Delayed evaluation of combat-related penetrating neck trauma

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Objective: **The approach to penetrating trauma of the head and neck has undergone significant evolution and offers unique challenges during wartime. Military munitions produce complex injury patterns that challenge conventional diagnosis and management. Mass casualties may not allow for routine exploration of all stable cervical blast injuries. The objective of this study was to review the delayed evaluation of combat-related penetrating neck trauma in patients after evacuation to the United States.**

Method: **From February 2003 through April 2005, a series of patients with military-associated penetrating cervical trauma were evacuated to a single institution, prospectively entered into a database, and retrospectively reviewed.**

Results: **Suspected vascular injury from penetrating neck trauma occurred in 63 patients. Injuries were to zone II in 33%, zone III in 33%, and zone I in 11%. The remaining injuries involved multiple zones, including the lower face or posterior neck. Explosive devices wounded 50 patients (79%), 13 (21%) had high-velocity gunshot wounds, and 19 (30%) had associated intracranial or cervical spine injury. Of the 39 patients (62%) who underwent emergent neck exploration in Iraq or Afghanistan, 21 had 24 injuries requiring ligation (18), vein interposition or primary repair (4), polytetrafluoroethylene (PTFE) graft interposition (1), or patch angioplasty (1). Injuries occurred to the carotid, vertebral, or innominate arteries, or the jugular vein. After evacuation to the United States, all patients underwent radiologic evaluation of the head and neck vasculature. Computed tomography angiography was performed in 45 patients (71%), including six zone II injuries without prior exploration. Forty (63%) underwent diagnostic arteriography that detected pseudoaneurysms (5) or occlusions (8) of the carotid and vertebral arteries. No occult venous injuries were noted. Delayed evaluation resulted in the detection of 12 additional occult injuries and one graft thrombosis in 11 patients. Management included observation (5), vein or PTFE graft repair (3), coil embolization (2), or ligation (1).**

Conclusions: **Penetrating multiple fragment injury to the head and neck is common during wartime. Computed tomography angiography is useful in the delayed evaluation of stable patients, but retained fragments produce suboptimal imaging in the zone of injury. Arteriography remains the imaging study of choice to evaluate for cervical vascular trauma, and its use should be liberalized for combat injuries. Stable injuries may not require immediate neck exploration; however, the high prevalence of occult injuries discovered in this review underscores the need for a complete re-evaluation upon return to the United States. (J Vasc Surg 2006;44:86-93.)**

Military conflicts have advanced the management of penetrating vascular injury. Ambroise Paré[1] recorded the first carotid ligation, saving the life of a French soldier >400 years ago. Although simple ligation became standard practice for centuries to follow, reports from both World Wars have documented many cases of irreversible neurologic deficit from this practice. More recently, as shown in the Korean and Vietnam conflicts, early exploration with expeditious intervention has reduced mortality. However, controversy continues about the proper assessment and management of penetrating cervical vascular injury.

The recent conflicts in Iraq and Afghanistan have produced a rise in the number of penetrating head and neck injuries. Mass casualty situations do not allow for routine exploration of all stable cervical blast injuries. Even with sophisticated aeromedical transport, injured soldiers often arrive in the United States more than a week after a penetrating cervical injury. The objective of this study was to review our diagnostic and therapeutic approach to the delayed evaluation of combat-related penetrating neck trauma after evacuation to the United States.

MATERIAL AND METHODS

From February 2003 through April 2005, a senior vascular surgeon evaluated all United States military casualties evacuated to Walter Reed Army Medical Center (WRAMC) with a military-associated penetrating cervical injury. These patients were prospectively entered into a clinical database, and the data were then retrospectively reviewed. Basic demographic data collected included patient age, gender, country where injured, date of injury,

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date of arrival at WRAMC, and presence of a prior surgical exploration.

Specific patterns of injury were documented, noting the mechanism of vascular injury, cervical zone involved, type of vessel injured, and the presence of any associated trauma or neurologic deficit. Vascular injuries were studied with respect to the specific vessel injured, type of repair performed, and use of autologous or prosthetic conduit. The initial outcome was documented, including complications or the need for reintervention. Patients were carefully re-examined after evacuation to the United States, and newly discovered occult injuries were documented.

