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ORIGINAL ARTICLE

Imaging findings of the injured in the massive Beirut blast

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Abstract

Purpose (1) Describe imaging utilization and findings within two weeks of the 2020 Beirut blast according to the mechanism of injury, (2) determine the appropriate imaging modality per organ/system, and (3) describe changes in the workflow of a radiology department to deal with massive crises.

Materials and methods Two hundred sixty patients presented to the largest emergency department in Beirut and underwent imaging within 2 weeks of the blast. In this retrospective study, patients were divided into early (1) and late (2) imaging groups. Patients' demographic, outcome, type and time of imaging studies, body parts imaged, and mechanism and types of injuries were documented.

Results Two hundred five patients in group 1 underwent 502 and 55 patients in group 2 underwent 145 imaging studies. Tertiary blast injuries from direct impact and falling objects were the most common type of injuries followed by secondary (shrapnel) injuries. Both types of injuries affected mostly the head and neck and upper extremities. Plain radiographs were adequate for the extremities and CT for the head and neck. A regularly updated and practiced emergency plan is essential to mobilize staff and equipment and efficiently deliver radiology services during crises.

Conclusion Because the powerful Beirut blast occurred at the port located in the periphery of the city, most injuries seen on imaging were of the upper extremities and head and neck caused by the severe blast wind or penetrating shrapnel and resulted from people using their arms to protect their heads and bodies from direct impact and falling objects.

Keywords Radiology · Wounds and injuries · Musculoskeletal · Abdomen · Head and neck

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Introduction

On August 4, 2020, at 6:07 pm, the city of Beirut suffered a massive blast, graded as one of the most destructive non-nuclear urban explosions in modern history [1]. This happened while Lebanon was going through a political and economic crisis that had already drained the country and health sector [2, 3]. The explosion started with a fire in a hangar where fireworks and 2750 tons of ammonium nitrate were unsafely stored. Several small explosions followed over 30 min culminating in a massive explosion that shook the city of Beirut, a city of 2 million people resulting in 220 dead, 7000 injured, hundreds missing, 300,000 homeless, and 15 billion dollars lost in property damage [1, 3, 4]. The cause of the blast remains unknown.

As a result of the explosion, nine of 30 of the capital's hospitals suffered various degrees of damage, including the American University of Beirut Medical Center (AUBMC) which has the largest emergency department (ED) in Beirut designed to accommodate 42 patients. Imaging in such major disasters plays a key role in the less critically injured patients who do not require immediate lifesaving intervention and in those who require anatomic mapping prior to intervention [5].

In this study, we focus on the patients who underwent imaging studies after the Beirut blast. Our aims are (a) to familiarize radiologists with the patterns, distribution, and imaging findings of major blast injuries as determined by the mechanism of injury; (2) to determine the most appropriate imaging modality for each organ system and minimize the use of modalities that contribute minimally to the identification of injuries, specifically the added value of CT as the initial modality for imaging injuries that are traditionally assessed by plain radiographs such as musculoskeletal injuries; and (3) to describe the necessary preplanning and impromptu changes in the workflow of a radiology department to deal with massive crises.

Types and mechanisms of blast injuries

Primary blast injuries result from the wave of compressed and expanding gases moving outwards from the explosion at a supersonic speed causing an increase in atmospheric pressure followed by a rapid fall [6–8] and causing damage to adjacent tissues of different densities such as bowel, lungs, eardrums, and brain.

Secondary injuries occur when explosives detonate in closed and crowded spaces and consist of the blunt and penetrating injuries that occur due to the propulsion of objects and shrapnel causing a wide spectrum of injuries [1, 7, 8].

Tertiary injuries are caused by the powerful blast wind causing sudden acceleration of the body followed by abrupt deceleration as it hits a solid surface and have variable effects depending on the force of impact and the type of surface [7, 8].

Quaternary injuries are due to exposure to extreme heat and contaminants and to post-blast environmental damage [1, 6]. Imaging plays no direct role in these injuries.

Materials and methods

Patients Institutional Review Board (IRB) approval was obtained for this retrospective study and the informed consent waived. Patients' demographics, clinical data, and outcomes were obtained from the Electronic Medical Records.

All patients injured during the Beirut blast who presented to the ED at AUBMC within two weeks of the blast and underwent imaging were included in this study. The injured patients were divided into two main groups:

- Group 1 (immediate imaging group): all injured patients who underwent imaging studies within 30 h of the blast (August 4 and 5). Those in this group who were admitted to the hospital or followed up in outpatient clinics and underwent repeat imaging were evaluated to determine if new injuries became apparent during the 2–week follow-up period.

- Group 2 (delayed imaging group): all patients with blast-related injuries who presented to the ED or outpatient clinics and underwent imaging for the first time after 30 h of the blast and up to 2 weeks (August 6–18).

Classification of injuries Injuries were classified according to the organ system that was involved as follows: head and neck, chest, spine, abdomen and pelvis, and upper and lower extremities. Injuries in each organ system were further subclassified anatomically according to the organ that was injured.

Injuries were also categorized according to the mechanism of injury into primary, secondary, or tertiary blast-related injuries. Primary injuries included blast lung, abdominal hemorrhage, globe rupture, and concussions/traumatic brain injuries without physical signs of head injury. Secondary injuries were those caused by shrapnel. Tertiary injuries included fractures and closed and open brain injuries resulting from the person being thrown by the blast wind against a hard surface and injuries caused by falling buildings.

