

Comparison of Multiplane Transesophageal Echocardiography and Contrast-enhanced Helical CT in the Diagnosis of Blunt Traumatic Cardiovascular Injuries

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Background: Multiplane transesophageal echocardiography (TEE) and helical computed tomography (CT) of the chest have been validated separately against aortography for the diagnosis of acute traumatic aortic injuries (ATAI). However, their respective diagnostic accuracy in identifying blunt traumatic cardiovascular lesions has not been compared.

Methods: During a 3-yr period, 110 consecutive patients with severe blunt chest trauma (age: 41 ± 17 yr; injury severity score: 34 ± 14) prospectively underwent TEE and chest CT as part of their initial evaluation. Results of both imaging methods were interpreted independently by experienced investigators and subsequently compared. All cases of subadventitial acute traumatic aortic injury were surgically confirmed.

Results: Seventeen patients had vascular injury and 11 had cardiac lesions. TEE and CT identified all subadventitial disruptions involving the aortic isthmus ($n = 10$) or the ascending aorta ($n = 1$) that necessitated surgical repair. In contrast, CT only depicted one disruption of the innominate artery. TEE detected injuries involving the intimal or medial layer, or both, of the aortic isthmus in four patients with apparently normal CT results who underwent successful conservative treatment. All cardiac injuries but two were identified only by TEE.

Conclusions: In patients with severe blunt chest trauma, TEE and CT have similar diagnostic accuracy for the identification of surgical acute traumatic aortic injury. TEE also allows the diagnosis of associated cardiac injuries and is more sensitive than CT for the identification of intimal or medial lesions of the thoracic aorta.

BLUNT traumatic cardiovascular injuries after severe chest trauma must be diagnosed and repaired rapidly to improve the prognosis of patients who survive long enough to reach the hospital.¹ A recent multicenter trial² that included 274 patients with acute thoracic aortic injuries (ATAIs) reported an overall mortality rate of 31%, with 63% of deaths attributable to traumatic aortic disruptions. In addition, the frequency of cardiac injuries

is presumably underscored in patients with severe blunt chest trauma.³

Traditionally, angiography is the accepted reference imaging method for the diagnosis of ATAI.⁴ Recently, transesophageal echocardiography (TEE)⁵⁻¹³ and contrast-enhanced computed tomography (CT) of the chest¹⁴⁻¹⁷ have been proposed as alternative noninvasive imaging methods for the routine evaluation of patients at high risk of ATAI. Recent development of multiplane high-frequency TEE probes and helical CT have overcome previous limitations of these imaging techniques and potentially improved their diagnostic capability. Although independently validated against angiography, the results of these imaging methods have not been prospectively compared in patients with suspected traumatic cardiovascular injuries.

Accordingly, we conducted a prospective study to determine the diagnostic accuracy of multiplane TEE and helical CT for the detection of traumatic cardiovascular injuries in patients with severe blunt chest trauma.

Methods

Study Population

During a 3-yr-period, consecutive patients at high risk of blunt traumatic cardiovascular injury who were referred to our institution underwent multiplane TEE and helical CT of the chest as part of their initial evaluation. Imaging methods were performed in random order, according to the availability of the medical staff, within 24 h of admission. If multiplane TEE or helical CT was contraindicated,^{5,18} only the alternative imaging method was performed. Angiography was performed when (1) traumatic injury to aortic branches was suspected,⁵ (2) multiplane TEE and helical CT both were inconclusive or yielded discrepant results, or (3) a large hemomediastinum without apparent ATAI was identified.¹⁹ Informed consent was not necessary to obtain in this clinical setting; the study protocol was approved by our Institutional Review Board (Dupuytren University Hospital, Limoges, France).

High risk for blunt traumatic cardiovascular injuries was defined by the presence of at least one of the following criteria^{5,18}: (1) history of violent deceleration trauma (head-on collision or fall from a height > 3 m); (2) unrestrained patient ejection from the vehicle or

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death in the accident; (3) pedestrian or bicyclist having been struck by an automobile; (4) chest trauma necessitating mechanical ventilation; (5) presence of acute coarctation syndrome or an external sign of direct chest injury; (6) associated traumatic injury reflecting violent impact to the body (e.g., diaphragmatic rupture, mesenteric tear); (7) unexplained hypotension or shock; and (8) enlarged mediastinum as seen on admission chest radiograph. Because ATAI and cardiac injury may occur even if a chest radiograph is unremarkable,^{9,17} patients with normal mediastinal contours were also enrolled in the study if one or more of the aforementioned criteria were present.

