



Recent developments in the assessment of the multiply injured trauma patient

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Purpose of review

To provide an update on the recent developments and controversies in the assessment of the traumatically injured patient.

Recent findings

Recent literature suggests that: whole-body computed tomography (CT) is an effective strategy in more severely injured blunt trauma patients; 64-slice CT scanning now provides an effective noninvasive screening method for blunt cerebrovascular injury; the need for MRI imaging, in addition to CT, for the diagnosis of occult ligamentous injury of the cervical spine remains an unresolved controversy; point-of-care testing has made significant improvements in our ability to predict which patients will need a massive transfusion; and thromboelastography has enhanced our ability to tailor a hemostatic resuscitation more accurately.

Summary

The recent advances in the assessment of the multiply injured patient allow clinicians to more efficiently diagnose a patient's injuries and implement treatment in a more timely manner.

Keywords

blunt cerebrovascular injury, cervical spine injury, massive transfusion triggers, trauma assessment, whole-body computed tomography

INTRODUCTION

Traumatic injury is the leading cause of death and disability for young adults and accounts for one in every eight male deaths and one in every 14 female deaths worldwide [1]. Road injuries alone are the eighth leading cause of years of life lost globally [2].

Rapid identification and management of a patient's injuries is felt to be a key factor in improving the morbidity and mortality of injured patients. The initial evaluation of the multiply injured patient is outlined by the Advanced Trauma Life Support guidelines [3]. This approach emphasizes the rapid and prioritized evaluation of patients in a matter sufficient to identify life-threatening injuries first. The following discussion will not reiterate the more basic principles of initial resuscitation and evaluation, but will focus on several topics related to the assessment of the multiply injured patient that are subjects of recent controversy and research.

WHOLE-BODY COMPUTED TOMOGRAPHY IMAGING

Computed tomography (CT) imaging has given clinicians a fast and accurate method to noninvasively

identify injuries. As CT technology has improved, increased image-acquisition speed and resolution has improved diagnostic accuracy and expanded its use to include vascular imaging. Many trauma centers are now advocating whole-body CT (WBCT) as part of the early assessment of multiply injured patients. WBCT typically includes a CT scan of the head, complete spine, chest, abdomen, and pelvis. The purported advantages of this method include more rapid identification and treatment of critical injuries, and potentially reduced morbidity and mortality. However, this strategy has raised concerns about the risks of excessive radiation exposure and increased cost as compared to more selective imaging strategies.

Multiple studies have been performed in an attempt to determine whether or not routine WBCT

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KEY POINTS

- Protocolized whole-body CT for diagnosis of traumatic injuries has recognized value, but the exact indications remain controversial.
- CT angiography, with at least 64-slice capacity, is adequate to replace conventional angiography for BCVI screening.
- High-resolution CT imaging alone is probably sufficient to clear the cervical spine of major injury in obtunded patients.
- Point-of-care testing, including TEG, allows hemostatic resuscitation to be tailored to individual patient needs.

imaging confers any survival benefit. Huber-Wagner *et al.* [4] published a German retrospective multicenter study of WBCT versus non-WBCT and found a survival benefit associated with WBCT after risk adjustment for trauma injury severity score (TRISS) and revised injury severity classification (RISC) scores. The relative risk reduction was between 13 and 25% depending on the risk score used [4]. The same authors also demonstrated a survival advantage in hemodynamically unstable patients undergoing WBCT [5*]. Other studies have shown somewhat mixed results, with some supporting a survival benefit to WBCT, whereas others were unable to demonstrate such an advantage [6–10]. All of the referenced studies on mortality with WBCT are retrospective in nature and suffer from potential bias and confounding. There has not been a randomized trial utilizing WBCT, published to date.

Whole-body CT has the potential benefit of shortening the time to definitive diagnosis of injuries by streamlining the diagnostic process. Several studies have shown a decreased time in the emergency room [8,9,11], and two studies demonstrated a decreased time to operative intervention [7,9]. Wurmb *et al.* [8] demonstrated in a retrospective study that the complete work-up of the patient was completed in 23 min after arrival in the WBCT group as compared to 70 min in the selective imaging group. This led to a decrease in the time to final management plan from 82 to 47 min [8]. A study by Tillou *et al.* [12] demonstrated that had physicians ordered selective imaging, they would have missed injuries in 17% of patients. However, the clinical impact of these potential missed injuries is not clear.