In the chaotic situation following an explosion, it is extremely challenging to accurately classify injuries according to the mechanism due to the lack of records and unclear histories obtained from the injured and witnesses. Therefore, the distinction between secondary and tertiary injuries was based on imaging alone [9] and only shrapnel-related injuries were classified as secondary.

Imaging data analysis Imaging findings for each organ system and anatomic subclassification were obtained from the original radiology reports in consensus by two authors (CA—R4 radiology resident and ChA—R3 radiology resident).

Data collected included the following: time of imaging, the body part that was imaged, the modality used for imaging, the presence or absence of traumatic findings on imaging, the specific organ(s) injured, a description of injury, and the presence and characteristics of shrapnel injuries.

We also documented discrepancies between the preliminary and final reports, including the type of imaging study, organ system injured, initial reader subspecialty, and whether the discrepancy was a miss or misinterpretation.

All CT scans were performed on an ICT 256 scanner (Philips, Amsterdam, Netherlands).

Multiplanar reformats were performed and Omnipaque™ 350 was used as the contrast medium, when needed.

Data analysis Microsoft Excel was used to aggregate and analyze the data.

Descriptive statistics were performed using mean and standard deviation (SD) for continuous variables.

Results

Patients The ED at AUBMC received at least 387 injured patients within a few hours after the blast. Of those patients, 270 (70%) were treated and released from the ED, 108 were admitted (28%), and 9 were dead on arrival (2%).

Of the 387 injured patients, 260 (67%) underwent imaging studies. Of those, 205 (79%) patients were in group 1 (immediate imaging group) and underwent 502 imaging studies, and fifty-five (21%) patients were in group 2 (delayed imaging group) and underwent 145 imaging studies. Additionally, 271 follow-up imaging studies were performed in group 1 patients during their inpatient or outpatient follow-up for two weeks after the blast.

The demographics of the imaged patients are shown in Table 1. Due to the massive influx of patients within a noticeably short time, many of whom were unconscious and unattended, some data are missing such as age, gender, and mechanism of injury.

Table 1 Characteristics of patients in the immediate and delayed imaging groups

	Immediate imaging group patients (group 1) (*n*=205)	Delayed imaging group patients (group 2) (*n*=55)
Age		
≤ 18 yrs	15 (7%)	2 (4%)
>18 yrs	151 (74%)	53 (96%)
Unknown	39 (19%)	0
Gender		
Male	110 (54%)	33 (60%)
Female	93 (45%)	22 (40%)
Unknown	2 (1%)	0

Group 1 (immediate imaging group) A total of 205 patients in this group underwent 502 imaging studies at presentation. The type and number of imaging studies performed and percentage of acute traumatic findings on imaging in each organ system are detailed in Table 2. Most patients in this group (*n*=90, 44%) were imaged within the first 4 h of the blast.

The majority (*n*=310, 61%) of the imaging studies were radiographs, mostly of the upper (*n*=145) and lower (*n*=93) extremities, followed by CT scans of the head and neck (*n*=94) and chest radiographs (*n*=60).

Acute traumatic injuries were seen in 153 patients (75%) and 275 (54.7%) imaging studies. There were acute traumatic injuries in more than 50% of the extremity radiographs and in 79% of head and neck, 63% of chest, and 56% of abdominal and pelvic CT scans.

Head and neck injuries were the most common on imaging in 35% of patients, followed by extremity fractures (29%) and chest injuries (19%). The anatomic subclassification of injuries is detailed in Table 3. The most common types of injury in the head and neck were bleeding and fractures (Fig. 1). The most common type of extremity injuries were upper extremity fractures (Fig. 2), slightly more than lower extremity fractures. The most common types of injuries in the chest were pneumothorax and parenchymal injuries. Examples of injuries in the abdomen were gastric intramural hematoma and devascularized kidney (Fig. 3b, c). The most common spine injury was vertebral fracture (Fig. 3d).

Shrapnel were found in 93 patients, predominantly in the extremities and head and neck, with one shrapnel found in the scrotum and another in the airway (Fig. 4a, b). The distribution of shrapnel throughout the body is detailed in Table 4. The largest shrapnel measured 10 cm (Fig. 5a, b) and extended through the orbital cavity into the nasal cavity and maxillary sinus causing traumatic globe rupture that necessitated enucleation.

The mechanism of injury determined by the type of injury and imaging findings is detailed in Table 5. They were predominantly tertiary in 54% and 33% of patients in groups 1

Table 2 Number and type of imaging studies per organ system and proportion of studies positive for traumatic injury

