Invited Commentary

Pneumomediastinum Following Blunt Trauma
Are We Closer to Unlocking Its Significance?

Christian de Virgilio, MD; Dennis Yong Kim, MD

The discovery of pneumomediastinum following blunt trauma is a source of great consternation for trauma surgeons because pneumomediastinum comes in 2 forms: the one that you do not have to worry about and the other that is really bad and that you do need to worry about. Fortunately, most cases are the former. Nevertheless, to date, there are no distinguishing features on a computed tomographic scan that can help one to decipher whether the pneumomediastinum is concerning and justifies a myriad of diagnostic studies and close observation in the intensive care unit, or whether the pneumomediastinum is a benign, incidental finding.

Related article

While the relative rarity of pneumomediastinum makes it hard to create clear guidelines, the liberal use of computed tomography, due to its accessibility and rapidity, means that cases of pneumomediastinum are being seen more often. We thus continue to grapple with this disquieting dilemma. And whenever we encounter a large series of patients with blunt trauma who had pneumomediastinum, as reported in the study by Lee et al,[1] hope springs eternal, as we envision that the diagnostic pneumomediastinum puzzle has finally been solved. Similar to previous studies, the overall incidence of pneumomediastinum was low (2.2%) in the study by Lee et al.[1] They found that the presence of pneumomediastinum and its location in the posterior mediastinum or within all mediastinal compartments were associated with in-hospital mortality. Interestingly, of the 72 patients who received a diagnosis of pneumomediastinum, only 2 had a tracheobronchial injury (1 whose injury was fatal), and none had a confirmed esophageal injury. Of the 9 patients who died, only 2 appeared to die of severe intrathoracic injury, and 3 died of head injury.

The question then remains: where is this air coming from? One possible explanation is the Macklin effect, as emphasized by Lee et al.[1] Described in the late 1930s, the Macklin effect entails 3 steps: alveolar rupture, dissection of air along perivascular sheaths, and spreading of this air into the mediastinum.[2] Among a series of patients with severe blunt chest trauma, Wintermark and Schnyder[3] identified the Macklin effect as the etiology of pneumomediastinum in 39% of patients whose computed tomographic chest scan at admission revealed pneumomediastinum.

No doubt, as confirmed by Lee et al,[1] pneumomediastinum is associated with more severe injury. As with every provocative study, however, this finding generates more questions. Is pneumomediastinum (either in the posterior location or in all mediastinal compartments) an independent predictor of mortality, a surrogate for injury severity, or a sequela of associated injuries such as pneumothorax or rib fractures with subcutaneous emphysema? Is the location of the pneumomediastinum enough to dictate the need for further workup or intensive monitoring? Lee et al[1] are to be congratulated on their efforts to provide clarity regarding a rare yet potentially challenging radiographic finding that is being seen with increasing frequency as a result of the widespread availability and use of computed tomography.

ARTICLE INFORMATION

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Original Investigation | PACIFIC COAST SURGICAL ASSOCIATION

Computed Tomographic Findings and Mortality in Patients With Pneumomediastinum From Blunt Trauma

Wayne S. Lee, MD; Vincent E. Chong, MD, MS; Gregory P. Victorino, MD

Invited Commentary

IMPORTANCE The care of most patients with pneumomediastinum (PNM) due to trauma can be managed conservatively; however, owing to aerodigestive tract injury and other associated injuries, there is a subset of patients with PNM who are at higher risk of mortality but can be difficult to identify.

OBJECTIVE To characterize computed tomographic (CT) findings associated with mortality in patients with PNM due to blunt trauma.

DESIGN, SETTING, AND PARTICIPANTS A retrospective review of medical records from January 1, 2002, to December 31, 2011, was conducted at a university-based urban trauma center. The patients evaluated were those injured by blunt trauma and found to have PNM on initial chest CT scanning. Data analysis was performed July 2, 2013, to June 18, 2014.

MAIN OUTCOMES AND MEASURES In-hospital mortality.

