Chapter 4
Introduction to Imaging of Penetrating/ Perforating Blast and Ballistic Injuries

Keywords NATO litter · Level 3 facility · Traua czar · Surgeon of the Day · Damage control surgery · Damage control imaging · CT Scout · Retriage · Protocolization · Surge/ Mass casualty

Diagnostic imaging in combat has many unique characteristics and situations that are briefly covered in this chapter. The diagnostic radiology mission is only a part of the complex system that needs to be understood. A team approach with integration with ED, OR, and ICU/ wards is imperative. Some of the unique aspects of combat radiology include the horrific nature of injuries, the multiplicity of severe trauma, and sheer number of injuries and casualties that can come at once. A common practice that may not be initially intuitive is diagnosing and treating regardless of "sides" in that we treat insurgents, prisoners, local nationals, Iraqi police, Military Working Dogs, children [1], and pregnant women with threat to life, limb, or eyesight.

The severity of battle injuries and necessity for immediate treatment relates to US trauma centers in some ways. However, in the haze of battle, resource limitations, physical and emotional fatigue, the intensity seen in a civilian facility simply cannot compare to that of a combat hospital. These limitations are somehow miraculously overcome thanks to the spirit, determination, and motivation of all hospital staff to do the right thing. We press on to the point of exhaustion, pass out (sleep), exercise and start each day all over again. There are no real weekends since we work every day; in fact, some refer to each day as Groundhog Day (like the movie, not 2 Feb). In the words of Colonel Masterson, our medical group commander in 2007, "everyday is an eternity, every month is a moment."

From an imaging perspective, for example, hypoperfusion complex and hypovolemia CT findings are enhanced (more periportal fluid, flatter IVC, enhanced, fluid filled small bowel, etc.). Casualties are often dehydrated and volume depleted and/or hypertonic to begin with from the extreme heat and protective gear. They also often have severe blood loss, and have been transported in a tight,

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hot environment such as a helicopter with hot air blowing in the open bay. Included in this chapter is a case of shock bowel/flat IVC as a radiographic surrogate for hypovolemia, hypoperfusion complex, and impending bowel ischemia.

When new hospital staff arrive in a deployed field hospital, they have three days to learn from the staff that are on their way out. Imagine changing out 95% of trauma level 1 hospital staff in three days while keeping operations at full capacity without limitation. This may be done a few times a year. It is truly amazing how people can be trained up in workflow and procedures in such a short period of time; somehow this seemingly complex event happens without fail or compromise in patient care. My most recent deployment to Iraq included an additional transition where we moved our entire trauma hospital from the original tent configuration to a hardened facility. With months of preparation, the actual move occurred in less than 90 min with continual care. In radiology, we had combat trauma patients being imaged in both hospitals at the same time with dual staff and split equipment [2].

Within a few weeks, the deployed providers are exposed to the near-overwhelming workload and are already blunted to the point that regularly called trauma codes with urgent patients massively wounded become seemingly routine. America can claim victory over the most successful recoverability of combat casualties in history with the highest rates of survivability, fastest transport, optimal body armor and protection, and the best technology.

4.1 Trauma Flow and Throughput of Casualties in a Deployed Combat Hospital

The most critical patients arrive by helicopter; however, patients also arrive by ambulance and walk in, and injured patients are often dropped off at the base gate from the local area. Urgent and priority litter patients are wheeled into the main emergency department from the helicopters using NATO litters (see Fig. 4.1). These litters have locks that turn into the "table" where the patient receives resuscitation and triage in the ER. Ambulatory and routine litters go to a separate section. See Fig. 4.2 showing how the NATO litter is being pushed by one OR tech in the tent facility.

The radiologist plays a key role in radiologic triage and protocolization. The radiologist and radiologic technologist respond as part of the primary trauma response team. There is at least one radiologist covering the department for trauma and critical care follow-up 24/7, as many US trauma centers now do. When many urgent casualties come at one time (a "surge"), the radiologist, ED doctor, and traumatologist (trauma czar) triage the imaging resources (techs, portables, CT's) since many casualties will have to wait for imaging during surges (e.g., 20–30 combat casualties at once). This radiologist/ traumatologist triage of imaging resources has been recommended in the past [3].

Like most trauma centers and emergency departments, the first imaging obtained on warfighters in combat hospitals is the CXR, and on occasion, the pelvis.

