Chapter 6
Imaging Thresholds of Salvageability of Life, Limb, and Eyesight

Keywords Salvageability · Traumatic brain injury · Imaging mortality threshold · Radiology-assisted autopsy

6.1 Introduction

Important considerations in triage and re-triage are identifying the most critical casualties and separating out those who can be saved, and injuries so severe (expectant) that trying to save would unnecessarily drain resources from those who could live. The challenge of recent advances now saving more lives than ever is shifting the mortality threshold toward the more severe injuries; many considered expectant in prior conflicts and put to the side to die in the past are now saved. Perhaps, the most dramatic example of this is in head injuries with advent of faster transport times to neurosurgical capability on the battlefield as mentioned previously, and MDCT availability with correlations showing better survival predictability. Additionally, extremities not previously salvageable now are readily diagnosed by CTA (for example) with volume rendered 3D and multiplanar reformations with tools such as vessel tracking.

The most urgent situations anywhere in emergency management traditionally call for (and still call for), the saving of life, limb, and eyesight. In deployed combat hospitals in hostile territories, this mantra is what dictates what noncombat injuries and conditions of the local population will be treated at combat hospitals. Since the military capability often exceeds local country medical abilities, those too severe to be saved at local hospitals are transported to combat hospitals. Once saved with modern coalition forces technologies and capabilities, patients are transferred back to host nation medical care.

A paradoxical tradeoff of increased survival results in more living patients with more severe injuries than ever before. An example is the large number of soldiers, sailors, airman, and contracted civilians sent to war that are left with lost limbs; many times several limbs having been amputated. Fortunately, advances in prosthetic technologies have progressed to the point of helping these otherwise disabling wounds to be coped with better than ever before.

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Cases will be presented in this chapter on both sides of the current imaging life and death threshold to put this concept into perspective. Based on our experiences at the only combat hospital in Iraq with neurosurgical capability, imaging severity spectrums will be proposed that are still in need of further validation. I believe that standardizing the terminology and methods of consistent reporting from this point on will be imperative for epidemiological purposes and more effective data mining in the future when looking back at imaging findings and correlating with outcomes. A few extremity cases are also presented to demonstrate how CTA can guide surgeons to determine limb salvageability. The last section will present several penetrating globe injuries of various severity where some globes and vision were saved, others not so fortunate.

6.2 Pushing the Imaging Threshold of Mortality: Cases on the Edge of Life

6.2.1 Imaging Spectrum of Penetrating and Perforating Head Trauma on the Battlefield

Our hospital is the main hub for neurosurgical cases in Iraq. In addition, all HEENT related casualties in need of definitive treatment are seen at Balad Air Base. Of note, penetrating brain injuries from IEDs far much better than those with nearly identical scans that result from higher-energy projectiles (i.e., gunshot wounds) are seen in the US. Blast fragments can be high velocity, but are typically low-velocity and can cause less damage, even though fragments are often large. The CT results are compared with GCS score and used in concert with CT findings to fully evaluate prognosis.

Traditionally, Non Enhanced CT (NECT) was performed on mTBI (mild Traumatic Brain Injury). Based on evolving science and experience of our neurosurgical and diagnostic imaging teams, we considered to include CTP (CT Perfusion) imaging to provide the most sensitive baseline possible. Even though there is a paucity of prospective studies to prove that perfusion imaging is more sensitive in mTBI detection than CT without contrast [1], there is no gold standard yet for diagnosing mTBI definitively (MRI is not a possibility in deployed combat hospitals at the time of this writing). Until then, we considered using the most sensitive tool possible in a combat environment. There are several neurocognitive tests depending on the level of facility and workup. Front-line screening on suspected mTBI is performed with the Military Acute Concussion Evaluation (MACE). Theater referral center evaluation involves Automated Neuropsychological Assessment Metrics (ANAM).

"No head injury is too trivial to ignore" (Hippocrates, 460–377 BC, in Ingebrigsten) [2]

Missile injuries and CT severity have been addressed in the literature with Shoung et al. reporting on 56 cases and correlating to CT [3] and Kaufman et al. describing two cases where aggressive treatment allowed salvage in cases previously thought not to be possible [4].

There are many recent advances in TBI, to include extensive craniotomy techniques with more severe head injuries. At the onset of the recent campaign in Iraq, a skull flap was removed and placed into the abdomen for later recovery [5]. This was soon replaced by computer-aided design and manufacturing of methomethacralate synthetic implants mirrored from the normal half of the skull for optimal cosmetic fit.

In our experience in the only combat hospital in Iraq with neurosurgical capability, the image severity findings of penetrating trauma on CT exhibited a predictable parallel clinical prognosis spectrum. In other words, neurosurgeons and radiologists could come to conclusions quickly as to prognosis of survivability when it came to CT triage (expectant vs. survivable severe injury).

While deployed, I developed a standard report to allow radiologists to more effectively communicate penetrating head injury findings to neurosurgeons, emergency department physicians, and ICU medical staff. The written preliminary triage report was easier for radiologists to complete in that parameters could be circled with a yes or no rather than writing out each time (most everyone preferred the binary yes / no circles over my handwriting). Medical staff could quickly assess the findings important to them. Prior to this, neurosurgeons had to search for information buried in a nonstandard report in various orders depending on each of the radiologist's style. Standardized reporting of penetrating head injuries provided more efficient communication to neurosurgeons and other hospital medical staff over several months.

Parameters on the standard report include presence or absence of the following: Pneumocephalus, missle path (bihemispheric, multilobar, transventricular), skull fracture, evidence of elevated intracranial pressure (effaced sulci, basal cisterns, midline shift, etc.), hemorrhage (location choices: cisternal, SAH, IVH, extra-axial), and intraparenchymal hemorrhage. These parameters were arranged in a consistent table format with checklist-type responses (see Fig. 6.1). In addition to saving radiologist time, ED docs, trauma surgeons, neurosurgeons, orthopedic surgeons, etc. knew instantly where to look for the findings of their interest. Figure 6.2 is a zoomed up view of the head CT standard section. This minimized writing (a good thing in my case), and again, standardized our reporting in the parameters that radiologists and neurosurgeons found important. By completing this form that also acted as a checklist, told the neurosurgeon the questions they would have before arriving to include pertinent negatives (rather than going back and asking about pneumocephalus for example).

These preliminary reports were later entered into each casualty's computer medical record that would go with them through the medical echelons back to their home medical centers. The consistent format made it easier for the radiologist to look back on what was reported for entering into our EHR.

Another advantage to the standard reporting is consistent data mining in the future. Since we were seeing more penetrating head trauma than ever before, with

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				**Date:** Day Month Year
From:	Field	10th	FOB:	Other:	

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	

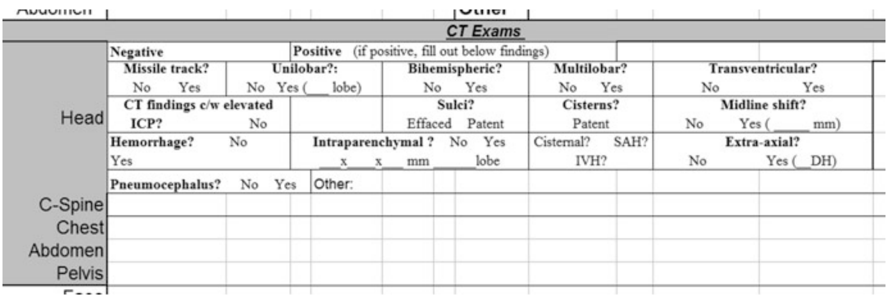
CT Exams

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. 6.1 I designed this handwritten report (modified from prior versions) while we were deployed to allow quick ordering of imaging studies in a consistent fashion while standardizing where results were reported by radiologists on the sheet. This was easier for radiologists in that there was less writing, at the same time medical staff knew where to look for the results they were interested in for more efficient communications



	CT Exams				
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		Sulci? Effaced Patent	Cisterns? Patent	Midline shift? No Yes (_____ mm)
	Hemorrhage? No Yes	Intraparenchymal ? No Yes ___x___x___ mm _____ lobe		Cisternal? SAH? IVH?	Extra-axial? No Yes (__DH)
	Pneumocephalus? No Yes	Other:			
C-Spine					
Chest					
Abdomen					
Pelvis					

Fig. 6.2 Section of the standard report that provided the information radiologists would place findings and that neurosurgeons agreed was the key information important to them. This was also helpful to nursing staff that had certain parameters to look for in follow-up care

some severe casualties surviving that had not survived previously, we felt it was important to capture this information in a way easier to correlate with clinical notes down the road.

The Marshall grading scale [6–9] was kept into consideration when developing this format with our neurosurgery department. When data from our Electronic Medical Record (EMR) is later accessed for evidence-based treatment and studies, this data can be consistently mined. This also simplifies where to look for the result and allows consistency in reporting with constantly changing radiologists. The ICU and neurosurgical teams can know that everything dealing with penetrating trauma was reviewed. Since the reports are handwritten initially (later entered into our EMR, JPTA), this minimizes extra writing and simplifies data entry.

