

# *Penetrating Neck Trauma: A Review of Management Strategies and Discussion of the 'No Zone' Approach*

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The evaluation and management of hemodynamically stable patients with penetrating neck injury has evolved considerably over the previous four decades. Algorithms developed in the 1970s focused on anatomic neck "zones" to distinguish triage pathways resulting from the operative constraints associated with very high or very low penetrations. During that era, mandatory endoscopy and angiography for Zone I and III penetrations, or mandatory neck exploration for Zone II injuries, became popularized, the so-called "selective approach." Currently, modern sensitive imaging technology, including computed tomographic angiography (CTA), is widely available. Imaging triage can now accomplish what operative or selective evaluation could not: a safe and noninvasive evaluation of critical neck structures to identify or exclude injury based on trajectory, the key to penetrating injury management. In this review, we discuss the use of CTA in modern screening algorithms introducing a "No Zone" paradigm: an evidence-based method eliminating "neck zone" differentiation during triage and management. We conclude that a comprehensive physical examination, combined with CTA, is adequate for triage to effectively identify or exclude vascular and aerodigestive injury after penetrating neck trauma. Zone-based algorithms lead to an increased reliance on invasive diagnostic modalities (endoscopy and angiography) with their associated risks and to a higher incidence of nontherapeutic neck exploration. Therefore, surgeons evaluating hemodynamically stable patients with penetrating neck injuries should consider departing from antiquated, invasive algorithms in favor of evidence-based screening strategies that use physical examination and CTA.

**I**N 2001, WE PUBLISHED a pilot study<sup>1</sup> describing a fundamentally different way to evaluate stable patients with penetrating neck trauma. In that study, computed tomographic angiography (CTA) was shown, irrespective of site of penetration, to be an effective method of identifying and excluding injuries and triaging patients to surgery, further testing, or observation. Ten years later, in this review, we discuss the evolution of the evaluation of stable patients with penetrating neck trauma and emphasize the use of a "No Zone" approach to their initial assessment and management.

The neck is a highly complex anatomic region with critical aerodigestive, vascular, and neurologic structures

concentrated into a very small area and volume. The evaluation and management of penetrating injury to this region is challenging to trauma surgeons and continues to evolve. According to the 2009 National Trauma Databank,<sup>2</sup> penetrating neck trauma represented only 1.04 per cent of all injuries reported that year. However, this relatively low incidence, compared with other injury types, is overshadowed by the complexity and potential severity of penetrating neck trauma. According to the 2009 data, the reported case fatality rate was 9.68 per cent making it the highest of all the Abbreviated Injury Scale body regions. Given the high associated mortality, the risk of airway compromise, and the anatomic complexity of the region, the evaluation and management of penetrating neck trauma often requires the expertise of many different acute care specialties including emergency medicine, trauma surgery, interventional radiology, ear, nose, and throat,

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and thoracic surgery. Clearly, prompt and efficient evaluation and triage is necessary to properly care for patients presenting with this highly morbid injury complex.

Traditionally, the identification and exclusion of injuries in penetrating neck trauma has been a highly invasive and labor-intensive process.<sup>3, 4</sup> However, modern imaging techniques allow for more efficient and expedient imaging triage resulting in decreased cost and morbidity by avoiding nontherapeutic neck exploration and obsolete diagnostic techniques.<sup>5-7</sup> With advanced technology, now readily available in all trauma centers, evidence suggests that previously used approaches and antiquated algorithms should be abandoned. In this review we summarize the evolution of penetrating neck trauma evaluation. Further, we propose a "No Zone" approach to imaging triage for these patients using multidetector CTA (Fig. 1) as a safe and very effective modality for the initial evaluation, trajectory determination, injury identification, and subsequent decision-making in patients presenting with penetrating neck trauma.