Fig. 4.1 The NATO litter is seen here in the ED of the new facility we moved into during our deployment

Fig. 4.2 This shows how the NATO litter can be pushed by one person, here in the tent facility OR

We rarely do lateral cervical spines in the extreme polytrauma encountered in combat since they will be getting a CT anyway. It must be kept in mind that most X-ray techs sent to combat are not CT techs, yet they must learn how to perform CTs in 3 days. Keeping the protocols simple and standard without much special sequences is key. Three technologists and a radiologist respond to every trauma code; one tech helps with movement and stabilization of the patient with a plate close by. When the patient is rolled to check the back for spinal deformity/ tenderness, abrasions, and rectal tone, the tech places the CXR plate under that patient's chest. With multiple patients or during surges, techs watch to see which patient will be ready for a CXR next (typically happens at certain stabilization phases), what the radiologist is gathering by the SOD (Surgeon of the Day) and individual ER docs (one doc per patient), and who is ready next. If the patient needs pelvis X-ray, this is often done immediately after the CXR.

Similar to US trauma centers, imaging is integral in management within the golden hour(s). If the patient does not require immediate damage control surgery, or has a negative FAST (Focused Abdominal Sonography for Trauma), the patient goes to CT for either a PanScan (in blast, or injury distraction scenarios) or dedicated anatomical regions for isolated GSW. From there, surgical intervention is planned, avoided if no indication, then off to ICU. A positive FAST and/or deteriorating hemodynamic state may dictate going strait to the OR for definitive management and skip CT.

The FAST is done by the ED doctors in combat hospitals and sensitive enough to help make the decision to go strait to the OR and save the CT resources for others. It is especially useful for level 2 facilities (hospitals without CT). It does not take long – a few days on the combat trauma scene – to really appreciate the usefulness of FAST. During our deployment, the emergency department evaluated E-FAST (Extended FAST) [4].

A new frame of treatment has evolved with battlefield medicine called damage control surgery [5], where emergent surgery is done to control bleeding and treat the most amount of casualties [6], and deployed radiology needs to parallel this thinking to be effective in combat. Regarding stabilization and assessment in the combat ER, one needs to understand the concept of damage control surgery. Rather than Airway Breathing Circulation, managing severe battle injuries in the field and in the combat ER requires a backward approach to this concept in that Circulation needs to be controlled first in the ED, then Breathing, then Airway.

Chest and Pelvis plain CR are often done before CT (or going to the OR), and C-Spine is done as part of the PanScan. The chest X-ray CR (Computed Radiography) plate is placed behind the patient when rolled up to check the spine and rectal tone. The chest (and pelvis, when obtained) CR plates are also run first as to not slow down the resulting of these to the ER docs and surgeons. For casualties going direct to the OR, extremities may be taken in a higher priority on those patients.

There are several instances in this book where the CXR, shot through lateral C-spine and pelvis plain X-rays, were not obtained in the emergency room. Since the X-ray technologist was often the limiting resource, time could be saved and resources allocated to allow technologists to get the portable CXRs and pelvis X-rays on casualties going directly to the OR. In our experience, we found that the CT scouts (AP and lateral) of the chest were fast and adequate in lieu of the portable CXRs in the ED. If we were getting the CT anyway on hemodynamic stable casualties, the CT scout view often sufficed for the CXR since we were going to obtain more detail on the CT findings minutes after that. We also felt that the CT scouts were faster, more efficient to reallocate our technologist resources, and of better quality of care overall.

When it comes to interpretation of massive volumes of CT images, extremities, ICU chests, there are methods to the madness. In combat, many surgeries are performed at the same time, with surgical specialists operating on any available surface. When we were in the tent facilities, the isoshelter operating rooms would often have multiple surgeries going on at time on each patient (i.e. neurosurgeon at the head of the patient, urologist in the abdomen and an orthopedic surgeon at the legs). I have seen up to seven surgeries being done at once in one isoshelter operating room. Keeping this in mind, an order of procedures is tailored to each patient, depending on severity and nature of the various injuries, and the tailoring of the CT needs to parallel this requirement. Deviating from an established routine is the only consistent thing in the fog of combat imaging. The following "damage control imaging" helped me.

