Radiology in combat injuries

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Authors: S. KOROPOULI¹, A. Gyftopoulos¹, M.-M. Chasioti², E. Seferos¹, M. Gkagkanasiou¹, G. Delimpasis¹, M. Varela¹, E. DESPOTOPoulos¹, ¹ATHENS/GR, ²Athens /GR
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Learning objectives

To become familiar with the various imaging characteristics of combat injuries with various imaging modalities.

To review the special characteristics of traumatic combat injuries in terms mechanism of wounding, process after injury and outcome.
Background

Rare in civilian society, blast injuries occur daily on the battlefield and in war-torn urban areas. The most common are the result of explosive munitions. Nearly one-third of all combat forces are exposed to a blast force. The IED (Fig. 2 on page 6) is the signature weapon of nowadays wars.

There are four types of blast injury. Usually there a complex mix of all four:

- **Primary:** the result of direct blast wave-induced changes in atmospheric pressure (i.e., barotrauma). The changes in atmospheric pressure that cause primary blast injuries arise because a high-explosive detonation results from the nearly instantaneous conversion of a solid or liquid into gasses. Momentarily these gasses occupy the same volume as the parent solid or liquid and thus they are under extremely high pressure. The gasses expand rapidly, causing compression in the surrounding air, forming a pulse of pressure (blast overpressure, positive phase of the blast wave) Fig. 25 on page 6. As the gasses continue to expand, the pressure drops, creating a relative vacuum (blast underpressure, negative phase of the blast wave). Extreme pressure differences occur as the blast wave reaches the body, resulting in both stress and shear waves.

Organs and tissues of different densities are accelerated at different relative rates, resulting in displacement, stretching and shearing forces. It primarily affects air-filled organs such as the lung, colon, and middle ear (tympanic membrane), but it may also cause cardiac contusions, bowel perforation, mesenteric shear injury, and brain injury.

Primary blast injuries are characterized by tissue edema. Extremity fasciotomies may be necessary to relieve the distal decrease in perfusion and to avoid the development of a compartment syndrome.

Pulmonary edema (so-called blast lung) and intestinal edema (open abdomen) are characteristic. The brain injuries associated with blast trauma also tend to be characterized by a disproportionate amount of cerebral edema relative to parenchymal hemorrhage. The edematous response of the tissue to a blast injury may be exacerbated by the massive fluid resuscitation that occurs in the field, superimposed on the primary blast force.

- **Secondary:** numerous penetrating injuries that result from multiple objects put in motion by the blast force. The patient's skin surface appears 'peppered' with innumerable wounds. Any body part may be affected.
- **Tertiary:** resulting from the victim being thrown or crushed by the collapse of a structure. These injuries resemble blunt traumatic injuries found in the
majority of civilian trauma such as a motor vehicle accidents, falls, and crush injuries. Any body part may be affected.

- **Quaternary:** usually a thermal injury resulting in varying degrees of burn severity. The inhalation of toxic fumes and asphyxia are also examples of quaternary blast injury. In particular, phosgene-like combustion by-products from the Teflon-coated interiors of armored vehicles may cause severe pulmonary compromise. Burns associated with IED explosions seem to behave differently from typical domestic burns; this may result from a combination of the thermal injury superimposed on the primary and secondary blast injury. Any body part may be affected.

Factors determine the severity of a blast injury:

- helmet and body armor; peak blast pressure; distance from the explosion; whether the blast occurs outdoors or in an enclosed space; the mass, velocity, and shape of the secondary blast fragments; and the type of tissue injured.

It should be noted that the peripheral nervous system is not immune to combat injury. Plantar fasciitis, tarsal tunnel syndrome (boot trauma), entrapment neuropathy (from constantly holding a weapon), penetrating peripheral nerve trauma, and demyelination from a blast injury are all encountered on the battlefield.