The principal deterrent to the more widespread use of CT is the risk of radiation exposure, approximately 10–20 mSv with WBCT. It is estimated that for every 10 mSv of radiation exposure, the risk of

cancer increases by one in 1000 [13]. This effect, however, is highly age-dependent, with children and adolescents being the most susceptible. Estimates of age-adjusted radiation risk suggest a greatly diminished effect after age 35 [14]. Clinical studies examining the radiation exposure of trauma patients during their initial work-up found that the use of WBCT led to at least twice the relative risk of being exposed to above 20 mSv [15]. This is consistent with other studies showing an increased risk of radiation exposure attributable to CT imaging in trauma patients [16–18].

As healthcare costs continue to increase, it is important to consider the financial implications of diagnostic imaging. None of the studies on WBCT specifically looked at the costs associated with this strategy. While CT imaging is clearly associated with increased costs, these may be offset by a decrease in missed injuries and decreased hospitalization requirements.

Whole-body CT is a promising strategy for managing patients with multiple blunt traumatic injuries. It likely decreases the time required to complete the work-up of patients and may lead to faster treatment decisions. It logically follows that decreasing time to treatment has the potential to save lives; however, this must be balanced against cost and a potential radiation risk to those with negative images. WBCT is currently used liberally in our practice for patients that are obtunded with a mechanism of injury concordant with multisystem trauma, and for patients with physiologic alterations suggestive of early shock that remain stable enough for CT imaging. We have a much lower threshold for WBCT in the elderly given a higher incidence of serious, clinically occult injuries and the minimal consequences of radiation exposure in that population.

DIAGNOSIS OF BLUNT CEREBROVASCULAR INJURY

Blunt cerebrovascular injury (BCVI) had been previously thought to be a rare event, but several studies over the past few decades have shown it to be much more common than was previously thought. BCVI is diagnosed in 1–2% of patients sustaining significant blunt trauma [19–21]. These injuries can lead to devastating neurologic complications such as stroke and death. The associated mortality for stroke resulting from BCVI has been reported at up to 50% in a recent study [20]. The early identification and treatment of BCVI may significantly reduce the stroke rate and mortality [22,23], and has led to efforts to identify the ‘at-risk’ population and the optimal method for BCVI screening.

The original studies of BCVI were performed using digital subtraction angiography (DSA) which had been considered the gold standard for diagnosis. However, this technique is invasive and is associated with a number of serious complications, including stroke, making it unattractive as a screening method for BCVI. Due to both resource issues and complications, clinicians have been searching for a less invasive screening method that would prove as effective as DSA in diagnosing BCVI. Improvements in CT technology with more helical 'slices' and faster speeds have allowed it to replace conventional DSA for a number of injuries, including BCVI.

Using computed tomographic angiography (CTA) as a screening tool for BCVI was described in a study by Rogers *et al.* [24] in 1999. Subsequent to this, a number of further studies were published evaluating the use of CTA in screening for BCVI. Sensitivity in published series has been wide ranging from 29 to 100%. Specificity has been much more consistent with most modern studies showing rates above 90% [25]. The sensitivity for detection of BCVI is likely a direct effect of speed and the capacity of the more modern scanners (number of slices). Many centers have changed their primary screening modality to CTA based on these early results. The group out of Memphis has published extensively on BCVI and had continued to utilize conventional DSA based on unconvincing results using CTA [26]. However, using a 64-slice CT scanner, they published a recent study demonstrating a sensitivity of 68% on a per-vessel basis and 84% on a per-patient basis [27]. This was significantly improved from their previous experience with 32-slice CTA where a sensitivity of 51% was found [26]. When they analyzed their rate of significant complications (0.5%), they found it to be similar to the morbidity associated with potential missed injuries at 0.4%, leading them to conclude that CTA with a 64-slice multidetector CT scan was well tolerated and effective as a primary screening modality for BCVI. This is consistent with conclusions from multiple other authors regarding multislice CTA [23,28,29]. Multidetector CT arteriography using 64 or more channels appears to be adequate for screening for BCVI, and is a reasonable replacement for DSA.

The Eastern Association for Surgery of Trauma (EAST) has published guidelines on screening for BCVI (listed below) [30].

