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EMERGENCY RADIOLOGY SPECIAL FEATURE: FULL PAPER

Radiological mass casualty incident (MCI) workflow analysis: single-centre data of a mid-scale exercise

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Objective: The aim of the study was to analyse and interpret radiological mass casualty incident workflow data.

Methods: In a mid-scale mass casualty incident exercise, the on-site triage assigned 12 cases to the investigated institution (11 included in the study). Two out of five institutional multislice-CT-scanners were used and the whole CT workflow and radiological service process chain were simulated as close to realistic as possible. The respective time intervals for reaching defined milestones were measured.

Results: The average CT in-room time, i.e. from entering to leaving the CT room was 9.43 min [(standard deviation) SD: 2.27 min; 95% (confidence interval) CI: 7.90–10.95 min]. Time spent on CT table was 6.75 min (SD: 1.67; CI: 5.63–7.87), and the pure scan time was 4.22 min (SD:

0.64; CI: 3.79–4.65). The first images after entering the CT room were available at a dedicated CT workstation after 5.85 min (SD: 2.20; CI: 4.37–7.32) and institution wide *via* picture archiving system (PACS) after 7.85 min (SD: 1.27; CI: 7.00–8.71). However, the PACS archiving process, that is, transfer of standard reconstruction set of CT images into the PACS was finished after 20.85 min (SD: 2.97; CI: 18.85–22.84).

Conclusion: Up to six patients may be served per hour and per CT scanner by using a standard whole body CT polytrauma protocol. Dedicated CT triage protocols may even increase this number. The time portion until images were available at end points was relatively long. A solution has to be developed in order to avoid scenarios of patients being faster at end points than their images.

INTRODUCTION

The medical handling of mass casualty incidents (MCI; e.g. aeroplane/train crashes, bomb attacks and others) is very time-critical and obviously of outmost importance. As MCIs are rare, staff and workflow training remain particularly challenging. Every part of the rescue chain including police, fire, ambulance departments and medical institutions need to be prepared whenever such MCI events become a sad reality.¹ The normal workflow has to be suspended and simultaneously a large number of severely injured patients have to be handled near-simultaneously; (strictly speaking in all MCIs, all normal clinical activity must immediately be cancelled and “normal” patients must be sent home/back to ward).^{2–4} Despite the relevance of MCIs, there are only few guidelines available, which mainly cover trauma room and CT workflow management. Therefore, only a few theoretical routines are implemented.^{5,6} In order to be ready for such rare but dramatic situations,

simulations of MCI events enable training of staff and identification of the potential for workflow optimization.^{7–9}

Field triage concepts initially are established by the military to combine most effective patient treatment with limited resources; they have been adapted to rescue and provide medical services.^{10–12} One of these concepts is to use patient diversification matrices. They assure optimal patient distribution with respect to the surrounding trauma centres and resources such as disposability of CT being one of those.^{13,14} Focused assessment with sonography for trauma (FAST) ultrasound is established to quickly screen for those life-threatening injuries which imply inevitable surgery without further diagnostics.¹⁵ The power, accuracy and high availability of modern multislice-CTs drive on-going replacement of conventional X-ray examinations in initial polytrauma handling. It is also known that initial CT scouts often provide comparable^{16–18} or sometimes even additional

information compared to conventional chest X-ray examinations.^{19,20} When performed as a standard, whole body CT (WB-CT) has also been already proven as an independent factor for significant contribution to increased patient survival.^{21–23} With increasing numbers of simultaneously and severely injured patients like in some MCI events, the CT service may rapidly stretch to its limit, particularly at centres where only one CT scanner is available. But even in centres with more than one scanner, the efficiency depends on a variety of parameters such as facility factors, number of CT staff, scanning time and protocol choice as well as on image reconstruction, processing, reading, reporting and distribution time.^{6,24}

The aim of study was to analyse and interpret radiological MCI workflow data.

METHODS AND MATERIALS

As human subjects were not part of this study, no approval from the Institutional Review Board was needed.