All patients had radiologic evaluation on arrival to the United States. The imaging protocol was not predetermined; however, patients with prior neck exploration only had arteriography when noninvasive images were inconclusive or fragmentation also involved zones I or III. The findings of imaging modalities used for delayed evaluation, including computed tomography angiography (CTA), color-flow duplex scans, and arteriography, were analyzed.

Arteriographic findings were documented, including the presence of occult arterial injury and the use of catheter-based techniques to treat selected vascular injuries. Complications and outcomes were reviewed. These data were collected with the approval of the institutional review board.

RESULTS

Demographics. Sixty-three patients (62 men, 1 woman) were transferred to WRAMC with a diagnosis of penetrating neck trauma. Sixty were injured during Operation Iraqi Freedom, and the remaining three were injured in Afghanistan during Operation Enduring Freedom. Their average age was 27 years (range, 19 to 58 years).

Twenty-one (33%) of the 63 patients evaluated had arrived from Iraq with documentation of a recent vascular repair. The remaining patients were evaluated for a suspected vascular injury, and all patients had careful re-evaluation on arrival to the United States. The median time to arrival was 8.5 days (range, 3 to 14 days).

Injury pattern. The cervical vascular injuries were isolated to zone II in 33%, zone III in 33%, and zone I in 11%, and 23% were diffuse injuries involving multiple zones, including the lower face or posterior neck. Fifty patients (79%) were wounded by explosive devices, including rocket propelled grenades, antipersonnel landmines, high-explosive mortars, and improvised explosive devices. High-velocity gunshot wounds were associated with vascular injuries in 13 patients (21%).

Table I summarizes the distribution of vascular injuries managed in Iraq and Afghanistan. Multiple fragment injuries resulted in severe soft-tissue defects associated with complex craniofacial injuries that were frequently associated with a major vascular injury. All but eight patients had associated injuries, including a tracheoesophageal injury, facial or cervical spine fracture, globe rupture, or intracranial injury. Nineteen patients (30%) had an associated intracranial or cervical spine injury, and 41% (26/63) had motor paralysis or a major neurologic deficit. Half of all patients had facial fractures or complex ocular trauma, and 13 (20%) required tracheostomy for airway management.

Table I. Distribution of cervical vascular injuries managed in Iraq and Afghanistan

Vessel	*Repair type*	*Total repairs*
Carotid artery	Vein/PTFE	3/1
Carotid artery	Ligation	8
Jugular vein	Ligation	10
Superior vena cava	Primary repair	1
Innominate artery	Pericardial patch	1
Total		24

PTFE, Polytetrafluoroethylene.

Initial management of penetrating cervical injuries. Thirty-nine patients (30%) underwent immediate neck exploration in Iraq or Afghanistan, of which 65% (25/39) were positive for a major injury. Twenty-one patients underwent 24 vascular repairs for 13 arterial and 11 venous injuries (Table I). The most common vascular injuries were to the carotid artery in 50% (12/24) and the jugular vein in 42% (10/24).

Urgent exploration in the combat zone revealed carotid injury with segmental arterial loss, necessitating interposition graft repair in four injuries. Saphenous vein was used in three and a polytetrafluoroethylene (PTFE) graft in one. Arterial ligation was used less commonly. Two patients had emergent ligation of the internal carotid artery, and both had postoperative strokes. All external carotid and jugular venous injuries were ligated and well tolerated. Of the 11 venous injuries included with this report, eight internal jugular vein injuries and two external jugular vein injuries were managed by ligation. One superior vena cava injury was managed by primary repair.

Delayed evaluation with noninvasive imaging. All patients were carefully re-examined after evacuation to the United States. Patients underwent vascular evaluation, usually supplemented with an imaging study. Of the 63 patients in this series, 51 (81%) had some form of noninvasive imaging to assess for injury and determine the need for arteriography. Color flow duplex was performed as an alternative to arteriography in six patients (10%), to evaluate a previous repair or stable fragmentation injury in three patients (5%) each. Color flow duplex was often suboptimal due to mechanical ventilation, large soft-tissue wounds, or injuries to the patient's cervical spine. CTA was performed at WRAMC in 45 patients (71%), including six zone II injuries without previous exploration, providing detailed arterial and venous imaging. Metallic fragments, however, often produced artifact leading to equivocal studies (Fig1), and contrast arteriography was required in these cases to further evaluate for an occult injury. Ultimately, CTA correctly identified only two patients with an occult injury that was subsequently confirmed by arteriogram.