- (1) Unexplained neurological abnormality
- (2) Massive epistaxis from arterial source
- (3) Glasgow coma score below 8
- (4) Petrous bone fracture
- (5) Cervical spine fractures:
 - (a) of C1–C3

- (b) through the foramen transversarium
- (c) with subluxation or rotational component
- (6) Lefort II or III facial fractures

These and similar guidelines are widely used in trauma centers across the world. Some recent articles suggest that it may be time to expand the indications for screening in order to decrease the approximately 20% of patients with BCVI that do not have one of the screening criteria [31]. Additional indicators that may increase the screening sensitivity for BCVI include mandibular fractures, any basilar skull fracture, complex frontal skull fractures with orbital involvement, and combined traumatic brain injury with thoracic injuries [32,33]. Overall, as the noninvasive diagnosis of BCVI continues to expand with CTA, so will the indications for screening. Some institutions have begun to include routine CTA of the neck with WBCT in order to increase the diagnostic rate of BCVI, but this technique will need continued study to ensure that the sensitivity and specificity is similar to a dedicated CTA [33].

The main goal of screening for BCVI is to allow early treatment and reduce the morbidity and mortality associated with BCVI. In addition to its diagnostic efficacy, CTA is far more accessible in many centers than conventional DSA, potentially reducing both the time from injury to diagnosis and the ultimate stroke rate. In a study by Eastman *et al.* [23], the use of a screening protocol for BCVI was associated with a decrease in time to diagnosis from 31.2 to 2.65 h, and a decrease in the stroke rate from 15.2 to 3.8%. These data suggest that the replacement of DSA with CTA may lead to faster diagnosis which would allow earlier treatment and thereby decrease the rate of stroke.

CTA with a 64-slice or greater multidetector CT scan to screen for BCVI is now widely accepted as a diagnostic alternative to DSA. The speed and accessibility of CTA provide additional advantages that should ultimately reduce the morbidity and mortality from BCVI-related strokes. Defining the precise risk factors that will accurately identify patients in need of BCVI screening and determining the cost, benefits, and outcomes for this screening warrant further study.

DIAGNOSIS OF CERVICAL SPINE INJURY

The consequences of missed cervical spine injuries, both in terms of cost and associated morbidity, have pushed tolerances for diagnostic error to almost zero. Plain films of the cervical spine had previously been the gold standard for the diagnosis of cervical spine injury, but they have been supplanted by CT

imaging [34]. Controversy still remains in determining which patients require diagnostic imaging at all, and the extent of imaging needed to reliably exclude occult ligamentous injury.

The ability to reliably 'clear' the cervical spine on the sole basis of the physical examination can reduce costs and expedite care while avoiding serious missed injuries. Groups such as the National Emergency X-Radiography Utilization Study (NEXUS) study group and the investigators for the Canadian C-spine rule evaluated clinical criteria to rule out cervical spine injury [35,36]. The decision rules based on the NEXUS and Canadian studies are easily adapted to the clinical environment and have gained wide acceptance. The Canadian C-spine rule, although considerably more sensitive, lacks specificity, making it less advantageous for practitioners dealing with major trauma. A major critique of these clinical clearance rules is that the studies that they were based on utilized plain films, an inferior modality to determine fractures as compared to CT imaging. The use of NEXUS criteria has been questioned in recent studies in the literature, reporting a significant number of missed injuries among major mechanism trauma patients [37]. The physical exam is particularly unreliable in the elderly. This population has a higher incidence of fracture, but a lower sensitivity (65.9%) using the NEXUS criteria, than a younger population in a recent study [38]. Clinical clearance criteria should be used with caution in patients with a significant mechanism of injury, particularly in the elderly.

Another area of controversy pertains to the optimal method for reliably excluding cervical spine injuries in patients who cannot be cleared on a clinical basis. Plain films, and more recently CT, are being utilized to diagnose fractures, with further imaging with flexion/extension fluoroscopy, or MRI used to evaluate potential ligamentous injuries. These ligamentous injuries may result in significant cervical instability and may lead to devastating neurologic consequences if missed. This leaves clinicians with the unfortunate choices of leaving cervical collars in place for extended periods of time, relying on CT findings to screen for major ligamentous injury, or routinely transporting critically ill patients to MRI scanners. Cervical collars have significant complications on their own and have been shown to contribute to increased intracranial pressure and significant wound problems [39–42].