The scenario took place on a Sunday morning in a tunnel (Figure 1a) of a major city with high traffic volume and was simulated as MCI in the mid range of 50–100 casualties. The actors, who simulated the patients, were trained in special workshops, weeks before the simulation and were also equipped with appropriate clothes and make-up. The setting was as realistic as possible and therefore the actors were also equipped with detailed information about their individual patient role. Casualties were assigned to seven surrounding trauma sites according to a dedicated MCI patient diversification matrix. This included our Level 1 trauma centre institution with two distinct CT sites as the only participating university hospital.

Each CT site had a study supervisor who was not further involved in the simulation course. To each patient, a personal observer with medical background was assigned who accompanied each case during the whole simulation and documented the times of reaching defined milestones. Within this interdisciplinary simulation (anaesthesia, surgery, radiology), every single process step was recorded for each patient. The data concerning CT and CT workflow were analysed and reported in this manuscript.

As the simulation has taken place on a Sunday, the present in-house personnel were representatives for weekends, public holidays and late shifts. The institutional emergency alarm system called-in two additional senior radiologists, who took the role of a radiology coordinator, one per CT scanner.

Following arrival, admission and second triage, all patients were taken to the trauma room (Figure 1b,c). Patients were transferred to the CT room as soon as possible. At both sites, FAST ultrasound was performed during first transits without any time delay. Vital parameters were monitored during the whole procedures. 13 casualties were assigned to the two participating CT sites by on-site triage (T1) and underwent the simulated in-house MCI/polytrauma workflow procedures including standardized polytrauma CT imaging. Owing to the fact that one patient role included a heart attack on the CT table and therefore underwent CPR, this case was marked as outlier with a significant longer stay in CT room and has therefore been excluded from the data analysis. All the remaining included cases have had a comparable duration of stay.

Course in CT room

According to the local patient diversification matrix, all patients arrived with a more or less constant time delay. Thus, all

Figure 1. (a) First care and triage at the site of accident; (b, c) preparation of a casualty right before CT; (d) patient in CT tube before exchange with dummy (reproduced with the kind permission from the Institutional Public Relations Department).

facilities such as trauma room and CT room were always on-hand at time of patient arrival and no patients queued up. In the CT room, the actors were handled like patients and only replaced by dummies for the pure CT scan procedure. After standardized polytrauma CT diagnosis (Figure 1d), and in order to keep the CT room discretionary, patients were immediately taken out of the CT room and were put on a so called “waiting position” until a simulated “first oral report” was available. As only dummies were scanned, reading and reporting of images could not be part of the evaluation. Instead it was assumed that the time interval between the arrival of the first reconstructed of axial thin section image at the workstation and the arrival of the last of those images from this stack was defined as a measure for the time of beginning to create a “first oral report”.

CT scans

The delay for exchanging patients with dummies was separately measured and has been subtracted from the rest of the “in CT-room” time intervals. In order to keep the simulation as realistic as possible, the CT scans were performed using the dummy as patient substitute, and image data were reconstructed as usual. The moment of patient replacement represented the end of “positioning of the patient on the table” in the CT gantry (laser alignment lights positioned on reference points) and the time mark “end of scan”. All cables and tubes necessary for monitoring and sustaining vital functions were simulated and attached to the patients in order to simulate potential problems (e.g. arrangement of cables, lost or stuck tubes etc.).

The standard polytrauma protocol as used in this study (MCI Protocol Standard as described in²⁵) included an unenhanced head CT scan followed by a contrast-enhanced (simulated) bolus-tracked scan of the chest and upper abdomen during the arterial phase, and finally a scan of the abdomen/pelvis during the portal venous phase with an additional standard delay of 50 s. As bolus tracking was not possible with dummies, fixed delays were used during the simulation (25 s for arterial phase and additional 50 s for portal venous phase).

Image processing

The first available images were automatically reconstructed, and these axial slices were transferred to a workstation. This dedicated and directly connected to the CT workstation automatically creates direct multiplanar reformations as described by Koerner et al.²⁶ Times from “scan start” to the “first images available on the workstation” were measured as well as the additional time span until “all images available on the workstation”. Immediately after reaching this point, the CT findings were taken from the patient role sheet in order to make clinical decisions. The image reformation performed manually by the radiological technician was based on automatically reconstructed 0.625-mm slices in soft tissue and bone kernel. These reformations consisted of axial, sagittal and coronal images in 3 mm for head, neck, thorax and abdomen in both kernels and were identical to the standard polytrauma protocols. Only these image sets were sent to the picture archiving system (PACS). Time duration for reformation and data transfer to the PACS was measured as well as image availability (first image to all images) in the PACS.

