Prediction of major vascular injury in patients with gunshot wounds to the neck.

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Prediction of Major Vascular Injury in Patients with Gunshot Wounds to the Neck

William R. Nemzek, Stephen T. Hecht, Paul J. Donald, Russell A. McFall, and Virginia C. Poirier

PURPOSE: To determine whether plain film and CT findings help predict the presence and severity of vascular trauma. **METHODS:** The records of 65 patients with gunshot wounds of the neck were reviewed. There were 58 men and 7 women ranging in age from 2 to 72 years. All had angiography of the cervical vessels; in addition, 64 had plain radiography, 22 had CT, and 14 had a barium swallow. The results of plain films, barium swallow, and CT scans were correlated. **RESULTS:** Eighteen patients (28%) had major vascular injury, which included 10 pseudoaneurysms, six vascular occlusions, four intimal injuries, and one arteriovenous fistula. Ten patients had prevertebral soft-tissue swelling (sensitivity, 59%; specificity, 77%), 14 had a bullet fragment close to a vessel (sensitivity, 78%; specificity, 36%), and 13 had missile fragmentation (sensitivity, 72%; specificity, 45%). **CONCLUSION:** Prevertebral soft-tissue swelling, missile fragmentation, and missiles adjacent to major vessels are useful but nonspecific radiographic signs and are present in many patients with normal angiographic findings. A knowledge of the physical findings, including the entry and exit wounds, plus the results of plain radiography and CT can help define bullet trajectories and guide angiographic evaluation.

Index terms: Blood vessels, injuries; Neck, computed tomography; Neck, injuries

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Firearm violence is a major public health problem in the United States. In 1993 there were 40 230 deaths caused by firearm injuries and 40 880 deaths related to motor vehicle accidents (1). By the year 2000 it is estimated that gunshot wounds will far outnumber traffic fatalities as the leading cause of traumatic death (2). It is also estimated that there are 7.4 nonfatal shootings for each fatality (3). The frequency of firearm-related injuries has increased dramatically in many urban centers (4). Treatment and evaluation of gunshot wounds are not confined to military medicine, but are facts of daily life. Analysis of military trauma indicates mortality from gunshot wounds has declined (5), but mortality and morbidity associated with civilian gunshot wounds have increased. McGonigal et al (6) report that death at the scene from wounds caused by semiautomatic weapons increased from 5% of the victims in 1985 to 34% in 1990. The increased mortality was attributed to a shift toward use of more sophisticated weapons and corresponding higher-caliber, higher-velocity ammunition (6). Despite information from many military conflicts and research of wound ballistics, controversy continues as to appropriate diagnostic evaluation and management of gunshot wounds of the neck (7).

The leading cause of death in penetrating neck trauma is vascular injury (8). However, predicting vascular injury in gunshot wounds of the neck is difficult because (*a*) erratic trajectories and missiles of different velocities and conformations create injuries with different characteristics, and (*b*) cavitation and secondary missile formation can produce tissue destruction outside the immediate path of the primary projectile (9, 10). We undertook a study to determine whether plain film and CT help predict the presence and severity of vascular trauma.

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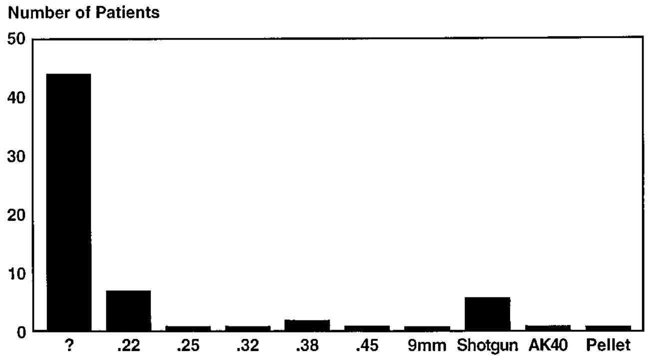


Fig 1. Types of weapons used in 65 patients treated for gunshot wounds during a 3-year period.