Arteriography and occult arterial injury. Forty of the patients (63%) evaluated in this series underwent arte-

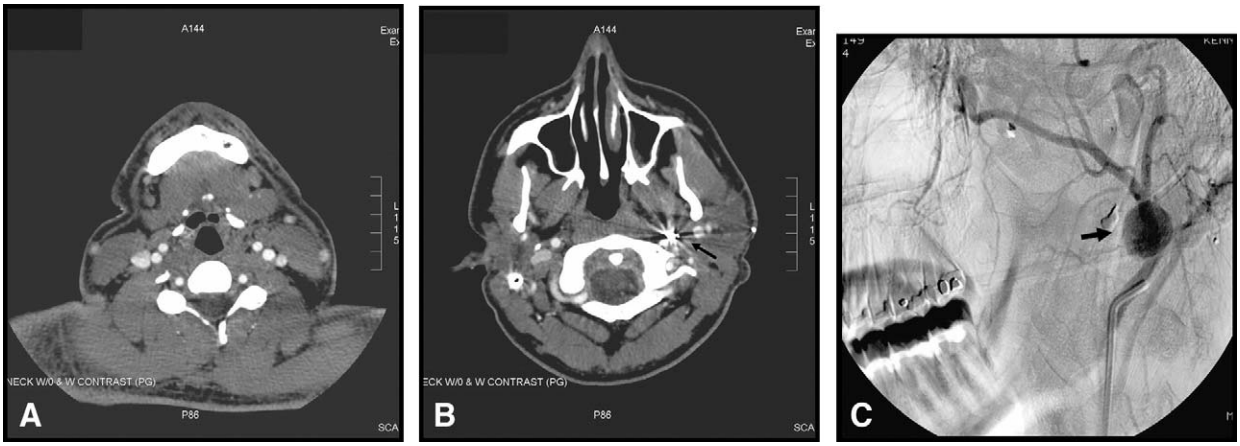

Fig 1. A, The quality of computed tomography angiography can be easily degraded by metallic artifact *(arrow)* **(B)** as depicted by subsequent sections acquired within the zone of injury. **C,** A carotid pseudoaneurysm *(arrow)* was later discovered on the arteriogram.

Table II. Cervical vascular injuries discovered on delayed evaluation after evacuation to the United States

Artery	*N*	*Finding*
Vertebral artery	6	Occlusion
Internal carotid artery	2	Occlusion
External carotid artery	2	Pseudoaneurysm
Common carotid artery	2	Pseudoaneurysm
Temporal artery	1	Pseudoaneurysm
Total	13	

riographic evaluation, of which 26 arteriograms were done to evaluate a suspected injury, and 14 were performed on patients with a previous vascular repair. Indications for arteriography included injury to zone I or III, an indeterminant CTA, multiple fragment injury, or an abnormal duplex ultrasound.

Eleven (27.5%) of the 40 patients undergoing arteriographic evaluation had an abnormal finding. Arteriography detected 12 occult injuries and one graft thrombosis in 11 patients (Table II). Three patients with occult injuries were among the 39 patients initially managed by exploration and repair of a vascular injury in Iraq or Afghanistan. Two of these patients with positive findings had an injury in zone II. All other occult injuries found were among the 24 patients who were not explored overseas but had a delayed evaluation in the United States. All abnormal arteriograms with fragments in the zone of injury had a negative or equivocal CTA. Of the 11 patients with abnormal arteriograms, CTA correctly identified only two with occult injury. Since neither patient had an embedded metallic fragment in the zone of injury, artifact was the usual cause for an indeterminant study.

Delayed surgical and endovascular therapy. Six of the 13 occult injuries detected radiographically in the United States required treatment. All vertebral occlusions were asymptomatic and treated nonoperatively. All pseudoaneurysms and one internal carotid artery occlusion were surgically repaired or coil embolized.

All pseudoaneurysms were successfully treated without complication. Catheter-based interventions were applied for treatment of two patients with pseudoaneurysms arising from the external carotid artery. Although a pseudoaneurysm of the lingual artery was correctly detected by CTA (Fig 2), another was masked by embedded metallic fragments and discovered later on the cerebrovascular arteriogram. Coil embolization was successful in both cases and eliminated the need for a lengthy and potentially difficult dissection.