Survivability surrogates, or CT grading of penetrating trauma, may be able to be determined after review of consistent data. Although a "CT GCS" is not proposed here, perhaps this is not an impossible concept in the future, based on clinical record review, CT findings (organized as above), and mechanism of injury. Once we become more familiar with penetrating head injury to include blast, resource (time, blood, staff, OR) determination may be better estimated by determining nonsurvivable (expectant) versus. survivable CT findings.

The real-estate mantra holds true, especially in penetrating and perforating injuries to the brain: location, location, location. I like to break each of these locations into their own category. Location #1: Entrance, Location #2: Exit (or resultant missile remnant), and Location #3: Trajectory: wound ballistics. One needs to ask, "what path did the missile take (hence, what organs were involved)?" in that the trajectory real-estate should be considered, not just the entrance and final location (or exit).

A severity scale based on these consistent findings was proposed in a case review of several traumatic brain injury cases [10]. The authors showed several cases of closed head injury of increasing severity to include a negative CT and MR, negative CT and positive MR (only on GRE), and positive CT and positive MR. Some authors have reviewed trajectories of GSW and related to outcomes [11]. A severity scale is being further studied at USU [12]. Penetrating head trauma CT studies are being reviewed and correlated with example reports, using the report format discussed above. The CT report format is being compared to neurosurgical procedures and findings with other predictability measures to include GCS and clinical follow-up of patients. Computer modeling may be applied to help determine survivability. Quantification and prognosis scores similar to Glasgow Coma Scale (GCS) and Injury Severity Score (ISS) may be possible with similar standard formats used over time. There is a paucity of literature on accuracy of trajectory measurements and actual locations in the brain, and especially the body.

6.3 Example Penetrating Head Injury Cases in Increasing Severity

A child fell head-first onto an 8″ long pipe (about 1″ in diameter) sticking in the ground. Since it happened in a remote area of Iraq without communication capability, the father pulled the child from the pipe and brought to our combat hospital. Since this is qualified as a life or death situation, even though the child was alert, crying, no reported LOC, with GCS 13, and stable vital signs, the pipe penetrated deep enough to effect the child's vision. A deep laceration was noted superior and right of the frontal sinus. A CT was performed and seen in the following Figures (Figs. 6.3–6.10).

While these images seem to indicate a severe penetrating head injury case, because of the brain area involved, the quick neurosurgical intervention and release of pressure and the mechanism, this child was not only saved, he was discharged after a few days on antibiotics.

For an intermediate perforating head injury case, refer to the keyhole injury discussed in the previous chapter. This case highlights a focused entrance and exit with indriven bone fragments that is often fatal. Due to immediate neurosurgical intervention, this casualty was saved as the keyhole pattern was recognized to be a serious injury even though it could initially seem trivial.

The following unfortunate case shows a perforating head injury case from a suicide. Figure 6.11 shows the entrance in the right parietal region of this right-handed soldier's head, with large open fracture and fragments. The bullet direction is shown by the arrow and traverses the midline and ventricles, a grave indicator. Note the blood in the ventricles, swelling, and midline shift. Figure 6.12 shows the exit on a higher cut. This person lived long enough to get the scans; however, with a GCS of three and other clinical indicators of death, this was not a salvageable injury. This upward right to left angle is consistent with a right-handed, close range, self-inflicted incident. Left-handed individuals would have a mirror image pattern and also inferior to superior.

Fig. 6.3 Photo of child's head from the top just prior to neurosurgery showing the skin laceration from the pipe injury. Reprinted with permission from Military Medicine: International Journal of AMSUS

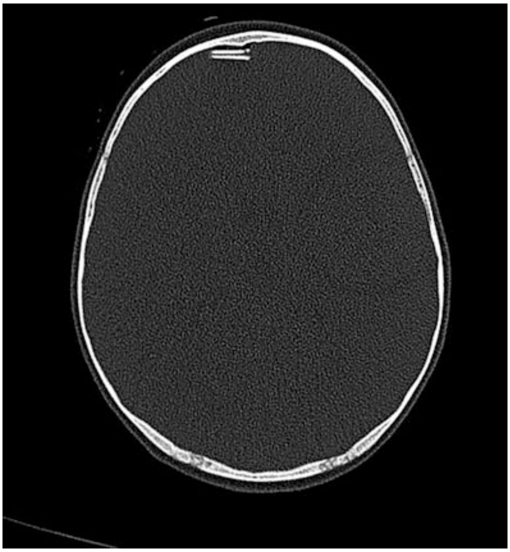


Fig. 6.4 Axial NCCT bone windows demonstrating a perplexing bone flap inside the right frontal bone. Reprinted with permission from Military Medicine: International Journal of AMSUS

6.4 Blast and Ballistic Injuries to the Neck

Penetrating neck injuries are a common cause of death in combat in that the body armor does not always cover the neck region major vasculature and airway. Penetrating trauma to the carotids results in extravasation or pseudoaneurysm as seen in the case in the previous chapter. That patient was saved due to severity of

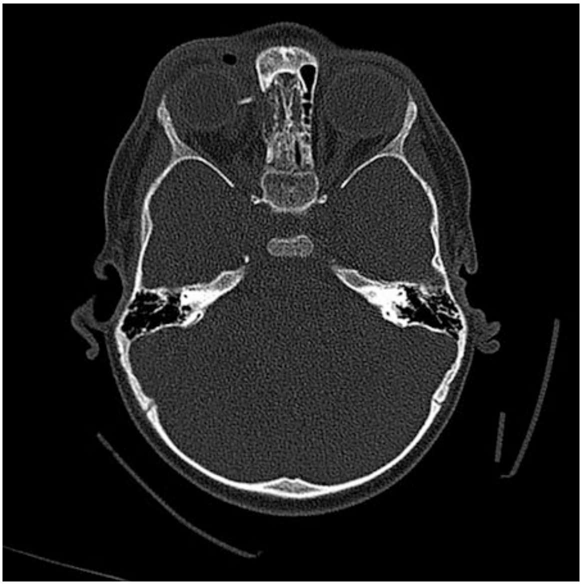


Fig. 6.5 Another axial bone window view now showing a bone fragment medial to the right orbit presumably from the nearby fractured lamina papyracea. Note the orbital emphysema as well. Reprinted with permission from Military Medicine: International Journal of AMSUS

Fig. 6.6 A coronal bone window again showing the bone flap in the extra-axial space in the right frontal region. Reprinted with permission from Military Medicine: International Journal of AMSUS

Fig. 6.7 Another coronal now helping explain the pipe entrance and how the pipe penetrated the skull. Reprinted with permission from Military Medicine: International Journal of AMSUS

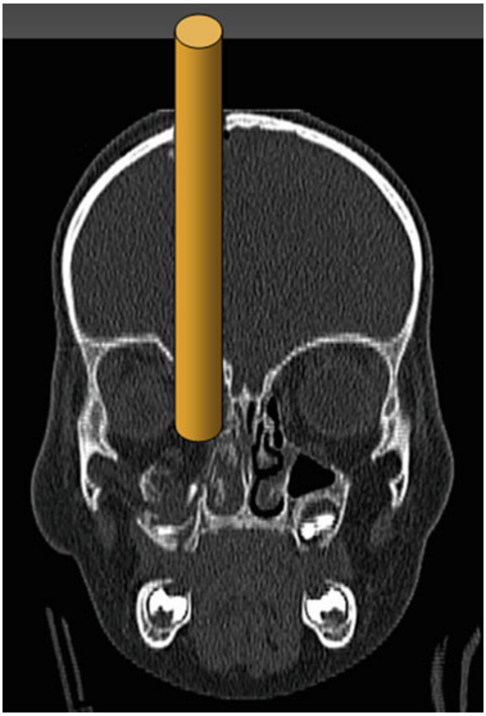


Fig. 6.8 The same coronal view now with an animated pipe showing what the neurosurgeon and I felt had happened based on the imaging and neurosurgical findings. Reprinted with permission from Military Medicine: International Journal of AMSUS

Fig. 6.9 A sagittal bone window CT reformat further explaining the skull flap that had essentially flipped under the skull from the pipe penetration. Also note damage to the orbital floor in the width of the pipe. Reprinted with permission from Military Medicine: International Journal of AMSUS

