Emerg Radiol (2017) 24:47–53
DOI 10.1007/s10140-016-1441-y

ORIGINAL ARTICLE

Emergency radiology and mass casualty incidents—report of a mass casualty incident at a level 1 trauma center

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Received: 15 June 2016 / Accepted: 2 September 2016 / Published online: 13 September 2016

Abstract The aims of this article are to describe the events of a recent mass casualty incident (MCI) at our level 1 trauma center and to describe the radiology response to the event. We also describe the findings and recommendations of our radiology department after-action review. An MCI activation was triggered after an amphibious military vehicle, repurposed for tourist activities, carrying 37 passengers, collided with a charter bus carrying 45 passengers on a busy highway bridge in Seattle, WA, USA. There were 4 deaths at the scene, and 51 patients were transferred to local hospitals following prehospital scene triage. Nineteen patients were transferred to our level 1 trauma center. Eighteen casualties arrived within 72 min. Sixteen arrived within 1 h of the first patient arrival, and 1 casualty was transferred 3 h later having initially been assessed at another hospital. Eighteen casualties (94.7 %) underwent diagnostic imaging in the emergency department. Of these 18 casualties, 15 had a trauma series (portable chest x-ray and x-ray of pelvis). Whole-body trauma computed tomography scans (WBCT) were performed on 15 casualties (78.9 %), 12 were immediate and performed during the initial active phase of the MCI, and 3 WBCTs were delayed. The initial 12 WBCTs were completed in 101 min. The mean number of radiographic studies performed per patient was 3 (range 1–8), and the total number of injuries detected was 88. The surge in imaging requirements during an MCI can be significant and exceed normal operating capacity. This report of our radiology experience during a recent MCI and subsequent after-action review serves to provide an example of how radiology capacity and workflow functioned during an MCI, in order to provide emergency radiologists and response

Electronic supplementary material The online version of this article (doi:10.1007/s10140-016-1441-y) contains supplementary material, which is available to authorized users.

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planners with practical recommendations for implementation in the event of a future MCI.

Keywords Mass casualty incident · Radiology · Emergency radiology · After action review · Mass casualty planning

Introduction

In a mass casualty incident (MCI), a large number of injuries occur in a relatively short period of time, typically due to acts of terrorism, natural disasters, or vehicle accidents [1]. Typically, the number of casualties will temporarily exceed available medical resources for individualized patient care, and medical resources will become strained [1–4].

Mass casualty plans anticipate these scenarios to optimize preparedness during these events. Mass casualty planning involves a complex multi-institutional and multidisciplinary approach in order to handle the large influx of casualties in a short period of time [5]. Many existing radiology disaster plans only address staffing, cancelation of routine cases, availability of equipment, and provision of manpower to address the incidents [5] and often underestimate the amount of imaging required [2, 6–9], creating a potential bottleneck in patient flow [6, 8].

The Center for Disease Control (CDC) guidelines suggest that radiology services should be able to coordinate a response within 2 h, for an explosion with 200 casualties, and to continue operations for a period of 72 h [9, 10].

The aims of this article are to describe the events of a recent MCI involving our institution and to describe the radiology response to the event. We also describe the findings and recommendations of our radiology department after-action review, in order to provide emergency radiologists and response planners with practical recommendations for implementation in the event of a future MCI.

Materials and methods

Mass casualty incident

On September 24 at 11:15 a.m., an amphibious military vehicle, repurposed for tourist activities, carrying 37 passengers collided with a charter bus carrying 45 passengers on a busy highway bridge in Seattle, WA, USA.

There were four deaths at the scene, and 51 patients were transferred to local hospitals following prehospital scene triage (Fig. 1). During scene triage, casualties are segregated according to severity of injury. Those that require immediate attention in order to survive are typically coded T1 (red), and those requiring medical attention, but can wait a little longer, are coded T2 (yellow) [4]. T3 (green) are those with minor injuries, the "walking wounded," and those coded T4 (black) are severely injured and are not able, or are unlikely, to survive.

Harborview Medical Center (HMC) is the only level 1 trauma center in the state and received 19 casualties from this incident (12 coded T1 (red), 6 coded T2 (yellow), and 1 coded T3 (green)).