RESULTS During the study period, 3327 patients with blunt trauma underwent chest CT. Of these, 72 patients (2.2%) had PNM. Patients with PNM had higher Injury Severity Scores ($P < .001$) and chest Abbreviated Injury Scale scores ($P < .001$) compared with those without PNM. Pneumomediastinum was associated with higher mortality (9 [12.5%] vs 118 [3.6%] patients; $P < .001$) and longer mean (SD) hospital stays (11.3 [14.6] vs 5.1 [8.8] days; $P < .001$), intensive care unit stays (5.4 [10.2] vs 1.8 [5.7] days; $P < .001$), and ventilator days (1.7 [4.2] vs 0.6 [4.0] days; $P < .03$). We evaluated several chest CT findings that may have predictive value. Pneumomediastinum size was not associated with in-hospital mortality ($P = .22$). However, location of air in the posterior mediastinum was associated with increased mortality of 25% (7 of 28 patients; $P = .007$). Air in all mediastinal compartments was also associated with increased mortality of 40.0% (4 of 10 patients; $P = .01$). Presence of hemothorax along with PNM was associated with mortality of 22.2% (8 of 36 patients; $P = .01$).

CONCLUSIONS AND RELEVANCE Pneumomediastinum is uncommon in patients with injury from blunt trauma; however, CT findings of posterior PNM, air in all mediastinal compartments, and concurrent hemothorax are associated with increased mortality. These CT findings could be used as a triage tool to alert the trauma surgeon to a potentially lethal injury.

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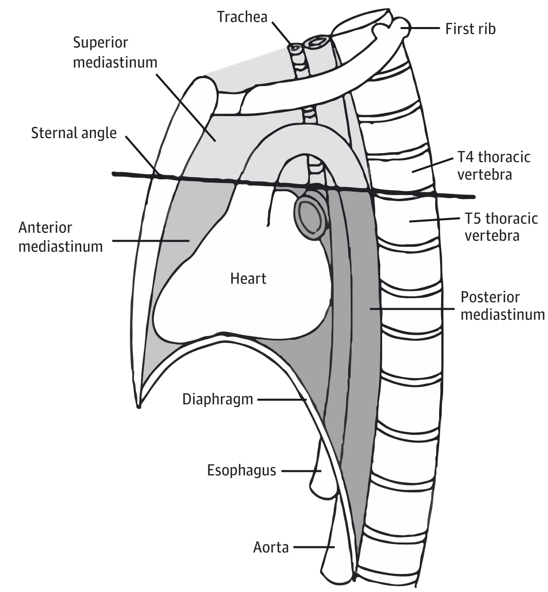
Traumatic pneumomediastinum (PNM) was first described by Laennec in 1819 in a 4-year-old boy who sustained blunt injuries from a dung cart.[1,2] In 1888, Müller reported physical examination findings of crepitations synchronous with the heartbeat.[3,4] In 1934, Hamman gained recognition for publishing a small case series to bring mediastinal emphysema to the attention of the medical profession, coining the term *Hamman sign*.[4-6] In 1939, Macklin[7] described in a cat model what is now known as the *Macklin effect*, demonstrating one potential cause of PNM: that of air dissecting along the pulmonary vasculature from ruptured alveoli.

Traditionally, PNM was identified on chest roentgenogram by several classic radiographic signs.[8] However, with the advent of computed tomography (CT), PNM is now more frequently identified[9] and may occur in up to 10% of patients with blunt chest injuries.[8,10] Pneumomediastinum is rarely due to severe injury; rather, it is thought mostly to arise from less severe injuries, such as pneumothorax, or the Macklin effect.[11] However, trauma surgeons should have a high index of suspicion for rarer causes of PNM, such as airway or esophageal injuries, since a missed aerodigestive tract injury could result in serious consequences. Because the cause of PNM and its outcomes can range from benign to devastating, the management of PNM remains controversial and depends on the associated injuries, varying widely from observation to panendoscopy and potentially operative intervention.

Many studies[2,10,12] suggest that PNM may be observed safely, but a more aggressive workup should be reserved for patients with a high suspicion of aerodigestive tract injury. The incidence of tracheobronchial injury after blunt injury is low (1%-3%) and is associated with high energy mechanism, such as high-speed motor vehicle crashes.[13] Blunt esophageal injury is an even rarer event (<1%).[14] A more recent retrospective study[10] of patients with blunt trauma with PNM has identified slightly higher incidences of tracheobronchial injury (6%) and esophageal injury (1.5%), possibly due to higher rates of endoscopic evaluation. Other studies have not shown any evidence of aerodigestive tract injuries in their PNM patient cohorts.[9,12] In fact, some authors have suggested that 60% to 90% of all patients with PNM may be safely observed.[2,10]

Because PNM is usually clinically insignificant but on occasion may be associated with serious injury, this situation may lead to costly workups with little yield or to complacency on the part of the health care team, potentially leading to missed injuries or a delay in diagnosis. To help circumvent these problems, we wanted to develop a way in which this patient population could be risk stratified early in their clinical course. Therefore, the goal of this study was to identify CT findings that are associated with mortality in patients with PNM. Our hypothesis was that there are certain findings characterized by the initial chest CT image that portend an increase in mortality in patients with PNM due to blunt trauma.