### Initial Assessment

Like with all injured patients, the initial evaluation and management of patients sustaining penetrating neck trauma is largely dependent on the physiologic status of the patient and findings on physical examination. Patients presenting with hemodynamic instability or with "hard signs" of injury (Table 1) to vital structures should undergo immediate operative exploration and repair and are not candidates for imaging triage. Hard signs of vascular injury are pulsatile bleeding, expanding hematoma, bruit, unilateral upper extremity pulse deficit, and signs of stroke/cerebral ischemia. Hard signs of aerodigestive injury are extensive subcutaneous emphysema, wound bubbling, hoarseness, stridor, or airway compromise. There is no role for secondary testing early in the evaluation of these patients. Thorough operative exploration is indicated with repair or control of all injured structures.

### Classical Approach

Traditionally, the evaluation of hemodynamically stable patients with penetrating neck trauma, who present without specific "hard signs" of injury, has been based on anatomic criteria. Injuries are classified by penetration site into the three anatomical "zones of the neck" as described by Roon and Christensen<sup>4</sup> in 1979. Using external landmarks, these are: Zone I, sternal notch to cricoid cartilage; Zone II, cricoid cartilage to angle of the mandible; and Zone III, angle

of mandible to base of the skull. Classically, Zone II injuries that penetrate deep to the platysma have been managed with immediate operative exploration.<sup>3, 5, 8</sup> In contrast, Zone I and III injuries, as a result of their anatomic inaccessibility, have traditionally been evaluated more selectively.<sup>9, 10</sup> In some early series, these injuries were managed with simple observation<sup>9</sup>; over time, an algorithmic approach developed relying on routine use of a combination of four-vessel digital subtraction angiography (DSA) and endoscopy to separately examine the vascular and aerodigestive structures of the neck and upper thorax.<sup>4, 10</sup>

### Selective Approach

Over time, the rigidity of this zone-based algorithm was called into question.<sup>11, 12</sup> Mandatory exploration of Zone II injuries was the first concept to be scrutinized. It was observed that with these injuries, routine mandatory exploration alone had a high nontherapeutic rate, led to missed injuries, and significantly increased hospital length of stay.<sup>11, 12</sup> In 1994, Atteberry<sup>13</sup> described the management of 53 patients with penetrating injury to Zone II. In this series of patients, 19 underwent immediate operation based on physical signs. The remaining 34 were managed selectively based on physical examination: six patients had angiograms, 18 had carotid duplex, and the others were observed. There were no missed vascular injuries. Despite its persistent emphasis in surgical training programs, the dogma of mandatory surgical exploration for Zone II injuries was clearly discredited in the surgical literature.<sup>11-13</sup>

Subsequently, clinicians began to also question the use of these complex algorithms and invasive procedures for the evaluation of stable patients with Zone I and III injuries.<sup>1, 14</sup> Although proven to be accurate and reliable to identify and exclude injuries, the classic approach using angiography, bronchoscopy, and esophagography/esophagoscopy has very real disadvantages. Obviously, this strategy is labor- and resource-intensive<sup>14</sup> and often requires input from multiple specialties, delaying care. Furthermore, it is expensive and, as authors have indicated, has a low diagnostic yield with often less than 10 per cent of those patients undergoing selective management have clinically significant findings on angiography or endoscopy.<sup>15</sup> Finally, these diagnostic procedures are invasive and carry a small but real risk of complications.<sup>16</sup> Risks of DSA include bleeding, vascular injury, and distal embolization of plaque or thrombi as well as the risk of renal injury from intravenous contrast.<sup>7, 17, 18</sup> This technique also fails to visualize adjacent soft tissues and bony structures.<sup>19</sup> Furthermore, DSA requires a specialized team and location, services that are not