Multiplane Transesophageal Echocardiography

Transesophageal echocardiography was performed as previously described⁸ using a SONOS 5500 imaging system (Hewlett-Packard, Andover, MA) equipped with a 7-MHz multiplane esophageal transducer. Blood pressure, electrocardiography, and arterial oxygen saturation were closely monitored. In patients undergoing spontaneous ventilation, the esophageal probe was inserted after pharyngeal anesthesia and mild sedation (midazolam 0.05–0.1 mg/kg). Patients undergoing ventilation received an intravenous injection of midazolam (0.15 mg/kg) and vecuronium bromide (0.1 mg/kg) as necessary. The nasogastric tube was removed. Particular attention was directed toward the evaluation of the different anatomic segments of the thoracic aorta, using two-dimensional echocardiography (transverse and longitudinal planes) and color Doppler. A complete examination of the heart was also routinely performed. TEE was recorded on videotapes for further interpretation by an investigator experienced in echocardiography and who was unaware of the medical history of the patient and the results of helical CT.

The TEE diagnosis of ATAI relied on the presence of (1) a (dilated) aortic isthmus with abnormal contour, (2) an acute false aneurysm formation or an intraluminal medial flap associated with a subadventitial disruption, or both,⁸ (4) echocardiographic signs consistent with a traumatic aortic dissection⁸; (5) a mobile image appended to the aortic wall consistent with an intimal tear or a mural thrombus⁸; and (6) a crescentic or circumferential thickening of the aortic wall (with or without echolucent areas and displaced intimal boundary), reflecting the presence of an intramural hematoma.^{20,21} The presence of a traumatic hemomediastinum was defined by an increased distance (> 3 mm) between the esophageal probe and the anteromedial wall of the aortic isthmus or the presence of blood between the posterolateral aortic wall and the left visceral pleura.²² A left-sided hemothorax was identified as the presence of fluid between the left lung and the thoracic wall.²³

In addition, the following TEE findings were recorded: presence of a regional wall motion abnormality without

transmural myocardial infarction detected on electrocardiogram and consistent with a myocardial contusion,²⁴ acute valvular regurgitation attributable to a traumatic injury, hemopericardium or mediastinal hematoma contiguous to the heart (eventually associated with a tamponade physiology).

Helical Chest Computed Tomography

If indicated, an unenhanced CT scan of the head and spine was performed before chest CT. Axial scanning was performed using a HiSpeed Advantage helical scanner (General Electric, Milwaukee, WI) and using the Advantage Windows 1.2 software (General Electric) for CT angiography reconstruction. In each patient, the following protocol was followed. The patient's arms were raised overhead when possible, and a digital localization scout view of the chest was obtained during voluntary apnea (or ventilator pause). Nonionic contrast media (300 mg/ml iodine; Xenetix[®], Guerbet, France) was injected through an arm vein (2.5 ml/kg) using a power injector at 2.0–2.5 ml/s. Continuous 5-mm helical scans were obtained from the mandibular angle to the diaphragm (1:1.5 pitch) at 120 kV and 290 mA. A retrospective two-dimensional reconstruction was performed every 3.0 mm. Images were recorded on 35.0 × 42.5-cm (14 × 17-in) radiographic films for subsequent analysis. Duration of helical acquisitions and computer reconstruction usually were 25–30 s and 12–15 min, respectively. Patients were typically immobilized in the radiographic suite for approximately 20 min.

All CT scans were independently interpreted by an experienced radiologist who was unaware of the medical history and had no access to the results of the multiplane TEE. Direct CT findings of ATAI included¹⁸: (1) polypoid (clot) or linear (medial flap) intraluminal areas of low attenuation; (2) false aneurysm formation; (3) irregularity of the aortic wall or contour; (4) pseudocoarctation, (5) intramural hematoma; or (6) aortic dissection. In addition, signs on the CT scan associated with hemomediastinum, left hemothorax, hemopericardium, and mediastinal hematoma contiguous to the heart were also recorded.