With the advent of multidetector CT imaging of the cervical spine, many investigators are questioning the need for prolonged c-spine immobilization. A number of studies have been performed looking at the rate of missed injuries with modern multidetector CT technology. A meta-analysis performed in

2011 demonstrated sensitivity and specificity of above 99% for CT imaging of the spine to rule out unstable skeletal or ligamentous injury, and concluded CT alone to be sufficient for this purpose [43]. Conversely, another recent meta-analysis of CT imaging in the obtunded patient showed a negative predictive value for clinically significant injury of 92.9% with a negative predictive value for surgical intervention of 99.6% [44]. Using similar data, the authors arrived at a disparate conclusion that MRI was still an essential modality to evaluate for ligamentous injury in patients unable to undergo an adequate physical examination. This is despite the fact that they did not include a single study that was published after the 2011 meta-analysis. The reasons for the disparities seem to be due to a different interpretation of what constitutes an unstable injury and what amount of risk is considered acceptable. However, given the rarity of unstable ligamentous injury, it will be important for large surgical societies to provide consensus on what rate of missed injury would be acceptable, given the potentially devastating consequences. Our current practice is to accept a radiographically normal 64-slice CT scan of the cervical spine as an acceptable imaging modality to clear the cervical spine in the absence of any demonstrable neurologic abnormality.

MASSIVE TRANSFUSION TRIGGERS AND TRAUMA-RELATED COAGULOPATHY

In 2007, Holcomb *et al.* introduced data from the conflicts in Iraq and Afghanistan showing that a balanced resuscitation of packed red blood cells and fresh frozen plasma in a ratio nearing 1:1 was associated with improved mortality in military casualties [45,46]. This strategy, referred to as damage control resuscitation (DCR), has subsequently been associated with reduced mortality in the civilian population as well [47]. Over the next several years, this concept has been widely adopted throughout trauma centers all over the world.

An important tenet of DCR is the early provision of blood product support. The early identification of patients who will ultimately require massive transfusion has remained a challenge. Multiple scoring systems have been developed to address this, but many are overly complex and rely on data that are not readily available in the trauma bay. Recent advances in point-of-care testing have made it possible to gain important laboratory information within minutes of the patient arriving. These data have been utilized in the PROMMTT (PROspective, Observational, Multi-center Major Trauma Transfusion) trial to validate various transfusion triggers in a prospective manner. In this study, international

normalized ratio (INR) greater than 1.5, SBP below 90 mmHg, hemoglobin below 11 g/dl and base deficit at least 6, and penetrating mechanism and heart rate above 120 were associated with an increased risk of massive transfusion [48[■]]. As identified in a previous retrospective study, INR was the most predictive single factor [49]. Adding these factors in an equally weighted fashion gives a stepwise increase in massive transfusion risk in which two factors showed an approximate 30% chance of massive transfusion and up to 80% if all six met their targets. This index gives clinicians a simplified manner with which to assess the risk of requiring massive transfusion.

In addition to point-of-care standard laboratory testing, thromboelastography (TEG) and rotational thromboelastometry (ROTEM) have come into more widespread use in trauma resuscitation. These devices measure the viscoelastic properties of blood utilizing a moving pin or cup, and provide measures of clotting time, clot firmness, and clot lysis. A number of studies suggest that rapid TEG may supplant more conventional coagulation factor testing in the coagulopathic trauma patient [50,51]. A prospective evaluation of the rapid TEG on 1974 patients found rapid TEG values to be more predictive for massive transfusion than INR [50]. In another study, TEG-guided resuscitation was compared to a standard massive transfusion protocol. The results suggested that TEG-guided resuscitation outperformed the massive transfusion protocol in penetrating trauma patients [52[■]]. Utilization of TEG as a replacement for traditional coagulation studies will need to be validated in studies at other centers, but shows great promise.

The rapid bedside determination of laboratory studies is likely to continue to proliferate and offers significant opportunity to improve care in extremely dynamic clinical scenarios such as the massively bleeding patient. TEG and ROTEM allow rapid evaluation of a patient's ability to properly form and breakdown clot in a real-time manner. This allows clinicians to rapidly tailor their resuscitation to the specifics of a given patient and should be integrated into massive transfusion protocols in the future.

CONCLUSION

The assessment of multiply injured trauma patients is an area of active research. New imaging and laboratory technologies have provided significant advances in our ability to rapidly diagnose injuries in the most critically ill. It is essential that physicians managing the care of the critically injured stay abreast of the latest developments in trauma assessment.

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Conflicts of interest

There are no conflicts of interest.

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- of special interest
- of outstanding interest

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