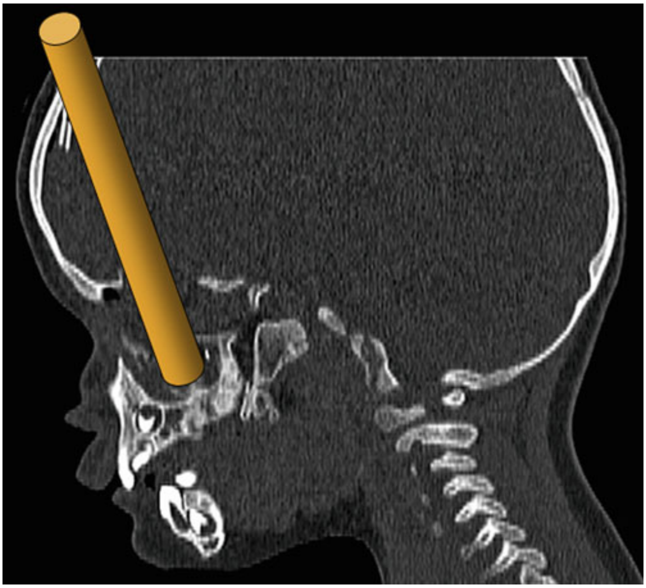


Fig. 6.10 The same sagittal CT reformat from above, now with the animated pipe to demonstrate the severity of the injury. Reprinted with permission from Military Medicine: International Journal of AMSUS

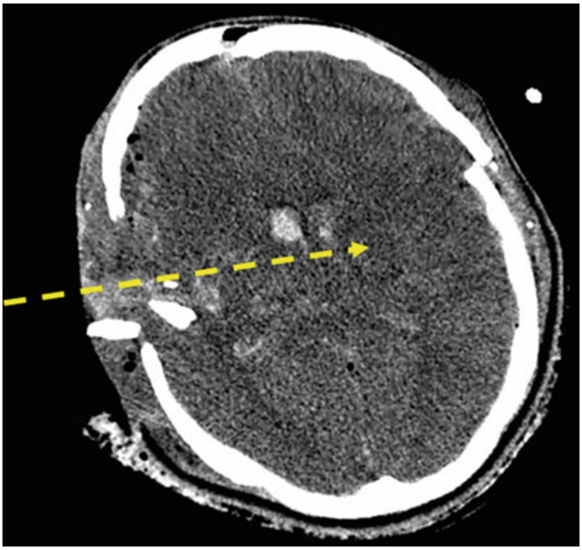


Fig. 6.11 Note the entrance of this patient that committed suicide. Note the angle of the bullet that crossed the midline, also blood in the lateral ventricles anteriorly, swelling of brain, loss of gray-white matter differentiation, pneumocephalus, indriven bone fragments. Reprinted with permission from Military Medicine: International Journal of AMSUS

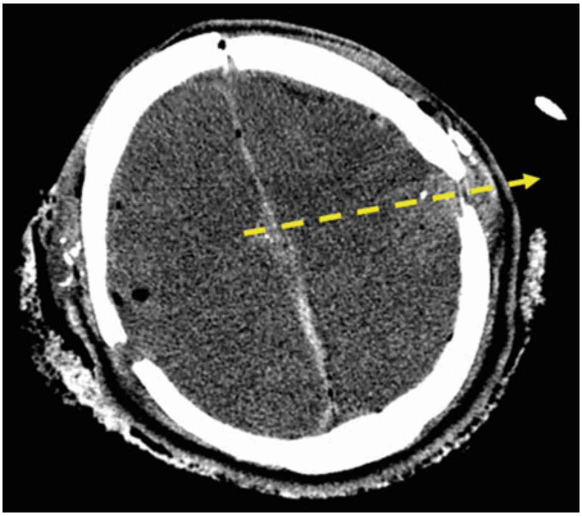


Fig. 6.12 The exit wound was higher and exhibited beveling to support this and clinical indicators of exit. Close range shots like this will have a reversal of the exit and entrance wound size expectations in that the exit is sometimes smaller than the entrance. Reprinted with permission from Military Medicine: International Journal of AMSUS

Fig. 6.13 Child caught in firefight shot in the neck with resultant pseudoaneurysm on CTA (*arrow*)

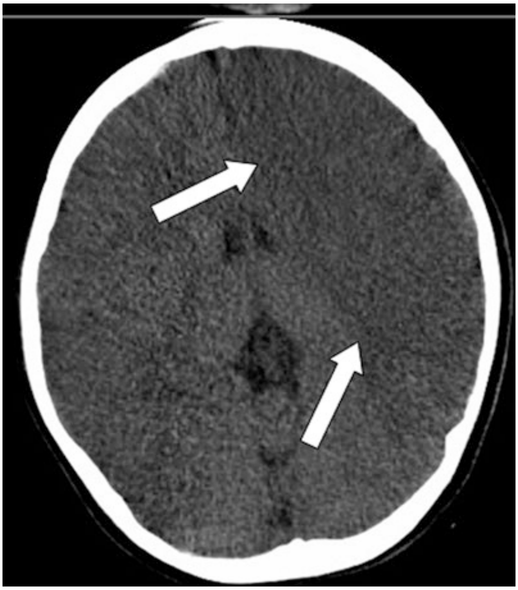


Fig. 6.14 Noncontrast CT showing large ACA, MCA distribution infarct (*arrows*)

injury and rapid evacuation to neurointerventional capability. Another case of a pseudoaneurysm in a child, however, was not so fortunate. See Fig. 6.13 for the CTA MIP of the carotids of a 7 year old shot through the neck accidently in a firefight. Note the large pseudoaneurysm on the left that resulted in severe neck distension. This was not a survivable injury, however, due to presumed clots from the carotid injury on the left. See CT of head without contrast for large ACA, MCA infarct (Fig. 6.14).

The previous chapter showed a GSW to the neck in a soldier that lived only long enough to survive the trip to the hospital. This bullet went through the spinal cord in the cervical spine region high enough to deem the patient insalvageable.

6.5 Eyesight Salvageability in Penetrating Trauma

Despite aggressive preventive measures with eye protection and education, a significant number of ocular injuries have occurred during recent combat operations mostly due to blast injuries. Many include intraocular foreign bodies from IED fragmentation. Advances in ophthalmologic microsurgery have significantly increased the chances of globe salvageability. Also, the use of computed tomography in theater has been instrumental in showing the extent of injury. Several cases of orbital trauma are reviewed here with analysis of each injury seen on CT scan. A discussion follows as to whether the globe in each case was salvageable. More information on these and other cases have been described and will be published soon [13].

Several factors have been identified as to globe salvage probability in penetrating trauma. Factors that usually lead to a good prognosis include an anterior wound location, wounds less than 10 mm in size, initial visual acuity at the time of injury to be 20/200 or greater, and a sharp intraocular foreign body(causes less ocular disruption) [14]. CT has only recently been considered in determining salvageability, however, may add to the prognosis equation significantly.

Lemeley et al. [15] lists several factors associated with globe loss after an intraocular foreign body injury. Poor prognostic factors included a wound larger than 10 mm, injuries that involved the retina, an afferent papillary defect, initial visual acuity less than 5/200 at the time of injury, and injuries from blunt objects (such as BBs).

Ehlers et al. [16] found similar prognostic factors when they analyzed 96 patients with metallic foreign body injuries. The factors most strongly associated with globe loss were an afferent papillary defect, BB/pellet mechanism of injury, and no light perception at the time of injury. Excellent visual outcome (>20/50) after injury was associated with a normal lens at presentation, an anterior segment IOFB, and vision better than 20/200 at time of presentation. Organic foreign bodies also tend to have a worse prognosis because they are more prone to infection or inflammatory reaction [17].

Computed Tomography was used as the primary imaging modality when these patients were first evaluated in the combat causality hospital. CT provides invaluable information when evaluating penetrating orbital injuries. It provides the location of any foreign bodies, visualization of soft tissues, and determination of whether the globe has been ruptured or perforated. It can also demonstrate whether the injury is isolated to the orbit or if there is associated intracranial and paranasal sinus injury. Computed tomography can help determine the extent of injury and identify those factors that are associated with globe salvageability and globe loss.

MRI and Ultrasound are additional imaging modalities that can be used to assess intraocular foreign bodies. These imaging modalities, however, were not used in the combat hospital due to limited resources and space. MRI does provide better resolution if the IOFB is made of organic material. MRI may also give better resolution for detecting optic nerve lacerations or optic nerve avulsions [18]. However, caution must be used before using MRI as it potentially could cause further injury if the foreign body is ferromagnetic. Ultrasound can also assist in detecting both radiolucent and radio-dense intraocular foreign bodies to provide more information on size, shape, and relative position.

See Fig. 6.15 for an axial image of a face CT, which shows a blast fragment that penetrated deep into the right orbit. While only one fragment is seen in this image, several fragments were seen retrobulbar after CT analysis. Only one fragment tangentially affected the globe (Fig. 6.16). The right eye was salvaged in this case. The important factor in this case was that while several fragments did penetrate the orbit, none of the fragments penetrated the globe.