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**Fig. 2**

<table>
<thead>
<tr>
<th>TYPES OF EXPLOSIVES</th>
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<tbody>
<tr>
<td><strong>IED:</strong> Improvised Explosive device</td>
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<tr>
<td><strong>RPG:</strong> Rocket Power Grenade</td>
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<td><strong>EFP:</strong> Explosive Formed Penetrator</td>
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<td><strong>VBIED:</strong> Vehicle-Borne IED</td>
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<tr>
<td>SYSTEM</td>
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<tr>
<td>Auditory</td>
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<td>Eye, Orbit, Face</td>
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<td>Extremity injury</td>
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<td>Digestive</td>
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<td>CNS injury</td>
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<td>Circulatory</td>
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<td>IED</td>
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<td>RPG</td>
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<td>VBIED</td>
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Fig. 2

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Fig. 25: Blast Wave

© http://www.grahamwindows.com/blast/about_blast.html
**Fig. 26:** Horizontal fracture of the temporal bone (arrow). There is extension into the middle ear cavity without incudomalleal separation.

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**Fig. 18:** Blast injury. Abdominal trauma. Hematoma of the adductors muscles (blue arrow) with a concomitant fracture of the left ischial bone.

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Imaging findings OR Procedure details

We hospitalized some wounded soldiers and civilians who were transported from Libya. All patients were young male. They were air transferred from Libya in terms of interstate's agreements. The majority had multiple and severe wounds due to penetrating missiles, explosive mechanisms such as high-velocity shells and reversed vehicles. In generally we faced injuries concerning brain, lung, abdomen, muscles, bones. Due to the nature of their lesions most of the injured were in a critical condition. The contribution of imaging studies was significant for the treatment process.

X-rays as well as ultrasound and Computed Tomography (multislice) were performed in the majority of patients. As CT remain the diagnostic imaging tool of choice in combat we will mainly review the ct findings, presenting at the same time the concomitant us and xray findings Fig. 14 on page 26.

CT scans were performed with the use of a multidetector CT scanner (8 slice MSCT-Lightspeed GE Medical).

The majority of the patients had severe head injuries. Explosions fragments caused penetrating trauma of the brain. Therefore patient had fracture of the skull, intracranial and sudarachnoid hemorrhage.

We had many thoracic, abdominal and musculoskeletal injuries as well.

Due to the nature of their lesions their status was in a critical condition in some cases. The contribution of imaging studies was significant for the treatment process.

Overview of Explosive-related Injuries
**Fig. 1:** Overview of Explosive-related Injuries

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**Most common Blast Injuries**

**Brain Injury (TBI)**

The brain is clearly vulnerable to both secondary and tertiary blast injury. A still unresolved controversy is whether primary blast forces directly injure the brain.
Shear and stress waves from the primary blast could potentially cause traumatic brain injury (TBI) directly (e.g., concussion, hemorrhage, edema, diffuse axonal injury). The primary blast can also cause formation of gas emboli, leading to infarction.

Troops are also susceptible to the same types of crush injuries and the rapid acceleration/deceleration injuries and blunt trauma found in civilian TBI, such as diffuse axonal injury and coup contrecoup hemorrhage.

The most common types of TBI are diffuse axonal injury, contusion, and subdural hemorrhage.

Diffuse axonal injuries (DAI) are very common following closed head injuries. They result when shearing, stretching, and/or angular forces pull on axons and small vessels. It leads to focal axonal swelling and (after several hours) may result in axonal disconnection. DAI is usually located at the corticomedullary junction (particularly in the frontal and temporal areas), internal capsule, deep gray matter, upper brainstem, and corpus callosum. Magnetic resonance imaging (MRI) is more sensitive than computed tomography (CT) in detecting diffuse axonal injury. Multifocal hypointense foci on T2* GRE secondary to susceptibility from blood products at characteristic locations leads to the diagnosis.

Contusions Fig. 17 on page 29 occur when the brain moves within the skull enough to impact bone, causing bruising of the brain parenchyma (hemorrhage and edema). The most common locations are the superficial gray matter of the inferior, lateral and anterior aspects of the frontal and temporal lobes. Occipital lobes or cerebellum are less often involved Fig. 21 on page 31. The imaging appearance of contusion is variable.

Edema has lower signal intensity than brain on CT. In the absence of hemorrhage, CT may initially be only minimally abnormal. If hemorrhage is present, there are commonly multiple bright areas of variable size. Edema appears bright on T2 weighted or FLAIR MRI. The most common sequence in the appearance of hemorrhage on T2 weighted MRI is from bright initially, to mildly strongly dark within the first 2-3 days, to bright again by 2-3 weeks. Small areas of hemorrhage may be most easily identified with gradient echo MR. Progression is common.

FLAIR may show hyperintense SAH.

