</tr>
</tbody>
</table>


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decompression. Muscle viability may be broadly assessed via the ‘four Cs’: colour, consistency, contractility, and capacity to bleed. Immediate assessment of muscle viability may be negatively influenced by the shocked state and local vasoconstriction, and may prove to be viable at reassessment (Mendelson, 1991). In the civilian context, wound re-inspection at 48 hours is a pragmatic means of re-evaluating muscle of genuinely uncertain viability (Hull, 1996). Primary closure of the widely debrided wound is avoided. Conventionally, a second look procedure is planned after an interval of 48 hours. In the interim the wound is managed via open drainage and antibiotic prophylaxis. Provided there is adequate viable soft tissue cover, delayed primary closure is planned at approximately day five post injury (Bowyer and Rossiter, 1997). Large soft tissue defects may require tissue grafting or transfer techniques to assist closure.

A more conservative approach has been explored in the case of low energy transfer wounds, in which tissue destruction and associated injury is of a much lesser degree. One hundred sixty-three such wounds without associated fracture or neurovascular injury were assessed in a prospective randomised control trial (Brunner and Fallon, 1990). The wounds of 89 patients received debridement and local wound care (irrigation, dressing) and 74 patients local wound care only. Four superficial infections occurred in the debridement group and two occurred in the nonoperatively managed group, with a satisfactory response to antibiotics in each case. A series of 3390 similar minor GSW treated conservatively has been reported, with an infection rate of 1.8%, not significantly affected by the provision of antibiotic prophylaxis, but negatively influenced by a delay between wounding and treatment (Ordog et al., 1993). Minimal debridement of devitalised skin at the wound edges, irrigation and healing by secondary intention is then adequate in minor soft tissue injuries (Volgas et al., 2005).

**Fractures**

Gunshot fractures have traditionally been considered as open injuries with a high risk of infection and subjected to rigorous surgical debridement under antibiotic cover. However, some low energy transfer fractures may be amenable to minimal surgical intervention. In an early study, infection rates in 80 and 52 low-energy transfer gunshot fractures treated with intravenous and oral cephalosporin antibiotics, respectively were compared (Woloszyn et al., 1988). Wounds were of Gustilo type I, receiving local wound care, lavage and minimal skin edge debridement and were left open. The intravenous group included 17 patients with fractures requiring open reduction and internal fixation. The remainder were treated via closed reduction and cast application. No formal surgical debridement was performed in either group. The authors reported only two infections, both in the group treated with oral antibiotics and concluded no advantage in the use of intravenous antibiotics in this injury category. This has been supported by a prospective, randomised trial of 190 patients with low energy transfer gunshot fractures not requiring operative stabilisation who received three days of antibiotics (Knapp et al., 1996). Eighty-nine patients received oral ciprofloxacin as outpatients and 101 patients received an intravenous cephalosporin and gentamicin. A 2% infection rate was reported in each group. There have been multiple similar reports such that the consensus of the current evidence is that low energy fractures do not require aggressive surgical debridement. Local wound care and oral antibiotic prophylaxis is adequate. Operative intervention is applied if appropriate to the fracture type (Bartlett et al., 2000).

High energy transfer wounds (Gustilo type III) are associated with severe soft tissue and neurovascular injury; bony comminution may be severe. Additionally, there may be bone devitalisation with loss of the soft tissue envelope, or loss of bone fragments via the exit wound. Immediate gunshot fracture management must provide bony stability during the period in which soft tissue and vascular injuries are addressed and permit debridement. Damage control principals may be indicated in the severely injured patient. Debridement and external fixation provide temporary injury stability while gross physiological derangements are addressed (Taeger et al., 2005).