Complications. Six (29%) of the 21 patients who underwent emergent major vascular repairs in Iraq and Afghanistan had an associated complication. Two were reexplored for bleeding, one died of a massive pulmonary embolism, and one had an early graft occlusion. Postoperative strokes occurred in both patients with ligation of the internal carotid artery, with one resulting in a permanent deficit. Injuries to the common carotid artery had the highest complication rate. No immediate or early complications were associated with venous ligation. Repair of the occult injuries discovered during the delayed evaluation caused no immediate or early complications. Moreover, there were no access complications from arteriography.

DISCUSSION

The modern management of penetrating neck trauma has emerged from the principles applied from previous military conflicts.[2] The current war in Iraq has resulted in numerous casualties with multiple fragment wounds from explosive devices.[3] Penetrating facial and cervical trauma is common during wartime. The incidence when reported by anatomic area is about 5% to 10% of all combat injuries.[4] Moreover, a leading cause of death in the wars in Iraq and Afghanistan is now from injury to the head and neck. Numerous patients with stable penetrating neck injuries

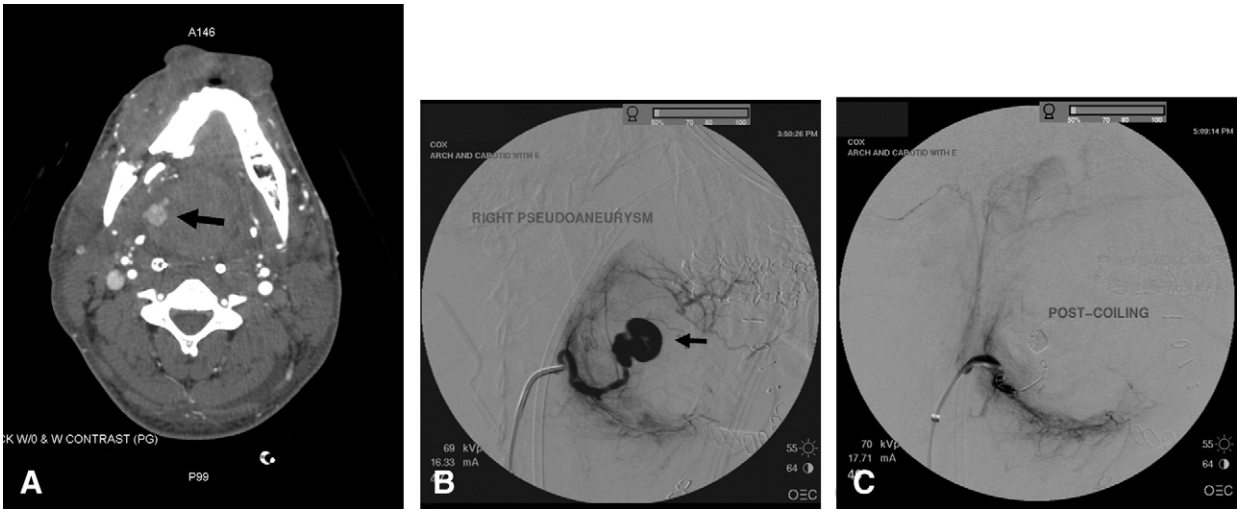

Fig 2. A, The lingual artery pseudoaneurysm *(arrow)* is demonstrated on the initial computed tomography angiography. **B,** The subsequent arteriogram shows the pseudoaneurysm *(arrow)*. **C,** Arteriogram illustrates the utility of endovascular coiling to manage an occult injury in a difficult location.

have arrived in our medical center more than a week after injury, some without prior neck exploration. Many have severe associated craniofacial, ocular, or cervical spinal trauma. The complexity of these injuries, coupled with current management controversies, has prompted a review of this experience.[5–8]

Historic military data report that carotid injuries represent about 5% of all arterial injuries,[9] and our recent findings reflect past experience. For centuries, carotid ligation was standard practice, but devastating neurologic outcome has led to more conservative approaches in the contemporary management of carotid injury. In World War I, Makins reported that one third of 128 cases of carotid artery injury treated by ligation resulted in irreversible deficit.[10] Despite the poor outcome, there were very few reports of carotid repairs during World War II and the Korean War.[11,12] During the Vietnam War, Rich[13] reported on 50 carotid injuries. With advances in operative technique and diagnosis, carotid repair rather than ligation became the accepted treatment, and the neurologic complications subsequently diminished.

