Contribution of imaging in the initial management of ballistic trauma

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**KEYWORDS**
Gunshot wound; Trauma; Conventional x-ray; Computed tomography; Ultrasound

**Abstract**

\textbf{Introduction:} The purpose of this study is to specify the role of imaging in the initial management of ballistic traumas.

\textbf{Methods:} This is a retrospective study that colligated 83 victims of a gunshot wound during demonstrations, treated in our trauma centre between 12 January and 3 February 2011. All of the patients were haemodynamically stable and examined by conventional radiography and/or ultrasound and/or 16-slice CT-scan (CT).

\textbf{Results:} The mean age of the victims was 26 years with a sex ratio of 0.02. All wounds were unique. Injury to the limbs was most common in 75.5\% of the cases ($n=64$) followed by that of the torso in 19.5\% of the cases ($n=16$). Wounds in the spine ($n=2$), brain ($n=2$) and facial skeleton ($n=1$) were observed. Conventional x-rays objectified 32 cases of open fractures 95\% of which were in the legs. Twenty-one of the victims of gunshot wounds had a CT-scan that objectified the path of the bullet and an assessment of the wound was made in all cases. The confrontation of the data from the CT-scan and that noted during surgery and during the monitoring demonstrated that the CT-scan is very efficient in the diagnosis of pleural effusion, vascular wounds, thoracic parenchymatous wounds and wounds of the solid organs and brain lesions and the facial skeleton. However, the sensitivity is low for the diagnosis of hollow organs.

\textbf{Conclusion:} The CT-scan is very useful in the initial care of stable patients with gunshot wounds as regards the haemodynamics and helps objectify the path of the bullet and obtain a precise assessment of the damage. Conventional x-rays are unavailable for wounds to the legs and spine.

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Ballistic traumas result from a projectile entering the body: bullet, birdshot, metal fragment from the casing or the contents of an explosive device. They often cause serious wounds characterised by the multiplicity of clinical pictures and the frequency of the associated wounds. These wounds may be life threatening by loss of blood, respiratory distress and contamination of the wound [1]. The functional prognosis may also be involved in wounds to the central nervous system or the limbs. Before January 2011, ballistic traumas were a rare or even exceptional reason for consultation in emergency units, resulting from hunting accidents or soldiers who made a mistake in handling firearms. The uprisings of 14 January 2011 led to the care of a great many ballistic traumas over a short period of time in mainly young civilians.

The purpose of this study is to specify the role of imaging in the initial management of ballistic traumas based on the experience in our trauma centre.

Methods

This is a retrospective study of patients with ballistic traumas treated in our institution during a period ranging from 12 January to 3 February 2011.

The patients included in this study had at least one penetrating ballistic wound, were haemodynamically stable and were explored by conventional x-rays and/or ultrasound and/or CT-scan. The criteria for exclusion were patients that did not need to be hospitalised and were monitored on an outpatient basis.

All of the CT explorations used a 16-slice scanner (Bright Speed, GE Medical Systems) with volume acquisitions in fine slices 1.25 mm thick and soft and hard filters. The images were interpreted on native slices using coronal, sagittal and oblique views using multi-plane reconstructions in mediastinal, parenchymatous, soft tissue, wide and bone windows.

The brain acquisitions were obtained without the injection of iodine contrast agent (120 kV, 300 mAs) whereas the abdominal-pelvic sections were obtained at venous time immediately after the injection of the contrast agent (120 kV, 250 mAs) but without gastric opacification or late acquisition.

Results

Between 12 January and 3 February 2011, we treated 83 patients suffering from a penetrating trauma by firearms. There were 81 men and two women whose mean age was 26 years with extremes ranging from 17 to 46 years. 96% of these ballistic traumas involved the civilian population (n = 80), 6% of which were escaped prisoners. 4% of the wounded were soldiers (n = 3).

All wounds were unique resulting from standard bullets (5.56 × 45 mm NATO), fired by an arm such as an assault rifle. Each victim received a single bullet. Leg wounds were most common in 75.5% of the cases (n = 64) followed by that of the torso in 19.5% (n = 16). Wounds in the spine (n = 2), brain (n = 2) and facial skeleton (n = 1) were also observed. These bullets weren’t removed during the surgical interventions.