Traumatic subdural hemorrhage can also occur. The most common locations are the frontal and parietal convexities on the same side as the injury.

The initial, primary head injury sets in motion a series of deleterious biochemical processes (secondary TBI) that worsen patient outcome.
Ischemic infarction affects young troops Fig. 17 on page 29. The reasons are displayed in the following table.

**Causes of ischemic infarction in young troops**

- Increased incidence of penetrating injuries results in a combination of vascular occlusion, dissection, and pseudoaneurysm formation.
- Hypotension due to massive blood loss from amputation(s) and/or coagulopathy.
- Hypoxemia in the setting of an inhalational burn (both chemical e.g., chlorine and thermal) or drowning.
- Embolic infarction secondary to an atrial septal defect or patent foramen ovale.
- Increased incidence of pulmonary emboli.
- Increased risk factors in troops for deep vein thrombosis include dehydration, sepsis, and prolonged air-evacuation with constraining straps.
- Traumatic vasospasm.
- Hyperthermia (heat stroke).
- Post-herniation infarction.
- Cardiovascular derangement (triad: apnea, bradycardia, hypotension).
- Meningitis resulting from implanted clothing and debris in penetrating injuries.
- Air embolism secondary to disrupted pulmonary alveoli.
- Fat embolism Fig. 4 on page 16 from long bone disruption or blast injury. This can result in cerebral infarction directly or indirectly via ARDS Fig. 10 on page 21 Fig. 8 on page 23.

Gunshot wounds in the head and neck are identified by the presence of gas and metallic fragments along the bullet paths that connected to entry and exit defects that were present along the skin surface. When the bullet passed through bone, bone spicules were embedded in the bullet path. The specific track can be hard to identify in some cases.

**Lung Injury**

"Blast lung" is a direct consequence of the HE over-pressurization wave. It is the most common fatal primary blast injury among initial survivors. Signs of blast lung are usually present at the time of initial evaluation, but they have been reported as late as 48 hours after the explosion. Fig. 9 on page 22 Blast lung produces a characteristic "butterfly" pattern on chest X-ray.

Wound tracks are characterized by a linear path of gas containing small metallic and bone fragments surrounded by higher-attenuation hemorrhage and multiple cystic spaces that
vary in diameter Fig. 16 on page 27. There may be injury to major vascular structures within the chest.

**Abdominal Injury**

Gas-containing sections of the GI tract are most vulnerable to primary blast effect. This can cause immediate bowel perforation, hemorrhage (ranging from small petechiae to large hematomas), mesenteric shear injuries, solid organ lacerations, and testicular rupture. Clinical findings may be absent until the onset of complications.

On MSCT the tracks through the abdomen are associated with collections of gas and metal along the bullet path Fig. 3 on page 15. Perforation of the colon may be present Fig. 12 on page 20 Fig. 23 on page 32.

The imaging approach in the acute setting is no different from civilian trauma. *Computed tomography remains the initial exam of choice*. However, there are numerous differences between civilian and combat imaging.

- Total-body scans are routine on the battlefield due to the extreme polytrauma nature of combat injuries.
- Plain radiographs are obtained more often because of the large number of troops with extremity injuries. There is a greater incidence of foreign bodies in battlefield trauma and these are also well visualized on plain radiographs.
- The evolving nature of combat lesions tends to warrant more follow-up imaging examinations.
- The combination of total-body scans with multiple follow-up studies increases the radiation exposure to this young patient population.
- MRI must be performed in selected cases because of the frequent contamination of the wounds by ferromagnetic foreign bodies.

After recovery various functional imaging techniques (MRI) may provide evidence of metabolic derangement not evident on macroscopic anatomic imaging Fig. 4 on page 16. There are wounds that we currently cannot see with routine CT and MRI.

**Extremity Injury**

Traumatic amputation, fractures Fig. 7 on page 19 Fig. 13 on page 24, crush injuries, compartment syndrome, burns, cuts, lacerations, acute arterial occlusion, air embolism-induced injury may all happen Fig. 20 on page 30 Fig. 22 on page 31 Fig. 5 on page 17. They are followed by mild and severe complications Fig. 4 on page 16.
TISSUE injury

Because the predominant mechanism of injury in battlefield trauma is a blast injury from an IED, the tissue literally explodes. It is lacerated, shredded, or crushed, but not cleanly cut. Fig. 3 on page 15 The resultant mangled soft tissue defects and embedded foreign bodies require multiple wound 'washouts', serial debriding, and a heightened vigilance for sepsis. Unlike small arms fire, most secondary blast injuries are contaminated. The superimposed burn injuries also contribute to the horrific physical appearance and the heightened risk for infection. The soldier’s body armor helps protect the torso, but leaves the extremities vulnerable, hence the high number of single, double, and triple amputees returning from combat.