Pelvic fractures are notable for their association with massive haemorrhage, with a mortality in the range 5–30% (Grotz et al., 2005). Haemorrhage is a significant contributor to this mortality, arising
from the rich pelvic vascular plexus and disrupted pelvic cancellous bone. It is exacerbated by fracture instability, which impedes basic haemostatic mechanisms and prevents tamponade of retroperitoneal haematoma (Grimm et al., 1998). Gunshot injury may produce pelvic fracture primarily due to passage of the projectile, or as a secondary ballistic event according to the circumstances of the injury. Concomitant pelvic organ injury – rectal (18–64%) and genitourinary (24–57%) is common (Grotz et al., 2005). The priorities in pelvic fractures are haemorrhage control and fracture stabilisation with the latter aiding the former. Evidence of pelvic fracture must be sought in the primary survey and the plain AP pelvic films obtained in the trauma series (American College of Surgeons, 1997). The technique of ‘springing’ the pelvis to elicit pelvic instability is painful, may exacerbate haemorrhage and has a sensitivity as low as 59% (Grant, 1990) and should be avoided. A number of techniques are available to provide ameliorate pelvic fracture haemorrhage by providing fracture stabilisation. The simplest method is to wrap a sheet around the pelvis at the level of the greater trochanters and secure it anteriorly by knotting or with towel clips (Routt et al., 2006). External fixation devices are in common use. They may be applied in the resuscitation room and comprise fixing pins which are inserted into the pelvic wings, upon which bridging arms are secured and used to reduce each hemipelvis (Botha et al., 2002). The device should be arranged such that it does not impede the surgeon if laparotomy must proceed. The device is recognised to provide effective anterior stabilisation only, with ongoing posterior instability (Simonian et al., 1995). The pelvic ‘C-Clamp’ provides effective posterior stability although concerns have been expressed regarding complications resulting from pin placement, including pelvic perforation (Pohlemann et al., 2004; Archdeacon and Hiratzka, 2006).

Laparotomy with the sole intention of addressing pelvic fracture-associated haemorrhage is likely to be a bloody and fruitless ordeal. A historical report, prior to adjuncts such as embolisation, cited a 20% mortality, and recommended a 20 unit transfusion availability prior to opening the abdomen (Hawkins et al., 1970). However if laparotomy is indicated because of extra-pelvic injury external fixators should be applied prior to laparotomy (Ghanayem et al., 1995) to ameliorate the haemorrhage after loss of the abdominal tamponade. A pelvic retroperitoneal haematoma should not be explored. In the case of an expanding haematoma, packing, bony stabilisation and angiographic embolisation is the most pragmatic option (Botha et al., 2002).

The advent of angiographic embolisation has contributed enormously to the management of fracture associated pelvic haemorrhage. Agolini et al. (1997) have reported success in haemorrhage control in 15 out of 35 patients undergoing arteriography for pelvic fracture-associated haemorrhage. Intervention within 3 hours of injury was noted to be of benefit. It may serve as an adjunct to external fixation when haemorrhage is incompletely controlled by this means (Sadri et al., 2005). In massive pelvic haemorrhage bilateral internal iliac artery embolisation may be necessary for haemostasis (Velmahos et al., 2000) although rectal and perineal necrosis have been reported from bilateral approaches (Perez et al., 1998; Yasumura et al., 2006).

**Antibiotic therapy**

Bullet wounds are not inherently sterile or sterilised as a result of the heat generated to produce their propulsion (Wolf et al., 1978). Primary contamination may result either from introduction into the wound track by the wounding missile, or be sucked into the entrance or exit wounds during the process of temporary cavitation (Tian et al., 1982). Microbiological contaminants may then arise from the environment and skin commensals. Gross contamination results from clothing, environmental debris and wadding in the case of shotgun wounds. Contamination may also result from the transfer of commensal micro-organisms from one body cavity to another, particularly the colon (Sarmiento et al., 1997). Historically, clostridia species were the feared contaminants of war-wounds, precipitating ‘gas gangrene’, requiring prophylaxis or treatment with benzylpenicillin. Gunshot fractures pose an additional risk of staphylococcal osteomyelitis. Emerging penicillin resistance requires broader coverage with a cephalosporin (Bowyer et al., 1997). Although a consensus is lacking, high velocity, shotgun and intra-articular wounds generally receive 48–72 hours intravenous...
antibiotic cover with benzylpenicillin and a cephalosporin (Bartlett, 2003; Simpson et al., 2003). An aminoglycoside (e.g. gentamicin) should be added in cases where faecal contamination is suspected (injuries sustained on farmland, or with breach of bowel). Longer courses are required in cases of gross contamination. The acquisition of wound swabs at presentation will assist later rationalisation of antibiotic treatment.