Materials and Methods

Between June 1991 and March 1994, 95 patients were treated at our institution for gunshot wounds to the neck. Of these 95 patients, the records of 65 patients who had had arteriography were reviewed. There were 58 men and 7 women ranging in age from 2 to 72 years, with a median age of 22 years. All had angiography of the cervical vessels. In our institution, emergency angiography is performed as soon as the patient is clinically stable. Selective common carotid and vertebral arteriograms are obtained. An arch aortogram is added for zone 1 injuries. Sixty-four patients had plain radiography which was performed with a 100-cm target film distance. Twenty-two patients had CT, and 14 had esophagography. The results of plain films, esophagograms, and CT scans were correlated. In 44 patients the type of weapon was unknown (Fig 1). Most patients were the victims of assault with a handgun.

The location of neck wounds is categorized according to three zones: zone 1 = clavicles to cricoid, zone 2 = cricoid to angle of mandible, and zone 3 = mandible to skull base (11–13). Entry wounds were located in zone 3 in 58% of patients (n = 38), in zone 2 in 22% (n = 14), in zone 1 in 14% (n = 9), and in multiple zones in 6% (n = 4) (Fig 2). Exit wounds were located in zone 3 in 26% of patients

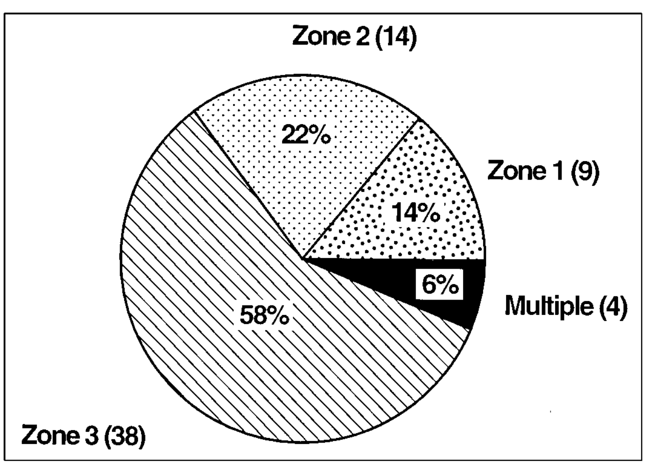


Fig 2. Location of entry wounds in 65 patients.

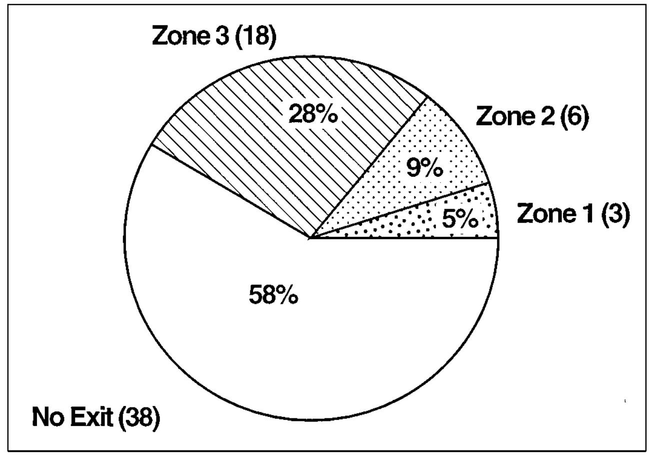


Fig 3. Location of exit wounds in 65 patients.

(n = 8), in zone 2 in 9% (n = 6), and in zone 1 in 5% (n = 3) (Fig 3). There was no exit wound in 58% of the patients (n = 38). Lack of an exit wound is characteristically associated with injury by a low-velocity weapon, such as a handgun.