INTERPRETATION HINTS

• For complete evaluation of the injuries, you have to consider not only the entrance and exit of the missile, but the path it took.
• In other words, if possible you have to make trajectory analysis, if possible. Critical structures can only be detected by giving attention of the wound path.
• War wounds are often not on axial plane (sniper shots above, bomb blasts from below).
• MPR, MIP and 3D (Volume Rendering) analysis is very helpful in this task.
• First of all you have to start with a para-axial MPR between entrance/exit points. You must find the middle cut and the angle between the points.
• There may be complex or multiple wound tracts.
• Many patients are usually sedated and there may be respiratory artifacts that may stimulate disease Fig. 6 on page 18.

Virtual autopsy with multidetector CT can be used for the prediction of the site of lethal injury and the extent of organ injury in subjects who have died from high-velocity gunshot wounds.
<table>
<thead>
<tr>
<th>SYSTEM</th>
<th>INJURY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auditory</td>
<td>TM rupture, ossicular disruption, cochlear damage, foreign body</td>
</tr>
<tr>
<td>Eye, Orbit, Face</td>
<td>Perforated globe, foreign body, air embolism, fractures</td>
</tr>
<tr>
<td>Extremity injury</td>
<td>Traumatic amputation, fractures, crush injuries, compartment syndrome, burns, cuts, lacerations, acute arterial occlusion, air embolism-induced injury</td>
</tr>
<tr>
<td>Respiratory</td>
<td>Blast lung, hemothorax, pneumothorax, pulmonary contusion and hemorrhage, A-V fistulas (source of air embolism), airway epithelial damage, a spiration pneumonitis, sepsis</td>
</tr>
<tr>
<td>Renal Injury</td>
<td>Renal contusion, laceration, acute renal failure due to rhabdomyolysis, hypotension, and hypovolemia</td>
</tr>
<tr>
<td>Digestive</td>
<td>Bowel perforation, hemorrhage, ruptured liver or spleen, sepsis, mesenteric ischemia from air embolism</td>
</tr>
<tr>
<td>CNS injury</td>
<td>Concussion, closed and open brain injury, stroke, spinal cord injury, air embolism-induced injury</td>
</tr>
<tr>
<td>Circulatory</td>
<td>Cardiac contusion, myocardial infarction from air embolism, shock, vasovagal hypotension, peripheral vascular injury, air embolism-induced injury</td>
</tr>
</tbody>
</table>

**Fig. 1:** Overview of Explosive-related Injuries

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Fig. 3: 20 years old man with numerous penetrating injuries (blue arrows). Small missile fragments are identified in soft tissues (orange arrow) as well as in the abdominal cavity as hyperdense foci.

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Fig. 4: 20-year-old man. Non-head-injured trauma (bilateral femur open fractures). He underwent surgical repair. He was initially lucid and subsequently developed (18 h) an acute mental status deterioration. Flair T2-weighted image shows multiple punctiform hyperintense lesions in the white matter of both cerebral hemispheres. Hyperintense lesions were identified at pontine while at the same time diffusion-weighted sequence revealed that several of these lesions are of high signal intensities as well as high signal bilaterally at basal ganglia. This indicated areas of restricted diffusion due to cytotoxic edema. The findings were consistent with fat embolism.

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Fig. 5: 25-year-old old soldier with back pain after sudden fall from a moving vehicle. Burst fracture of the body of L1 with slight posterior displacement and a small prevertebral hematoma. Axial images, Sagittal MPR and 3D volume rendering images show burst fracture of the body of L1.

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Fig. 6: Thorax CT. Sedated patient due to multiple trauma. Respiratory artifacts stimulate disease (fracture of the body of the sternum) on Sagittal MPR images.

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**Fig. 7:** Pelvis X-ray. Pubic fracture (red arrow). Urinary bladder rupture. Folley catheter (thin black arrow).