Data Analysis and Definitions

Acute thoracic aortic injuries were classified as subadventitial⁸ or superficial,^{5,8} involving the intimal layer (e.g., intimal tear, mural thrombus) or the medial layer (e.g., intramural hematoma) of the thoracic aorta. This distinction is mainly based on distinct management of subadventitial (surgical) and more superficial injuries (conservative treatment) of the aortic isthmus.^{5,8,20}

Diagnosis of cardiovascular injury using either multiplane TEE or spiral CT and confirmed by angiography, surgery, or necropsy was considered as a true-positive result. When multiplane TEE and helical CT yielded dis-

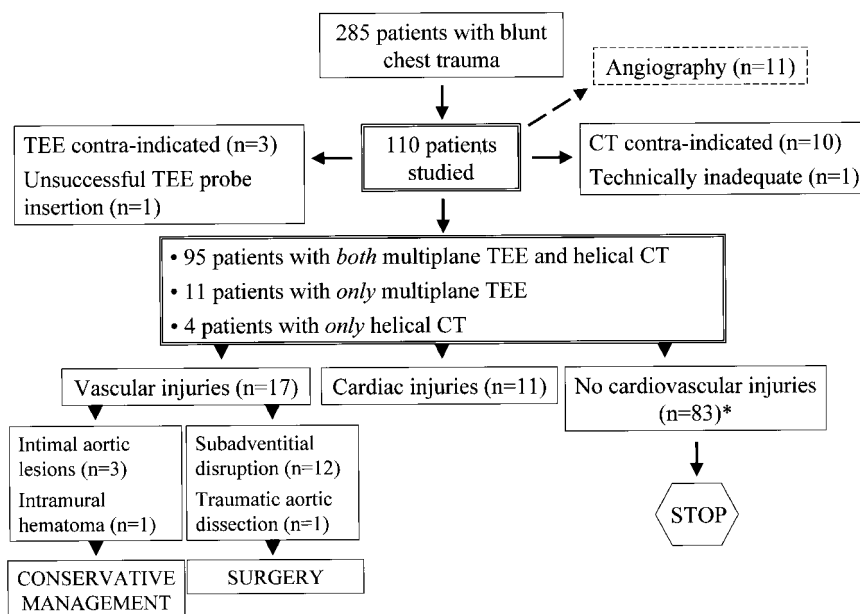


Fig. 1. Flow chart summarizing the imaging methods performed and traumatic cardiovascular injuries diagnosed in the study population. *One patient had both a vascular and a cardiac injury.

crepant results, the following protocol was followed. In the presence of a suspected subadventitial ATAI, angiography was performed. When a superficial ATAI was suspected, a serial follow-up using the same noninvasive diagnostic method was performed. An abnormal aortogram or diagnosis confirmed during this follow-up period was interpreted as a false-negative result of the alternative noninvasive diagnostic technique. Conversely, a normal aortogram or the identification of radiologic¹⁸ or echocardiographic²⁵ findings associated with imaging artifacts corresponded to a false-positive result of the imaging method erroneously interpreted as abnormal. Finally, a true-negative result was defined by the absence of cardiovascular injury shown by multiplane TEE and helical CT in patients with unremarkable courses. Accordingly, the follow-up of all patients was obtained by calling the respective attending physicians after patient discharge from the hospital.

Descriptive statistics were applied to patient characteristics and diagnostic findings during multiplane TEE and helical CT. Results are expressed as mean \pm standard deviation or percentage. The diagnostic capability of multiplane TEE and helical CT of the chest for the identification of ATAI was assessed by calculating their respective sensitivity, specificity, and positive and negative predictive values, with corresponding 95% confidence intervals.

Results

Study Population

During the study period, 285 patients were admitted to our Intensive Care Unit because of severe blunt chest trauma. Among them, 110 (mean age: 41 ± 17 yr; 88 men and 22 women; injury severity score: 34 ± 14) were

considered to be at high risk of traumatic cardiovascular injury (fig. 1). A single noninvasive imaging method was performed for 15 patients (14%). Multiplane TEE was contraindicated in three patients (3%) because of severe facial trauma, unstable cervical spine injuries, or pneumoperitoneum, and the esophageal probe could not be inserted in another patient. Helical CT was not performed in 10 patients (9%) who were hemodynamically unstable and could not be transported to the radiology suite (fig. 1). All TEE studies were judged as technically adequate for interpretation, whereas helical CT was not deemed proper for analysis in one patient. Finally, 95 patients underwent both procedures (fig. 1). Angiography was performed in 11 patients (10%) for suspected injury to aortic branches ($n = 4$), inconclusive studies or discrepant results ($n = 5$), or large traumatic hemomediastinum without evidence of associated ATAI ($n = 2$). Twelve patients (11%) died during their stay in the intensive care unit. One died rapidly in the emergency room of exsanguination secondary to traumatic aortic disruption diagnosed using multiplane TEE.