Low energy transfer wounds are increasingly subject to more conservative management as described, with wound irrigation complemented by either a single intramuscular dose or short (48–72 hour) oral course of a cephalosporin or ciprofloxacin.

Tetanus prophylaxis is necessary in all cases. 0.5 mL of tetanus toxoid is administered to patients known to have received a booster within the previous five years. This is supplemented with 250 units of tetanus immunoglobulin if a booster dose has been administered in the preceding five years, the immunisation history is unknown, or in grossly contaminated wounds. A full course of vaccine is required if the individual has not completed the primary immunisation schedule.

Summary
Extremity GSWs are likely to result in morbidity rather than mortality unless the junctional areas are involved. A multidisciplinary approach is likely to be needed to deal with the vascular, soft tissue, nervous, and bony injuries that may often coexist. Restoration of vascular supply takes priority. High energy transfer GSWs are a devastating injury but many low energy transfer injuries may be managed with minimal debridement and oral antibiotics even if there are associated fractures. Junctional injury and ballistic fractures must be treated aggressively — angiography both diagnostic and therapeutic is a useful modern addition to the techniques available.

Special situations

The discussions so far have concentrated on the management of GSWs from ‘standard’ bullets in a ‘standard’ adult patient. GSWs may however be caused by other weapons such as shotguns and air rifles which may produce a modified pattern of injury. Injury in the pregnant woman and children raise problems of physiological and anatomical considerations.

Shotguns

Shotguns discharge a missile comprising a bolus of multiple pellets or ‘shot’. On exiting the shotgun the pellets disperse into a conical pattern. Their spherical nature confers a poor aerodynamic profile in comparison to pointed bullets and they are subject to rapid decreases in kinetic energy. Energy transfer and wounding potential is then heavily dependant upon distance from the target. Shot may be manufactured from lead (drop/soft shot), copper or nickel (plated shot), or steel and antimony may be added as a hardening agent (Di Maio, 1993). Pellet diameter varies but is essentially of two types: birdshot (diameter up to 0.14in.) and buckshot (diameter 0.24–0.33in.). The shot is loaded into a plastic shell, together with paper or plastic based wadding which separates the shot and powder. Shot dispersal varies inversely with barrel length and is additionally influenced by the ‘choke’, a constriction of the barrel end, partially reducing the bore, which serves to restrict pellet spread. The illegal practice of ‘sawing off’ shotgun barrels is thus intended to enhance spread at close range. British law forbids civilian possession of shotguns with a barrel length less than 24 inches.

The wounding potential of a shotgun blast is a function of multiple factors: the distance between weapon and target, shot type and wadding, choke and barrel length. The effect of distance is paramount due to dispersal and reduced shot density and kinetic energy attenuation. Shotgun wound severity has been classified in terms of weapon-target separation (Sherman and Parrish, 1963; Ordog et al., 1988) and pellet scatter (Glezer et al., 1993). At distances less than 2 m, wounding results not only from shot, but additionally from contamination with wadding and shell fragments. At less than 5 m, there is minimal dispersal and high energy transfer. The shot bolus acts as a single unit, with massive tissue damage and high fatality. Penetration tends to be limited to the deep fascia at distances between 5 and 12 m and to the skin at distances greater than 12 m (Sherman and Parrish, 1963). Thus although muzzle velocity (305–460 m/s)
allows classification of the shotgun as a low velocity weapon, their energy transfer characteristics at close range are equivalent to that of military assault weapons. Beyond 70 m, most pellets will fail to penetrate skin (Barach et al., 1986), although the greater mass of buckshot means that it can produce significant wounding at distances up to 140 m. Due to the softer tissue comprising the globe, penetrating ocular injury may occur even at large wound-target separations and has been reported at ranges of up to 90 m (Roden et al., 1987).