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Fig. 12: 23 years old patient. Severe perineal injury due to a gunshot. Two small jejunal ruptures were revealed on surgery. Complete cut of the urethra and a 80% anal sphincter injury. Loop left colostomy, suprapubic cystostomy and an end to end anastomosis of the urethra were performed. Thickening of small bowel loops due to edema. Extraperitoneal rupture of the urinary bladder. Air is identified at Retzius space. We observe at the same time air inside the bladder as well as two missile fragments. Intraperitoneal fluid collections.

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Fig. 10: Severe wounds after blast injury. Head injury, abdominal rupture. Chest radiograph shows alveolar infiltrates and left pleural effusion. Over the next 24 hours, there was pronounced progression of disease. The patient developed clinical ARDS.

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Fig. 9: Chest radiograph. Severe wounds after blast injury. Head injury, abdominal rupture. Multiple bone fractures. Bilateral airspace consolidations.

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Fig. 8: CECT. Lung and soft tissue algorithm images demonstrate posterior left condensations and diffuse ground-glass patchy ill-defined opacities which slightly predominate in the right lung, highly suggestive of ARDS. Normal heart size.

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Fig. 13: Blast injury. Abdominal trauma. Hematoma of the adductors muscles (blue arrow) with a concomitant fracture of the left ischial bone.

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Fig. 11: 23 years old patient. Severe perineal injury due to a gunshot. Two small jejunal ruptures were revealed on surgery. Complete cut of the urethra and a 80% anal sphincter injury. Loop left colostomy, suprapubic cystostomy and an end to end anastomosis of the urethra were performed. Thickening of small bowel loops due to edema.

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Fig. 15

CT scan confirms the lumbar vertebra fracture suspected by Xrays.

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X-rays of an ambulance driver reversed after an explosion. He had back pain. There is a fracture of a lumbar vertebra, shown by the black arrow.

Fig. 14

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Fig. 16

Man transferred in our hospital from battle field intubated. CT scan revealed a great hypodermal emphysema (first figure), pneumomoesothorax (second figure) and pneumothorax (third figure).

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Fig. 18: Blast injury. Abdominal trauma. Hematoma of the adductors muscles (blue arrow) with a concomitant fracture of the left ischial bone.
Fig. 17: Head injury by missile fragments. Operated in Libya. CT scan at admission revealed right frontal lobe contusion (black arrows), as well as subarachnoid hemorrhage and parenchymal edema. 20 days later (second row images) there is adsorption of the hemorrhage and gliotic changes (white arrow).
Fig. 19: CT scan of a young soldier who fell down after an explosion and hit his head. CT revealed a hematoma located on right basal ganglia (red arrow). 18 days after the first scan (second row images) there is absorption of the hemorrhage and gliosis.

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Fig. 20: This man was amputated (right leg bellow the knee) after a bomb explosion. He had also severe muscle injury. X-ray shows the fracture of the distal femur and the amputated tibia and fibula. Nail stabilization by orthopedics.
Fig. 21: Head injury with temporal bone fracture. CT scan at admission revealed hematoma at left cerebellar hemisphere.
Fig. 22: Gustillo-Anderson grade I open fracture. Intramedullary nailing of left femur under fluoroscopic control. Debridement of his wound was performed subsequently.

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Fig. 23: 23 years old patient. Severe perineal injury due to a gunshot. Complete cut of the urethra and a 80% anal sphincter injury. Extraperitoneal rupture of the urinary bladder. Echogenic material in the urinary bladder due to hemorrhage.

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**Fig. 26:** Horizontal fracture of the temporal bone (arrow). There is extension into the middle ear cavity without incudomalleal separation.

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Conclusion

Explosions can produce unique patterns of injury seldom seen outside combat. Combat injuries vary in terms of epidemiology, mechanism of wounding, process after injury and outcome. Recognition of the various imaging characteristics helps with its diagnosis and treatment management.
Personal Information

251 HELLENIC AIR FORCE & V.A. HOSPITAL
KANELLOPOULOU 3, GOUDI
11525
ATHENS
GREECE

RADIOLOGY

Gyftopoulos Anastasios MD, Msch
Radiology Consultant

e-mail: tassosg@hotmail.com

tel: +302107465904
Fig. 24: 251 HELLENIC AIR FORCE & V.A. GENERAL HOSPITAL

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