Limb wounds

The victims wounded in the limbs were men, with a mean age of 28 years. Conventional x-rays of the wounded limb, with two orthogonal front and profile views were obtained in all cases. These x-rays objectified 32 open fractures with lead debris in the soft tissue. In 95% of the cases, the fractures were located in the lower limbs, including 39.5% (n = 15) in the leg (Fig. 1), 29% (n = 11) in the femur, 13% (n = 5) in the foot, 5% (n = 2) in the knee and 5% (n = 2) in the ankle (Fig. 2). A right greater trochanter fracture was observed in one case (Fig. 3) as well as a wrist fracture.

Isolated wounds were observed in 28 cases including 77.5% (n = 24) in the lower limbs, predominantly in the thigh (n = 14) (Fig. 4).

The association of wounds and fractures was observed in five cases (Fig. 5).

Table 1 sums up the distribution of the wounds and fractures in the limbs.

Upon admission, seven patients presented signs of ischaemia in the lower limbs, explored by arterial Doppler ultrasound in two cases and angio-CT in five cases. The Doppler ultrasound was normal in both cases. The angio-CT of the lower limbs was carried out according to the automatic detection of an iodine bolus. It revealed vascular lesions in both cases: one lesion of the infrapopliteal artery associated with a thrypsis of two bones in the leg (Fig. 6) and one wound of the left common femoral artery with extravasation of contrast agent observed following a bullet wound in the right buttock (Fig. 7). In the other cases (n = 3), the angio-CT did not reveal any anomalies.

All patients received tetanus antiserum and antibiotic therapy. The treatment consisted of a wound excision and a suture in 51% of the cases, a wound excision, a suture and immobilization in 9% of the patients, external fixation in 31% of the cases, pinning in 3% and immediate amputation in 6% of the cases. The mean hospitalization was 2.6 days.

Figure 1. Front x-ray of the left leg. Midshaft thrypsis of the bone of the leg with lead debris in the soft tissue.
Contribution and darthrosis cases (The nerves following with debris a and bullet (Image 93x136 to 321x307) = paralysis in the popliteal nerves (n = 2), external and internal popliteal nerves (n = 1) and radial nerves (n = 1). Pulmonary embolism was noted in one case.

After a period of about two years, the evolution was marked by healing of the skin wounds in 100% of the cases and recovery in the case of paralysis of the radial nerve. The fractures were complicated by malunion (n = 1), pseudarthrosis (n = 1), sepsis on material (n = 1) and elephantiasis (n = 1).

The immediate complications were neurological in five cases such as paralysis of the external popliteal nerve (n = 2), external and internal popliteal nerves (n = 1) and radial nerves (n = 1). Pulmonary embolism was noted in one case.

After a period of about two years, the evolution was marked by healing of the skin wounds in 100% of the cases and recovery in the case of paralysis of the radial nerve. The fractures were complicated by malunion (n = 1), pseudarthrosis (n = 1), sepsis on material (n = 1) and elephantiasis (n = 1).

Figure 2. Front x-ray of the ankle. Thrupsis of the outer malleolus with lead debris in the soft tissue.

Figure 3. Front x-ray of the hips. Right per-trochanter fracture following a bullet wound.

Torso wounds

Those wounded in the torso by bullets (n = 16) were men, with a mean age of 25 years. The bullet hole was in the thorax in six cases, in the abdomen in 10 cases. Table 2 sums up the entry wound of the projectiles. An exit wound was identified in six cases including two opposite the tip of the scapula, three at the right iliac fossa and one at the right buttck.

All patients had a Glasgow score of 15/15. They were haemodynamically stable and did not present any signs of respiratory distress or peritoneal irritation.

Five patients had a frontal x-ray of the thorax taken, which was interpreted as normal in three cases and objectified a haemothorax in two cases (Fig. 8).

Eleven patients were examined by CT-scan. Five had a thoracic-abdominal-pelvic CT-scan, four an abdominal-pelvic CT-scan and two were examined by thoracic CT-scan.

The CT-scan objectified the path of the bullet in all cases.