Classification of shotgun injuries according to weapon/target separation was developed to facilitate triage, predict injury severity and mortality and potentially guide the need for intervention. Mandatory exploration has been advocated in all close range injuries (Wilson, 1978). Accuracy in reporting the separation of assailant and victim is inconsistent, particularly by a traumatised and possibly unconscious or intoxicated patient. In addition, it considers only a single factor in a multi-factorial wounding process. Of greatest importance is the overall assessment of the patient. In common with other gunshot injuries, policies of mandatory surgical exploration are being abandoned by experienced centres. Decisions regarding operative intervention are then made primarily on the basis of clinical evaluation (Velmahos et al., 1999) as described previously. Urgent surgery is particularly indicated in the case of exsanguinating injury unresponsive to basic measures, limb threatening vascular injury or contaminated fracture, and peritonism. The wound pattern should be examined – the size, presence of soot markings, and distribution of injurious debris (shot, wadding, clothing) will assist estimation of wound severity. Plain radiographs will demonstrate depth of penetration of shot (but not radiolucent contaminating debris) and fractures.

Soft tissue injury may exist in isolation. Contaminated wounds should be irrigated copiously and foreign material sought and removed, haemostasis established and necrotic tissue debrided. Debrided regions and initially contaminated wounds tend not to be closed primarily. Re-inspection and delayed closure may be planned for 48–72 hours post injury (Bartlett, 2003). Soft tissue may be peppered with shot but without penetration of body cavities, bony injury or neurovascular injury as seen in long range wounds. Serial exploration and removal of the shot is unnecessary – simple wound care is sufficient (Sherman and Parrish, 1963). Lead shot in the soft tissues becomes encased by scar tissue, preventing systemic distribution (Beazley and Rosenthal, 1984). However, the presence of lead shot within a joint is at risk of systemic absorption of the lead via synovial fluid which may produce systemic toxicity (Dillman et al., 1979) or even death (Linden et al., 1982). Such intra-articular shot must be removed.

Airguns

Airguns otherwise known as ‘nonpowder’, ‘BB’, or ‘pellet guns’, use the energy stored in compressed gas to expel a projectile. There are three principal types delivering energy via gas compression obtained by spring loading, canister stored carbon dioxide or a manual ‘pump action’. Muzzle velocity varies according to type. Spring loaded models produce a muzzle velocity of up to 90 m/s, carbon dioxide driven weapons up to 180 m/s and pump action models, in which the ‘priming’ of the compressed air pump is user dependant, up to 274 m/s (Keller et al., 2004). For comparison, handgun muzzle velocity is of order 260 m/s and that of a 0.22 calibre rifle 305 m/s. In Britain, most airgun pellets are of the diabolo waisted type, of calibre 0.177 or 0.22 inches (Milroy et al., 1998). They have a poor aerodynamic profile and rapidly lose velocity with the probability of injury becoming diminishingly less likely at target distances greater than 6 m (Harris et al., 1983). Penetration of tissue is dependent both upon both tissue type and projectile velocity on impact. Penetration of the eye occurs at 39.6 m/s, which is approximately the same for skin, but bone penetration requires a 3-fold greater incident velocity (106.7 m/s) (Committee on Accident and Poison Prevention, 1987). Airgun pellets do not give rise to a blast effect, tend not to tumble following penetration of tissue and produce little cavitational injury (Keller et al., 2004). There is an ill-founded perception that airguns are ‘toy’ weapons as they have more relaxed restrictions governing their acquisition (Chakravarty et al., 2006). The injurious potential of airguns must not be underestimated as, fatalities occur, particularly at close range (Milroy et al., 1998). Both injuries and fatalities occur.
predominantly in children. Between 1990 and 2000, 39 nonpowder gun-related deaths were recorded by the Consumer Product Safety Commission, of which 32 were children aged less than 15 years (Laraque, 2004). Fatal injury has resulted from cranial, thoracic, and abdominal penetration (Milroy et al., 1998). Ocular injury due to airgun pellets is particularly well documented (Shuttleworth and Galloway, 2001).

Injury due to airguns must be managed in a manner identical to that due to any other gunshot wound. If a history is forthcoming, the nature of the weapon and weapon-target distance should be established, such that the potential penetration may be predicted. Plain radiographs are of particular value in determining the pellet pathway and potential visceral injury. Isolated soft tissue injury may be adequately treated by irrigation and pellet removal if sufficiently superficial (Scribano et al., 1997). Tetanus prophylaxis is given if appropriate and prophylactic antibiotics considered for contaminated wounds or in cases of delayed presentation. In all other cases, initial management should proceed in the manner described elsewhere in this series. In consequence to their lower mass compared to powder driven missiles, airgun pellets have a propensity to embolise following vascular penetration (Keller et al., 2004). This occurs particularly following thoracic wounding (Shannon et al., 1987). Absence of both an exit wound and of the pellet on plain radiograph in the injured region should arouse suspicion of this phenomenon. In consequence, some authors recommend removal of a pellet lodged in the vicinity of a major blood vessel (Ceylan et al., 2002).