Statistics

The data were analysed using PASW Statistics 23.0.0 (IBM Corp., New York, NY; formerly SPSS Inc., Chicago, IL). For statistical testing, the *t*-Test was used. The significance level was set at 0.05, and the 95% level was used for confidence intervals (CI).

RESULTS

An overview of the results is provided in Figure 2 and Table 1.

The following data already include the correction of the dummy exchange process for the CT scanning procedure.

CT workflow

The average time for patient stay in the CT room (*i.e.* from entering to leaving the CT room) was 9.43 min [(standard deviation) SD: 2.27; 95% CI: 7.90–10.95]. The time span from “entering CT room” until the patient was on the CT table was 1.30 min (SD: 0.83; CI: 0.75–1.86).

The mean time the patient spent on the CT table was 6.75 min (SD: 1.67; CI: 5.63–7.87). 37% of this time was needed for preparation and correct patient positioning on the CT table (2.53 min; SD: 1.67; CI: 1.41–3.65). After correct positioning of the patient, the whole CT scan procedure was performed in less than 5 min (4.22 min SD: 0.64; CI: 3.79–4.65).

Transferring the patient from CT table back to the patient bench and leaving CT room took another 1.37 min (SD: 1.12; CI: 0.62–2.12).

Images availability on the workstation

It took 5.85 min (SD: 2.20; CI: 4.37–7.32) from entering CT room and 1.71 min (SD: 1.92 min; CI: 0.42–3.0) from CT scan start until first images on the workstation were available. All images were available on the workstation in less than 10 min (9.81 min; SD: 3.76; CI: 7.29–12.34) after entering the CT room and 5.68 min (SD: 2.20; CI: 4.37–7.32) after scan start.

Image reconstruction and data transfer

Overall, the whole reformation process took a mean time of 13.48 min (SD: 0.97; CI: 12.83–14.14.32) until all reformations were finished. To be available for all physicians at patient end points in the hospital, these data had to be transferred to the PACS. For this, the pure data transfer time was 6.26 min (SD: 0.95; CI: 5.62–6.90).

Image availability in the PACS

After entering the CT room until first images in the PACS are available, it took a mean time of 7.85 min (SD: 1.27; CI: 7.00–8.71). The data transfer process was completed and the whole examination was accessible through the PACS after an average duration of 20.857 min (SD: 2.97; CI: 18.85–22.84) after entering CT room. This implies data reconstruction and sending reconstructed running partially in parallel.

DISCUSSION

Bomb attacks and terror acts are permanent fears with high threat level and increasing public perception. Nevertheless, those

Figure 2. Measured times spent in CT room, on CT table, CT scans and availability of images on workstation and *via* picture archiving system.

and the even more likely other causes of MCI fortunately like airplane, train, ship and bus disasters remain rare events. In addition, the knowledge in radiological literature is limited.^{5,7} Particularly rare are publications concerning dedicated CT workflow in MCI handling.^{6,24} In this context, a very realistic MCI simulation offered the possibility to analyse existing CT

workflow with respect to process optimization, identification of bottlenecks and other limitations.

As in recent MCI literature only two dedicated protocols were available, both for 4-row detector CT,^{6,24} this caused the decision to the institutional standard polytrauma protocol for the

Table 1. Time spent in CT room

Measured milestones	Mean time (min)	Standard deviation	95% confidence interval	
Entering CT room to CT table	1.30	0.83	0.75	1.86
Patient preparation and positioning	2.53	1.67	1.41	3.65
Head scout and scan planning	0.30	0.18	0.18	0.42
Head scan	0.78	0.54	0.42	1.14
Body scout and body planning	1.72	0.79	0.40	2.25
Body scan	1.42	0.45	0.42	1.72
Leaving CT room	1.37	1.12	0.62	2.12
Scan time	4.22	0.64	3.79	4.65
Time on CT table	6.75	1.67	5.63	7.87
Time in CT room	9.43	2.27	7.90	10.94