Cardiovascular Lesions

A traumatic arterial injury was diagnosed in 17 patients (15.5%). Among them, 16 had ATAI, and the one other patient presented with a laceration of the innominate artery. With the exception of one subadventitial disruption of the ascending aorta, all ATAI involved the aortic isthmus. ATAI included subadventitial disruptions ($n = 11$), traumatic dissection ($n = 1$), and superficial aortic lesions (intimal tear [$n = 1$], mobile thrombi, [$n = 2$], intramural hematoma [$n = 1$]). Patients with superficial ATAI underwent conservative treatment. With the exception of two patients who died before surgery, the other patients with ATAI underwent surgical repair (fig. 1).

Table 1. Diagnostic Accuracy of Multiplane TEE and Helical Chest CT for the Identification of Traumatic Arterial Injuries in Consecutive Patients Sustaining Severe Blunt Chest Trauma*

	Sensitivity (%)	Specificity (%)	Negative Predictive Value (%)	Positive Predictive Value (%)
Multiplane TEE (n = 106)	93 (68–100)	100 (96–100)	99 (94–100)	100 (77–100)
Helical chest CT† (n = 99)	73 (45–92)	100 (96–100)	95 (89–99)	100 (71–100)

* Numbers in parentheses correspond to the 95% confidence intervals. † Importantly, helical computed tomography (CT) of the chest identified all traumatic subadventitial injuries necessitating surgical repair and provided no false-positive result (see text for details).

TEE = transesophageal echocardiography.

A traumatic cardiac lesion was diagnosed in 11 patients (10%): uncomplicated hemopericardium (n = 1), large anterior mediastinal hematoma contiguous to the heart (n = 3), acute severe aortic regurgitation as a result of valvular disruption (n = 1), thrombus entrapped in a patent foramen ovale (n = 1), and severe myocardial contusions (right ventricle, n = 2; left ventricle, n = 3). The patient with the aortic valve disruption also had a subadventitial disruption of the aortic isthmus.²⁶ Surgery was performed in 3 of 10 patients with hemodynamic compromise. No evidence of traumatic cardiovascular lesion was found in the other 83 patients who did not undergo additional work-up (fig. 1). Among them, all patients who were discharged from the hospital were alive, with no symptoms attributable to a potential cardiovascular condition during follow-up (17 ± 11 months).

Diagnostic Capabilities of Imaging Methods

Diagnostic accuracy of multiplane TEE and helical CT for the identification of ATAI is detailed in table 1. Both imaging methods were reliable for the identification of surgical ATAI, whereas multiplane TEE was more sensitive for the detection of traumatic lesions involving the intimal or medial layers of the thoracic aorta (table 2). All subadventitial disruptions of the aortic isthmus or confined to the ascending aorta, and the single traumatic dissection of the descending thoracic aorta, were accurately detected by both imaging procedures. Multiplane TEE missed the laceration of the innominate artery that was depicted by helical CT scan (figs. 2A and B) and confirmed during surgery. Helical CT failed to detect intimal injuries in three patients, whereas multiplane TEE clearly depicted intimal tear or mural thrombi of the aortic isthmus (figs. 2C–F). TEE follow-up showed progressive healing of these aortic changes. Similarly, multiplane TEE identified an intramural hematoma confined to the aortic isthmus in a patient whose CT scan was unremarkable and who died of massive pulmonary embolism (table 2).

Multiplane TEE allowed rapid diagnosis of cardiac lesions in 11 patients (fig. 3), whereas helical CT only depicted the presence of an uncomplicated hemopericardium and retrosternal hematoma. Both imaging methods identified a traumatic hemomediastinum in a similar

proportion of patients, whereas multiplane TEE tended to be more sensitive for the detection of mild hemothorax (table 2).

In the 15 patients assessed using a single imaging method, multiplane TEE identified two subadventitial disruptions of the aortic isthmus and four traumatic cardiac injuries that resulted in hemodynamic compromise.

Discussion

This study is the first to prospectively compare the diagnostic accuracy of multiplane TEE and helical CT for the detection of ATAI and cardiac injuries in patients with severe blunt chest trauma. Both imaging techniques were reliable for the identification of subadventitial traumatic injuries to the aortic isthmus or the ascending aorta, which potentially can lead to lethal adventitial rupture. Helical CT also allowed the diagnosis of one supraaortic vascular lesion, whereas multiplane TEE seemed to be more sensitive for the detection of superficial aortic injuries (*i.e.*, involving the aortic intimal or medial layers of the thoracic aorta) and blunt cardiac trauma (table 2).