In the thorax, pleural effusions were observed: pneumothorax (n = 2), haemothorax (n = 1) and haemopneumothorax (n = 1) and parenchymatous lesions in the form of polished glass hyperdensity and condensation in four cases (Fig. 9). No mediastinal lesions were observed by CT-scan in our series.

At the abdominal-pelvic level, the CT-scan objectified seven cases of haemoperitonitis. This was associated with wounds in the solid organs in three cases: liver (n = 1), spleen (n = 1) (Fig. 10) and right kidney (n = 1) (Fig. 11). In four cases, the haemoperitonitis was isolated without obvious lesion of a solid organ and/or hollow organ in the CT-scan. A wound of the rectum was suspected in view of the presence of extra-gastric sub-peritoneal air and peri-rectal effusion (Fig. 12). In this case, the bullet entered the top of the right thigh.

An association of a wound of the lower vena cava, retroperitoneal haematoma and pneumoperitonitis was observed in one case (Fig. 13).

Eleven patients underwent emergency surgery, including four who had a thoracotomy and seven a laparotomy. Five patients benefited from medical treatment with monitoring of the respiratory, haemodynamic and abdominal state.
Figure 5. Bullet wound of the left foot (a) associated with a fracture of the base of the fifth metatarsal and multiple lead debris in the soft tissue (b).

Table 1 Distribution of wounds and fractures in the limbs.

<table>
<thead>
<tr>
<th>Limb</th>
<th>Wound (n)</th>
<th>Fracture (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arm</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Forearm</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Wrist</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Hand</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Hip</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Thigh</td>
<td>14</td>
<td>11</td>
</tr>
<tr>
<td>Knee</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Leg</td>
<td>5</td>
<td>15</td>
</tr>
<tr>
<td>Ankle</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Foot</td>
<td>1</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 3 sums up the abdominal lesions noted during surgery.

The procedures carried out on the thorax were the drainage of a haemothorax in one case and a suture of parenchymatous wounds in three cases. In the abdomen, the procedures consisted of a suture of the wounds of the small intestine and stomach, anastomosis resection in one case and a stoma in two cases. The evolution was marked by the occurrence of complications such as: septic shock (n = 1), biliary peritonitis (n = 1) and lung infection (n = 1). The mean period of hospitalization was five days.

The confrontation of the peroperative findings and those of the CT-scan showed that the CT-scan did not diagnose the only diaphragmatic wound in our series. However, the sensitivity and specificity were excellent in the diagnosis of the pleural effusions and parenchymatous wounds. In the abdomen, the sensitivity of the CT-scan was low at 14% in the

Figure 6. 26-year-old man with a bullet wound in the left leg. Left lower limb cold and absence of pressure values. a, b: Angio-CT of the lower limbs with MIP reconstructions (a) and volume rendering reconstructions (b). Vascular lesion of the tripod tibial muscle.
Contribution of imaging in the initial management of ballistic trauma

Figure 7. 20 year-old man with a bullet wound in the right buttock. Ischaemia of the left lower limb. Axial CT section at arterial time (a) and MIP reconstruction (b) reveal extravasation of the contrast agent at the left common femoral artery and early opacification of the homolateral femoral vein related to an arteriovenous fistula.

Table 2  Cutaneous entry wounds of the projectiles.

<table>
<thead>
<tr>
<th>Seat</th>
<th>n</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thoracic</td>
<td>6</td>
<td>37.5</td>
</tr>
<tr>
<td>Epigastrium</td>
<td>2</td>
<td>12.5</td>
</tr>
<tr>
<td>Right hypochondrium</td>
<td>1</td>
<td>6.25</td>
</tr>
<tr>
<td>Right iliac fossa</td>
<td>2</td>
<td>12.5</td>
</tr>
<tr>
<td>Right side</td>
<td>1</td>
<td>6.25</td>
</tr>
<tr>
<td>Hypogastrium</td>
<td>1</td>
<td>6.25</td>
</tr>
<tr>
<td>Peri-umbilical</td>
<td>1</td>
<td>6.25</td>
</tr>
<tr>
<td>Right groin</td>
<td>1</td>
<td>6.25</td>
</tr>
<tr>
<td>Right buttock</td>
<td>1</td>
<td>6.25</td>
</tr>
<tr>
<td>Para-vertebral</td>
<td>1</td>
<td>6.25</td>
</tr>
</tbody>
</table>

diagnosis of lesions of the hollow organs. A bladder wound was not diagnosed by the CT-scan.