Eighteen casualties arrived at HMC in a 72-min period (from the arrival of the first patient), 16 of whom presented within 1 h. During this initial period, 17 were brought in by ambulance and 1 was a walk-in to the emergency department

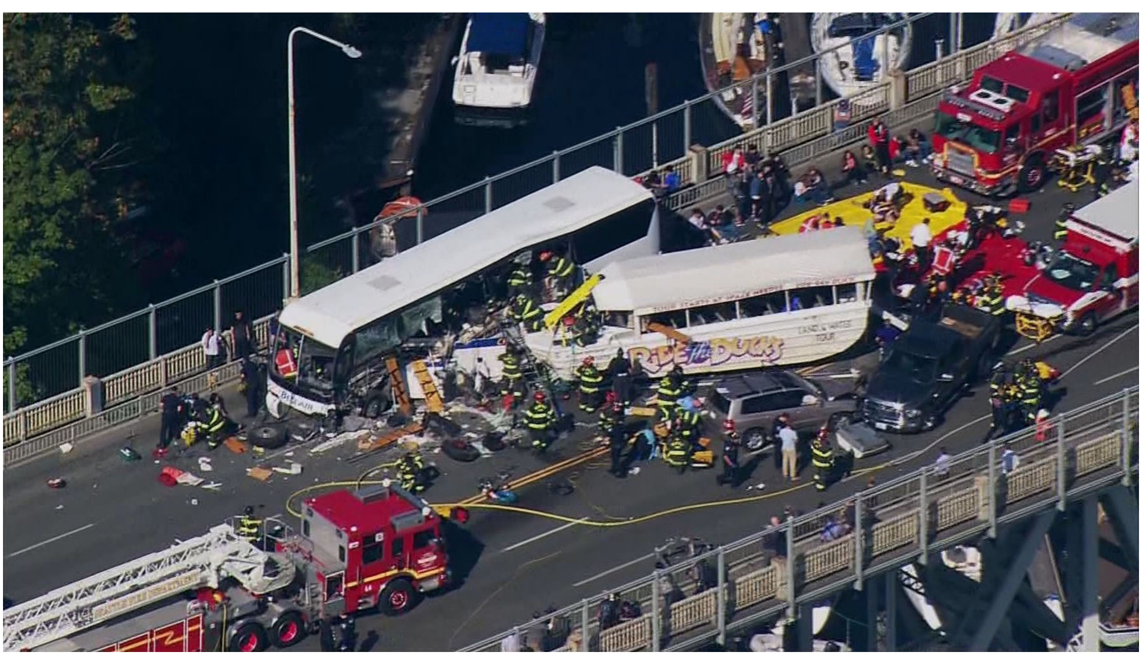

Fig. 1 Image demonstrates the crash scene and onsite prehospital triage with *red* and *yellow* tarpaulins (image used with permission of King5 News, Seattle, WA, USA)

(ED). The last patient was a hospital transfer who arrived 4 h after the initial MCI activation for management of traumatic injuries at our institution.

Radiology mass casualty staffing

Normal emergency radiology staffing during the day (7 a.m.–10 p.m.) consists of an attending, a fellow (or physician assistant (PA)), and a radiology resident. As the MCI occurred during late morning and during daytime hours, additional resources were rapidly mobilized to the ED, resulting in an MCI radiology response group of six emergency radiology faculty (five MDs and one PA), two emergency radiology fellows, a neuroradiology fellow, and a radiology resident.

The emergency radiologist attending on service at the time of the MCI assumed the role of lead radiologist for the duration of the mass casualty activation. The lead radiologist's role was to communicate and coordinate directly with lead trauma surgeons, lead emergency medicine physicians, lead administrators, and lead radiology technicians to ensure efficient access to imaging and rapid throughput. The lead radiologist also directed imaging protocols and allocated roles for the other onsite radiology faculty and trainees.

Three emergency radiologists (two faculty and one fellow) were stationed at the three CT scanners in our facility (described below) to provide immediate verbal reports to clinical teams in attendance and to document the reported results in a brief handwritten report to be referenced in the final electronic report. A neuroradiology fellow rotated between all three scanners to provide preliminary interpretation of the head and neck CT angiography (CTA) scans.

The lead radiologist assigned two radiologists and an emergency radiology fellow to three of the four available picture archiving and communication system (PACS) stations in our ED. The final PACS station was used intermittently by the lead radiologist during coordination and communication activities. One of the assigned PACS station to attending radiologists was charged with coordinating initial trauma series acquisition, with the lead radiology technician interpreting the trauma series radiographs and communicating these results to the clinical teams directly. The other assigned PACS station attending was charged with generating final interpretations of cross-sectional imaging (whole-body CT in most cases), as they became available, and assisting with trauma series results communication. As the initial wave of trauma series radiographs were completed, interpreted, and communicated during the first hour after MCI activation, the first designated PACS station attending began providing final interpretations for cross-sectional imaging. These individuals were later joined by the radiologists stationed at the CT scanners to assist with final cross-sectional imaging report generation and results communication. The emergency radiology fellow assigned to the fourth PACS station did not interpret examinations in real time but acted in the role of consultant to address specific questions from various clinicians with respect to the imaging being performed.