Imaging modalities and organ systems	Group 1: immediate imaging group (*n*=502 studies)		Follow-up imaging studies of group 1 (*n*=271 studies)		Group 2: delayed imaging group (*n*=145 studies)	
	No. and % of imaging studies per organ system from 502 studies	No. and % of positive studies from the total studies performed for each organ system	No. and % of imaging studies per organ system from 271 studies	No. and % of positive studies from the total studies performed for each organ system	No. and % of imaging studies per organ system from 145 studies	No. and % of positive studies from the total studies performed for each organ system
Radiographs	310 (61%)	149 (48%)	203 (74.9%)	33 (16.2%)	97 (66.8%)	36 (37.1%)
Head and neck	4 (0.8%)	2 (50%)	1 (0.3%)	1 (100%)	2 (1.3%)	0
Chest	60 (11.9%)	23 (38.3%)	161 (59.4%)	10 (6.2%)	27 (18.6%)	7 (25.9%)
Abdomen and pelvis	0	0	1 (0.3%)	0	0	0
Spine	8 (1.6%)	0	0	0	4 (2.7%)	0 (0%)
Upper extremities	145 (28.8%)	77 (53.1%)	19 (7%)	10 (52.6%)	32 (22%)	12 (37.5%)
Lower extremities	93 (18.5%)	47 (50.5%)	21 (7.7%)	12 (57.1%)	45 (31%)	21 (46.6%)
CT scans	189 (37.6%)	123 (65%)	57 (21%)	21 (36.8%)	38 (26.2%)	27 (71%)
Head and neck	94 (18.7%)	74 (78.7%)	29 (10.7%)	7 (24.1%)	16 (11%)	10 (62.5%)
Chest	27 (5.3%)	17 (62.9%)	7 (2.6%)	5 (71.4%)	7 (4.8%)	5 (71.4%)
Abdomen and pelvis	30 (5.9%)	17 (56.6%)	8 (2.9%)	2 (25%)	6 (4.1%)	3 (50%)
Spine	28 (5.5%)	7 (25%)	11 (4%)	6 (54.5%)	4 (2.7%)	3 (75%)
Upper extremities	2 (0.4%)	2 (100%)	1 (0.3%)	1 (100%)	2 (1.3%)	1 (50%)
Lower extremities	8 (1.6%)	6 (75%)	0	0	6 (4.1%)	5 (83.3%)
US scans	2 (0.4%)	2 (100%)	2 (0.7%)	0	0	0
Head and neck	1 (0.2%)	1 (50%)	0	0	0	0
Abdomen and pelvis	0	0	2 (0.7%)	0	0	0
Upper extremities	1 (0.2%)	1 (50%)	0	0	0	0
MRI	1 (0.2%)	1 (100%)	9 (3.3%)	8 (88.8%)	10 (6.8%)	9 (90%)
Head and neck	0	0	1 (0.3%)	1 (100%)	1 (0.6%)	1 (100%)
Spine	0	0	5 (1.8%)	4 (80%)	6 (4.1%)	5 (83.3%)
Upper extremities	0	0	0	0	1 (0.7%)	1 (100%)
Lower extremities	1 (0.2%)	1 (100%)	3 (1.1%)	3 (100%)	4 (2.7%)	4 (100%)
Total studies	502	275 (55%)	271	62 (23%)	145	72 (50%)

and 2, respectively, and included fractures and brain injuries resulting from blast wind instability. Secondary blast injuries caused by penetrating shrapnel sometimes resulted in fractures.

Only 2 ultrasounds were performed including of the brain of a 1–month-old with subarachnoid hemorrhage and another of the wrist of an adult patient and rupture of the extensor digiti minimi tendon was found. Bedside FAST (Focused Assessment with Sonography in Trauma) performed in the emergency department, vascular ultrasounds, and echocardiographies were excluded from our study. Only 1 MRI of the knee was performed for a patient with acute partial ACL tear and bone contusions.

Follow-up imaging studies for group 1 patients There were 45 patients in the immediate imaging group who were admitted to the hospital or had outpatient visits and underwent follow-up imaging within two weeks after the blast as detailed in Table 2. These patients underwent 271 imaging studies, mostly daily chest radiographs. Only 16% of the radiographs had additional positive findings during the 2–week follow-up period, for example, a Maisonneuve injury (Fig. 6).

Table 3 Anatomic subclassification of injuries in each organ system (the numbers do not add up due to the presence of multiple concurrent injuries)

Organs injured and type of injuries	Group 1: immediate imaging group No. and % of patients with injuries from the total 205 patients	Group 2: delayed imaging group No. and % of patients with injuries from the total 55 patients
Head and neck	72 (35.1%)	8 (14.5%)
Brain injuries	63 (30.7%)	8 (14.5%)
Total intracranial hemorrhage	46 (22.4%)	0
Subarachnoid hemorrhage	21 (10.2%)	1 (1.8%)
Subdural hematoma	17 (8.3%)	0
Epidural hematoma	12 (5.8%)	0
Hemorrhagic contusions	16 (7.8%)	0
Subgaleal hematoma	32 (15.6%)	3 (5.4%)
Skull and facial fractures	37 (18%)	3 (5.4%)
Venous sinus thrombosis due to fracture	2 (1%)	0
Infarcts	1 (0.5%)	0
Vocal cord paralysis	1 (0.5%)	0
Brain death	1 (0.5%)	0
Shrapnel in head and neck	26 (12.6%)	4 (7.2%)
Orbit	23 (11.2%)	3 (5.4%)
Orbital wall fracture	20 (9.7%)	1 (1.8%)
Lens dislocation	2 (1%)	0
Vitreous hemorrhage	1 (0.5%)	1 (1.8%)
Globe rupture	1 (0.5%)	1 (1.8%)
Shrapnel in orbit	10 (4.8%)	0
Chest	39 (19%)	8 (14.5%)
Parenchymal injury	9 (4.4%)	3 (5.4%)
Pneumothorax	9 (4.4%)	4 (7.2%)
Rib fracture	13 (6.3%)	3 (5.4%)
Sternum fracture	1 (0.5%)	0
Pneumatocele	3 (1.5%)	1 (1.8%)
Hemothorax	1 (0.5%)	0
Hemopericardium	1 (0.5%)	0
Shrapnel in the chest	3 (1.5%)	0
Abdomen and pelvis	19 (9.3%)	3 (5.4%)
Liver injury	4 (1.9%)	1 (1.8%)
Kidney injury	3 (1.5%)	0
Splenic injury	2 (1%)	0
Intra-abdominal hemorrhage	9 (4.4%)	3 (5.4%)
Adrenal hematoma	1 (0.5%)	0
Gastric hematoma	1 (0.5%)	0
Shock bowel	1 (0.5%)	0
Shrapnel in the abdomen and pelvis	3 (1.5%)	0
Musculoskeletal	104 (50.7%)	21 (38.1%)
Upper extremities	74 (36.1%)	9 (16.3%)
Upper extremity fracture	38 (18.5%)	6 (10.9%)
Upper extremity dislocation	6 (2.9%)	1 (1.8%)
Lower extremities	47 (22.9%)	8 (14.5%)
Lower extremity fracture	24 (11.7%)	4 (7.2%)
Lower extremity dislocation	5 (2.4%)	0
Upper and lower extremity fractures	60 (29%)	11 (36.3%)
Pelvic fractures	6 (2.9%)	2 (3.6%)