Injuries to the brain and facial skeleton

Two cases of brain injuries were observed. Both were women, 36 and 29 years old. They were immediately intubated upon arrival to the emergency unit in view of the alteration in their state of awareness and underwent a CT brain scan without injection of contrast agent.

Figure 8. Front x-ray of the thorax. Bullet in projection of the left pulmonary base with homolateral liquid pleural effusion.
In one case, the CT-scan revealed a haematoma of the left fronto-parietal scalp containing metallic debris with fracture of the homolateral frontal bone associated with meningeal haemorrhage and acute left parietal subdural haematoma. In the other case, the CT-scan revealed an anterior frontal entry wound with multiple intra-cerebral metallic debris (Fig. 14). After reanimation, the evolution was favourable in both cases with awakening without sequela.

One case of a bullet wound in the facial skeleton was observed in a young 23-year-old man. The entry wound was anterior the level of the base of the nose. It was explored by profile x-ray of the skull and a CT brain scan without injection. The x-ray showed that the bullet was located in the sphenoid sinus (Fig. 15a). The CT-scan (Fig. 15 b, c) objectified the path of the bullet and confirmed that it stopped at the sphenoid sinus, the origin of the fractures of the bone walls of the latter. Study at the parenchymal window did not detect any lesion.

**Spinal injuries**

Two cases of ballistic spinal injuries were observed. The entry wound was in the dorsal spine in one case and in the lumbar spine in the other case (Fig. 16). Both patients were paraplegic upon admission. They were explored by conventional x-rays of the spine and a thoracic-abdominal-pelvic CT-scan. In the case of the injury to the dorsal spine, the CT-scan revealed intra-canal as well as intra-parenchymatous lead debris in the thorax with pneumothorax. In the other case, the intra-canal lead debris stopped at the third lumbar
Contribution of imaging in the initial management of ballistic trauma

Figure 11. Left kidney wound. Abdominal CT-scan: axial section with injection of contrast agent revealing the left paravertebral posterior entry wound of the bullet and a wound in the homolateral kidney.

vertebra and the CT-scan did not reveal an abdominal or thoracic lesion.

Discussion

Ballistic traumas are common in Columbia, South Africa, Brazil and the United States [2,3]. In Tunisia, before the revolution, these traumas were an exceptional reason for consultation in the emergency unit. The uprising of 14 January 2011 led to the examination and treatment of a large number of persons injured by bullets. This study demonstrated that 96% of the cases of these ballistic traumas were civilians and in particular young men. These findings corroborate those in the literature where studies have reported that injuries by bullets currently more and more often concern young people in "politically unstable" countries or urban violence in large cities due to banditry or terrorism [4,5].

Firearms are responsible for two types of wounds: tunnel of attrition where the tissue is directly destroyed by the passage of the projectile and a peripheral zone where the tissue damage is caused by the transmission of the energy dissipated by the projectile [5]. This temporary zone of cavitation is more marked in case of tipping, fragmentation or deformation of the projectile and may amount to 25 times the calibre of the bullet [5]. All of these lesions depend on the ballistic properties of the bullet (energy, type, stability) and the medium crossed [1]. Therefore, not very dense and elastic organs such as the lungs and hollow organs easily absorb the energy transmitted and are relatively tolerant as regards bullet wounds while the solid organs are less elastic and more exposed to cavitation phenomena. However, bone is without any elasticity [1,5]. It breaks and splits up with the generation of multiple slivers and destabilizes the bullet, creating a change, a rotation or fragmentation of the latter with the creation of secondary lesions [5].

Figure 12. Bullet wound in the rectum: a, b: axial (a) and coronal sections (b) of the upper third of the thigh revealing the entry wound of the bullet at the top of the right thigh with major subcutaneous and scrotal emphysema; c: axial CT section with injection of contrast agent centred on the pelvis. Peri-rectal liquid effusion associated with extra-gastric air.