**GSWs in pregnancy**

All-cause trauma complicates approximately 7% of pregnancies in the United States (Esposito, 1994) and is the leading cause of nonobstetric foetal death. Blunt trauma accounts for the majority of incidents. However, one series from the United States documents firearm injuries in 4% of cases (Poole et al., 1996), with domestic violence a source of growing concern. Additionally, self inflicted GSW in an attempt to produce abortion are reported (Buchsbaum and Staples, 1985).

All women of childbearing age presenting with gunshot trauma should have their pregnancy status confirmed with urine or serum testing of β-Human Chorionic Gonadotrophin (β-HCG) levels. If pregnancy is present, the gestation should be determined. Management of trauma in the pregnant patient presents additional challenges: the presence of two patients – mother and foetus – and appreciation of the anatomical and physiological changes present in pregnancy (Greaves et al., 2001). Early involvement of an obstetrician is recommended.

Foetal viability is dependent upon maternal survival. Initial management should ensure maternal stability and proceed according to ATLS guidelines. Airway management must account for an increase in gastric reflex resulting from reduced smooth muscle motility and delayed gastric emptying – rapid sequence techniques are required. Pregnancy is associated with an increased oxygen demand and physiological hyperventilation and hypocapnia. This must be recognised and oxygen delivery given precedence: pCO₂ levels in excess of 5.3 kPa herald feto-maternal acidosis. Uterine enlargement displaces the diaphragm proximally. If thoracic wounding mandates chest drain insertion, entry at the third or fourth intercostal space just anterior to the mid-clavicular line will take account of this shift.

Significant haemodynamic changes are associated with pregnancy and can confound assessment. An increase in blood volume of 1.5 L and consequent rise in cardiac output permits the pregnant female to tolerate significant haemorrhage before circulatory shock becomes clinically apparent – blood is diverted from the foeto-placental unit to the mother. Apparent normovolaemia in the mother is a poor predictor of the adequacy of uterine perfusion (George et al., 1992) and may mask foetal hypovolaemia. Blood flow to the gravid uterus may reach 600 mL/min and swift haemorrhage may result from uterine injury (Knuppel and Hatangad, 1995). Concealed haemorrhage may be additionally due to placental abruption occurring, usually secondary to blunt trauma. However, gunshot wounding may be associated with blunt trauma both due to the violent episode producing the wounding or a fall by the injured party. Increases in heart rate may also occur but should not solely be attributed to pregnancy. Hypotension may be exacerbated in the supine position by compression of the inferior vena cava by the gravid uterus at

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greater than twenty weeks gestation, precipitating a fall in cardiac output of up to a third and may provoke decompensation in the bleeding patient. This may be ameliorated by wedge elevation of the right hip, ‘log-rolling’ the patient into the left lateral position or manual displacement of the uterus to the left. There is no role for permissive hypotension in the management of trauma in pregnancy. Hypotension in the injuredmother strongly correlates with foetal death (Rogers et al., 1999).

Radiographic investigations are not contraindicated in pregnancy and should not be deferred. The ‘trauma series’ of plain films of cervical spine, chest, and pelvis do not pose significant risk of radiation induced malformations or congenital disease (Osei and Faulkner, 1999). CT examination of the pelvis approaches the threshold risk for inducing foetal injury in early pregnancy. The risk of incomplete investigation and harm to the mother must be balanced against that to the foetus.