Radiographic evaluation of the wounds was as follows: an increase in the prevertebral soft tissues greater than 6 mm at the level of the body of C-2 was considered abnormal; fragmentation was defined as fracture of the bullet into two or more pieces; and a bullet or bullet fragment was considered to be in proximity to a major vessel if it was within less than a 2-cm radius from the vessel. Moreover, the presence of subcutaneous emphysema and mandibular and other facial fractures was tabulated, and the path of the projectile was approximated by marking the entrance and exit wounds at the time of angiography.

Results

Eighteen patients (28%) had major vascular injury, which included 10 pseudoaneurysms (8 carotid artery, 2 vertebral artery); 6 vascular occlusions (4 vertebral artery, 1 internal carotid artery, and 1 external carotid artery); 4 intimal injuries (1 vertebral artery, 1 internal carotid artery, 1 external carotid artery, and 1 subclavian artery); and 1 arteriovenous fistula (carotid jugular). Spasm and occlusion of small branches of the external carotid artery were not considered to be major vascular injuries.

All the carotid pseudoaneurysms, except one, and the carotid jugular arteriovenous fistula were repaired surgically. One patient with a carotid pseudoaneurysm required ligation of the internal carotid artery. The vertebral pseudoaneurysms were treated with permanent balloon occlusion. The vertebral occlusions were observed and required no further treatment, but the external carotid occlusion was surgically li-

TABLE 1: Clinical signs of vascular injury in healthy subjects and in patients with major vascular damage

Clinical Sign	Patients with Vessel Injury (72%)	Healthy Patients (32%)
Hematoma	8 (44%)	10 (21%)
Cranial nerve palsy	2 (11%)	2 (4%)
Extremity weakness	2 (11%)	1 (2%)
Bruit	1 (6%)	0
Pulsatile bleeding	1 (6%)	0
Questionable absent pulse	0	2 (4%)

gated. Patients with intimal injury were followed up with magnetic resonance (MR) angiography, duplex sonography, or catheter angiography. Three patients had normal findings and required no further treatment. The fourth patient with intimal injury was lost to follow-up.

Abnormal clinical signs were present in 13 (72%) of the 18 patients with vascular injury and in 15 (32%) of the 47 healthy patients (Table 1). No patient had an expanding hematoma, but eight (44%) of the patients with injuries and 10 (21%) of the healthy patients had a stable hematoma on physical examination. Four (22%) of the patients with vascular injury had neurologic findings (facial nerve palsy, dysfunction of cranial nerves IX, X, and XI, and upper extremity weakness) versus three (6%) of the healthy group. One patient had a bruit and one had pulsatile bleeding (two patients in the healthy group had a questionable absent pulse). The two patients with upper extremity weakness had bullet fragments adjacent to the spinal cord, causing contusion; but this neurologic finding was unrelated to the vascular injury.

Radiographic Findings

Ten (59%) of the patients with major vascular injury had prevertebral soft-tissue swelling vs 11 (23%) of the healthy patients (Figs 4 and 5). Prevertebral soft tissue was found equally in patients with either carotid or vertebral injury. Thirteen (72%) of the vascular injury group and 26 (55%) of the healthy group had evidence of missile fragmentation. Fourteen (78%) of the injured patients had a bullet fragment in proximity to the injured vessel (Figs 6 and 7) versus 30 (64%) of the healthy patients (Fig 4). Two (11%) of the injured patients had subcutaneous emphysema near the involved vessel versus 13 (28%) of the healthy patients. Three (17%) injured patients had a fracture of the mandible versus 15 (32%) of the healthy patients; and 6 (33%) of the injured patients had other facial fractures versus 10 (21%) of the healthy patients. All of the esophagograms showed normal findings.