4.2 Damage Control Imaging

While deployed, I developed a more streamlined imaging request form in concert with the ED and the trauma czar (representing all trauma surgeons) to guide ordering of studies and where to write results in a standard fashion (see Fig. 4.3). This change simplified the ordering by ED staff, made filling out by radiologists more efficient, and ease of finding the results for medical staff. A "primary survey" of the entire body is often helpful using the AP, and lateral scout provides an overview of metallic fragments, CXR, fractures, etc. A quick view bone windows of the head is useful looking for major fracture, soft tissue indicators of trauma, and/or metal. This is followed by brain windows in search for hematomas, cistern effacement, or midline shift. If there is time, viewing C spine keeps a methodical head to toe pattern, however, this is more often interrupted by trauma surgeons wanting to know if they need to operate (presence of lung or abdominal fluid, organ damage or penetration of peritoneum or retroperitoneum). The C Spine can be reviewed while the patient is being transported to the OR.

I found myself screening quickly through the Chest Abdomen and Pelvis (C/A/P), with a combination lung/ bone window (for example: W2000 L20) through whole body for a big picture of fragments, trajectories, free air, or other significant evidence of intraperitoneal compromise. This allowed me to get the most life threatening injury findings to the surgeons that needed to plan for immediate life saving surgery.

In combat hospitals, the focus falls on efficient throughput, detecting lung lacerations or hemothoraxes, recognizing vessel contrast extravasation, diagnosing free air in non-dependent abdomen and locating major displaced fractures of the spine or pelvis. All, of course, in as many patients as possible, in the shortest

Radiology Form: Trauma/ Surge/ MassCal
332 EMDG AGE:____ US Name, trauma # or TCN/LN#
Radiology Phone 443-8527 NOTE: for mass casualty, can substitute Trauma Number only for Name and SSN
Rad Tech Name: **Time of Exam:** **SS#** - -

Location: ER 443-8513 From: Field	10th	FOB:		Other:	**Date:** Day Month Year
History: (Circle one) IED Mortar Gunshot MVA EET Central Line NG/OG Tube					
Provider/ER staff: Please circle requested exams:					

X-Ray Exams			Results
CXR	CXR by CT Scout		
	Pelvis		
Other (eg. KUB, Lat C Spine)			
RT	LT	SHOULDER	
RT	LT	HUMERUS	
RT	LT	ELBOW	
RT	LT	FOREARM	
RT	LT	WRIST	
RT	LT	HAND	
RT	LT	FEMUR	
RT	LT	KNEE	
RT	LT	TIB/FIB	
RT	LT	ANKLE	
RT	LT	FOOT	

CT Exams						
PanScan	Head	Negative	Positive (if positive, fill out below findings)			
		Missile track? No Yes	Unilobar?: No Yes (___ lobe)	Bihemispheric? No Yes	Multilobar? No Yes	Transventricular? No Yes
		CT findings c/w elevated ICP? No Yes		Sulci? Effaced Patent	Cisterns? Patent Effaced	Midline shift? No Yes (_____mm)
		Hemorrhage? No Yes	Intraparenchymal hemorrhage? No Yes ___x___x___mm ___lobe		Cisternal? SAH? IVH?	Extra-axial? No Yes (__DH)
		Pneumocephalus? No Yes		Other:		
	C-Spine Chest Abdomen Pelvis					
	CTA COW CT Face CTA Carotids CTA Chest Other (eg. T+L Spine)					

[redacted]

Findings Continued on Back if Checked ☐
Additional forms available on t drive under T:\Radiology\Admin Files\Forms
Updated 21 July 2007
FIRMR (41 CRF) 101-11.806-8

Fig. 4.3 The streamlined form for ordering imaging studies and reporting in a standard fashion. Knowing where to look for reports on body regions and types of studies was proven helpful during our deployment

amount of time. Similar experiences from other radiologists have led to the creation of software to allow for a single trauma window to view lung, soft tissues and bone all in one sweep. Research is underway to study this universal trauma window at Walter Reed Army Medical Center.

After surgical disposition is determined on the current wave of patients, it is a good time to review the scans in more detail for a definitive final interpretation, or "secondary survey." Jotting findings down on the streamlined form acts as a good template for entering into the EMR at a later time. Many times the data entry is at the end of a shift when there is relief by the next radiologist shift. By the way, all this is going on while helicopters continue to land two, three, or four at a time while the base is under attack. The radiologists are also back and forth to the trauma bays providing updated answers as we discover them, as well as trips to the ORs, ICU on traumas evaluated and treated earlier. The noise of the helicopters and staff speaking loudly above that baseline noise in tents, heat, etc. can compound the stress and pressures of knowing your responsibility to help save life, limb, and eyesight in the fog of war.