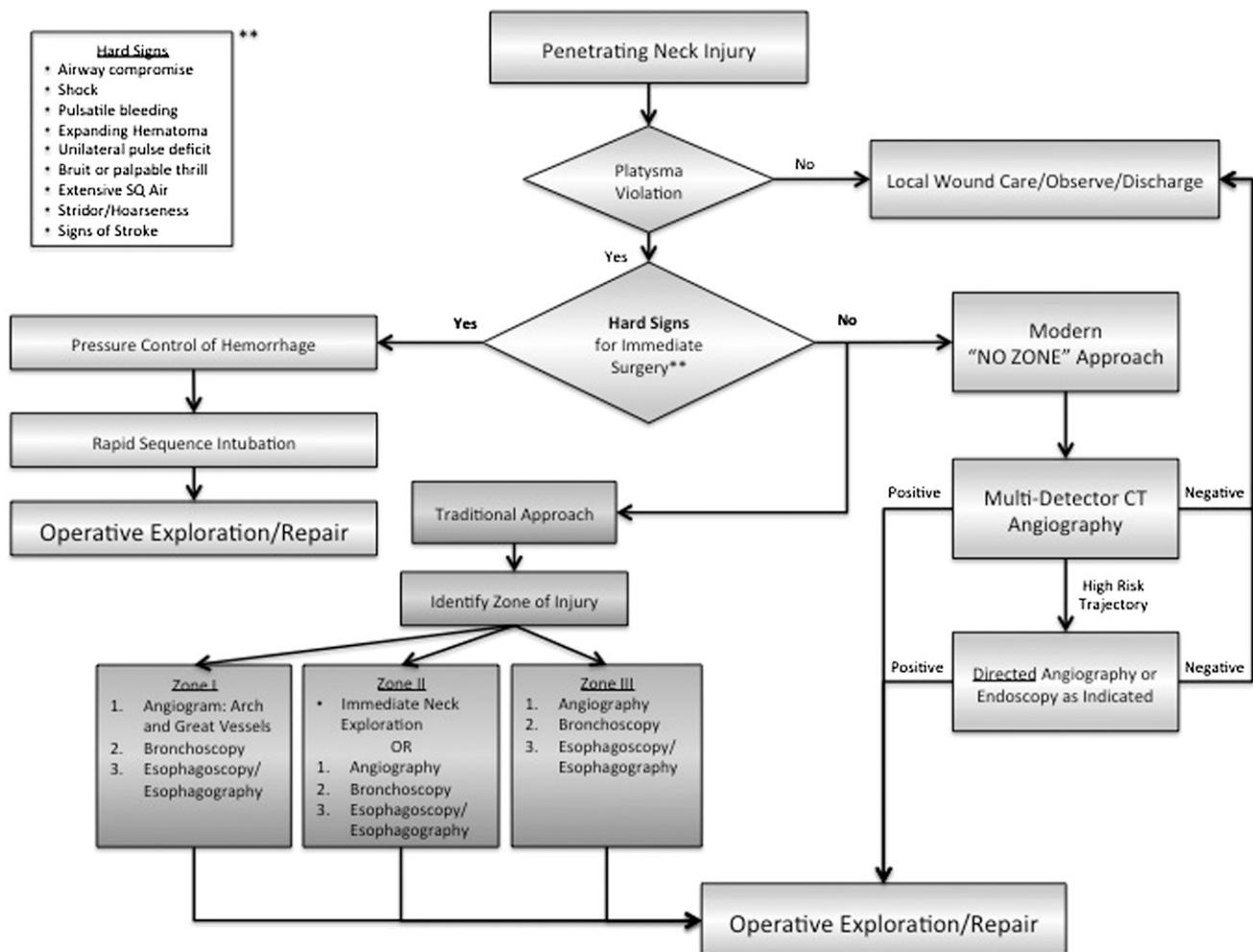


FIG. 1. Algorithm for the modern management of penetrating neck trauma.