study. If enough resources are provided (with regard to staff and facility) to treat a larger amount of patients and concerning data from “time spent in CT room” this would result in a theoretical capacity of 6.36 scans per hour. Probably, owing to the used patient diversification matrices, the CT rooms were never occupied for incoming casualties. Based on this, further patient preparation and stabilization in the CT room or on CT table was possible, what may have caused relatively long pre-scan times on the CT table. In four cases (36%), it was possible to leave the trauma room more or less as a transit room. In seven cases (64%), initial stabilization and preparation procedures did not allow to go directly into the CT room. But even more complex MCI scenarios with higher patient numbers or closer admission intervals may result in simultaneously arriving patients and thus potentially in patient accumulation. In such a setting, CT would quickly develop to a limiting factor for patient throughput capacity. In contrast to the observed scenario, this may be handled by more extensive patient preparation in the trauma room instead of the observed shift of these procedures more towards the CT table within this study. Under such conditions “Time spent on the CT table” may be shortened by extensive preparation (if patients are accumulating in the trauma room) as well as the revision and adaption of the standard polytrauma scan protocol as used in this study (MCI Protocol Standard) to current needs as more dedicated MCI scan protocols. For example, acquisition of unenhanced whole body CT scans as a CT triage tool may be a first step with the concept of a second enhanced scan in useful cases (MCI Protocol Alternative 1). Compared to the data reported in this study, this would save 1.25 min of delay times (25 s arterial, 50 s portal venous). A second approach could be the acquisition of a standardized WB-CT scan with fixed mA protocol and contrast media injected right before patient positioning or alternatively with manual CM application during transportation (MCI Protocol Alternative 2). Such strategies may include a standardized starting point at the end of the table and performing the scan with the maximum scan range and the maximum scan field of view. As acquisition of a scout view, additional scan range and scan field of view planning would then not be needed, this may save another 2.02 min (SD; CI) of scan time. Obviously, such solutions would imply restrictions as a contribution to time savings (e.g. MCI Protocol Alternative 2 would be most time effective without unenhanced head CT scan). As a consequence, such procedures should be limited to extraordinary exceptions and situations where the clinical treatment capacities are not the next bottleneck.^{25–27} An extreme protocol variant would be the combination of MCI Protocol Alternative 1 and 2, consisting of the time spent on CT table with 6.75 min and only 1 min for placing the patient on and off

the CT table. Such a procedure would theoretically reduce the time in CT room by 3.02 min (as this value is calculated no SD or CI can be provided). With the described ideas, the calculated total time in CT room would end up in an extreme of 4.73 (as this value is calculated, no SD or CI can be provided) minutes and under optimal conditions in a maximum capacity of 12.8 patients per hour and scanner.

Both CT sites used a workstation with immediate MPR capability, which is known to be the most efficient way to read images in three planes and proved to be possible within 10 min after entering the CT room for every included patient in this study.^{25,27} Considering an almost 15 min time interval for image reconstruction and PACS archiving, this can be very limiting for yielding diagnoses as fast as possible. This may turn out to be a particular problem if the radiologist would need to use the CT console itself for initial image reading. This would not only slowdown image reformation and data transfer to the PACS but also block the CT console for the next patient examination. Although it needs some time to get the patient to the operating theatre or the intensive care unit, situations may occur where a pre-surgical access to CT images is not possible in time. Feasible approaches to new solutions without impact on facility design or IT infrastructure may be live reports by radiologists *via* phone or, even better, real-time prints of important slices that could directly be taken to the operating theatre by the surgical team.

Limitations

- Although the number of patient was limited, all included patients and their roles had no further effect on the standardized CT workflow and therefore were as comparable as possible.
- The time for a first oral report was simplified as the transfer time of the initial, automatically reconstructed image set to the dedicated workstation with volume-reading capability. This may serve as a rough estimation but may not necessarily represent the time radiologists need for a first oral report and decision on further treatment.

This simulation showed that even in Level 1 trauma centres with dedicated and long-term proven polytrauma algorithms, there is a relevant and strong potential for optimization. Owing to inevitable restricted experience with MCIs, regular MCI simulations seem valuable to ensure such situations become routine to staff, in order to save time and resources in real MCI situations.^{8,9} Solutions for easy and much faster access to primary reconstructions for the clinical treatment team at end points (operation room or intensive care unit) have to be developed.

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