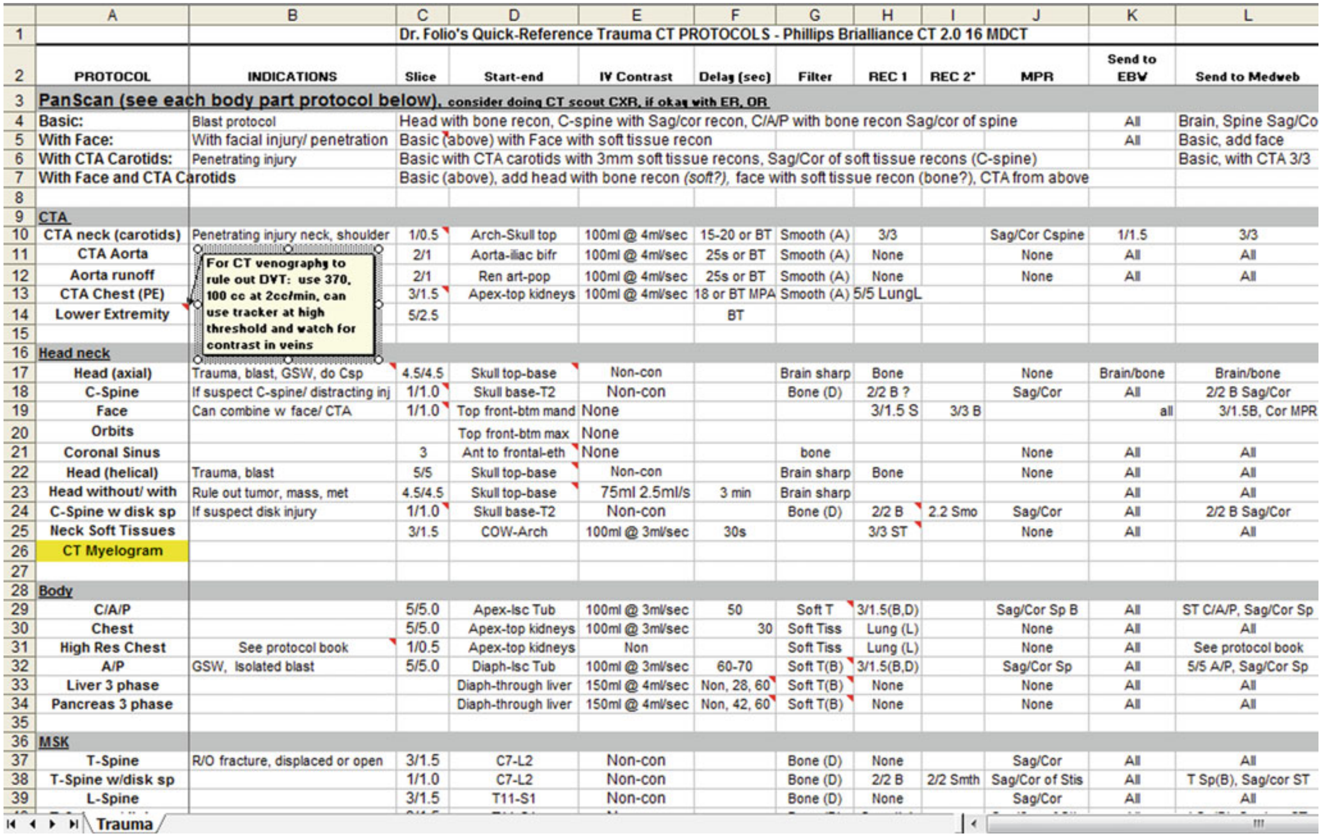
In a mass casualty or disaster, more hospital staff is called in from their rest, however, if prolonged, rest–work cycles as well as continued supply stocking, distribution, and modified roles and responsibilities are taken into consideration. The work cycle is a fast-paced, all-production operation for 120–180 days. One learns new ways of doing business – but one must know one's own field as a baseline: this is no place for brushing up on trauma skills. One must also be creative when seeming overwhelmed. We would often put our waiting outpatients to work (that were able) as they realized they would be tended to faster by helping radiology or ER staff (manpower, getting water for techs, communicating by running, etc.). Walkie-talkie triage works in combat; patients bending over in pain or unable to walk take higher priority over those who can walk and help.

4.3 Unique Radiology Protocolization in Extreme Trauma

See Fig. 4.4 for a quick-reference spreadsheet for trauma CT protocols that evolved for our deployed radiology department. The one page/quick reference highlights the combined studies and shortcuts that we could tailor to each patient. The CT of head without contrast, cervical spine, chest, abdomen, and pelvis with contrast (PanScan, not dissimilar to "ShanScan" commonly refered to at Baltimore Shock Trauma, thanks to Dr. Shanmuganathan) is very common and almost universally done in blast injuries. It was not a policy to do a PanScan on every patient coming to the ER, as this would not be time or radiation/contrast dose effective. This spreadsheet is available on the Air Force Readiness Skills Verification webpage, the online course for deploying radiologists mentioned earlier.