TABLE 1. *Indications for Immediate Surgery after Penetrating Neck Trauma*

- Shock
- Pulsatile bleeding
- Expanding hematoma
- Unilateral extremity pulse deficit
- Audible bruit or palpable thrill
- Airway compromise
- Wound bubbling
- Extensive subcutaneous emphysema
- Stridor
- Hoarseness
- Signs of stroke/cerebral ischemia

routinely available at all hours in most medical centers. In addition, the high interoperator variability renders this test a poor definitive evaluation. The negative exploration rate associated with positive DSA evaluation has been reported to be as high as 53 per cent.<sup>4</sup> Bronchoscopy for the evaluation of the trachea incurs risks of bleeding, aspiration, pneumothorax, and others. Finally, endoscopy and/or contrast swallow studies to

examine the esophagus can lead to bleeding, aspiration, or perforation.<sup>20</sup>

Rejection of this maximally invasive approach has led to a number of studies re-emphasizing the physical examination alone to triage patients to further diagnostic testing after penetrating neck trauma independent of zone. In a 1997 report, Demetriades and others<sup>15</sup> prospectively evaluated 223 patients with penetrating neck trauma. For all zones of injury, they compared physical examination findings with the results of angiography, duplex examination, and esophagram and concluded that physical examination could be used to triage patients for further vascular or esophageal studies. They and Montalvo<sup>21</sup> in 1996 also noted that duplex might be a reliable alternative to angiography in these patients. Subsequently, Sekharan and others<sup>22</sup> in 2000 reported a series of 145 patients with Zone II injuries of which 114 did not require immediate operative evaluation. Only 23 patients underwent angiography with one of these requiring surgery. The remaining

91 were observed with no further imaging and none of these patients developed delayed symptoms or had missed injuries. The authors concluded that patients with Zone II injuries could safely be observed without imaging in the absence of hard signs of vascular injury. Unfortunately, the study does not report the use of other diagnostic testing for the evaluation of the trachea, esophagus, or spine limiting its applicability. Also in 2000, Eddy and colleagues<sup>18</sup> suggested that physical examination and a chest radiograph alone are sufficient to triage patients with Zone I injuries, greatly reducing the use of DSA. Finally, in 2003, Azuaje and others<sup>23</sup> reinforced the sensitivity of physical examination to identify vascular injuries requiring repair. They retrospectively reviewed 152 stable patients who underwent four-vessel angiogram after penetrating neck injury. Of the 89 patients who had no physical examination findings suggesting vascular injury, only three had positive angiograms, none of whom required operative intervention. They reported a sensitivity of 93 per cent and negative predictive value of 97 per cent for physical examination to identify and exclude vascular injury after penetrating neck trauma and recommended a selective approach based on physical examination findings. Again, the focus of this study was limited to the diagnosis of vascular injury; the use of testing to triage the trachea or esophagus was not discussed.

Although data support the use of physical examination to triage imaging in stable patients after penetrating neck trauma to exclude vascular injury, especially for Zone II penetrations, the approach to the vascular and aerodigestive evaluation and to patients with Zone I or III injuries is less obvious when physical findings are lacking.<sup>18, 24-28</sup> Simple observation after physical examination in asymptomatic patients appears to be safe within certain limits: patients must be admitted and examined repeatedly, preferably by the same surgeon. Also, there must be a very low threshold for further evaluation or intervention with changes in examination or vital signs. Observation can be somewhat labor- and resource-intensive but remains useful in areas where technology is limited or in more austere environments.

In the modern trauma center, however, rapid and efficient triage has become the driving paradigm. Along with tremendous improvements in imaging technology, medicine in general, and trauma surgery specifically, has moved toward less invasive approaches to patient evaluation and management. As such, other modalities such as ultrasound, magnetic resonance imaging (MRI)/magnetic resonance angiography (MRA), and spiral computed tomography have been explored to evaluate penetrating neck trauma.

### Ultrasound and Magnetic Resonance Imaging/Magnetic Resonance Angiography

Color Doppler ultrasound has been proposed as a quick and efficient tool to evaluate stable patients penetrating neck trauma to exclude vascular injury.<sup>21, 29</sup> Although the equipment is readily available in most modern trauma centers, the technique is highly operator-dependent (often requiring specialized technicians) and again fails to assess the aerodigestive structures. MRA has also been proposed in the evaluation of penetrating neck trauma. Although it is a sensitive imaging modality, MRA is obviously impractical for the evaluation of acute trauma. Given its inconsistent availability, length of study time, and incompatible with various types of medical equipment, this modality is not a practical one.<sup>20</sup> There is also minor concern regarding the presence of metallic fragments lodged in the sensitive cervical tissues being exposed to the high-powered MR magnet.<sup>30</sup> Although excellent technologies, clearly neither color Doppler ultrasound alone nor MRI/MRA has proven useful as comprehensive tools in the evaluation of patients sustaining penetrating neck trauma.