This axial image of a head CT shows several metallic fragments located in the left globe (Fig. 6.17). There is also a small left-sided temporal lobe hematoma. In this case, the metallic fragments have penetrated the left globe. While the globe has

Fig. 6.15 Axial image of face CT show metal fragment in the right orbit with no compromise to the globe. Note severe soft tissue swelling anterior to the right globe. Reprinted with permission from Military Medicine: International Journal of AMSUS

Fig. 6.16 Axial image of face CT demonstrating metal fragment tangentially effecting right globe with minimal disturbance to globe integrity. Globe and eyesight were salvaged in this case

Fig. 6.17 Axial image of head CT shows two metallic fragments in the left globe. This globe was salvageable. Note the small left temporal lobe bleed (*short arrow*) and two other blast fragments and sub-q air on the left superficial facial soft tissues (*long arrows*). The right globe was not involved and not seen on this slice due to partial volume. Reprinted with permission from Military Medicine: International Journal of AMSUS

been penetrated, the globe integrity is still maintained. The total number of fragments are relatively few with just two penetrating the globe. The globe in this case was salvageable, and this was largely due to the ability to close the globe soon after injury. The small size of the metallic fragments and relatively few number of fragments in this globe also were factors in globe salvageability.

Next case shows an axial image of a head/neck CTA that shows multiple metal fragments in the left and right orbit (Fig. 6.18). The right orbit was more severely

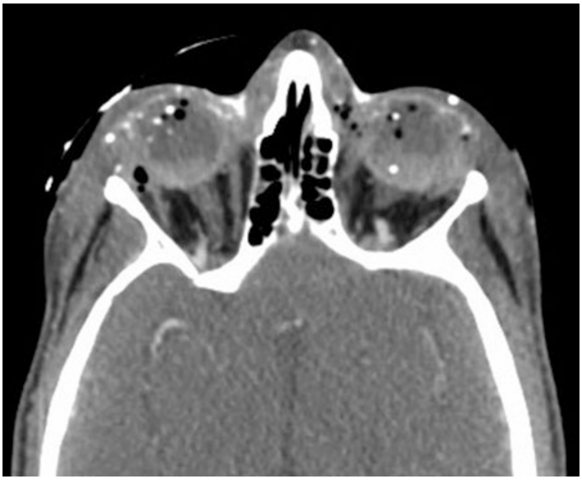


Fig. 6.18 CT image of orbits in shows multiple fragments within the right globe and left globe. These globes were not salvageable. Reprinted with permission from Military Medicine: International Journal of AMSUS

injured with significant fragmentation, eleven discrete areas of cavitation, and approximately 10% of air in the right globe. An attempt was made to salvage the right globe and the left globe. Unfortunately, the damage was too extensive in both globes to salvage due to the significant fragmentation.

The next case shows axial images of a head CT with two large fragments in the right globe (Figs. 6.19–6.21). The two fragments were removed in theater. The laceration to the right globe was extensive. Repair was attempted in theater, but the posterior aspect of the laceration could not be closed. Approximately, 20% of air was left in the globe after removal of the two fragments. When this patient was aero-evacuated, cabin altitude restrictions were required due to concerns of air expansion within the globe at altitude. Despite early intervention, this globe was not salvageable due to the size of fragmentation.

This is a sagital image of a head CT that shows a glass fragment penetrating the left globe (Fig. 6.22) from a blast. The glass fragment pierced the entire globe, and the damage was too extensive to salvage the eye. See Fig. 6.23 for operative photo of removed globe and glass.

CT shows bilateral globe disruptions from a gunshot wound crossing both eyes. This unfortunate casualty will never see again as both globes were immediately destroyed by a bullet crossing both eyes (Figs. 6.24–6.27).

Management of orbital trauma in a combat hospital offers many challenges but the primary goals are the same: immediate stabilization with closure of the globe and antibiotic administration. Definitive care may not occur until the patient is aeromedically evacuated out of theater. If there is significant air in the globe, consideration must be given to cabin altitude restrictions in the aircraft. A large

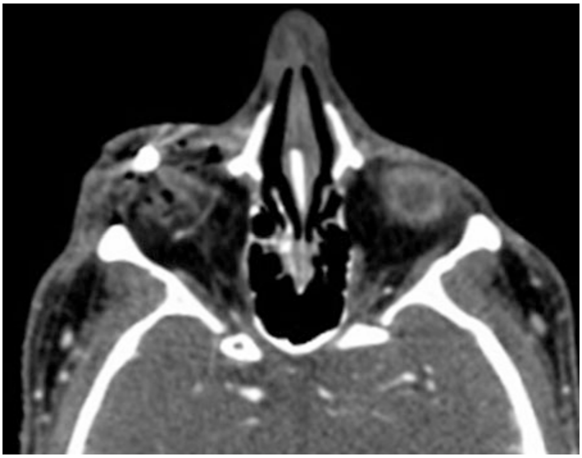


Fig. 6.19 CT axial image shows a large fragment lateral and anterior aspect of right globe with partially intruded right globe

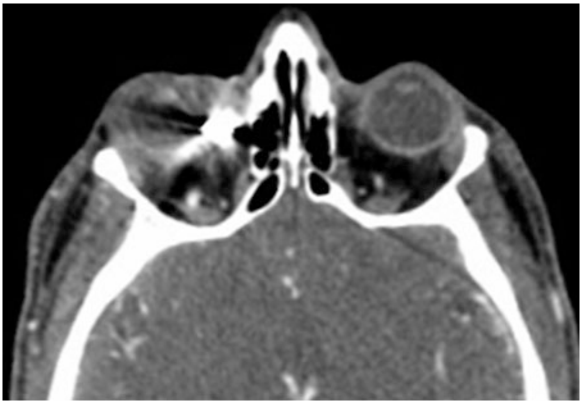


Fig. 6.20 CT axial slightly superior showing other large metallic fragment, this one in the medial aspect of globe

amount of air in the globe will expand at altitude (generally volume will double in size) and may cause further injury. Thus, cabin altitude restrictions may be required.

Removal of the foreign body may be delayed until after the patient has been evacuated, especially if the IOFB is posteriorly located and difficult to remove. There is some debate on whether delayed removal of an IOFB affects vision prognosis. Lemley et al. [19] found that a delay of 24 h in primary repair/removal of the foreign body increased the risk of endopthalmitis/severe vision loss fourfold. He goes on to state that delayed IOFB removal increases the formation of inflammatory fibrous tissue, condensation of the vitreous, and increases the risk of retinal

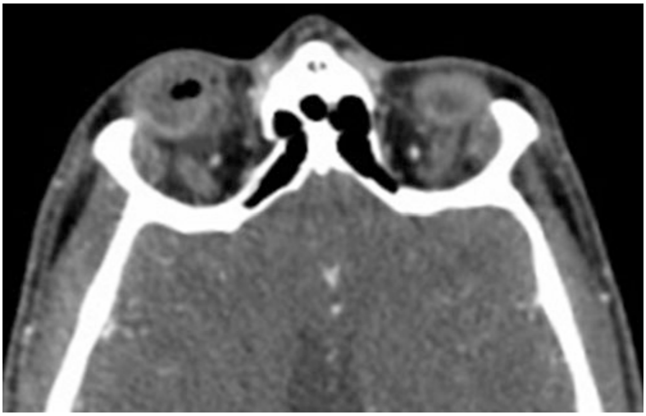


Fig. 6.21 More superior axial image showing significant air in right globe. It is important to quantify the amount of air within the globe to the flight surgeon before transport by aircraft

Fig. 6.22 CT axial bone window showing glass fragment that penetrated the left globe

detachment. However, recent studies of injured patients in Iraq have found that a delay in IOFB removal may not be as concerning as previously thought [20,21]. Ehlers et al. [22] in his own study found no significant association between time to surgical intervention and outcome. He goes on to say, "emergent IOFB removal may not be as necessary as previously thought as long as open-globe injury is closed promptly and systemic antibiotics are initiated quickly." The risk of endoopthalmitis after an open-globe injury was found to be 4–6% [23]. The risk of sympathetic opthalmia, a devastating complication of an open-globe injury, which results in vision loss of the uninjured eye has been low at 0.3% in recent studies [24].