A radiology departmental debriefing occurred in the emergency radiology department, 15 min after the end of MCI activation was called, and conventional ERad staffing level was resumed shortly after.

Mass casualty imaging utilization

Trauma series

Eighteen of the 19 casualties (94.7 %) underwent diagnostic imaging in the ED. The walk-in patient did not obtain imaging. Fifteen of the initial 18 patients underwent a trauma series (TS), consisting of a portable x-ray of the chest (CXR) and of the pelvis. Five of these exams were positive for injury, including two pelvis fractures and three extremity fractures.

Computed tomography There are three CT scanners in our department: Siemens AS+128, Siemens Somatom Force (Siemens, Erlangen, Germany) and GE LightSpeed 16 Pro (General Electric Medical Systems, Waukesha, WI).

Our typical whole-body CT (WBCT) scan protocol includes decision points regarding whether to obtain CTA of the head and neck or just of the neck, as well as whether to extend the arterial phase imaging of the torso through the pelvis. To expedite imaging of patients, these decision points were discarded and the same WBCT protocol was performed on all patients.

This included a non-contrast CT head, head and neck CTA, arterial phase imaging of the chest to the level of the iliac crests, and portal venous phase imaging of the abdomen and pelvis. A fixed delay of 25 s (following initiation of contrast injection) was utilized for the head and neck CTA arterial phase imaging of the torso, and a fixed delay of 70 s (following initiation of contrast injection) was utilized for portal venous phase imaging. No delayed images were obtained. CTs of the cervical, thoracic, and lumbosacral spines were reconstructed retrospectively.

WBCTs were performed on 15 out of 19 casualties. Twelve were immediate, performed during the initial active phase of the MCI. Three were delayed and performed after the initial active phase. One of the three had fluid on a focused assessment with sonography in trauma (FAST) scan and hemodynamic instability and obtained their WBCT later on that day following splenectomy. The other two patients did not initially appear to have significant injuries clinically and were imaged after the initial active phase of the MCI. Two patients were scanned on the GE LightSpeed scanner for 34 min. Four patients were scanned on the Siemens Somatom scanner for 62 min. Six patients were scanned on the Siemens Force scanner for 101 min. Each of the three CT scanners processed one

Table 1 Distribution of injuries

Body region	Number
Head	
Subdural hemorrhage	4
Subarachnoid hemorrhage	4
Intraparenchymal hematoma	3
Epidural	0
Diffuse axonal injury	1
Base of skull fracture	2
Skull vault fracture	0
Deep scalp laceration	1
Face	
Facial fractures	7
Orbital fractures	1
Chest	
Rib fractures	9
Pulmonary contusion	4
Pneumothorax	6
Hemothorax	3
Pneumomediastinum	1
Abdominal injuries	
Splenic	2
Liver	1
Retroperitoneal bleed	1
Pelvic	
Fractures	5
Spine	
Fractures	7
Vascular	
Carotid artery	3
Vertebral artery	3
Pelvic pseudoaneurysm (requiring embolization)	1
Soft tissue	
Body wall contusions	4
Muscle laceration	1
Extremity fractures	
Humerus	1
Clavicle	4
Femur	2
Ulna	1
Tibia	3
Fibula	2
Hand	1
Shoulder dislocation	1

patient for WBCT approximately every 15–17 min with all 12 immediate WBCT scans performed within 10 min.

One patient was transferred to interventional radiology to embolize a bleeding pseudoaneurysm in the pelvis and another to neuroradiology for cerebral angiography.

Table 2 Summary of radiographic studies performed

Radiography test performed	Number
Trauma series (AP chest and pelvis)	15
Chest x-ray (not part of TS)	3
Hip	2
Femur	3
Knee	5
Tibia and fibula	10
Ankle	3
Foot	1
Shoulder	4
Clavicle	3
Humerus	1
Elbow	1
Radius and ulna	2
Wrist	2
Hand	2
Cervical spine	1
Lumbar spine	1

TS trauma series

A summary of the distribution of injuries ($n = 88$) detected by body region per patient is presented in Table 1.

Additionally, while in the ED, 13 patients had 41 additional radiographic imaging studies performed, with a range of 1 to 8 additional radiographic studies per patient (mean = 3). These are summarized in Table 2.