Figure 13. 23 year-old man with a bullet wound in the abdomen and right posterior paravertebral entry wound: a: scout view. Debris from the bullet in the right hemi-abdomen opposite disc L3-L4. b, c: abdominal CT. Axial sections with injection of contrast agent revealing a wound of the inferior vena cava with retro-peritoneal haematoma containing bullet debris (b) and associated with pneumoperitoneum (c).
Table 3  Abdominal lesions noted during surgery.

<table>
<thead>
<tr>
<th>Lesions</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>White laparotomy</td>
<td>0</td>
</tr>
<tr>
<td>Hemoperitonium</td>
<td>7</td>
</tr>
<tr>
<td>Liver</td>
<td>1</td>
</tr>
<tr>
<td>Spleen</td>
<td>0</td>
</tr>
<tr>
<td>Kidney</td>
<td>0</td>
</tr>
<tr>
<td>Stomach</td>
<td>1</td>
</tr>
<tr>
<td>Small intestine</td>
<td>2</td>
</tr>
<tr>
<td>Colon</td>
<td>2</td>
</tr>
<tr>
<td>Rectum</td>
<td>1</td>
</tr>
<tr>
<td>Mesentery</td>
<td>1</td>
</tr>
<tr>
<td>Bladder</td>
<td>1</td>
</tr>
<tr>
<td>Vascular wound</td>
<td>1</td>
</tr>
</tbody>
</table>

Ballistic traumas require special care that depends on the topography of the projectile, the clinical state and the technical and logistic possibilities of the place of care. Currently, imaging is playing an increasingly important role in the care, in particular for haemodynamically stable victims. Conventional x-rays are unavoidable and represent the first line complementary imaging when confronted with any ballistic trauma of the lower limbs [4]. Damage to the limbs is the most common ballistic trauma and accounts for 70 to 80% according to the different series in the literature [4]. In this study, the impairment was assessed at 75.5%, explored in all cases by x-rays with two orthogonal views. Conventional x-rays reveal the seats of fractures but also radio-opaque projectiles and sometimes the presence of air [4]. They sometimes can be used to estimate the distance of the fire and the trajectory. Conventional x-rays are also unavoidable in bullet wounds in the spine. These wounds are rare and are estimated at 5%, although they are serious since they often lead to definitive neurological impairment.

Figure 14. 36-year-old woman, victim of a brain wound: a: brain CT with volume rendering reconstruction. Front anterior entry wound of the bullet. b, c: CT axial brain slices in parenchymatous window (b) and sagittal in bone window (c) revealing multiple intracerebral lead debris.

Figure 15. Bullet wound in the facial skeleton: a: profile x-ray of the skull showing a bullet in the sphenoid sinus; b, c: CT of the facial skeleton in axial (b) and coronal slices (c) in bone window revealing the trajectory of the bullet and confirming its final position in the sphenoid sinus.
The x-rays assess the spinal bone damage and whether it is unstable or not, as in conventional traumatology.

The development of multi-slice CT scans has greatly changed the care of stable ballistic traumas on the haemodynamic level due to its excellent spatial and temporal resolution. In the torso, the systematic surgical exploration of ballistic wounds was the rule [6]. This was justified by the assumption that only surgery is able to correctly diagnose all wounds, that the clinical examination is not very specific in the identification and classification of lesions, that the surgical morbidity is low, and that a delayed laparotomy may increase the rate of morbidity and mortality [7,8]. However, this attitude has led to negative or non-therapeutic surgery in 15% to 25% of the cases [9] as well as an increase in morbidity, the length of hospitalization and the cost of care [10]. This dogma of systematic surgery has greatly evolved over the last years due to the development of CT that has reduced the rate of useless surgery by a better selection of the injured [11,12]. Certain studies, such as that by Renz and Feliciano [13] or Grossman et al. [14] have reported excellent sensitivity and specificity of the multi-slice scan in identifying the trajectory of the bullet, the entry and exit wounds and provide a precise lesion assessment in ballistic traumas of the torso. Shanmuganathan et al. [15], in a prospective study on 200 victims with a penetrating wound of the torso, including those by bullet, demonstrated that the CT-scan associating an intravenous injection of contrast agent and high and low gastric opacifications (triple-contrast CT-scan) has a sensitivity of 97%, a specificity of 98% and a precision of 98% to confirm the penetrating nature of the wound and make an assessment of the impaired organs. Munera et al. [16] reported similar results as to the value of the triple-contrast CT-scan. Ramirez et al. [17], demonstrated that the precision of the CT-scan with intravenous injection of contrast agent alone was similar that of the triple-contrast CT-scan in the management of patients with a penetrating wound in the abdomen and had the advantage of improving the time of the diagnosis by avoiding all delay due to gastric opacification. In the present study, only the intravenous injection of contrast agent was carried out without gastric opacification.