### Multidetector Computed Tomography Angiography

Computed tomography (CT) has revolutionized nearly all aspects of medicine and the care of the injured is no exception.<sup>31, 32</sup> As spiral multidetector CT (MDCT) technology has evolved over the last decade, dramatically improving both imaging quality and speed, trauma surgeons have embraced it. Currently, most diagnostic algorithms for the evaluation of hemodynamically stable trauma patients,<sup>31</sup> including those with penetrating mechanisms, rely heavily on this modality. With up to 320-slice scanning technology, MDCT imaging offers rapid, high-quality imaging with multiplanar reconstruction and volume-rendering to clearly delineate trajectory and confidently identify or exclude clinically significant injury.

A number of groups have studied the use of MDCT angiography in stable patients with penetrating neck injuries. In one of the first reports, Ofer<sup>33</sup> published a series of 16 patients with potential carotid artery injuries and determined that CTA was highly accurate in diagnosing vascular injury and allowing successful nonoperative management in patients with negative CT scans. In 2001, Mazolewsk<sup>34</sup> prospectively compared trauma surgeon-evaluated CTA with mandatory operative exploration after Zone II neck penetration and found a sensitivity of 100 per cent for identifying injuries that would require operative intervention. Also in 2001, Gracias<sup>1</sup> reported a retrospective series of 23 patients and found that CTA was a safe and effective

modality to “to direct or eliminate further invasive studies in selected stable patients with penetrating neck injury.”

Munera et al.<sup>35</sup> compared 60 patients with penetrating neck injuries who underwent both CTA and conventional angiography. In that study, CTA had a sensitivity of 90 per cent and specificity of 100 per cent with a positive predictive value (PPV) of 100 per cent and a negative predictive value (NPV) of 98 per cent. In a follow-up study by the same group in 2002,<sup>19</sup> 175 patients with penetrating neck injury were evaluated by CTA. They were able to accurately characterize vascular injuries in 27 (15.6%) patients and direct them to appropriate therapy. The other 146 patients were successfully observed without further intervention and without missed injury. Using CTA, the authors reported that sensitivity, specificity, PPV, and NPV were 100, 98.6, 92.8, and 100 per cent, respectively. In the most recent contribution from this group in 2006, Inaba et al.<sup>6</sup> prospectively examined the use of four-detector CTA to screen 93 stable patients presenting with penetrating neck injuries. In this population there were no missed injuries with MDCT angiography. There were however five false-positive examinations leading to negative secondary evaluations (two surgical explorations, two endoscopy/esophagography evaluations, and one four-vessel angiogram). The authors attributed a 100 per cent sensitivity and 93.5 per cent specificity for the detection of vascular and aerodigestive injuries to MDCT angiography.

Limitations of MDCT angiography are few and are largely related to artifacts or errors of technique. Poor timing of contrast loads, patient movement or body habitus, or the presence of metallic foreign bodies (dental fillings, spinal hardware, or bullet fragments) can all lead to suboptimal imaging. Fortunately, however, imaging is only inadequate with properly performed MDCT in 1 per cent of examinations.<sup>19</sup> An additional disadvantage of MDCT angiography, compared with conventional angiography, is the lack of therapeutic potential.<sup>20</sup> Given that conventional angiography is not precluded by MDCT angiography, the only downside is second contrast load. Furthermore, because the treatment for most vascular and aerodigestive injuries is surgical, the triage potential of MDCT angiography far outweighs this inconvenience.