Discussion

The aim of a mass casualty plan is to do the most good for the most people in the shortest time possible. Resources are stretched and the capacity for individualized care is exceeded. The typical MCI follows a number of phases: an initial chaotic phase where new casualties arrive at the hospital, and the number of anticipated casualties is not yet known, followed by a plateau/definitive phase once the last patient arrives. The final phase is the pronouncement of the end of the MCI activation [2, 6].

The main roles of radiology during an MCI are to efficiently image the most critically injured or ill patients, for immediate medical or surgical intervention, and to communicate the relevant findings in a fast, appropriate, and accurate manner [9, 11, 12].

Interestingly, in a survey study performed to assess physicians' knowledge of MCI plans, the awareness of major incident plans was poor in general but worst among radiologists and radiology trainees when compared to other specialties [13]. Similarly, in a recent mass casualty emergency radiology review, based on multinational experience of the authors from several level 1 trauma centers, radiology departments are underrepresented or in many cases excluded from the disaster management plans of hospitals and associated drills [4].

An after-action review of an MCI is a vital part of the process of mass casualty preparedness and planning for future MCI events [2, 4, 11]. The purpose is to constructively evaluate performance and identify potential sites of improvement for response planners and future events and should encourage and enable staff to disclose any issues that arose during the MCI to management and disaster planners. A departmental debriefing, including hospital imaging staff and radiologists, occurred 15 min after the end of MCI activation. Emergency radiology faculty and fellows met the following week to perform an additional after-action review of radiology performance during the MCI. The aims of these meetings were to discuss the event of the MCI and to constructively evaluate radiology performance, with a view to providing our team and hospital response planners practical recommendations for implementation in the event of a future MCI. A number of potential issues and areas for improvement were identified:

Imaging throughput

The reported practical radiology approach to MCIs varies considerably [1–3, 7, 11, 12, 14]. Plain radiographs and trauma series (typically chest x-ray, pelvis x-ray, ±lateral C-spine) are often initially performed to rapidly identify injuries as part of the initial survey of the trauma patient [2, 6, 11, 14]. In our series, TS had positive radiologic findings in five patients.

In our event, 84.2 % of the patients (16 of 19) underwent CT as part of their initial assessment. This included 15 WBCTs and a CT of the cervical spine. We completed 12 of the immediate WBCTs in 101 min on 3 CT scanners, with an average of 1 CT scan every 15–17 min per scanner using a WBCT technique that included a non-contrast head CT; a CTA neck, chest, and abdomen followed by a portal venous phase abdomen; and a pelvis CT. Simulated MCI studies have demonstrated that with practice, the surge capacity of CT and throughput with WBCT can be increased over standard workflow by almost a factor of 3 by implementing an accelerated CT protocol for MCI in combination with immediate reporting at a stand-alone console in CT with a calculated theoretical CT capacity of 11 patients per hour with a 64-slice multidetector computed tomography (MDCT) [1, 3, 4, 9]. A comparison of our experience to a simulated study using an accelerated CT protocol for MCI [3] is listed in Table 3. In a scenario with fewer scanners available, or a larger number of casualties, CT would potentially have been a bottleneck of patient throughput and a source of diagnostic delay. During our MCI, rate-limiting steps included patient transportation from the resuscitation suites to the CT suite; transfer of patients from the gurney to the scan table due to tangled blankets, cables, and tubing; and time spent ensuring that there was adequate length of monitor cables and tubing to reach into the scanner during the acquisition.

In the future, we plan to change our MDCT protocol and implement an MCI MDCT protocol. This will include guidelines for both radiology and non-radiology emergency staff as to what is required for each patient undergoing CT in terms of patient preparedness, including adequate intravenous access, only one sheet

Table 3 Comparison of simulated mass casualty incident (MCI) with optimized MCI protocol to actual HMC MCI incident

	Simulation of MCIs with dedicated MCI CT protocol (Körner et al. [3, 4])	MCI Harborview Medical Center
Scenario	Explosion at sports arena	Motor vehicle collision
No. of casualties transferred to hospital	7	19
No. of casualties and arrival time	8 patients in 72 min	18 in 72 min
Trauma series	No	Yes
MCI protocol	Yes	No
MDCT protocol	NC head CT Single phase CAP	NC head Head and neck CTA CT cervical spine recons Arterial phase CT chest and abdomen Portal venous phase AP Thoracic and lumbar spine recons
Number of WBCT scanned in MCI	7	15 (12 initial response, 3 delayed)
Time per CT scan	5 min	16 min (for 12 initial scans)
No. of CT scanners	1	3
No. of WBCT scans per scanner per hour	11 (estimated)	4 (actual)

Simulated MCI demonstrates that 11 CTs can be performed per hour with optimized MCI CT protocol compared to rate of 4 per hour with "standard WB trauma protocol"

CAP chest abdomen and pelvis, *CTA* CT angiography, *AP* abdomen and pelvis covering the patient and optimizing positioning of tubes, lines, and monitors, to allow efficient transport in and out of CT.