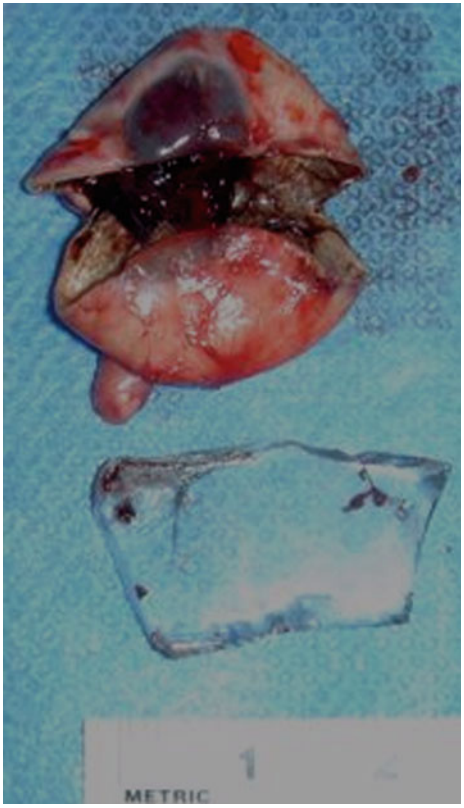


Fig. 6.23 Intraoperative photo of globe after removal with glass fragment that penetrated the left globe

If the globe is damaged beyond repair, evisceration is preferred over enucleation. Evisceration is technically easier and yields better cosmetic and functional results. In addition, enucleation can lead to several complications like hypoopthalmia, superior sulcus deformities, and motility disturbances [18]. These complications are minimized in eviscerations. Sympathetic opthalmia can occur but is generally very rare after evisceration [18].

These cases help illustrate the vast spectrum of ocular injuries that can occur after blasts. Computed Tomography can help to determine the extent of ocular injury. With more research in this area, CT grading may be possible in the future, providing further guidance on the extent of injury.

6.6 Imaging in Limb Salvage

Plain radiography, CT, CTA, and C-arm angiography can help orthopedic surgeons determine salvageability on the battlefield and what resources should be spent on surgical techniques such as vascular repair and external fixators. A few cases are

Fig. 6.24 Coronal image showing GSW path across both globes

Fig. 6.25 Coronal image bone windows showing extensive facial fractures including frontal and maxillary sinuses

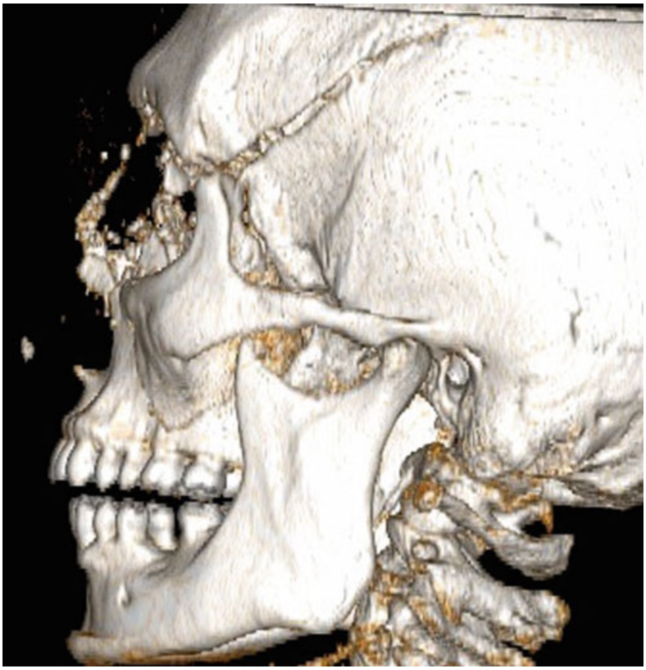


Fig. 6.26 Three dimensional volume rendered image looking through the bullet path just posterior to the nasal bones

presented to highlight how imaging can help guide trauma surgeons in saving extremities, where before CT were often not salvageable.

The first two cases highlight how CTA can quickly evaluate vascular status to the upper extremities. The first casualty was shot in the chest superiorly and centrally, with bullet transitioning through brachial region on left. A CTA of the chest was ordered to evaluate major vascular bleed. See Fig. 6.28 for the CT scout CXR showing the bullet, subcutaneous emphysema in the wound path, and a large hemothorax on the left. The bullet ended up posterior to the left scapula near the skin (Figs. 6.29–6.31).

The other case highlighting how CTA can help evaluate vessel integrity to an extremity is another GSW to the chest medial to lateral, going through the right scapula. See Fig. 6.32 for 3D rendered CT showing an intact left subclavian artery, in the path of a bullet that perforated the right scapula (Fig. 6.33).

This next case shows how a lower extremity CTA of a GSW to the thigh demonstrated a major extremity vascular injury. See Fig. 6.34 for a vessel tracking reformation of a CTA of the lower extremities. This thrombus in the femoral artery was repaired and resulted in saving of the leg based on CT localization.

Fig. 6.27 Photo from the side of this patient showing the wound path behind anterior superior nose

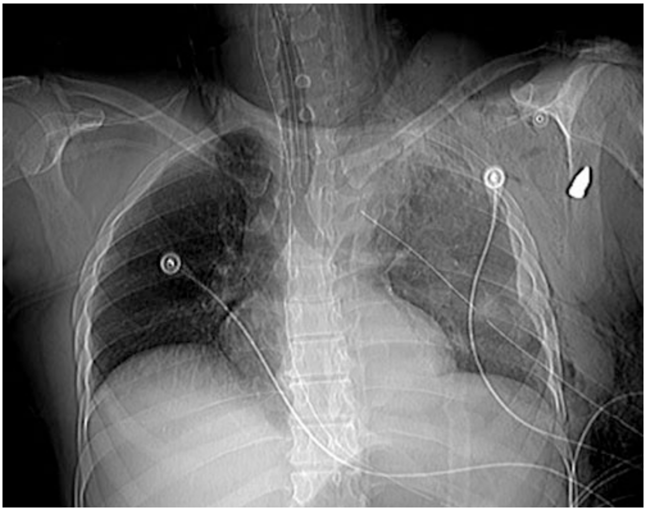


Fig. 6.28 CT scout CXR of casualty with GSW to the chest superiorly and left with weak pulse in left arm. Note large left hemothorax (especially toward apex) with subcutaneous emphysema in left axilla

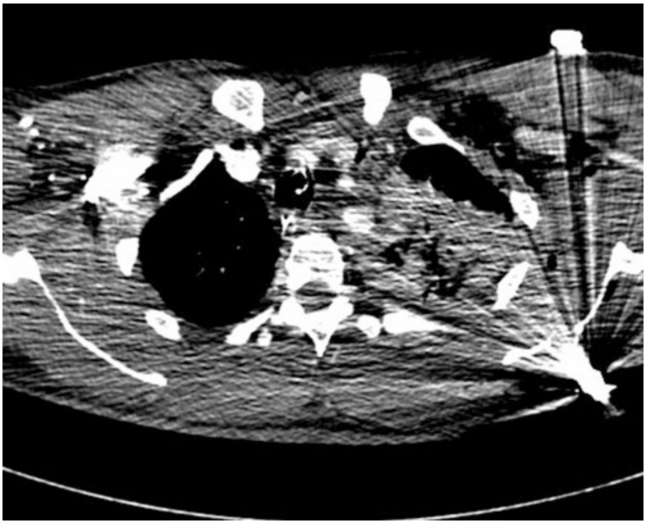


Fig. 6.29 CT Angiogram with bullet and lung contusion supporting anterior to posterior and medial to lateral wound path. Note great vessels partially seen (limited due to motion and, beam hardening)

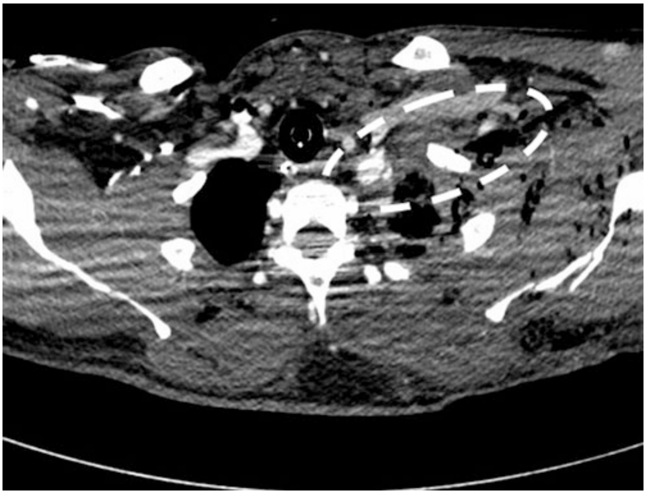


Fig. 6.30 CT Angiogram showing large subclavian artery disruption. This is better demonstrated on vessel tracking

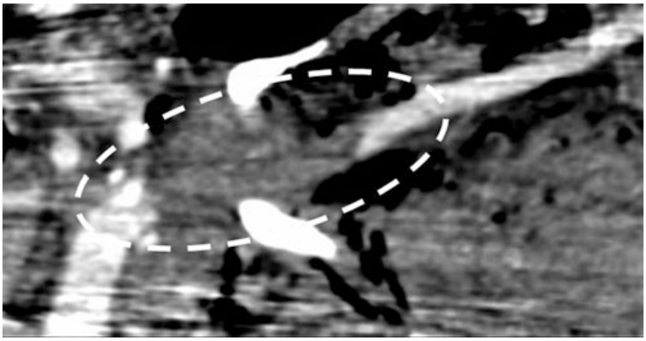


Fig. 6.31 CT vessel tracking reformat through left subclavian artery. This thrombus was repaired in surgery and the arm was salvaged