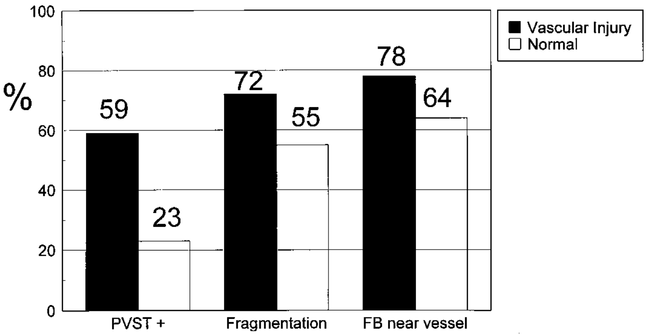


Fig 4. Radiographic findings in patients with gunshot wounds to the neck. *PVST+* = prevertebral soft-tissue swelling present, *Fragmentation* = fragmentation of missile, *FB near vessel* = missile fragment in proximity to vessel.

Discussion

Many variables determine the destructive capacity of a weapon. Missile velocity is an important consideration. Wounding capability of a missile depends on the amount of kinetic energy dissipated in the tissues (11) and is proportional to the difference between the kinetic energy on impact minus the kinetic energy on exit. Weapons are classified according to muzzle velocity as either low velocity (<1200 ft/s) or high velocity (>2500 ft/s) (4). Most handguns are low-velocity weapons, whereas hunting rifles and military weapons are high-velocity weapons.

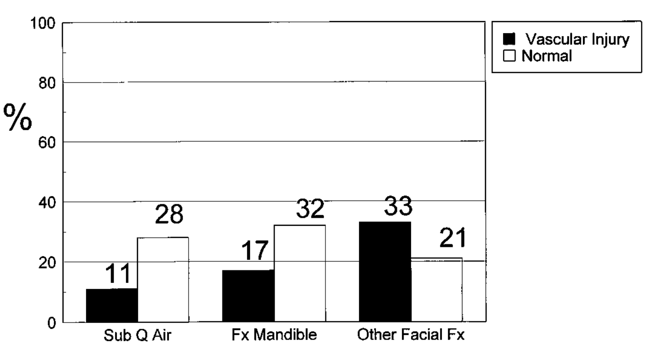
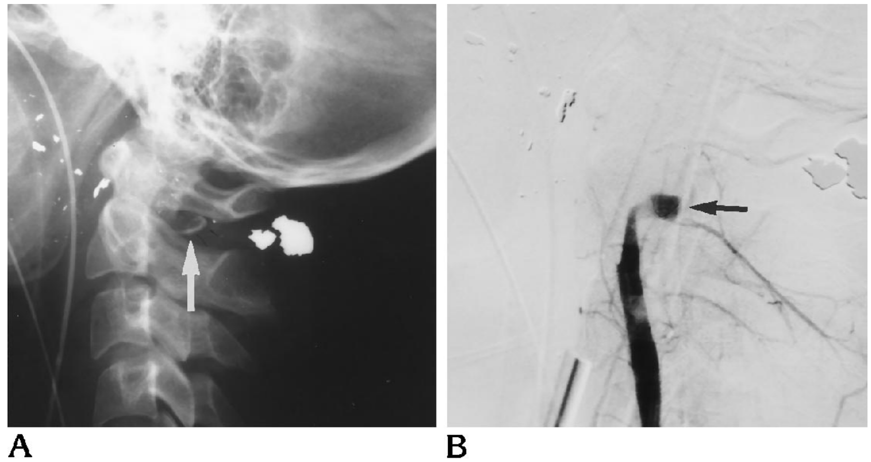


Fig 5. Radiographic findings in patients with gunshot wounds to the neck. *Sub Q Air* = subcutaneous emphysema, *Fx Mandible* = fracture of the mandible, *Other Facial Fx* = other facial fractures.

Fig 6. 25-year-old man with occluded vertebral artery resulting from gunshot wound to the face.

A, Plain radiograph shows fragmentation of the missile delineating the path of the projectile, which passes through the maxilla and crosses the path of the vertebral artery. Note fracture fragment (*arrow*) representing secondary missile formation in the bullet trajectory.

B, Lateral subtraction arteriogram shows occlusion of the distal vertebral artery (*arrow*).