Figure. Mediastinal Locations Based on Anatomic Relationship



The superior mediastinum is superior to the heart or, more specifically, to a line drawn from the sternal angle and T4-5 vertebral disk. The anterior mediastinum is anterior to the heart, and the posterior mediastinum is posterior to the heart.

Methods

Data Source

A retrospective review of medical records was performed on all patients admitted to a university-based urban trauma center from January 1, 2002, to December 31, 2011, due to blunt trauma. Patients who underwent initial chest CT were included in our study cohort. Patient characteristics, hospital course, and outcomes were extracted from the trauma database, which were collected on a prospective basis by trauma surgery registrars. The primary outcome was in-hospital mortality. Secondary outcomes included length of hospital stay, length of intensive care unit stay, length of ventilator use, and probability of survival. This study was approved by the Alameda Health System Institutional Review Board (reference number 13-11251B), as well as the Committee on Human Research at the University of California, San Francisco (reference number 14-12868). Informed consent was not obtained; the data were deidentified. Data analysis was performed July 2, 2013, to June 18, 2014.

The presence and characteristics of PNM, including size and mediastinal compartment location, and associated findings were collected from attending radiology interpretations. Size was categorized into small, moderate, and extensive per radiology interpretations. Any incomplete radiographic interpretative data were supplemented by individual review of stored CT images. Volumetric calculations were estimated from the product of the slice thickness and the area of PNM in each slice.

Anatomically, the mediastinum is traditionally divided into 4 compartments: superior, anterior, middle, and posterior. However, to better analyze the clinical findings of PNM based on CT imaging, for the purposes of this study we subdivided the mediastinum into 3 compartments in relationship to the heart: superior, anterior, and posterior to the heart (**Figure**).

Statistical Analysis

Statistical analysis of data used the Pearson χ^2 test, *t* test, and analysis of variance where appropriate. Statistical analyses were performed using Stata/SE, version 12.0 (StataCorp). We considered *P* < .05 as statistically significant.

Results

During the study period, 16 238 patients were admitted to our trauma center after sustaining blunt trauma. Of these, 3327 patients underwent initial chest CT and constituted our study population. Seventy-two (2.2%) patients had PNM noted on chest CT; 3255 patients (97.8%) had no evidence of PNM.

Table 1. Baseline Characteristics of 3327 Patients With Blunt Trauma and Initial Chest CT

Characteristic	Mean (SD)
Age, y	42.3 (18.9)
ISS	11.9 (11.3)
Chest AIS score	0.90 (1.5)
Blood pressure, mm Hg	
Systolic	137.8 (25.9)
Diastolic	81.8 (15.8)
Heart rate, per min	92.6 (19.7)
Respiratory rate, per min	21.5 (6.0)
Pulse oximetry, %	99.1 (15.6)
Ventilator, d	0.64 (4.0)
Intensive care unit, d	1.86 (5.9)
Hospital length of stay, d	5.3 (9.0)
Probability of survival	0.94 (0.16)

Abbreviations: AIS, Abbreviated Injury Scale; CT, computed tomography; ISS, Injury Severity Score.

Baseline characteristics of the study cohort are presented in **Table 1**. The 3327 patients with blunt trauma noted on chest CT had a moderately low mean Injury Severity Score (ISS) of 11.9. The incidence of PNM increased with the rising ISS: 0.9% (21 of 2333) in patients with an ISS of less than 15, 4.0% (30 of 753) in patients with an ISS between 15 and 29, and 8.7% (21 of 241) in patients with an ISS of 30 or more. Overall patient mortality was 3.8% (127 of 3327).

Patients with PNM were more severely injured compared with those without PNM (**Table 2**). Patients with PNM had a higher mean (SD) ISS of 23.8 (15.1) compared with 11.7 (11.1) in those without PNM (*P* < .001). Similarly, patients with PNM had a higher chest Abbreviated Injury Score of 3.1 (1.5) compared with 0.8 (1.5) in those without PNM (*P* < .001). Patients with PNM had a slightly lower Glasgow Coma Scale score of 13.0 (3.8) compared with 13.7 (2.9) in those without (*P* = .04). Regarding the vital signs on admission, patients with PNM vs those without PNM had lower systolic blood pressure (129 [30.3] mm Hg vs 138 [25.8] mm Hg; *P* < .005), higher heart rate (100/min [24.5] vs 93/min [19.5]; *P* < .005), and higher respiratory rate (24/min [6.8] vs 22/min [5.9]; *P* < .001). However, the diastolic blood pressure (81 [18.6] mm Hg vs 82 [15.8] mm Hg; *P* = .53) and pulse oximetry (97% [6.5%] vs 99% [15.7%]; *P* = .28) remained similar.