Fig. 6.32 Three dimensional CTA showing intact right subclavian that was in path of bullet that also perforated the right scapula

6.7 Radiology-Assisted Autopsy

An extensive review of forensic analysis is beyond the scope of this book, however, one should see from this chapter how imaging can play a pivotal role in cause of death, and more importantly, determining cause of life from an epidemiological

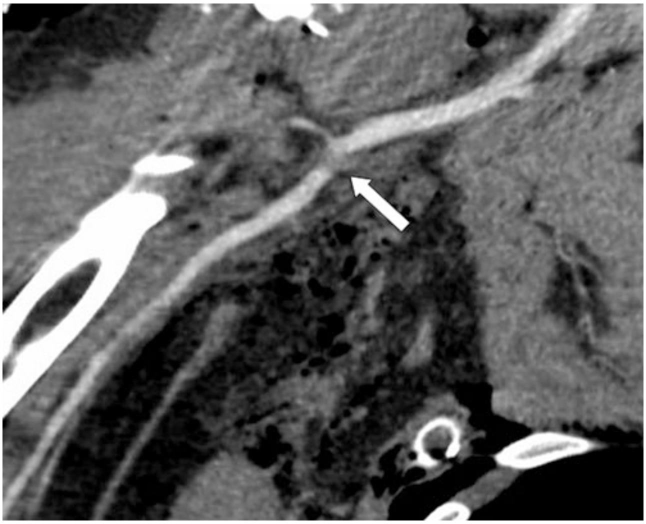


Fig. 6.33 CT vessel tracking showing the intact vessel. This image also shows how processing errors can be mistaken of thrombus (*arrow*)

Fig. 6.34 CT vessel tracking of the left lower leg showing a large thrombus in the femoral artery in the region of the GSW path in the medial thigh. Note extensive subcutaneous emphysema medial to the vessel

perspective. By studying casualties that have lived from combat medicine in recent years that otherwise died in previous conflicts, we can see the impact imaging has made and where to continue to make improvements in combat casualty care. See Fig. 6.35 for a threshold graph I put together to show in presentations when discussing this topic. I believe that identifying the imaging mortality threshold of life, limb, and eyesight will help save more lives by changing perceptions of survival – potentially moving the threshold toward increasing survival in the future. Radiologists can not only help forensic pathologists determine the cause and manner of death, we can all help determine the cause of life in those that in the past would have died.

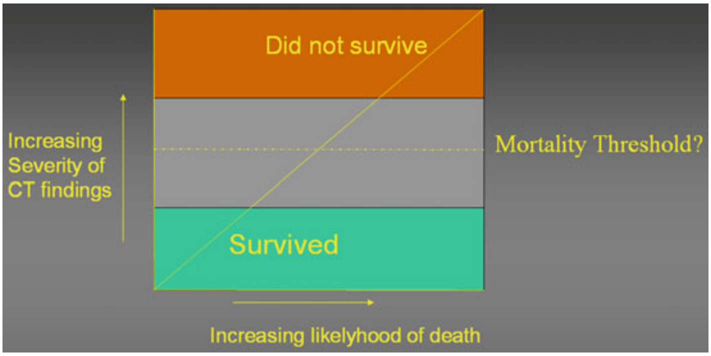


Fig. 6.35 A basic graph I show in presentations reflecting my perception on increasing severity of imaging findings and the resultant increasing likelihood of death based on worse imaging findings. I think most radiologists agree that there are findings so severe that death is imminent, especially true with head CT

Fig. 6.36 Cyclic control injury: Plain X-ray of right hand of the flying pilot shows a posteriorly displaced transverse fracture of the fifth MC likely from contact with the cyclic rest on impact (*arrows* in e). There is also a subtle lucency through the base of the first MC fracture often seen with right hand grasp of cyclic (*arrows*)

Postmortem plain film analysis has been helping forensic pathologists for years, [25] however, CT has added much more to the science recently by increasing spatial resolution and detection of projectiles better than ever before [26].

Similar to how trajectories can aid in incident investigation, RAA can add value to aircraft mishap investigation by analyzing injury patterns [27–30]. Folio et al. analyzed a helicopter crash based on the patterns of injury of the pilot in control of the aircraft during impact [31]. Knowing who was on the controls can help the accident board in figuring out potentially preventable human factors issues by looking into crew rest cycles, medications taken, events leading up to the crash, for future prevention of mishaps (when able). In the particular helicopter accident they analyze, the authors believed that RAA helped determine the pilot on the controls at the time of impact. See Fig. 6.36 for plain radiograph of the right hand showing fractures of the first and fifth metacarpals that they believe were the result of the cyclic while the pilot flying was holding firmly. See Fig. 6.37 for artist's depiction of how the fifth metacarpal may have occurred, and Fig. 6.38 for how the first metacarpal may have fractured. Figure 6.39 is a photograph in a military helicopter showing a pilot's hand position on the cyclic for correlation. Figure 6.40a is a gross postmortem photograph of right hand showing echymosis over the first MC from that fracture. Figure 6.40b is a gross postmortem over the area of the fifth MC.

Figure 6.41 shows the left hand and wrist fractures that likely occurred due to holding on of the collective. The collective is always controlled with the left hand, (Fig. 6.41d) and one can see how holding this during impact could result in a fracture dislocation of the left wrist.

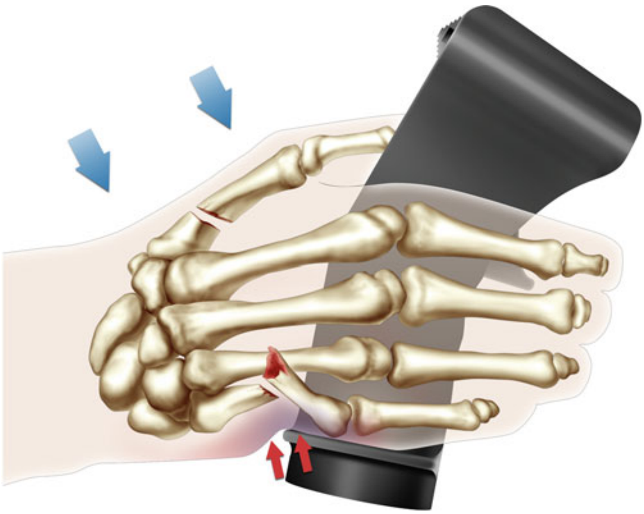


Fig. 6.37 Drawing illustrating how cyclic rest and fifth MC contact during impact

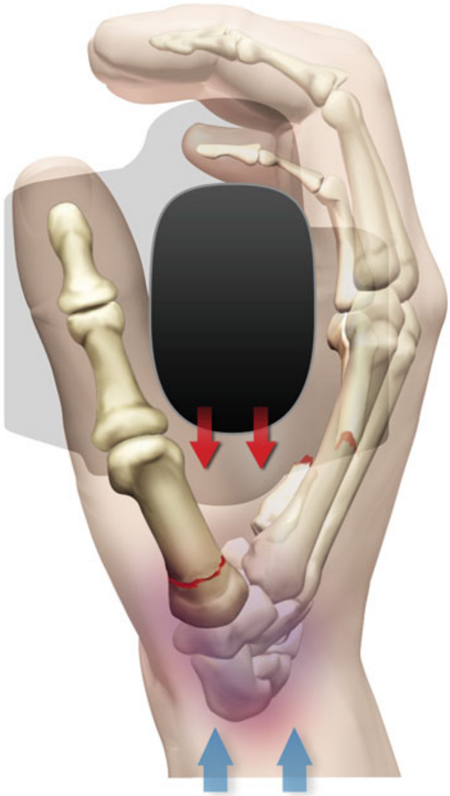


Fig. 6.38 Artist's rendition of thumb and cyclic contact that results in fracture of first MC

Fig. 6.39 Side photo showing typical hand position relative to cyclic rest. One can see the energy transfer of the fifth MC as it impacts the rest during sudden deceleration and downward force from a crash

Fig. 6.40 Gross postmortem photograph (**a**) of right hand showing echymosis over the first MC from the fracture likely resulting from the cyclic pressure during impact. Gross autopsy photo (**b**) showing echymosis over fifth MC

This particular mishap demonstrates other clues to direction of impact, occupyable space issues, and cause and manner of death. For example, the Radiology Assisted Autopsy is done with all clothing and gear worn at the time of death; Figs. 6.42 and 6.43 show 3D reconstructions of the head CT with helmet on and digitally subtracted. This way, helmet design and protection efficacy can be evaluated over time, and support for cause of death can be determined by survivability of injury covered in previous chapter. Additionally, a fracture-dislocation of the right hips of both pilots were noted due to cockpit panel contact, not dissimilar to dashboard injuries seen in automobiles. See Figs. 6.44 and 6.45 for pelvis X-ray, 3D CT of pelvis, and artist drawing of injury mechanism and dynamics.