The fundamental law of physics for determining the kinetic energy of any mass that is moving is

$$KE = 1/2\ MV^2/g,$$

where KE = kinetic energy, M = mass, V = velocity, and g = gravity (32.174 ft/sec) (14, 15). Doubling the mass of the projectile doubles the kinetic energy, but doubling the velocity quadruples the kinetic energy. Low-velocity missiles tend to crush and push tissue aside, creating a permanent tract that is nearly the same size as the projectile. The path of slower-velocity weapons may be erratic because the projectile may be deflected by the tissues that they strike. High-velocity missiles create a large temporary cavity that greatly exceeds the volume of the permanent tract. This is called *cavitation*. High-velocity weapons impart kinetic energy in a radial direction, stretching tissue (5) and creating a temporary cavity that can be 30 times larger than the missile diameter (14). As the bullet passes, tissue may be destroyed and either ejected out of the entrance or exit wound or compressed into the walls of the missile tract. This creates a permanent tract that is several times larger than the missile diameter (11), and may produce a large exit wound. Cavitation puts tissues that are outside the immediate path of the bullet at risk for injury. This is why some researchers advocate mandatory exploration of all wounds from high-velocity weapons (11).

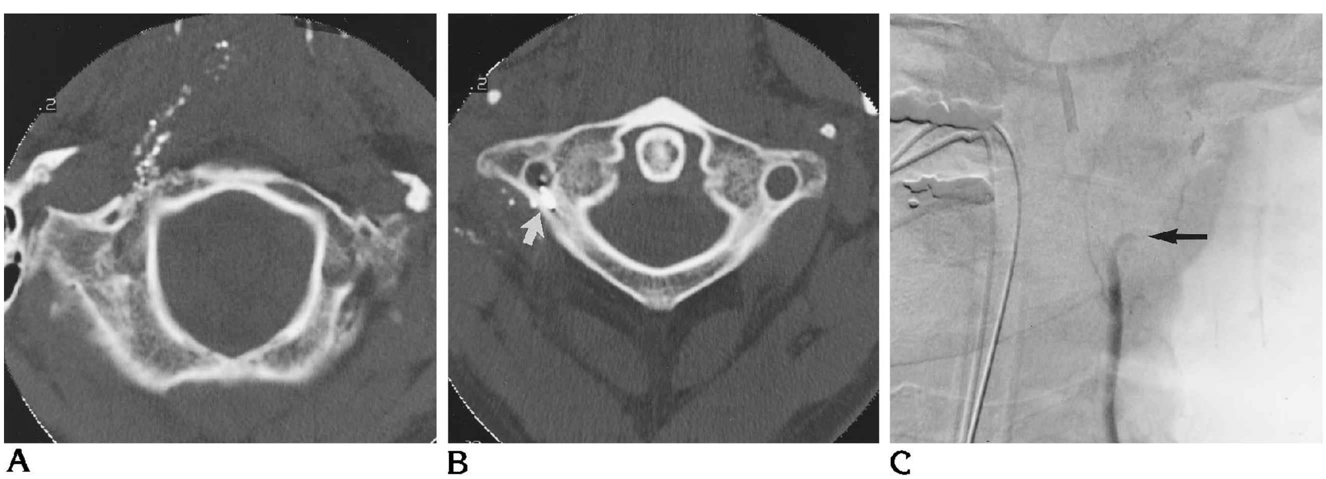


Fig 7. 38-year-old man with occlusion of the vertebral artery.

A and *B*, Axial CT scan shows the path of the bullet defined by fragments. Marked prevertebral soft-tissue swelling and fragments are seen in the transverse foramen (*arrow* in *B*).

C, Oblique arteriogram shows occlusion of the vertebral artery (*arrow*).

Fig 8. Radiograph of bone embedded in gelatin block after being struck by bullet shows secondary missile formation with multiple bone shards (from Flanagan [5]).