Surgical decisions about the timing of treatment were instrumental in reducing mortality from neck wounds. In 1956, Fogelman and Stewart[14] showed a 35% mortality rate in patients with delayed exploration vs 6% in those undergoing an immediate operation. Rich and Hughes[15] reported that it was customary practice during the Vietnam War to immediately explore all penetrating neck injuries and to repair them with a vein patch or interposition vein graft. Contemporary practice has been to divide the neck into three anatomic zones as described by Monson et al,[16] exploring those in zone II while obtaining further diagnostic information in areas of high or low cervical injury. Several modern studies now emphasize selective exploration of stable injuries, taking into consideration the ease of surgical exposure and the probability of injury based on the physical exam.[17–22]

Modern advancements in the aeromedical evacuation system have resulted in patients reaching tertiary stateside medical centers in much shorter time than in prior conflicts. Today, the median time to arrival for a critical care air transport team to WRAMC is about 8 days from the time of the initial injury. This is fivefold faster than the Vietnam War experience, where patients remained in evacuation hospitals located in Vietnam for several weeks to months before arriving in the United States.[23] Evacuation time to the continental United States has further improved since Operation Desert Storm in 1991.[23,24]

As a consequence of rapid evacuation, many of these patients now arrive at WRAMC in critical condition 3 to 7 days after injury. They are often septic, usually on mechanical ventilation, with open abdominal wounds and complex orthopedic injuries. In this review, one fourth of the patients required urgent operations upon arrival. Although surgeons located in the battle area performed repair of obvious cervical vascular injuries, only 39 of the 63 patients underwent immediate neck exploration.

Similar to the Vietnam experience, our findings show that common carotid injury was the most frequent cervical vessel injured, and repair by vein interposition rather than ligation was the preferred strategy. Ligation of the internal carotid artery in this series resulted in a neurologic deficit. All external carotid and jugular injuries were ligated and well tolerated. Many casualties arrived at the forward surgical sites en masse, and some combat hospitals that lacked CT or digital subtraction angiography quickly transferred stable patients to a higher echelon of care for the definitive evaluation. In this series, more than one third of the patients had a penetrating neck injury without immediate exploration. This required a delayed comprehensive evalu-

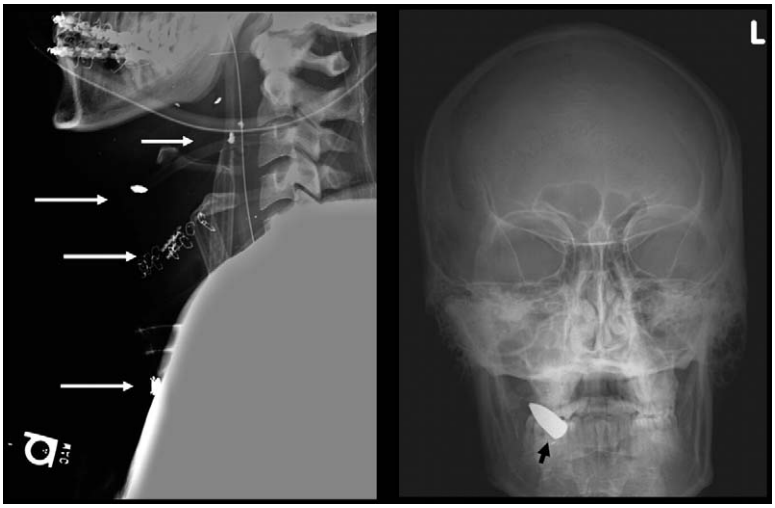

Fig 3. Plain radiographs demonstrate that metallic deposits by explosive munitions *(long white arrows)* or high velocity weapons *(short black arrow)* can predict the potential inaccuracy of a computed tomography angiography.

ation of injuries that were more than a week old by the time they arrived at WRAMC. More than half of the patients had facial fractures or ocular trauma, necessitating coordinated care with multiple services.