Drawings are by Sofia Echelmeyer and photos are by Dr. Les Folio.

AP Pelvis (Fig. 6.44) and 3D volume rendered reformations (Fig. 6.45) of the pilot presumed at the controls, showing right hip dislocation from secondary impact of cockpit dash. Figure 6.46 shows the dynamics of impact with cockpit panel effects. Note crushing and shearing from sudden deceleration in downward and rightward energy transfer.

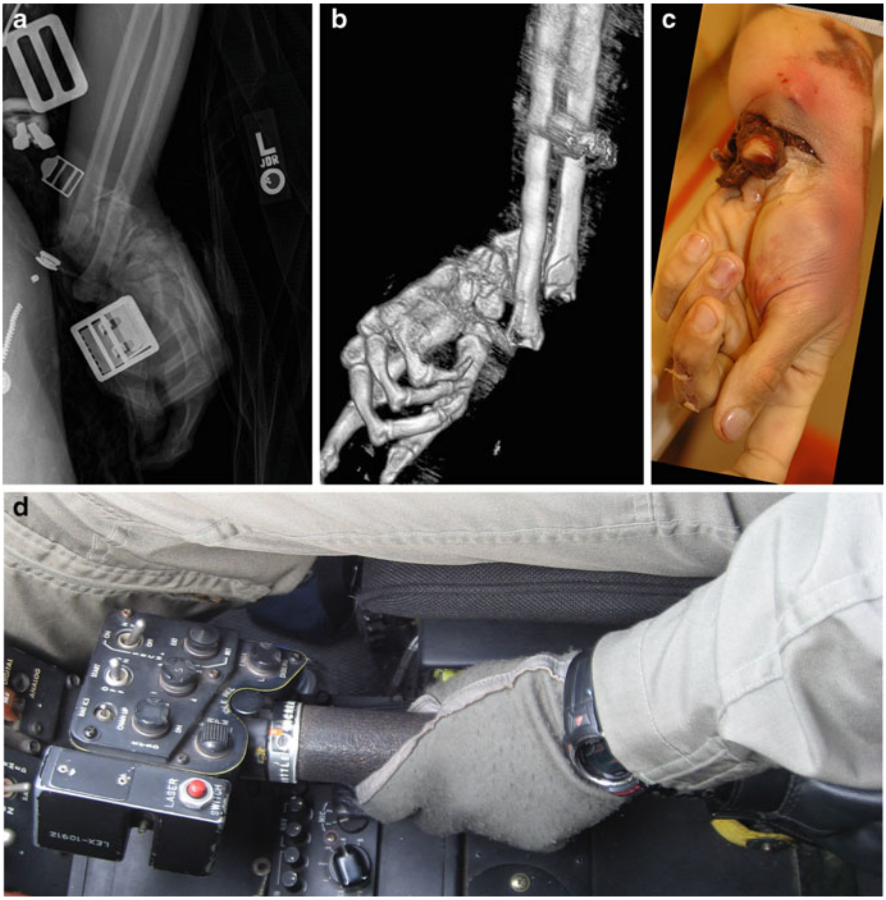


Fig. 6.41 Fracture patterns of left hand and wrist consistent with collective control injury: (**a**) Plain radiography of left hand demonstrating severely displaced open fracture-dislocation of distal radius and ulna. The 3D reformat in (**b**) better illustrates intact distal ulna, with complete dislocation from carpals, and comminuted distal radius fragments severely displaced posteriorly. Gross photo (**c**) from autopsy showing dislocated ulna protruding from open wound. Cockpit photo (**d**) shows typical left hand position on collective

At times in aircraft accidents, there may not be a discernable body or parts left over for investigation. This unfortunate aircraft incident resulted in a few body parts only detected by CT. Following an F-16 crash just off base, a body bag was brought to our hospital for evaluation and was mostly containing aircraft parts that remained from this horrific mishap. See Figs. 6.36 and 6.37 for the AP and lateral CT scouts for the overview of remains. After careful review of the entire axial scans, reformats were attempted to find discernable anatomy for further investigation such as DNA. Figure 6.38 demonstrated what looked to be a phalanx, and was correlated with review at the temporary mortuary in Iraq (Figs. 6.39, 6.47–6.50).

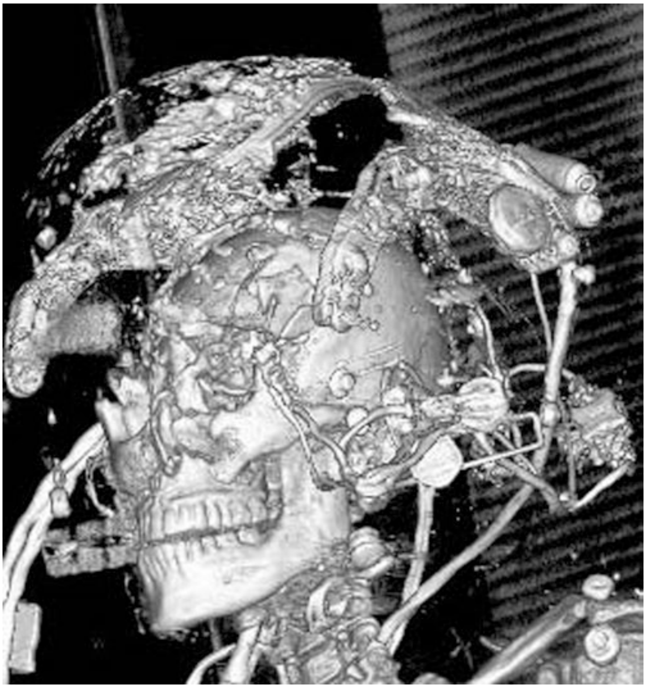


Fig. 6.42 Reformatted images showing the severe skull and facial injuries supporting forward and rightward deceleration blunt injury patterns. Protective gear is imaged in place in hopes to evaluate helmet damage patterns and any associations with cranial patterns

6.8 Summary

Imaging plays an important role in life, limb, and eyesight salvage on the battlefield. Standard reporting formats ensure evaluation of all significant penetrating head injury findings on CT and display pertinent negative findings at a glance. Fast and efficient communication is essential to patient care in the chaotic setting of deployed medicine. More objective severity determination and prognostic indicators on CT may be possible in the near future. This reporting format may be generalizable to busy civilian trauma centers as well. Epidemiologic trends and preventive measures can be better evaluated and refined.

Imaging in eyesight and globe salvageability will likely mature in the near future. Review of existing and future cases of penetrating eye trauma should help narrow the spectrum of salvage determination. Standard report mechanisms can make prospective research on CT grading scales possible for more consistent data mining of standard lexicon.

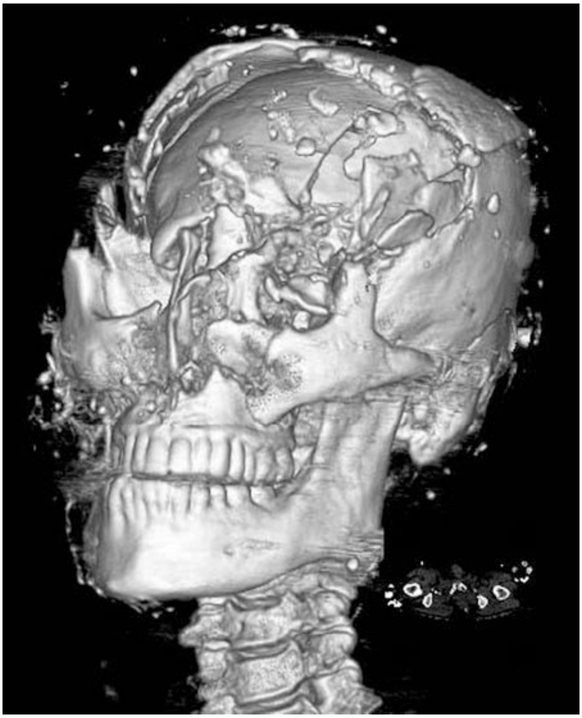


Fig. 6.43 Reformatted images showing the severe skull and facial injuries (with helmet digitally subtracted) supporting forward and rightward deceleration blunt injury patterns. Note the massive disruption of the right zygoma, orbit and frontal bones