As for the assessment of the injured viscera, the CT has excellent specificity, sensitivity and precision for the diagnosis of pleural effusion, wounds of the pulmonary parenchyma and solid abdominal organs [15]. One wound to the diaphragm was not diagnosed by the CT-scan in this study. One wound to the bladder also was not noticed and may be attributed to the non-achievement of a late phase to demonstrate the extravasation of the contrast agent. The sensitivity, specificity and precision of CT in the diagnosis of hollow visceral lesions that are frequent in abdominal bullet wounds are variable as reported in the literature [18,19]. In the present study, the sensitivity of CT was low in detecting lesions in hollow organs. Certain studies recommend the use of a contrast agent by oral and rectal route in order to

Figure 16. Bullet wound in the dorsal vertebra: a, b: thoracic CT-scan: axial sections in parenchymatous window revealing the entry wound of the bullet in the dorsal vertebra (a) and intra-parenchymatous bullet debris in the right apical (b); c: thoracic CT-scan in parenchymatous window. Bilateral haemo-pneumothorax. d: Sagittal reconstruction in bone window of the dorsal vertebra revealing intra-canal lead debris with fracture of T2.
improve the capacity of CT in the diagnosis of wounds of the hollow organs [15].

The initial assessment of wounds by bullets in the lower limbs may require, in addition to conventional x-rays, a vascular exploration in case of ischaemia. The angio-CT is currently the reference examination for the assessment of vascular lesions without delaying the care [4]. With multi-plane, maximum intensity projection (MIP) and 3D reconstructions, it helps provide a precise map of the lesions and orient the treatment. CT also plays a preponderant role in ballistic traumas of the spine, in particular in assessing the container and contents of the vertebral canal [20] and in assessing the often frequent, associated, possibly life-threatening lesions.

Finally, CT is unavoidable in the assessment of ballistic injuries to the brain and facial skeleton. It helps objectify the trajectory of the bullet with multi-plane reconstructions, assess the intra-parenchyma lesions, fractures and splinters and thereby determine the prognosis [21]. In the facial skeleton, 3D and denta-scanner reconstructions are of great help in assessing the injuries [22]. Nevertheless, the conventional x-ray and the CT-scan do not allow for a precise determination of the calibre of the projectile due to the fungiform deformation, fragmentation and mushroom effect of certain lead bullets whose tips are crushed, thereby increasing their diameter [5].

In addition to CT, emergency pleural, pericardial and peritoneal sonography or focused assessment with sonography for trauma (FAST) is now extensively carried out in the initial care of ballistic traumas of the torso due to the high sensitivity in the detection of liquid effusion [23,24]. However, it is not very sensitive in the assessment of impaired viscera [25]. In this series, emergency sonography was not carried out. In fact, all of the persons wounded in the abdomen were directly explored by CT. As for the magnetic resonance imaging (MRI), the main indication in ballistic traumas is the medullary trauma. It has to take into account the type of bullet that should not contain metal shards [21]. In this series, no MRI were carried out.

Conclusion

Imaging plays an important role in the initial care of haemodynamically stable persons wounded by bullets whatever the location of the projectile. CT is very useful in objectifying the trajectory of the bullet and in obtaining a precise assessment of the wounds, thereby providing precious information for the care of this group of patients. Conventional x-rays are unavoidable for lesions of the limbs and spine. Emergency sonography may be of use in the search for liquid or gas effusion. The indication for MRI in ballistic medullary traumas should take into account the type of projectile.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

References

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