Patient location and identification

Communication of TS results was straightforward as the technologist who took charge of the TS also directly informed the ED attending of the patient location. It was not readily apparent otherwise where in the ED each of the patients were located. Our standard electronic system for tracking patient location in the ED did not function adequately to identify patient names and locations, in part due to problems with electronic patient registration. A board with handwritten information was used by ED clinicians to track patient location during the MCI, but the emergency radiology staff was not aware of its existence during the incident. Patients were also moved during the course of the MCI, which made tracking the patients' location challenging.

A previously reported (separate) radiology MCI described a suboptimal patient naming convention [11]. In an attempt to ensure that there would be no confusion or overlap of assigned names with real names of other ED patients during our MCI, exotic given names with the surname DISASTER were pregenerated. These were difficult to pronounce and understand and led to some confusion and delays in communication and locating patients. Our naming convention will be revised in the future and will maintain the surname of DISASTER but provide simple one- or two-syllable first/given names. For example, DISASTER JOHN or DISASTER JANE.

Communication

Direct communication is essential to improve efficiency and decrease confusion [2]. In our MCI, communication was fluid and efficient and conducted directly face-to-face with the clinical team initially for all scans and all modalities (TS and CT). This was in part due to the large number of staff available as the MCI occurred during daytime hours as well as the proximity of the CT scanners to the trauma suites.

Manual, paper-based processes for ordering and reporting were considered superior to traditional hospital computerized systems during the MCI and allowed for rapid deployment and maximum flexibility, including initial written preliminary imaging reports. During the described MCI, the paper-based format for generating preliminary reports was ad hoc using available printer paper. In the future, this approach will be formalized at our institution and a three-part carbonless copy form with a structured report template consisting of body region-based checklists will be developed to allow copies to be available to the interpreting radiologists at the CT scanner, to the reporting radiologist at the PACS station, and to the clinical team (Supplementary Material 1). Methods of communication should be predetermined as part of the MCI protocol.

Ordering systems

We do not have a designated ordering system for an MCI in the event that normal ordering or computer-based systems become overwhelmed during a larger MCI. During this MCI, orders for WBCTs were placed face-to-face with the schedulers with a direct communication of patient location with the ED.

Due to the large influx of patients and the potential chaos of the initial phase, ordering during an MCI can be erratic, overutilized (too many scans ordered, duplicate orders, etc.), too cumbersome, or not function adequately during an MCI [11, 15]. Expedited or specialized MCI order entries for radiology studies may improve surge capacity during an MCI [15] and will be considered at our institution. For example, an MCI template could preorder both the TS and the WBCT, and the prepopulating of MCI orders could speed the process of throughput.

Staffing

This MCI occurred during the daytime when many off-service emergency radiology physicians were already in the building. While the hospital has a central (automatic) communication system and plan in place to summon emergency and trauma physicians during a mass casualty event outside of routine hours, this plan did not include emergency radiologists or radiology support staff. This has since been amended.

We are updating our procedures for contacting and scheduling emergency radiologists during an MCI. A fundamental first step is maintaining an accurate record of contact information, including pager numbers, home phone numbers, cell phone numbers, alternative numbers (vacation homes, family members), and e-mails, so that radiologists can be contacted by all available means. It is essential to update these periodically, ideally by radiologists, when any of this information changes and also to verify this information periodically (perhaps every 6 months).

The technologists and other critical team members also need a robust method for contacting and scheduling their staff during the MCI.

One major limitation of our report is that we do not have reliable information on the role of ultrasound during our MCI. This is in part because emergency medicine and trauma physicians perform most of the FAST exams at our institution. These scans are not routinely uploaded onto PACS, and no formal report is provided. We cannot therefore obtain accurate metrics on the role that ultrasonography played during the MCI for these reasons. One casualty had a positive FAST scan and was triaged for urgent laparotomy and splenectomy based on the positive ultrasound findings, but accurate information on the utilization of ultrasound in the other casualties was not readily identifiable in the patient records.

In conclusion, this report of our radiology experience during a recent MCI and subsequent after-action review serves to provide an example of how radiology capacity and workflow functioned during an MCI. MCIs are rare, unexpected, and challenging events. Innovations and experiences of such incidents should be shared among the wider community in order to improve future preparedness and outcomes.

Compliance with ethical standards

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

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