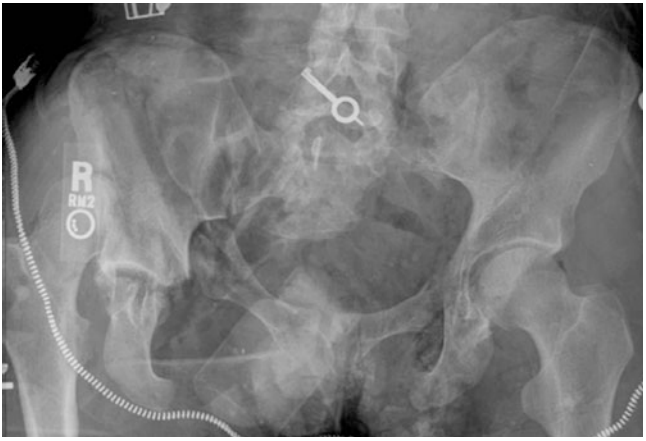


Fig. 6.44 AP pelvis of the pilot presumed at the controls, showing right hip dislocation from secondary impact of cockpit dash

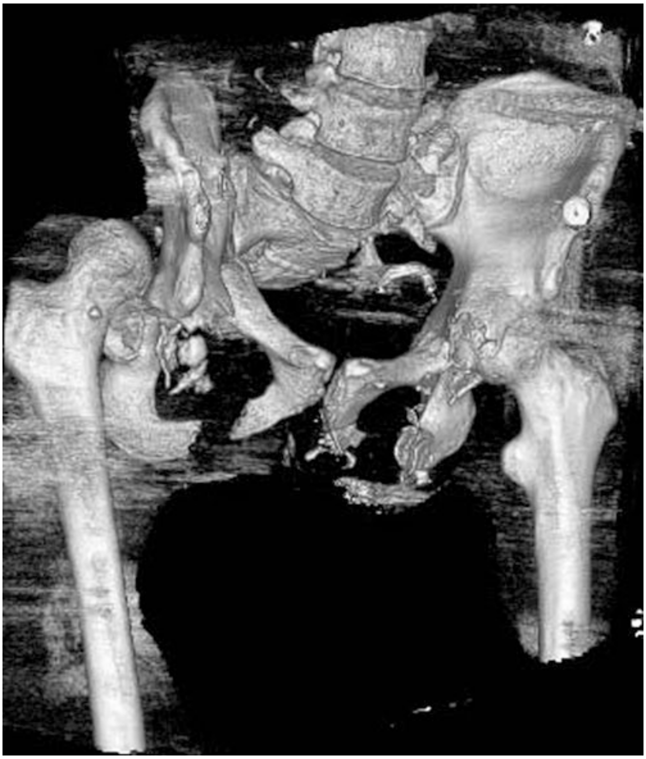


Fig. 6.45 3D volume rendered reformations of the pilot presumed at the controls, showing right hip dislocation from secondary impact of cockpit dash

Blast and ballistic extremity injuries can be evaluated by plain radiography CT and CTA, with determination of severity. CTA of major vessels leading to extremities can be especially helpful in guiding trauma surgeons in triaging these injuries and repairing expeditiously.

Lastly, Radiology Assisted Autopsy (Virtual Autopsy) can be a force multiplier in forensic analysis to help determine cause of death, or cause of life and help medical interventions save more lives in the future; or more importantly, determine the cause of life and help medical interventions save more lives in the future. The unfortunate fatally injured are the heros of medical developments in that the analysis of their injuries will at times help save the lives of those to follow. See Fig. 6.51 for the National Museum of Health and Medicine display on forensic analysis that is doctrine in military medicine. This exhibit is entitled "RESOLVED: Advances in Forensic Identification of US War Dead." This exhibit demonstrates the importance of forensic medicine and the commitment to the identification and commemoration of fatally wounded warriors.

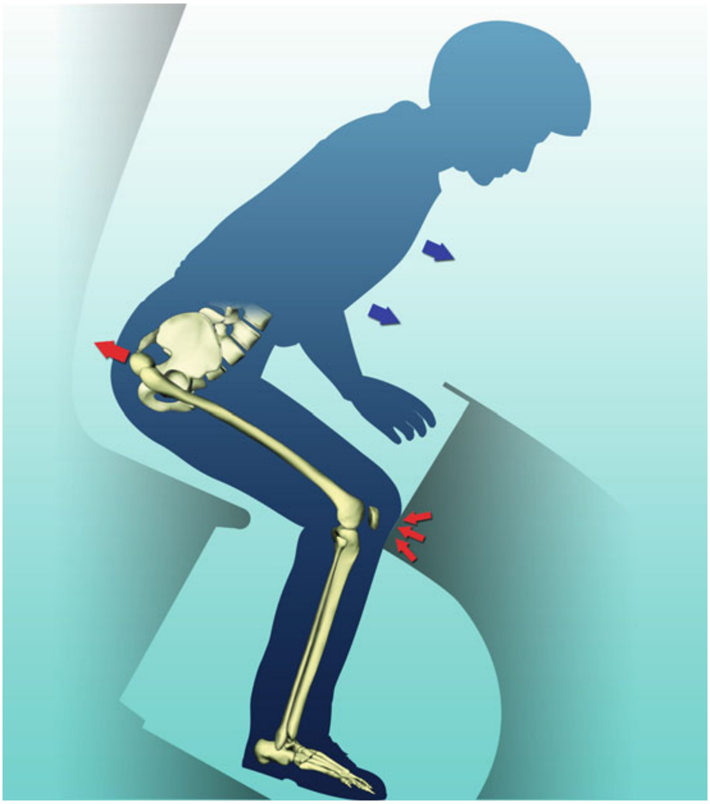


Fig. 6.46 Shows the dynamics of impact with cockpit panel effects. Note crushing and shearing from sudden deceleration in downward and rightward energy transfer

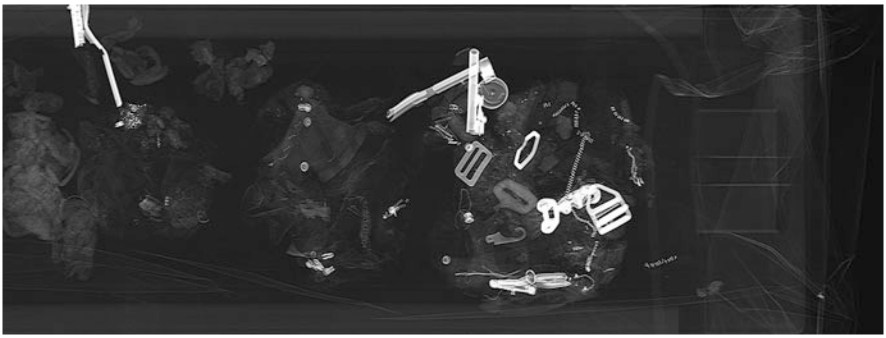


Fig. 6.47 AP CT scout of the only remains salvageable at the site of an F-16 crash where the pilot had no time to eject. No discernable anatomical features were visible on close inspection or plain X-ray

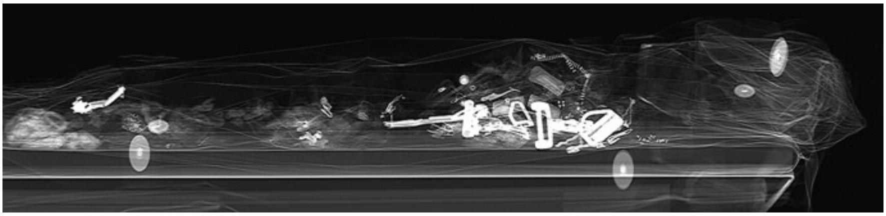


Fig. 6.48 Lateral CT scout again demonstrates mostly aircraft parts rather than recognizable anatomy

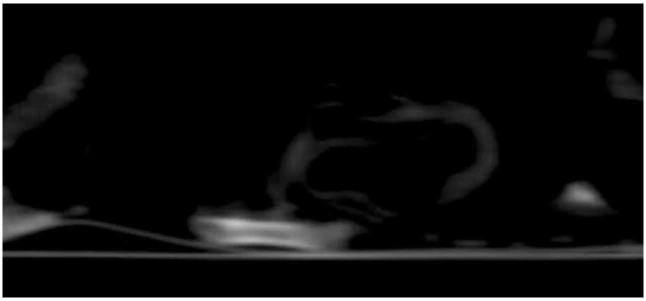


Fig. 6.49 Only after careful review of thin axial slices and reformations was a body part recognized. This lead to closer inspection of the remains in our local mortuary

Fig. 6.50 After careful review of the CT, a small phalanx was discovered among the aircraft debris. This was separated for further review back in the US

Fig. 6.51 The "RESOLVED: Advances in Forensic Identification of US War Dead" demonstrates the importance of forensic medicine and highlights milestones in forensic identification; from the development of dog tags to DNA analysis and Radiology Assisted Autopsy. In addition to the traditional tools used for positive forensic identification: material evidence, fingerprinting, forensic dentistry, forensic anthropology and forensic pathology, and DNA analysis; Radiology Assisted Autopsy is now routine and mandated in identification of service member and helping determine cause of death (or more importantly, cause of life in future wounded warriors). Donated graciously with permission to reprint by the National Museum of Health and Medicine, Armed Forces Institute of Pathology

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