All 63 patients were carefully re-examined for occult injury. Fragment injury was the most common mechanism of injury. One third had a repair of a cervical vascular injury before arrival in the United States. Two thirds of the penetrating neck injuries were in zone II or III. The use of individual body armor, which has a short neck collar, may account for the smaller percentage of injuries isolated to zone I. Blast injuries frequently involved a large surface area, and 23% had fragment injuries of multiple zones, including the lower face or posterior neck. Multiple injuries were common, as 30% had associated traumatic brain or spinal injury, and 20% required tracheostomy for airway management. Mechanical ventilation and the use of rigid cervical collars could obscure wounds, challenge physical evaluation, and raise the potential for a missed injury.

Proponents of selective management of penetrating neck injury claim that patients can be spared unnecessary surgical procedures and that there is no mortality advantage to mandatory exploration when examined by experienced surgeons.[25,26] Although the application of arteriography is still debated, there is general agreement that physical examination and sophisticated imaging techniques can be used in lieu of mandatory exploration, particularly when the injury is isolated to zone I or III.[26–29] Immediate neck explorations in Iraq resulted in positive findings in 25 (65%) of 39 patients. Four patients had isolated injury to the trachea or esophagus, and the rest had one or more vascular injuries. In comparison, delayed evaluation of the 24 patients not explored in Iraq identified eight patients (33%) with an occult injury. Three (7.6%) of 39 patients immediately explored had an additional occult injury discovered upon re-evaluation at WRAMC, including two vertebral occlusions and a carotid pseudoaneurysm that required coil embolization.

This suggests that there is a high risk of vascular injury with cervical fragmentation, even in patients who are otherwise stable. Furthermore, multiple zone of injury is common, and injuries to zone III or I need careful and continuous assessment in tertiary centers. This emphasizes the importance of meticulous and continuous re-evaluation regardless of the initial management strategy.

Our approach for patients with penetrating neck trauma incorporated a physical examination and some form of noninvasive imaging, regardless of how the patient was initially managed in Iraq. The rare exception may be a patient with an isolated nonfragment zone II injury, arriving after a negative exploration, with a normal physical examination result. Color Doppler ultrasound examination is well established for trauma.[30] In our experience, it was useful to evaluate previous repairs, but was technically limited for zone I or III injuries or cervical wounds with large soft-tissue defects. Moreover, it was often impractical for the critically ill, especially patients with cervical spine injury, as manipulation of rigid collars and ventilator tubing is cumbersome.

CTA has been used as a noninvasive alternative to conventional angiography.[31–34] We found this to be an acceptable method to evaluate a stable injury, particularly if the neck had been explored previously or a vascular repair was already done and the results of the patient's examination were normal. With a properly sequenced protocol, the imaging quality can be very good. The potential disadvantages are the administration of a contrast agent and degradation of image quality from the artifact produced by metallic fragments embedded in the soft tissues.[35] For this reason, we prefer to obtain a plain radiograph (Fig 3) to examine the neck for metallic fragments before ordering a

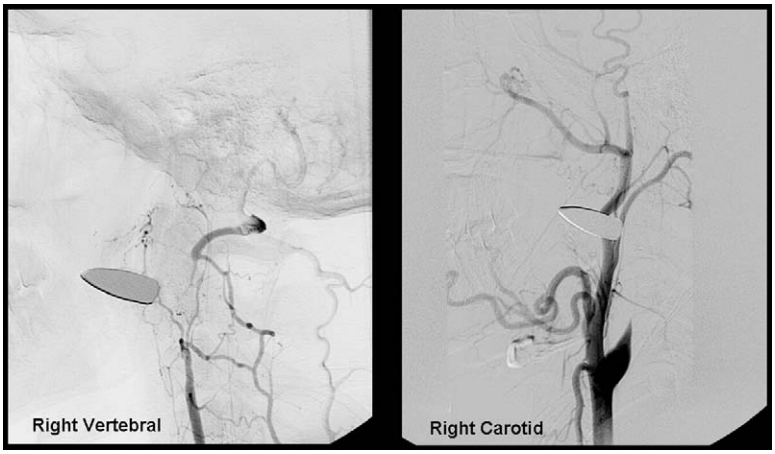

Fig 4. Contrast arteriography is recommended when metallic fragments are in the zone of injury, as illustrated by this combined internal carotid and vertebral artery injury from a cervical gunshot wound.