Table 3 (continued)

Organs injured and type of injuries	Group 1: immediate imaging group No. and % of patients with injuries from the total 205 patients	Group 2: delayed imaging group No. and % of patients with injuries from the total 55 patients
Ligamentous/tendinous injury	1 (0.5%)	1 (1.8%)
Spine	16 (7.8%)	2 (3.6%)
Odontoid fracture	1 (0.5%)	0
Compression fracture	6 (2.9%)	1 (1.8%)
Distraction injuries	3 (1.5%)	0
Posterior element fractures	9 (4.4%)	1 (1.8%)
Shrapnel in the extremities	51 (24.9%)	7 (12.7%)

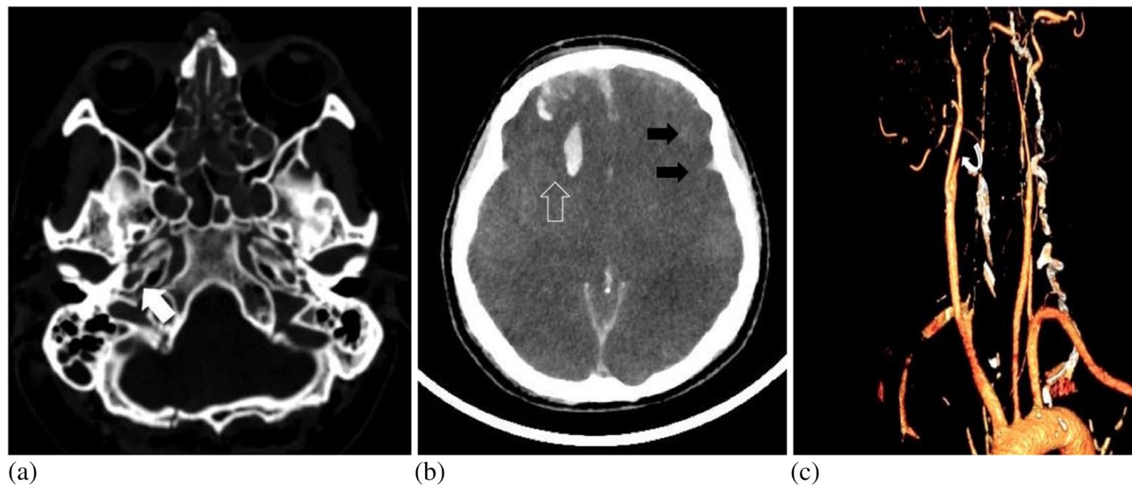

Fig. 1 Axial unenhanced CT images of the skull base on bone settings (**a**) and of the brain (**b**) and 3D reconstructed CT angiogram of the head and neck (**c**). There are skull base fractures involving the right carotid canal (solid white arrow) causing occlusion of the right internal carotid artery (ICA) distal to the bifurcation (curved white arrow) and subarachnoid and right frontal parenchymal hemorrhages (open white arrow). There is also diffuse hypoxic ischemic brain injury manifested as lack of gray-white matter differentiation and diffuse edema with effacement of the sulci (solid black arrow) secondary to right carotid artery occlusion

There were 9 follow-up MRI studies, and most of these (88%) were positive. The injuries seen on follow-up MRI were ligamentous tears in the spine, acetabular tears, spinal cord contusions, and scapholunate ligament injury. These findings were likely present at presentation but were not visible on plain radiographs. Other findings noted at follow-up CT scans were dural venous sinus thrombosis due to skull fractures, brain infarcts, vocal cord paralysis, and diffuse brain edema.

Group 2 (delayed imaging group *n*=55) There were 55 patients in this group, 49 presented within the first week and 6 in the second week. These 55 patients underwent 145 imaging studies. The type and number of imaging studies performed and percentage of acute traumatic findings on imaging in each organ system are detailed in Table 2.

The majority (*n*=77, 53%) of the imaging studies were plain radiographs of the upper (*n*=32) and lower (*n*=45) extremities. This was followed by chest radiographs (*n*=27) and head and neck CT scans (*n*=16).

Acute traumatic injuries were identified in 28 patients (51%) and 72 (49.6%) imaging studies. There were acute traumatic injuries in 46% of the extremity radiographs, 26% of the chest radiographs, and 63% of the head and neck CT scans. The distribution and characteristics of acute traumatic injuries are detailed in Table 3.