Immediate assessment must ensure stability of the mother. When this is established, the clinician may proceed to foetal evaluation, assessing foetal maturity, uterine and placental integrity and the presence of foetal distress. Estimation of foetal maturity enables viability to be predicted should delivery become necessary. The threshold varies, but is generally taken to be about 26 weeks. Ongoing resuscitation of a less mature foetus will not improve foetal survival (Morris et al., 1996). Foetal maturity may be obtained from the history if available, clinical assessment of fundal height (reaching the umbilicus at 20 weeks) or ultrasound, which may also be used to visualise foetal movement. Uterine examination per abdomen should discern tenderness, premature contractions, and extrauterine foetal parts. Vaginal examination for blood and amniotic fluid is hazardous, and may precipitate haemorrhage in cases of placental abruption or placenta praevia and should ideally be undertaken by an obstetrician. A Doppler probe may detect the foetal heart rate (FHR) at 10 weeks gestation and continuous monitoring is required above 20 weeks gestation (Tsuei, 2006). A cardiotocogram monitors FHR and uterine contraction. Foetal distress is indicated principally by bradycardia (less than 100 beats per minute) and repeated decelerations in response to uterine contractions (Greaves et al., 2001). Absent foetal heart tones at presentation indicate a nonviable foetus at any gestational age (Morris et al., 1996).

Laboratory analysis of blood samples must include Kleihauer-Betke testing to exclude sub-clinical foetomaternal haemorrhage. Isoimmunisation of a Rhesus negative mother requires only 0.001 mL of foetal blood, with a requirement for subsequent anti-D immunoglobulin therapy (Kuhlmann and Cruickshank, 1994).

The risk of uterine penetration increases as the uterus enlarges in established pregnancy, arising above the pelvic brim after 12 weeks gestation and displacing intra-abdominal organs proximally. The thick musculature of the gravid uterus has a high capacity for energy absorption, thus it may arrest the progress of a bullet with the foetus at higher risk of significant injury than the mother. Maternal visceral injury rates in penetrating abdominal trauma have been reported to be as low as 16–38% in pregnancy, in comparison to the 80–90% risk in the general population (Stone, 1999). The occupation of a greater volume of the abdominal cavity by the gravid uterus may account for this. Conservative management is not contraindicated but the evidence suggests it is practicable only in the haemodynamically stable patient with an entrance wound below the level of the uterine fundus, radiographic evidence of an intra-uterine bullet and confirmed foetal death (Iliya et al., 1980). Vaginal delivery of the foetus may then be subsequently induced. Management is normally in line with that described for the nonpregnant patient (Tsuei, 2006) and most authorities continue to recommend a policy of exploratory laparotomy with experienced obstetric involvement in all cases of penetrating abdominal trauma in pregnancy (Greaves et al., 2001). Caesarean section is not mandatory at laparotomy, but is required if the gravid uterus prevents assessment and repair of maternal visceral injury, or if injury of a viable foetus is suspected (Franger et al., 1989).

Perimortem caesarean section during maternal cardiopulmonary arrest should be considered if a viable foetus is deliverable. It should be performed within 4 minutes of maternal cardiac arrest (Katz et al., 1986). Salvage of both mother and child has been reported (Katz et al., 2005). Caesarean delivery must be rapid and the ‘classical’ approach is favored, via a long midline incision facilitated by the diastasis of the recti in late pregnancy.
A 12–15 cm uterine incision is made longitudinally in the midline of the uterine wall, with the free hand protecting the foetus. The child is delivered to a clinician trained in neonatal resuscitation. If maternal survival is possible, careful 3-layer closure is required to ensure haemostasis after the placenta is delivered and uterus cleared of foreign material.

GSWs in children

GSWs are a significant global cause of paediatric injury. In children aged 14 years and younger, an annual rate of 4.9 nonfatal and 1.2 fatal injuries per 100,000 people has been estimated in the US (Eber et al., 2004). A significant proportion of reported injuries (43.1% nonfatal and 20.7% fatal) were ‘unintentional’, resulting from misadventure among children with access to firearms. The majority of the remainder were due to assault. Death occurred in 20% of children within this age range sustaining a gunshot injury. In common with the adult population, gunshot fatalities in children result most commonly from injury to the brain, accounting for 52–62% of all such deaths (Beaver et al., 1990, Nance et al., 2003). Thoracic injuries pose the next most significant risk of death, accounting for 78.5% of nonintracranial fatal woundings (Nance et al., 2003), with the majority of deaths occurring within the first 24 hours post injury.