Imaging Modalities

The 25% incidence of traumatic cardiovascular injuries in our high-risk study population (27 of 110 patients) emphasizes the critical importance of the choice of the first-line imaging method routinely used for the assessment of patients with severe blunt chest trauma. Aortography has long been recognized as the only reliable screening imaging method for the assessment of patients with suspected ATAI.^{4,27} Recently, alternative noninvasive imaging methods, such as multiplane TEE^{6–8,12,13} and the new-generation CT scanning,^{14–16} have been validated in this setting. Their numerous advantages over angiography^{4,5} allow a more liberal use, potentially decreasing the number of undiagnosed traumatic cardiovascular injuries.^{9,11,12} Accordingly, indications of angiography become frequently restricted to contraindicated or inconclusive noninvasive tests, and suspected injuries to aortic branches, as in the current series.

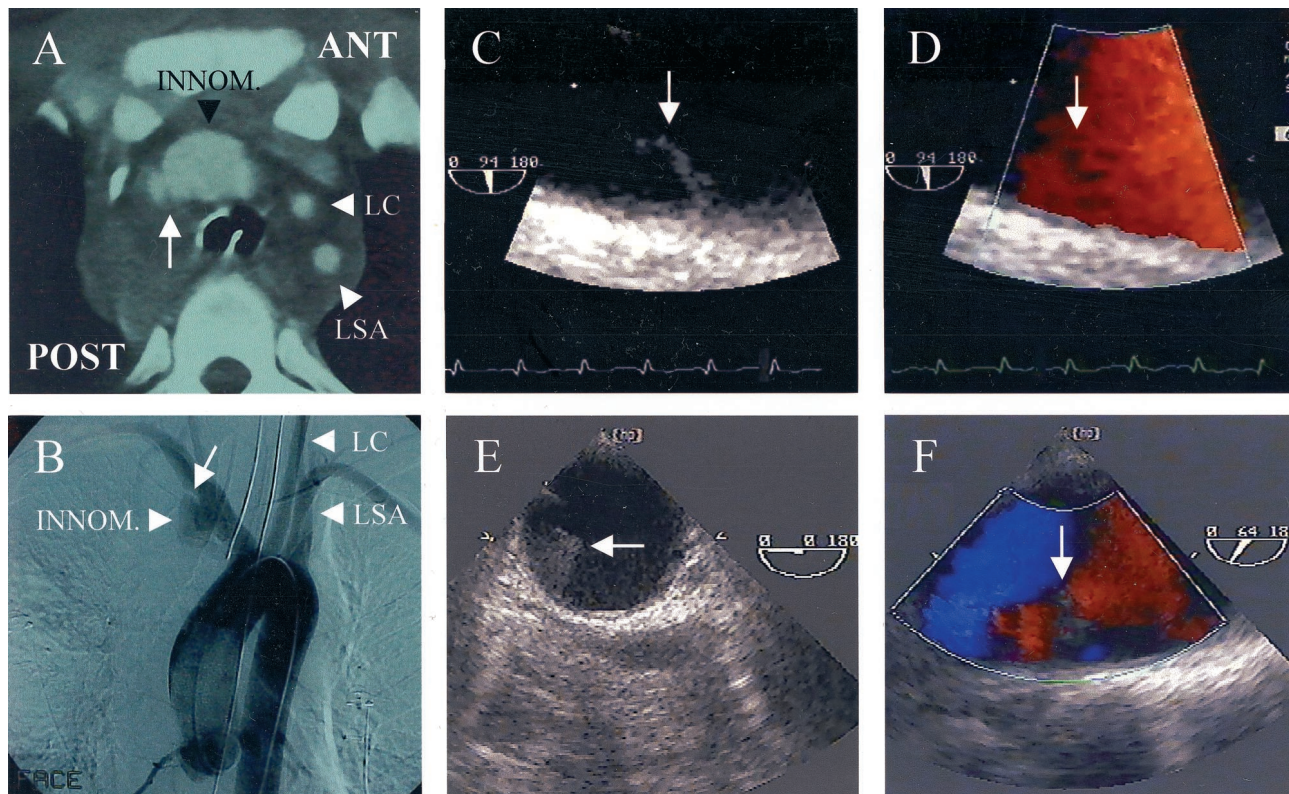


Fig. 2. (A,B) Examples of traumatic disruption of the innominate artery and (C–F) superficial lesions of the aortic isthmus. (A) Helical computed tomography (CT) showed a laceration of the innominate artery (white arrow) that was confirmed by angiography (B, white arrow), whereas results of multiplane transesophageal echocardiography (TEE) were interpreted as normal. Conversely, TEE identified an aortic intimal tear (white arrows, C and D) and mobile thrombi (white arrows, E and F) that were not identified by chest CT. These superficial aortic lesions were too small to result in blood flow turbulence, as shown by color Doppler (D and F). INNOM = innominate artery; LC = left common carotid artery; LSA = left subclavian artery.