Extremity fractures were the most common type of injuries seen in 38% of patients on imaging followed by head and neck and chest (15% each) and abdomen (5%) injuries. The most common types of injuries were fractures of the upper extremities in the musculoskeletal system, intracranial

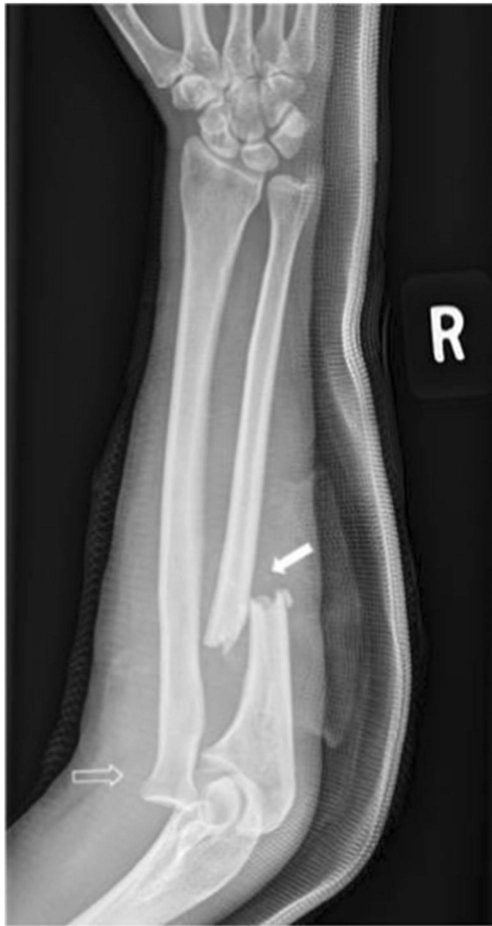

Fig. 2 Plain radiograph of the forearm AP view. There is displaced proximal ulnar fracture (white arrow) with dislocated radial head (open arrow) (Monteggia fracture dislocation)

bleeding in the head and neck, and pneumothorax in the chest.

Shrapnel were found in 8 patients, predominantly in the extremities (n=7) and head and neck (n=1) with resultant penetrating injuries. The distribution of shrapnel throughout the body is detailed in Table 4.

The type of injuries according to the mechanism of injury is detailed in Table 5.

Discrepancies Discrepancies between the preliminary and final reports were limited and documented only on CT in 9 of group 1 patients. Non-displaced fractures were the most missed (Segond, clavicle, acromion, rib, and vertebral transverse process fractures and acromioclavicular subluxation). Other misses were grade 1 splenic injury, partial lens subluxation, and a small intramuscular hematoma. All misses were by senior residents except for the Segond fracture, which was missed by a non-MSK attending radiologist. There were two misinterpretations by non-abdominal attending radiologists including a liver hemangioma called laceration and retroperitoneal gas described as intraperitoneal necessitating an exploratory laparotomy (Fig. 3a).

Discussion

Most injuries that were documented on imaging after the Beirut blast were tertiary injuries in 54% of group 1 and 33% of group 2 patients and involved predominantly the head and neck and upper extremities. This was followed by secondary injuries, caused by shrapnel, seen on imaging in 32% of group 1 and 15% of group 2 patients with upper extremity penetrating injuries being the most common. This is different from what has been reported in other blast imaging studies [6, 8, 10] that reported predominantly type 2 injuries of the central body. This reflects the pattern, location, and effect of the explosion. Beirut blast occurred at the port, which is located at the periphery of the city of Beirut, in an open space, and was preceded by smaller shock waves triggering people to seek shelter in buildings. Most injuries seen on imaging resulted from people being thrown by the blast wind against hard surfaces and objects falling from damaged buildings. This is different from the effect of explosive devices used in terrorist attacks, which are usually detonated within crowds and/or in closed spaces and often packed with shrapnel that cause secondary injuries.

Primary blast injuries were the least type of injuries seen on imaging in only 10% of patients in group 1 and 9% of patients in group 2 and included abdominal hemorrhage (peritoneal, retroperitoneal, and abdominal organ hematomas), intestinal perforation, blast lung (pneumothorax, ground-glass opacities, and/or pneumatoceles), and globe rupture. Most of these patient (14 in group 1 and all 5 in group 2) underwent follow-up imaging with no new or worsening findings. This type of injury is not commonly seen on imaging because those close to the blast usually die or are hemodynamically unstable to undergo imaging, and those farther out may have mild concussions that are occult on or do not require imaging.

Musculoskeletal injuries were the most common type of injuries seen after the Beirut blast in 48% of the imaged patients in both groups. The upper extremity was the most injured region, and hand radiographs had the most positive findings. Head and neck injuries were the second most common. The patterns of injuries are in keeping with sudden deceleration injuries caused by hitting hard surfaces after rapid acceleration by the blast wind and related to using the arms for protection from the impact and from falling objects. This is different from terrorist bombs that often result in serious central body injuries [10].