For penetrating injuries potentially involving the subclavian arteries or other great vessels near the neck and chest, the arm opposite the penetration is injected. This minimizes beam hardening artifact from contrast concentration in the brachiocephalics near the potential damaged vessels.

For pelvic fracture stability determination, we commonly reconstruct the pelvis from the PanScan in transparent 3D to provide a pseudo X-ray inlet/ outlet view, without spending time to take plain radiographs. This allows for diagnosing with



	A	B	C	D	E	F	G	H	I	J	K	L
1			Dr. Folio's Quick-Reference Trauma CT PROTOCOLS - Phillips Brialliance CT 2.0 16 MDCT									
2	PROTOCOL	INDICATIONS	Slice	Start-end	IV Contrast	Delay (sec)	Filter	REC 1	REC 2"	MPR	Send to EBV	Send to Medweb
3	PanScan (see each body part protocol below). consider doing CT scout CXR, if okay with ER, OR											
4	Basic:	Blast protocol	Head with bone recon, C-spine with Sag/cor recon, C/A/P with bone recon Sag/cor of spine								All	Brain, Spine Sag/Co
5	With Face:	With facial injury/ penetration	Basic (above) with Face with soft tissue recon								All	Basic, add face
6	With CTA Carotids:	Penetrating injury	Basic with CTA carotids with 3mm soft tissue recons, Sag/Cor of soft tissue recons (C-spine)									Basic, with CTA 3/3
7	With Face and CTA Carotids		Basic (above), add head with bone recon (soft?), face with soft tissue recon (bone?), CTA from above									
8												
9	CTA											
10	CTA neck (carotids)	Penetrating injury neck, shoulder	1/0.5	Arch-Skull top	100ml @ 4ml/sec	15-20 or BT	Smooth (A)	3/3		Sag/Cor Cspine	1/1.5	3/3
11	CTA Aorta		2/1	Aorta-iliac bifr	100ml @ 4ml/sec	25s or BT	Smooth (A)	None		None	All	All
12	Aorta runoff		2/1	Ren art-pop	100ml @ 4ml/sec	25s or BT	Smooth (A)	None		None	All	All
13	CTA Chest (PE)		3/1.5	Apex-top kidneys	100ml @ 4ml/sec	18 or BT MPA	Smooth (A)	5/5 LungL				
14	Lower Extremity		5/2.5			BT						
15												
16	Head neck											
17	Head (axial)	Trauma, blast, GSW, do Csp	4.5/4.5	Skull top-base	Non-con		Brain sharp	Bone		None	Brain/bone	Brain/bone
18	C-Spine	If suspect C-spine/ distracting inj	1/1.0	Skull base-T2	Non-con		Bone (D)	2/2 B ?		Sag/Cor	All	2/2 B Sag/Cor
19	Face	Can combine w face/ CTA	1/1.0	Top front-btm mand	None			3/1.5 S	3/3 B		all	3/1.5B, Cor MPR
20	Orbits			Top front-btm max	None							
21	Coronal Sinus		3	Ant to frontal-eth	None		bone			None	All	All
22	Head (helical)	Trauma, blast	5/5	Skull top-base	Non-con		Brain sharp	Bone		None	All	All
23	Head without/ with	Rule out tumor, mass, met	4.5/4.5	Skull top-base	75ml 2.5ml/s	3 min	Brain sharp				All	All
24	C-Spine w disk sp	If suspect disk injury	1/1.0	Skull base-T2	Non-con		Bone (D)	2/2 B	2.2 Smo	Sag/Cor	All	2/2 B Sag/Cor
25	Neck Soft Tissues		3/1.5	COW-Arch	100ml @ 3ml/sec	30s		3/3 ST		None	All	All
26	CT Myelogram											
27												
28	Body											
29	C/A/P		5/5.0	Apex-Isc Tub	100ml @ 3ml/sec	50	Soft T	3/1.5(B,D)		Sag/Cor Sp B	All	ST C/A/P, Sag/Cor Sp
30	Chest		5/5.0	Apex-top kidneys	100ml @ 3ml/sec	30	Soft Tiss	Lung (L)		None	All	All
31	High Res Chest	See protocol book	1/0.5	Apex-top kidneys	Non		Soft Tiss	Lung (L)		None	All	See protocol book
32	A/P	GSW, Isolated blast	5/5.0	Diaph-Isc Tub	100ml @ 3ml/sec	60-70	Soft T(B)	3/1.5(B,D)		Sag/Cor Sp	All	5/5 A/P, Sag/Cor Sp
33	Liver 3 phase			Diaph-through liver	150ml @ 4ml/sec	Non, 28, 60	Soft T(B)	None		None	All	All
34	Pancreas 3 phase			Diaph-through liver	150ml @ 4ml/sec	Non, 42, 60	Soft T(B)	None		None	All	All
35												
36	MSK											
37	T-Spine	R/O fracture, displaced or open	3/1.5	C7-L2	Non-con		Bone (D)	None		Sag/Cor	All	All
38	T-Spine w/disk sp		1/1.0	C7-L2	Non-con		Bone (D)	2/2 B	2/2 Smth	Sag/Cor of Stis	All	T Sp(B), Sag/cor ST
39	L-Spine		3/1.5	T11-S1	Non-con		Bone (D)	None		Sag/Cor	All	All