Kinetic energy, however, is only one factor in a complex process, and too much emphasis has been placed on cavitation (16).

Fragmentation, yaw (tumbling), and secondary missile formation increase the profile of the missile, and thus increase the magnitude of the injury. Fragmentation of the missile increases the area of the wound as the multiple fragments of irregular shape penetrate and destroy tissue (5). Bullets may fragment even if there is no contact with bone (5, 9, 16). Yaw is deviation of the bullet along its longitudinal axis. Secondary missile formation occurs when the bullet strikes such objects as bone, teeth, and buttons and drives these objects (missiles) into the wound (Figs 6 and 8). Each secondary missile creates its temporary cavity and permanent tract that may be even more destructive than the primary missile (9, 16). Missile configurations vary. Hollow-point ammunition is designed to mushroom on impact, increasing the cross-sectional area of the projectile. The delivery of kinetic energy to the tissue and the severity of injury are thereby increased (14). Frangible and exploding ammunition are being developed.

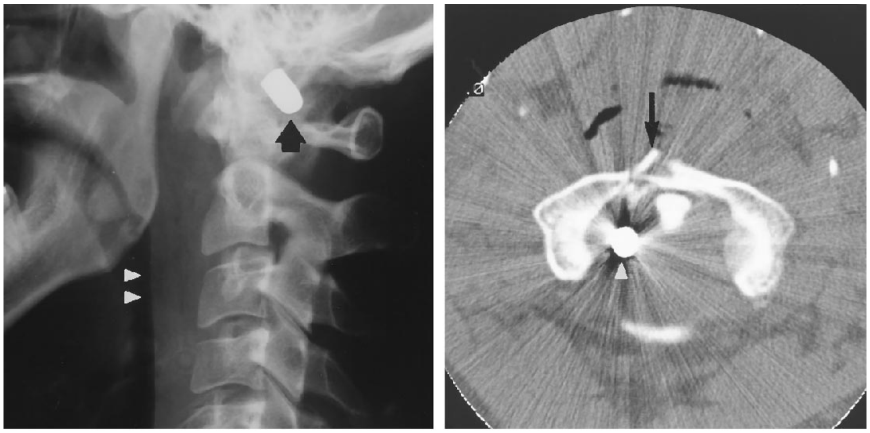
Bleeding, shock from injury to the major vessels in the neck, and compromise of the airway are the major factors causing death after penetrating neck injury (8). Patients with active bleeding, who are in shock, or who have an expanding hematoma or airway compromise require immediate surgical exploration (7, 8). Vascular injuries in zone 1 have the highest mortality rate, because they produce concomitant injury to the subclavian and innominate arteries and veins, which results in rapid exsanguination (8). Physical examination of zones 1 and 3 is very difficult, and angiography is recommended for patients who are hemodynamically stable with injury traversing zone 1 or 3 (8). None of the 65 patients in our group had an indication for immediate exploration, so angiography was performed.

TABLE 2: Sensitivity and specificity of radiographic signs of vascular injury

	Sensitivity, %	Specificity, %
Prevertebral soft-tissue swelling	59	77
Fragmentation	72	45
Missile adjacent to vessel	83	36

Some surgeons champion surgical exploration of all penetrating neck wounds (17) and other promulgate selective management based on clinical judgment and diagnostic imaging (7, 8). In one study of 246 patients with penetrating neck wounds that were explored surgically, 63% had negative findings (17). In light of such statistics, many surgeons believe the morbidity associated with surgical exploration is unacceptably high (18). However, those who advocate exploration of all penetrating neck wounds cite the lack of clinical findings in patients with significant injury. In one series, 13 of 90 patients with major structural injuries had no clinical findings and their injuries would have been missed without mandatory neck exploration (17). The clinical signs of arterial injury include pulse deficit, bruit, expanding hematoma, and arterial bleeding. In our series, 28% of the patients with vascular injury had no abnormal clinical findings and 32% of the healthy patients had abnormal clinical signs (Table 1). Clinical and radiographic signs were nonspecific findings seen in both the healthy and injured patients (Table 2) (Fig 9). Prevertebral soft-tissue swelling was a useful finding. Using Bayes' theorem (19), we found the probability of vascular injury to be 56% if prevertebral soft-tissue swelling was present (21% if absent). If there were no abnormalities on plain films or CT scans, the probability of finding an abnormal vessel was 14%.