Increased mortality was noted in patients with vs those without PNM (9 [12.5%] vs 118 [3.6%] patients; *P* < .001). Patients with PNM also had a longer hospital stay (11.3 [14.6] days vs 5.1 [8.8] days; *P* < .001), intensive care unit stay (5.4 days [10.2] days vs 1.8 [5.7] days; *P* < .001), and ventilator use (1.7 [4.2] days vs 0.6 [4.0] days; *P* = .03) (Table 2).

Of the 9 deaths in patients with PNM, 1 patient (11.1%) died on the way to the operating room for a thoracotomy owing to high chest tube output. Three patients (33.3%) had closed head injuries that led to brain death with subsequent withdrawal

Table 2. Comparison of Patients With and Without Pneumomediastinum

Characteristic	Pneumomediastinum No (n = 3255)	Pneumomediastinum Yes (n = 72)	*P* Value
Male, No. (%)	2291 (70.4)	56 (77.8)	.17
Age, mean (SD), y	42.4 (19.0)	39.2 (16.0)	.15
ISS, mean (SD)	11.7 (11.1)	23.8 (15.1)	<.001
Chest AIS score, mean (SD)	0.8 (1.5)	3.1 (1.5)	<.001
Mortality, No. (%)	118 (3.6)	9 (12.5)	<.001
Blood pressure, mean (SD), mm Hg			
Systolic	138 (25.8)	129 (30.3)	.004
Diastolic	82 (15.8)	81 (18.6)	.53
Heart rate, mean (SD), per min	93 (19.5)	100 (24.5)	.002
Respiratory rate, mean (SD), per min	22 (5.9)	24 (6.8)	<.001
Pulse oximetry, mean (SD), %	99 (15.7)	97 (6.5)	.28
Glasgow Coma Scale score, mean (SD)	13.7 (2.9)	13.0 (3.8)	.04
Ventilator, mean (SD), d	0.6 (4.0)	1.7 (4.2)	.03
Intensive care unit, mean (SD), d	1.8 (5.7)	5.4 (10.2)	<.001
Length of stay, mean (SD), d	5.1 (8.8)	11.3 (14.6)	<.001
Probability of survival, mean (SD), %	0.94 (0.15)	0.86 (0.27)	<.001

Abbreviations: AIS, Abbreviated Injury Scale; ISS, Injury Severity Score.

Table 3. Mortality in Patients With Pneumomediastinum by Compartment Location

Location	Mortality, %	*P* Value
Compartment		
Superior	15.4	.54
Anterior	12.5	.95
Posterior	25.0	.007
No. of compartments		
1	8.7	
2	0	.01
3	40.0	

of support. One patient (11.1%) developed cardiopulmonary arrest due to unknown reasons on hospital day 41 while awaiting skilled nursing facility placement. One patient (11.1%) died on hospital day 10, likely due to sepsis. Two patients (22.2%) had incomplete hospital records. Only 1 patient (11.1%) who died had a confirmed tracheal injury: a nonsurvivable laceration at the carina was identified during thoracotomy. One patient (1.6%) of the 63 individuals with PNM who lived had a tracheal injury shown on CT, but survived with nonoperative management. Airway injury occurred in 2 of 72 patients with PNM, with an overall incidence of 2.8%. No confirmed esophageal injuries were identified.

Although there was a linear correlation between the size of PNM and mortality noted in analysis of the initial CT image, the results were not significant (small, 9%; moderate, 15%; extensive, 30%; $P = .22$). However, PNM in the posterior location and air in all mediastinal compartments were associated with increased mortality ($P = .007$ and $P = .01$, respectively) (**Table 3**). Computed tomographic findings of PNM in the posterior location in predicting in-hospital mortality has a sensitivity of 88% and a specificity of 63%; the presence of air in all 3 mediastinal locations has a sensitivity of 50% and specificity of 90%. Positive predictive value, negative predictive value, and likelihood ratio for posterior mediastinal air were 25%, 97%, and 2.4, respectively. The positive predictive value, negative predictive value, and likelihood ratio for PNM in all 3 compartments were 40.0%, 92.7%, and 4.8, respectively.