There were fewer and less severe injuries in the late imaging group (group 2) compared to the early imaging group (group 1) with no difference in the type of injuries. This

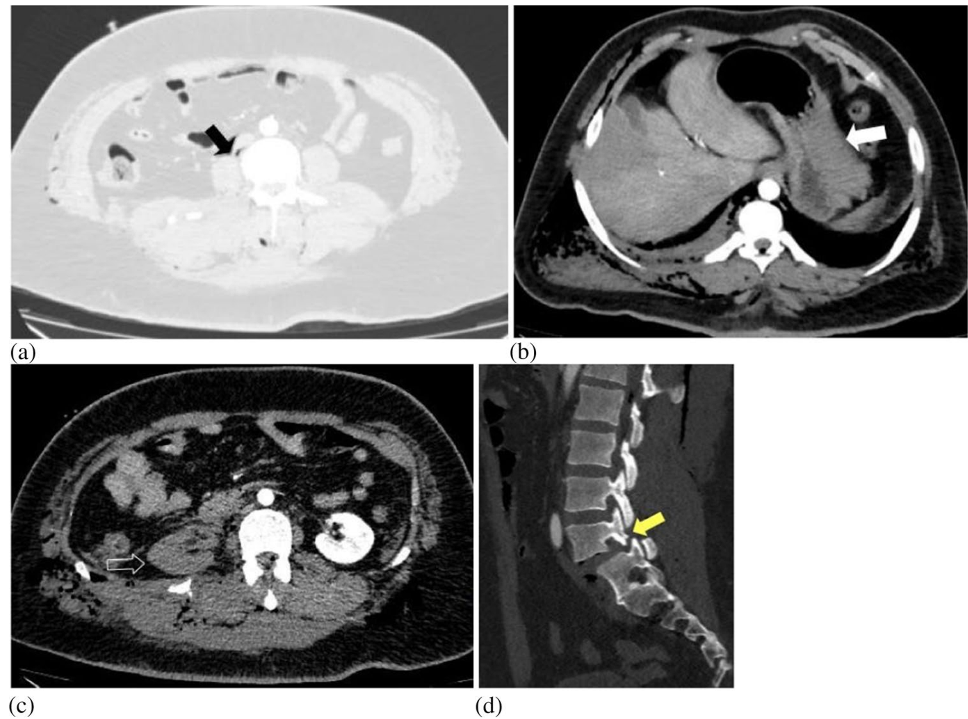

Fig. 3 Axial enhanced CT images of the lower abdomen (**a**) on lung settings, upper abdomen (**b**) and lower abdomen (**c**) on soft tissue settings, and sagittal reformatted image of the spine (**d**) on bone settings in a patient with multiple tertiary injuries. There is air in the retroperitoneum (black arrow) that extended from a pneumomediastinum and was misinterpreted as intraperitoneal air, a large intramural hematoma involving the greater gastric curvature (white arrow), a devascularized right kidney (open white arrow) secondary to spine injury with anterior translation of L5 over S1 level due to bilaterally locked and fractured facets (yellow arrow)

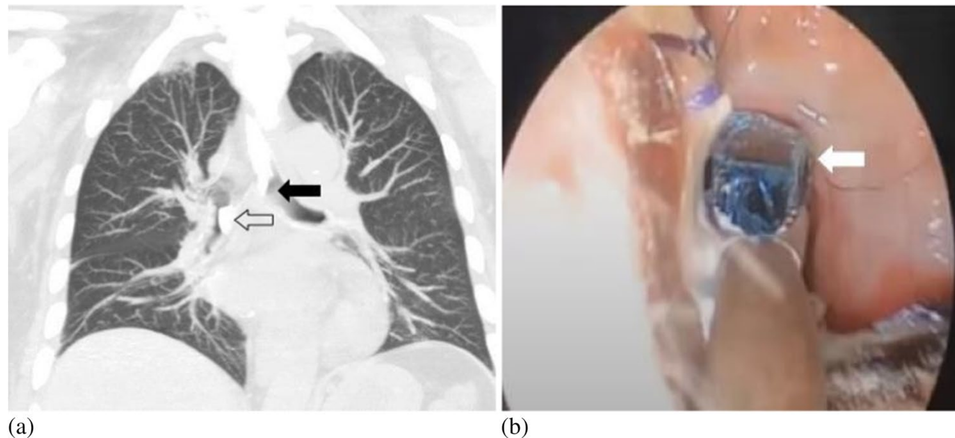

Fig. 4 Coronal unenhanced reformatted CT image through mid-chest on lung settings (**a**) and a matching image from a bronchoscopy study (**b**) in a patient with secondary injury. There is a glass piece in the bronchus intermedius (open black arrow) with selective intubation of the left main bronchus (black arrow). Note the glass piece on bronchoscopy (white arrow) (bronchoscopy image courtesy of Dr. Usama Hadi Department of Otolaryngology, Head and Neck Surgery at AUBMC)

categorization into early and late imaging groups was done to determine if there are differences between immediate and delayed blast injuries and their imaging requirements. On follow-up of group 1 patients who were admitted and/or had regular follow imaging, there were more soft tissue, ligamentous, and tendinous injuries that required more MRI studies.