Much of the evidence for paediatric GSW management comes from case reports as prospective studies are understandably scarce. The initial management of the severely injured child mandates a structured approach in which the priorities of airway, breathing, and circulation are addressed in sequence. Comparison with adult management may be made only in broad principle as marked anatomical and physiological differences between adult and child must be considered in the resuscitation process, influencing anticipated injury severity and resuscitation goals (Advanced Life Support Group, 2001).

The mediastinum occupies a larger proportion of the chest in children and is more vulnerable to injury in penetrating thoracic trauma, the risk being inversely proportional to age. A retrospective study of 51 thoracic gunshot injuries in children under 16 years of age reported a need for thoracic surgery in 35.3% of children aged 12 years and younger in comparison to 23.5% in the remainder. Additionally, unstable vital signs were more common at presentation (41.2% vs. 26.5%), (Nance et al., 1996). A Turkish study has supported the practice of limiting management of stable patients to tube thoracostomy in the absence of gross pulmonary laceration, airway and cardiac injury (Eren et al., 2003). In a series of 110 children sustaining thoracic gunshot injury, 84 (76.3%) were successfully treated in this manner. The authors further reported that 10 patients (9.1%) were managed initially by observation alone with three requiring chest drain insertion between 12 and 48 hours for delayed presentation of haemo- or pneumothorax. Thoracotomy remained a requirement in the unstable patient with penetrating thoracic injury, performed immediately in 10 patients (9.1%). Lung lacerations were the most commonly encountered injury at operation (8/31 procedures). In addition to plain chest radiographs, stable patients were investigated via CT or bronchoscopy according to whether lung parenchymal or airway injury was suspected. The authors suggest a minimum period of observation of 48 hours in the conservatively managed group to allow for delayed presentations requiring intervention. Mortality is highest in the shotgun injured child.

Concentration of the abdominal organs into a smaller cavity in the child increases the risk of multi-organ injury in abdominal gunshot wounding. The small bowel is most commonly injured, with one series reporting an injury rate of 62% (Valentine et al., 1984). The colon and liver are next most commonly injured (Valentine et al., 1984, Dokucu et al., 2000). Multiple organ injury rates up to 79% have been reported (Dokucu et al., 2000). No large series supports the use of nonoperative management of penetrating abdominal GSW in the paediatric population. Exploratory laparotomy remains recommended practice (Advanced Life Support Group, 2001). Diagnostic laparoscopy has been proposed in the assessment of tangential wounds, but has not been tested in large series (Feliz et al., 2006).

Gunshot fractures in children are managed acutely in the manner of their adult counterparts with special reference to the consequences upon growth. Growth plate injury may provoke premature closure and limb length discrepancy (Letts and Miller, 1976; Washington et al., 1995).
Paediatric vascular injury presents specific difficulties, as arterial injury in children precipitates intense vasospasm and arteriography is itself associated with iatrogenic injury due to smaller vessel size (Lazarides et al., 2006). Papaverine may be used to overcome vasospasm and facilitate repair (Harris and Hardines, 2003). Hard signs of vascular injury mandate urgent exploration without pre-operative angiography as in the adult case. Hand held Doppler probes assist with identifying distal arterial flow where vascular injuries are less apparent. A 9 year series of 44 patients under the age of 14 years suffering peripheral gunshot vascular trauma identified only three cases in which arteriography was necessary to identify injury (Goz et al., 2006). Doppler ultrasound and clinical examination findings were insufficiently conclusive in these cases. Early revascularisation is recommended owing to the risk of skeletal growth retardation.

Summary
Shotgun wounds at close range are a high energy transfer wound and the soft tissue destruction may be massive – at greater distances the risk of significant injury falls off significantly. Air rifles are not toy guns and produce a steady stream of penetrating injuries, usually in children which may be fatal. In both cases management is as for other ballistic wounds. GSWs in pregnancy present two patients, however the priority remains the mother throughout, not least because the best way to ensure foetal viability is by maternal survival – attention must be paid to the physiological changes in the mother that will affect the resuscitation and the alteration in the injury pattern produced by the presence of the gravid uterus displacing the abdominal contents. Children’s anatomy is such that the pattern of injuries differs from adults and this should be borne in mind in the paediatric gunshot victim. In neither the paediatric or obstetric gunshot victim is hypotensive resuscitation or conservative management of penetrating abdominal trauma viable except in highly selected circumstances.

References


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