Diagnostic Accuracy of Multiplane Transesophageal Echocardiography and Helical Computed Tomography

Both imaging methods had a similar diagnostic accuracy for the identification of subadventitial disruptions of the aortic isthmus that necessitated surgery (table 2). Compared with aortography, TEE sensitivity and specificity have been reported to range from 57–100% and 87–100%, respectively.^{6–8,12,13} The higher diagnostic accuracy observed in our series (table 1) is presumably attributed to the routine use of multiplane TEE in the setting of severe blunt chest trauma by experienced operators. This probably overcame substantial limitations related to either technical characteristics of monoplane esophageal probes^{6,7} or an inadequate learning curve.²⁸ The current study also confirmed the reliability of helical CT for the diagnosis of subadventitial ATAI. In this clinical setting,^{14–17} this imaging method had a 95–100% sensitivity and approximately an 82–100% specificity. In contrast, authors²⁹ have emphasized the substantial limitations of conventional CT for the detection of traumatic injuries to the thoracic aorta or its branches.

In the current series, multiplane TEE missed a laceration of the innominate artery, which was correctly identified by helical CT (fig. 2). Although multiplane TEE

allows the visualization of the initial portion of supraaortic arteries,³⁰ aortic branch lesions are usually out of the scope of vision of the esophageal probe.³¹ The diagnosis, using helical CT, of traumatic injuries of supraaortic arteries has only been sporadically reported.^{14,17,32} However, distal arterial injuries¹⁴ or intracranial vascular lesions³² may not be detected by this imaging method. Although duplex ultrasound may be an alternative non-invasive approach,³³ selective angiography is necessary when traumatic lesions of aortic branches are suspected.^{8,14}

Multiplane TEE identified a superficial ATAI that was missed by helical CT in four patients (table 2). Using reconstruction algorithms of helical CT scans, localized aortic lacerations and small pseudoaneurysm formations may be obscured by volume averaging with the normal aortic wall or adjacent aortic lumen.^{17,18} In these cases, retrospective reconstruction of additional axial CT images may be useful to detect smaller aortic lesions.¹⁸ The higher spatial resolution of high-frequency esophageal probes (~2 mm) accounts for the greater sensitivity of multiplane TEE for the diagnosis of traumatic intimal tears, mural thrombi, or small aortic wall lesions (fig. 2).

Although less frequently reported,³⁴ blunt traumatic cardiac injuries may be life-threatening or lead to severe