Conventional radiography is the initial study of choice for quick screening for fractures and radiopaque shrapnel. In our study, most extremity injuries were detected by conventional radiography and only 6 of 104 patients who underwent CT because of continued symptoms that could not be explained by the X-ray findings or for other non-musculoskeletal indications had additional findings at CT. These included a trimalleolar fracture diagnosed as bimalleolar on X-ray, acromioclavicular joint injury, and non-displaced pelvic and rib fractures that were not seen on the initial radiographs. Therefore, CT is of added value if fractures are suspected but not seen on X-rays, but in the case of extremities, radiographs are sufficient to make the

Table 4 Shrapnel distribution in anatomic locations

Shrapnel distribution	No. of patients with shrapnel injuries from the total number of patients in the group	
	Group 1: immediate imaging group (*n*=205)	Group 2: delayed imaging group (*n*=55)
Soft tissues of the head and neck	23 (11.2%)	4 (7.2%)
Orbit	10 (4.8%)	1 (1.8%)
Upper extremities	36 (17.6%)	3 (5.4%)
Wrist and hand	19 (9.3%)	1 (1.8%)
Forearm	12 (5.8%)	0
Arm	5 (2.4%)	2 (3.6%)
Shoulder	6 (2.9%)	0
Lower extremities	22 (10.7%)	4
Foot and ankle	7 (3.4%)	2 (3.6%)
Leg	3 (1.5%)	1 (1.8%)
Knee	5 (2.4%)	0
Thigh	3 (1.5%)	1 (1.8%)
Hip	4 (1.9%)	0
Chest wall	2 (1%)	1 (1.8%)
Airways	1 (0.5%)	0
Abdomen and pelvis	3 (1.5%)	0
Scrotum	1 (0.5%)	0

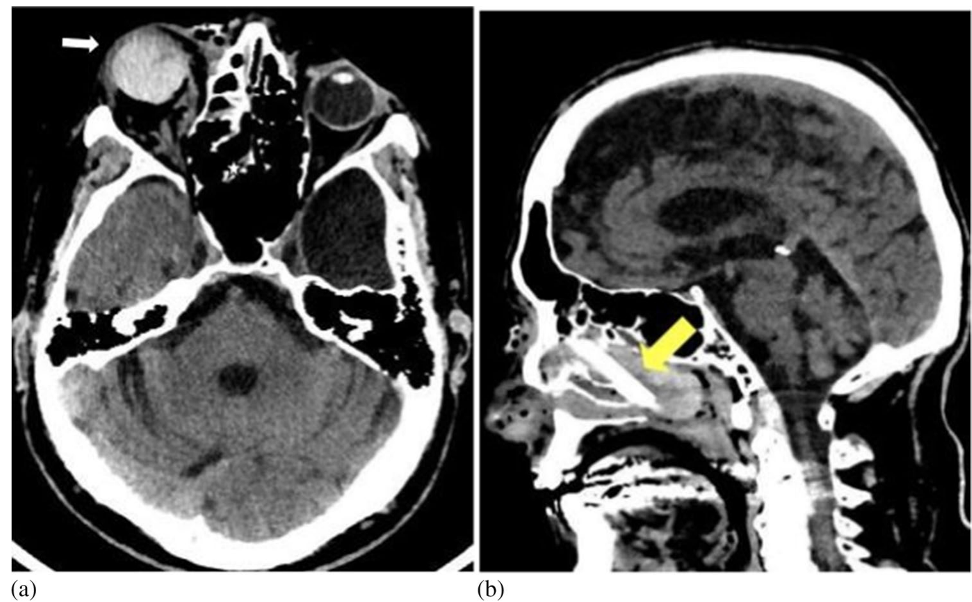

Fig. 5 Unenhanced axial images of the head at the level of orbits (**a**) and a reconstructed image in the sagittal plane (**b**) in a patient with secondary type injury. There is traumatic right globe rupture and exophthalmos (arrow) due to a large piece of glass (yellow arrow) perforating the globe and extending from the orbit into the nasal cavity and maxillary sinus

diagnoses. MRI is useful if significant ligamentous and tendinous injuries are suspected as these cannot be seen on X-rays.

There are certain injuries where CT has been shown to be more beneficial than conventional radiography including head and neck, spine, and abdominal injuries. Plain radiographs were more commonly performed than CTs after the Beirut blast although, in some smaller explosions, CT scans were used more than radiographs due to a smaller number of non-critical patients [11].

CT is not the panacea and has limitations; for example, shrapnel is not always radiopaque, and early central nervous system injuries are not always apparent. MRI has a limited initial role after major blasts because of the long examination times when speed is of the essence, and the effect of the strong magnetic field on unknown types of shrapnel may

Table 5 Type of injuries according to the mechanism of injury. Due to the challenge in distinguishing secondary from tertiary blast-related injuries based on imaging findings alone, we considered injuries to be tertiary in the absence of shrapnel in the imaged body part

Types of injury	Group 1 (*n*=205)	Group 2 (*n*=55)	Clinical presentation
Primary	20 (10%)	5 (9%)	Globe rupture, blast lung, intestinal perforation, abdominal hemorrhage
Secondary	65 (32%)	8 (14%)	All injuries caused by shrapnel
Tertiary	110 (54%)	18 (33%)	Fractures and skin breaches without the presence of shrapnel
No injuries	10 (5%)	24 (44%)	