### The No Zone Approach

Although the management of unstable patients or those with “hard signs” of injury has not changed, the evaluation of hemodynamically stable patients with penetrating neck trauma has evolved significantly since the “zone”-based algorithms were created in the

1970s. Before having the luxury of rapid, noninvasive, and highly accurate diagnostics, patient safety mandated the liberal use of surgery, angiography, and endoscopy to identify or exclude injuries. In that era, surgeons used risk–benefit analysis to weigh various invasive techniques against one another to assure the best possible outcomes for their patients. The product of that analysis was the anatomic division of the neck into zones and the creation of the zone-based algorithm.

Since that time, however, the world of medicine and trauma has moved on. An emphasis has been placed on “minimally invasive” techniques where possible. This fact, coupled with tremendous advances in technology, has radically changed many long-held beliefs and diagnostic practices. As such, the standard of care for imaging the cervical spine after trauma, once requiring three to seven separate radiographs, is now accepted as MDCT using multiplanar reconstruction.<sup>36</sup> Similarly, the diagnostic peritoneal lavage, long considered an essential tool for abdominal triage after trauma, has all but disappeared, being completely replaced by MDCT.<sup>37</sup> Even in thoracic<sup>38</sup> and extremity trauma,<sup>39</sup> MDCT angiography has largely supplanted DSA for both initial and preoperative evaluation as a result of its superior imaging quality, speed, safety, and lack of interuser variability.<sup>40</sup> After trauma, because MDCT angiography also effectively visualizes surrounding structures, this modality demonstrates distinct and important advantages over conventional angiography, MRI, and ultrasound.<sup>41</sup>

Because MDCT angiography has evolved as an effective and comprehensive technique to triage all areas of the neck after penetrating trauma, it has become apparent that the need to distinguish between neck zones, as described more than 30 years ago, has been eliminated. Injuries to any of the three neck zones can efficiently and safely be evaluated using MDCT. In patients with injuries to Zone II, CT has been shown to be effective as a surgical decision-making tool<sup>34</sup> and reduces the incidence of both the need for secondary testing and negative surgical exploration.<sup>42–44</sup> With injuries to Zones I and III, MDCT angiography has been shown to be a reasonable, efficacious, and cost-effective alternative to DSA. The use of CTA as a triage too independent of injury zone has been shown to decrease the number of nontherapeutic explorations as well as lower the use of potentially dangerous diagnostic modalities.<sup>43</sup> Gracias et al.<sup>1</sup> demonstrated a 50 per cent decrease in the use of arteriography and a 90 per cent decrease in endoscopy after instituting the “No Zone” algorithm. Overall, studies using CT to evaluate penetrating neck trauma demonstrate it to be a highly sensitive and specific modality with PPVs of 75 to 100 per cent and NPVs of 98 to 100 per cent.<sup>19, 35, 45</sup> Like with all penetrating injury, in penetrating neck

trauma, identifying the missile trajectory is important for the determination of subsequent diagnostic and therapeutic intervention. The trajectory is easily determined with the use of MDCT angiography independent of neck zone. Once the trajectory is identified, patients can safely be triaged to surgery, further imaging, or to observation.<sup>1</sup> Using the No Zone technique summarized in Figure 1, resource use is more efficient, a notable and important consideration in a cost-conscious era.

### Conclusion

The “No Zone” approach is an evidence-based, technologically advanced method of evaluating hemodynamically stable patients with penetrating neck trauma. This method eliminates the artificial and nonanatomic distinctions between neck “zones” created before the availability of advanced imaging. Using this approach, all injuries, in stable patients without hard signs of vascular or aerodigestive injury, should be evaluated using a comprehensive physical examination combined with the use of CTA. Current evidence has proven that this clear and simple triage sequence for stable patients can effectively identify or exclude vascular and aerodigestive injury after penetrating neck trauma. Continued reliance on zone-based algorithms leads to increased use of invasive diagnostic modalities as well as a higher incidence of nontherapeutic neck exploration. Describing neck injuries by “zone” may no longer be necessary; physicians evaluating these patients should consider departing from these antiquated, invasive algorithms in favor of CTA-based triage to screen hemodynamically stable patients with penetrating neck injuries.

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