In this series, nearly all the patients had wounds caused by handguns, which are low-velocity weapons without sufficient energy to cause cavitation and remote injury. Energy dis-



A B

Fig 9. 42-year-old man with gunshot wound to the mouth and normal findings on arteriogram.

A, Lateral radiograph of the cervical spine shows massive prevertebral soft-tissue swelling (*arrowheads*) and projectile lodged in the upper cervical spinal canal (*arrow*).

B, Axial CT scan shows prevertebral swelling, subcutaneous emphysema, and a fracture of the anterior arch of the atlas (*arrow*). The bullet is located in the anterior cervical canal (*arrowhead*). Findings on an arteriogram of both carotid and vertebral arteries (not shown) were normal.

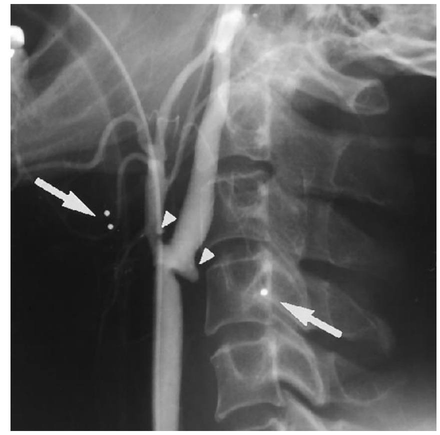


Fig 10. 40-year-old man with gunshot wound to the neck. There are no fragments to define the bullet path. The entrance and exit wounds (*arrows*) were marked on the skin. The trajectory of the missile crosses the common carotid artery. There is intimal injury of the external carotid artery and a pseudoaneurysm of the internal carotid artery (*arrowheads*).

sipation and tissue damage are determined by the density, elasticity, and cohesiveness of the target tissue (10, 15, 16). A wound of brain tissue, with almost no elasticity, would cause much more tissue destruction than would a comparable wound of the soft tissues of the neck. A bullet wound of the lung would be less severe than that of the liver, because the density of the lung is lower.

In patients with vascular trauma, either the bullet fragments were immediately adjacent to the artery or the missile passed through the injured vessel. Defining the entrance and exit wounds with plain films or CT scans, plus marking the entrance and exit wounds with radiopaque markers before angiography, is useful in defining the path of the bullet and in directing the investigation of the angiographer (Fig 10).

Increasing violence and diminishing resources demand a more selective approach to the management of penetrating neck wounds. Even surgery is not the standard of reference, and significant vascular injuries may be missed at exploration (20). In a series of 72 patients, arterial injuries were missed in 8%; in another series of 133 patients, angiograms did not show arterial injuries in 6% (21, 22). A combination of arteriography and surgical exploration may be the best method to avoid missed vascular injuries (21).

In the future, spiral CT angiography may prove valuable in excluding major vascular injury, although artifacts associated with adjacent metallic fragments may obscure significant disease processes.

Conclusion

The clinical findings of neurologic deficit, expanding hematoma, bruit, and absent pulse associated with major vascular injury are often absent. Prevertebral soft-tissue swelling and bullet fragments adjacent to major vessels are useful radiographic signs for predicting vascular injury. These signs are nonspecific and are present in many patients who have normal angiographic findings. In this series of predominately low-velocity missile wounds, vascular injury was located in the direct path of the bullet with little lateral destruction of the surrounding tissues. A knowledge of the physical findings, including the entry and exit wounds and plain radiography and CT findings, can help define bullet trajectories and guide angiographic evaluation.

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