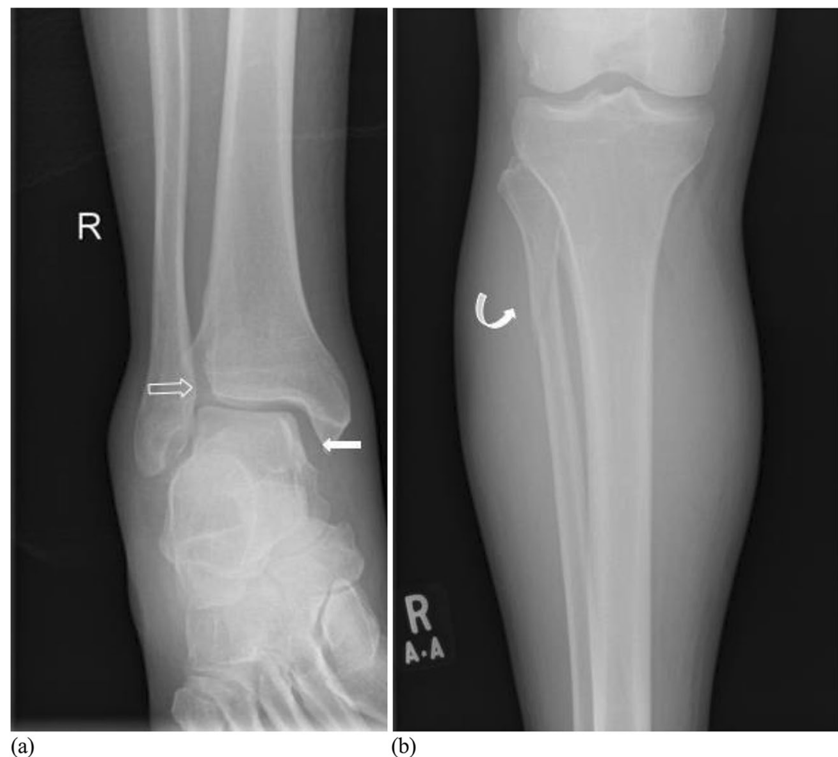

Fig. 6 Plain radiograph of the right ankle (mortise view) (**a**) and right tibia and fibula (**b**) performed on August 4. There is a widened medial clear space (arrow) and decreased tibiofibular overlap (open arrow) raising the possibility of Maisonneuve injury. The emergency department was informed of the need to perform a leg radiograph to exclude Maisonneuve injury. A radiograph of the tibia and fibula performed on 7 Aug 2020 and there is a spiral fracture of the proximal fibular metaphysis (curved arrow) consistent with Maisonneuve injury

exacerbate injuries. MRI is often reserved for added evaluation after the immediate post-blast period [10].

This is another study that underscores the vital role of radiology in the initial assessment of patients after major explosions. The radiology department during such events must ensure adequate access to imaging resources and fast imaging and interpretation of the studies. A priori knowledge of which X-ray and ultrasound equipment can be mobilized to the emergency department is important and often required along with cancelation of all non-urgent imaging to provide maximum capacity and prompt service. After the Beirut blast, and since it occurred early in the evening while most physicians and staff were still in the hospital, all available attending physicians and residents were mobilized. Some, especially those with surgical background, went straight to the emergency department and helped triage patients with other physicians. Others interpreted radiographs on the spot, performed bedside ultrasounds, recommended the most appropriate imaging tests to the ED physicians, and moved patients to and from the imaging rooms. Senior radiology residents and attending radiologists of all subspecialties provided verbal or written preliminary on-the-spot reports of the X-rays, and attending radiologists interpreted CT scans on the spot, usually at the console as soon as they were completed, conveyed the relevant findings to the treating team either directly or by telephone, and documented the communication on the request form. Formal reports were issued the following day.

A major challenge was the lack of patient identification and adequate history documentation on the electronic medical record system, which caused problems during the reporting process. CT studies of patients without identification were assigned special accession numbers, and the reports were later changed to regular accession numbers and

reconciled with the proper patient's medical record. This scenario is not unexpected in a mass casualty situation. It is therefore essential to conduct a gap analysis after any disaster to improve the disaster plan for future events. The importance of regular reassessment of the disaster plan and regular practice drills cannot be overstressed. There should also be a plan in place for dealing with major power outages with multiple back-up systems.

Our study has several limitations. First, clinical data may be missing due to the mass influx of patients, many of whom without history and/or identification. Second, serious and minor injuries may have been underestimated as many of these did not undergo imaging due to hemodynamic instability or unnecessity. Third, the exact mechanism of injury could not be always determined on imaging alone. Fourth, the exact added value of CT is not known in the setting of musculoskeletal trauma as not all extremity injuries had follow-up CT studies.

Lastly, this is a single-center study that reflects only trauma cases that were imaged at this center.

In conclusion, we found that injuries identified on imaging following the massive Beirut blast were somewhat different from other explosions and were mostly tertiary injuries of the upper extremities and head and neck caused by the impact of severe blast wind. This is related to the distant location of the blast at the port, the surrounding open space, and the preceding shockwave that prompted people to seek shelter. Also, people used their arms to protect themselves when hitting hard surfaces and to shield their heads from falling buildings. We found that plain radiography was adequate for assessing suspected extremity injuries and that CT added little in those patients who underwent CT, whereas CT was necessary for the evaluation of head and neck injuries. The response of radiology departments to mass casualty events should be prompt and encompass mobilizing equipment, staff, and radiologists to participate in the triaging, transporting, imaging, and on-the-spot interpretation of studies. Having a comprehensive, regularly practiced, and updated disaster plan for rapid mobilization and delivery of equipment/service is essential to efficiently provide the much-needed radiology service during major disasters. Some initial misses and misinterpretations of the wet reads are inevitable under such stressful circumstances.

Author contribution All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by CA, ChA, FAZ, and MK. The first draft of the manuscript was written by CA, YJ, and HH, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Declarations

Ethics approval This research study was conducted retrospectively. We consulted with the IRB of American University of Beirut who determined that our study did not need ethical approval. An IRB official waiver of ethical approval was granted from the IRB.

Conflict of interest The authors declare that they have no conflict of interest.

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