Fig. 4.4 This one page Excel spreadsheet carried all the protocol information developed by previous radiologists and radiologic technologists. It is conditionally formatted with pop-up information to provide more information in a condensed, easy to refer to format

SSN	Name	From:	Injuries	☐ H/P ☐ 3899 # Proc
☐ CT Head ☐ CT C/A/P ☐ Spine ☐ CTA ☐ Other		☐ IED ☐ VBIED ☐ GSW ☐ BLUNT		
SSN	Name	From:	Injuries	☐ H/P ☐ 3899 # Proc
☐ CT Head ☐ CT C/A/P ☐ Spine ☐ CTA ☐ Other		☐ IED ☐ VBIED ☐ GSW ☐ BLUNT		
SSN	Name	From:	Injuries	☐ H/P ☐ 3899 # Proc
☐ CT Head ☐ CT C/A/P ☐ Spine ☐ CTA ☐ Other		☐ IED ☐ VBIED ☐ GSW ☐ BLUNT		
SSN	Name	From:	Injuries	☐ H/P ☐ 3899 # Proc
☐ CT Head ☐ CT C/A/P ☐ Spine ☐ CTA ☐ Other		☐ IED ☐ VBIED ☐ GSW ☐ BLUNT		

Fig. 4.5 The SOD (Surgeon of the Day) sheet was used by the lead trauma surgeon for a shift to keep track of casualties for personal use and handing off to the next SOD. I used these myself to keep track of casualties and retriage to CT and to OR based on assessments and CT findings. This would provide a checklist of all patients I would need to provide textual reports for our medical record, and which ones that may need additional attention

familiar views for typing pelvic fracture stability and management. The value of instant coronal, sagittal, 3-D, MIP, and vessel tracking is paramount in combat trauma imaging. This has been described elsewhere [9] and within this text, and will be illustrated here, as combat injuries are no exception.

I also used an SOD sheet (see Fig. 4.5) for tracking small surges (mini-mass casualties that we got regularly). It would allow me to keep track of which patient was where with what major mechanism of injury, what CT we were going to do, and where. It is optimal to keep the least hemodynamically stable patient in the ED CT scanner since it is closer to the most ACLS providers. In addition, all radiologists in the Air Force are ACLS certified/current. One hospital is trying a method of re-triaging to CT vs. OR vs. ICU using Air Traffic Control (ATC) methods. Hoskins, et al studied the potential for using ATC in field exercises [10] based on our experiences in Iraq. See Fig. 4.6 for how we tested this retriaging tool in a field exercise with our university.

Blast injuries deserve special attention since we are still researching effects of blast, especially primary effects [11]. These principles will be discussed further in the next chapter. Distracting multiple injuries, high adrenaline of battle in young athletic military types, and high doses of morphine on board dictated a lower threshold for CT from head to pubes. Like anywhere else, CT is pivotal in poly-trauma for surgical triage, planning, and guidance. The epidemiological principles of pre and posttest probability and prevalence of "disease" should be kept in mind in that in our patient population, there is 80–90% trauma, whereas in many military medical centers in the US, it may be only 10–20%.

Fig. 4.6 This photo was taken during field exercises while testing Air Traffic Control methods to keep track of casualties. This method was more efficient and accurate in tracking casualties and now being evaluated in civilian trauma centers and a combat hospital

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