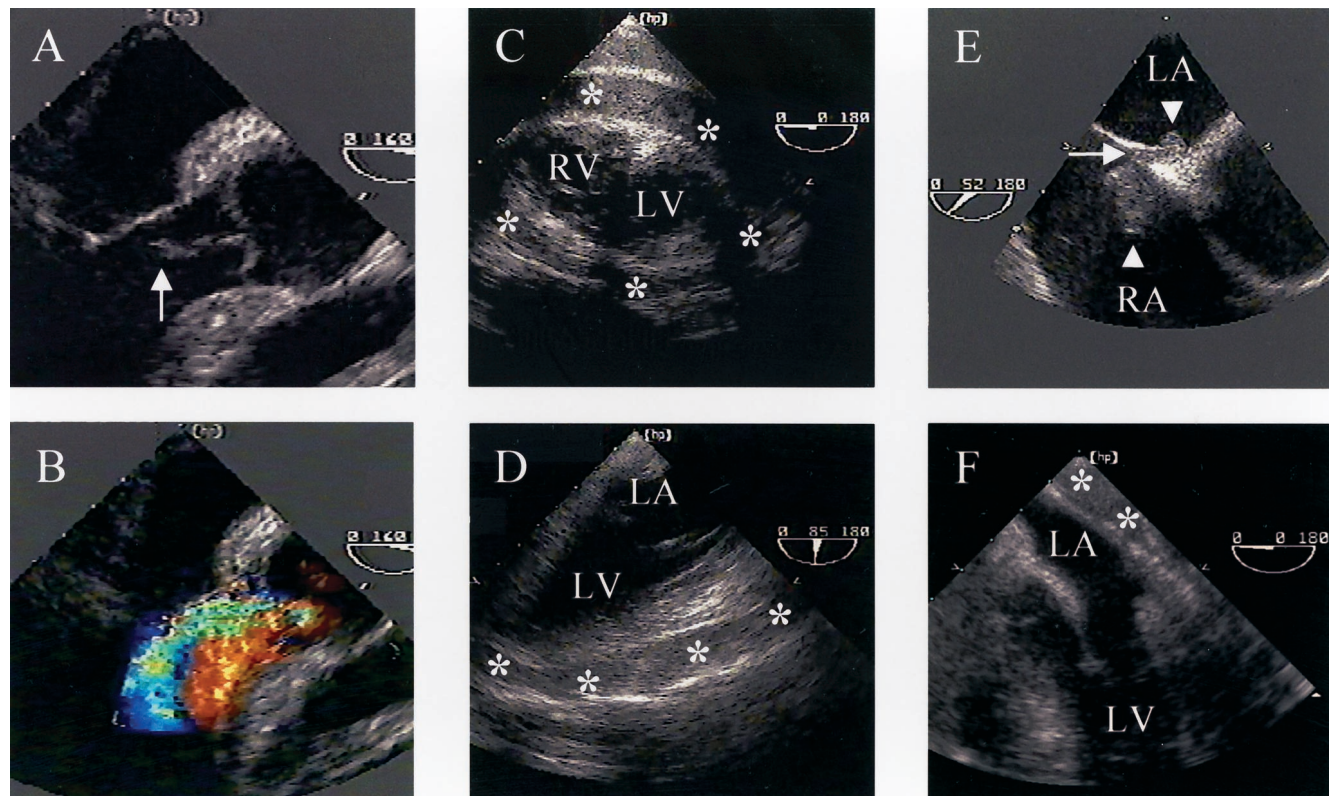


Fig. 3. Examples of blunt traumatic cardiac injuries detected by multiplane transesophageal echocardiography (TEE) in four patients. In the first patient, a disrupted aortic valve was identified in the longitudinal view (160°) of the ascending aorta (A, arrow). This valvular lesion resulted in a severe aortic regurgitation that necessitated surgery, as shown by color Doppler (B). In the second patient, two-dimensional echocardiography detected a noncompressive hemopericardium (asterisks) in both the transgastric short-axis (C) and the long-axis views (D). In the third patient, who had a comminuted femoral fracture associated with severe blunt chest trauma, multiplane TEE was performed shortly after admission because of unstable hemodynamics. TEE showed a normal thoracic aorta but fortuitously visualized an entrapped thrombus (E, arrowheads) in a patent foramen ovale (white arrow) with associated cor pulmonale. The fourth patient experienced severe hemorrhagic shock with associated restriction to diastolic left ventricular filling by a compressive posterior hemomediastinum (F, asterisks). LA = left atrium; LV = left ventricle; RA = right atrium; RV = right ventricle.

complications when unrecognized (fig. 3).^{11,12} In the current study, helical CT detected only two of the blunt traumatic cardiac injuries diagnosed using multiplane TEE (table 2). Current helical CT scanners are not suited to provide accurate examination of the heart. Newly developed, ultrafast CT provides valuable information on global and regional cardiac function,^{35,36} but these scanners are not widely available and require extensive postprocessing.

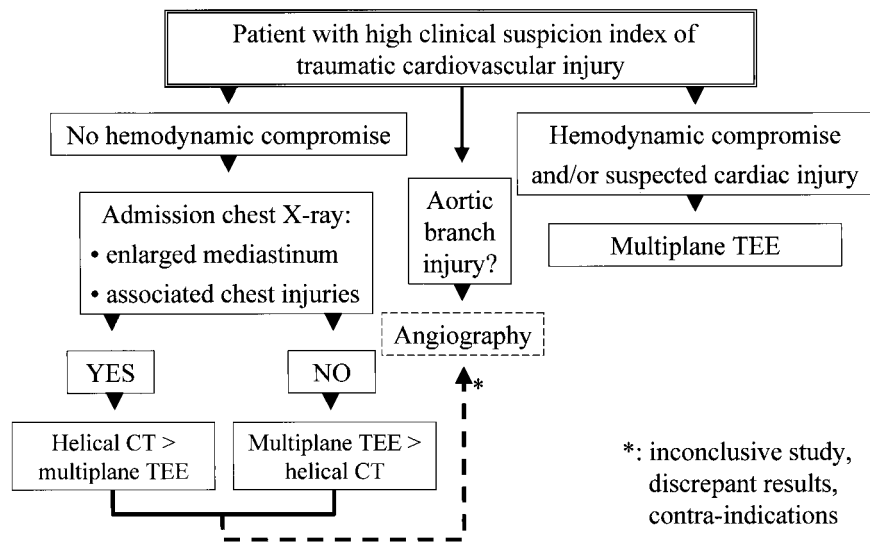
Clinical Implications

Although patients at high risk of blunt traumatic cardiovascular injury can be objectively identified,^{5,18} the choice of the optimal screening imaging method is controversial.^{4,37} Because of similar diagnostic accuracy, multiplane TEE and helical CT can interchangeably be used (e.g., contraindication) for the assessment of hemodynamically stable patients with suspected subadventitial ATAI (fig. 4). In these cases, chest radiography at admission typically shows an enlarged mediastinum, with associated radiographic findings reflecting the presence of a hemomediastinum or acute false aneurysm