CTA. If fragments are localized to the zone of injury, (Fig 4) contrast arteriography is recommended.

Cerebrovascular arteriograms were also performed for injuries to zones I or III, an abnormal or indeterminant CTA, or if the patient's examination suggested that a therapeutic intervention would be necessary after the diagnosis. Forty arteriograms detected abnormalities in 11 patients (27.5%). All of the occult injuries were occlusions or pseudoaneurysms, and no arteriovenous fistulas were seen. CTA was performed on eight of these 11 patients and correctly identified only two patients with an occult injury. Interestingly, neither of the two patients had embedded metallic fragments in the zone of injury.

Contrast arteriography is especially useful when an intervention is required, because it has the potential to serve as both a diagnostic and therapeutic maneuver. Excessive contrast administration represents a limitation of CTA, particularly if additional contrast-enhanced imaging becomes necessary.[35] A CTA is therefore most helpful when no intervention is anticipated and potential artifacts are considered before obtaining the study.

The distribution of occult injury was evenly split between the carotid and vertebral arteries. Six patients (10%) required a subsequent intervention to repair an occult injury after the results of arteriogram were abnormal. One patient required revision of a thrombosed vein patch repair of the common carotid artery. This case illustrated the high potential for graft failure when near circumferential injuries are repaired by patch angioplasty. When a vein patch is placed over an arterial laceration, minimal loss of the arterial wall is essential to avoid a subsequent stenosis. Fragment injuries will usually result in segmental loss of the artery and are best repaired with vein interposition grafts. We continue to encourage the use of autologous grafts for all wartime vascular injuries secondary to the size and degree of contamination that are typical of these cavitary wounds.[36] Therefore, the extremities of all patients who are returned to the operating room are prepared for potential vein harvest.

Endovascular therapies have been incorporated into the routine management of traumatic vascular injuries.[37–42] We have previously applied this technology to successfully treat several critically ill patients, thereby avoiding a potentially complicated and difficult reoperative procedure. In one case, a lingual artery pseudoaneurysm was correctly identified on CTA. In the second case, the CTA was indeterminant because of metallic artifact, and a subsequent arteriogram revealed a pseudoaneurysm of the external carotid artery. Both carotid pseudoaneurysms were successfully treated by coil embolization using a low-profile sheath and catheter system with a series of tornado coils.

CONCLUSION

Current findings confirm the historical experience that penetrating, multiple fragment injuries are common during wartime. Wounding patterns are complex and are usually associated with multiple injuries that require specialty care. Because strict mandatory exploration may overburden available resources, neck exploration is sometimes deferred for stable cervical injuries. Multiple providers, prolonged aeromedical evacuation, and delayed evaluation necessitate that all patients have careful assessment to identify occult injuries once they are in a tertiary center.

Computed tomography angiography is useful in the delayed evaluation of stable patients, but retained fragments produce suboptimal imaging in the zone of injury. Therefore, plain radiographs should first be examined for fragments to avoid an indeterminant study and additional contrast administration. Arteriography remains the best imaging study to evaluate for cervical vascular trauma, and its use should be liberalized for combat injuries. Arterial defects are best managed by primary repair or interposition grafting with autologous conduit. Because of the degree of wound contamination, prosthetic materials are not advised.

Selective exploration and the use of endovascular techniques represent modern changes in the care of wartime vascular injuries. However, current battlefield medical capabilities and sophisticated aeromedical transport to a state-

side tertiary center are probably the major advancements in the management of neck injury from prior conflicts. Although stable patients with cervical injuries may not require immediate neck exploration, the high prevalence of occult injuries discovered in this review underscores the need for complete re-evaluation upon return to the United States.

AUTHOR CONTRIBUTIONS

Conception and design: CJF, DLG, NMR, SDO
Analysis and interpretation: CJF, DLG, NMR, SDO MWC, JSH, CMC, MAW
Data collection: CJF, DLG, SDO MWC, JSH, CMC, MAW
Writing the article: CJF, DLG
Critical revision of the article: DLG, SDO
Final approval of the article: CJF, DLG
Statistical analysis: CJF
Obtained funding: CJF, DLG
Overall responsibility: CJF

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