formation.^{9,18} Associated chest injuries noted on the chest radiograph at admission (e.g., flail chest wall, severe pulmonary contusion) or the suspicion of associated extrathoracic lesions (e.g., severe head injury, intra-abdominal hemorrhage) should lead to use of helical CT as the screening imaging method.¹⁴ When chest radiography at admission shows an unremarkable mediastinum in a patient at high risk of traumatic cardiovascular injury (e.g., violent deceleration),⁹ a multiplane TEE should be used because of its greater sensitivity for the detection of superficial ATAI and blunt cardiac trauma (fig. 4).

In hemodynamically unstable patients presenting with multisystem trauma, transportation to the radiology department is unsafe and may result in undue delay.^{38,39} In these cases, multiplane TEE can be safely performed at the bedside during ongoing short-term care and seems ideally suited to rapidly rule out ATAI and to detect potential associated blunt cardiac injuries (fig. 4).^{11,12,26} Finally, patients with suspected traumatic injury to aortic branches should still be referred for selective angiography,^{4,8,31} but helical CT shows promise in identifying supraportic lesions (table 2). Similarly, angiography

Fig. 4. Flow chart summarizing the proposed noninvasive approach for the initial assessment of patients with suspected blunt traumatic cardiovascular injuries (see text for details).



should be performed if results of examinations are inconclusive,^{5,14,17} especially when a large hemomediastinum is observed without apparent ATAI or associated vertebrate fractures.^{17,19}

Study Limitations

The main limitation of this prospective study was the absence of systematic angiography, traditionally referred to as the reference imaging technique for the diagnosis of ATAI. Importantly, TEE and helical CT were previ-

ously validated against aortography.^{6-8,13-16} Accordingly, we only sought to compare the respective diagnostic capabilities of these noninvasive imaging methods in patients at high risk of cardiovascular injury. We considered routine angiography to be unethical for the following reasons. First, this additional procedure would have considerably increased the patient evaluation time and further delayed potential surgical repair.⁷ Second, angiography may also lead to false-negative,^{8,9,27} and false-positive results.¹⁸ Third, it has been argued that clinical follow-up findings—in contrast to negative angiography—may not constitute adequate proof that ATAI is not present.¹⁵ However, on the basis of the natural history of untreated ATAI,⁴⁰ the absence of a complicated course during follow-up can be considered as strong evidence that combined negative multiplane TEE and helical CT were reliable in excluding a traumatic injury to the thoracic aorta.¹⁵ Finally, the observed traumatic cardiac injuries ($n = 11$) would not have been visualized using aortography.²⁶

Conclusion

In the current study, multiplane TEE and helical CT showed a similar diagnostic accuracy for the identification of subadventitial ATAI. Multiplane TEE provided rapid diagnosis of superficial ATAI and blunt cardiac injuries and proved of particular value in patients with hemodynamic compromise. Based on the results of the current study, a novel, noninvasive approach can be proposed for initial evaluation of patients at high risk of blunt traumatic cardiovascular injuries.

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Table 2. Comparison of Multiplane TEE and Helical Chest CT Findings Prospectively Encountered in 95 Patients with Suspected Traumatic Cardiovascular Injuries*

Traumatic Injuries	Multiplane TEE	Helical Chest CT
Traumatic vascular injuries		
Subadventitial (surgical) lesions		
Disruption of the aortic isthmus	8	8
Disruption of the ascending aorta	1	1
Dissection of the descending aorta	1	1
Aortic branch injury†	0	1
Medial or intimal lesions (conservative management)‡		
Mobile thrombus	2	0
Intimal tear	1	0
Intramural hematoma	1	0
Cardiac injuries		
Myocardial contusion	4	0
Retrosternal hematoma	1	1
Hemopericardium	1	1
Entrapped thrombus in a PFO	1	0
Associated lesions		
Hemomediastinum	31	33
Left hemothorax	62	52

* Fifteen additional patients underwent only a single procedure (see text for details). † Laceration of the innominate artery. ‡ All lesions involved the aortic isthmus.

TEE = transesophageal echocardiography; CT = computed tomography; PFO = patent foramen ovale.

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