Pneumomediastinum was associated with additional radiographic findings on initial chest CT. Subcutaneous emphysema (44 of 72 patients [61.1%]), pneumothorax (45 of 72 [62.5%]), hemothorax (36 of 71 [50.7%]), rib fractures (51 of 72 [70.8%]), and pulmonary contusions (45 of 71 [63.4%]) were identified in patients with PNM. Of these, only the CT finding of hemothorax was associated with higher in-hospital mortality (8 of 36 [22.2%] vs 1 of 35 [2.9%]; $P = .01$) in patients with PNM.

Discussion

Pneumomediastinum is often observed in patients with blunt trauma, and its presence is usually clinically insignificant. However, on occasion the presence of PNM may signify a more serious injury, such as pharyngoesophageal or laryngotracheal rupture.[11,15-17] We sought to develop a way in which this patient population could be risk stratified early in their clinical course. Therefore, the goal of the present study was to identify CT findings that are associated with mortality in patients with PNM. Our hypothesis was that there are certain findings characterized by the initial chest CT image that portend an increase in mortality in patients with PNM due to blunt trauma. We found that mediastinal air posterior to the heart or in all 3 mediastinal compartments (superior, anterior, and posterior to the heart) were associated with an increased risk of death. Concurrent hemothorax was also a risk factor for in-hospital mortality.

With technologic advancement and increasing use of CT in blunt trauma, the sensitivity of detecting PNM has increased, and in one study[9] only 11% of PNM found on CT could be seen on chest roentgenogram. Although these patients with PNM had a mean ISS of 22, there were no tracheobronchial or esophageal injuries.[9] The significance of PNM seen only on CT but not on chest roentgenogram was also studied in patients with blunt chest trauma.[12] The authors found a 5.9% incidence of occult PNM, which had resolved on follow-up CT conducted a median of 3 hours after injury. Furthermore, none of these patients with blunt chest trauma had aerodigestive tract injuries. The authors concluded that all occult PNM resolved spontaneously and appeared to be of no clinical significance.

In contrast, in a mixed population of patients with penetrating (15%) and blunt (85%) injuries[18] there was a 5% incidence of mediastinal organ injury in patients with PNM found on CT. In this mixed population, 4% of the patients had airway injuries and 1% had esophageal injuries. However, of the 10 airway injuries only 3 (30%) were due to a blunt mechanism, and of the 3 esophageal injuries only 1 (33%) was due to a blunt mechanism. Similarly, in another study[2] looking at PNM in a mixed mechanism population, also with a mix of 15% penetrating injuries and 85% blunt injuries, 7 of 68 patients (10.3%) of patients were found to have an aerodigestive tract injury; however, this study did not differentiate between blunt and penetrating mechanisms, making it difficult to determine the effect of blunt trauma on aerodigestive tract injury. These studies[2,18] demonstrate that blunt and penetrating mechanisms have distinct risks of aerodigestive injury, with the risk of sustaining an aerodigestive injury higher with penetrating trauma.[19,20]

Despite the low incidence of aerodigestive tract injuries in blunt trauma, several series have attempted to characterize their presence in the isolated blunt trauma population. In a large study[9] of 2052 patients with blunt trauma with an average ISS of 22, none sustained a mediastinal organ injury. In a study[12] of 897 patients admitted for blunt chest trauma with a mean ISS of 23, there also were no aerodigestive tract injuries. However, in contrast to these 2 moderately sized studies, which reported no aerodigestive tract injuries, a study[10] of 136 patients with PNM due to blunt trauma reported on 10 patients who sustained an aerodigestive injury requiring operative intervention. These included 5 (50%) laryngeal injuries, 3 (30%) tracheal disruptions, and 2 (2%) esophageal perforations. No ISS was reported; however, the patients had a low overall mortality rate of 3%. Our study had a comparable mortality rate of 3.8% and a low incidence of airway injury of 2.8%, but we had no esophageal injuries in our series.

Although aerodigestive tract injuries are the most serious cause of PNM from blunt trauma, not all morbidity and mortality in these patients are due to these particular injuries. In patients with severe blunt trauma, PNM can be associated with other critical injuries that may lead to the patients' eventual death. Our study demonstrated that, based on ISS, chest Abbreviated Injury Score, and Glasgow Coma Scale score, patients with PNM are more severely injured compared with those without PNM. In addition, PNM was associated with increased in-hospital mortality, hospital stay, ICU stay, and ventilator days. Because the presence of PNM places patients in a group with a higher risk of death and other complications, we sought to explore potential findings on CT that may help to risk stratify patients to help guide subsequent management.

In our analysis of PNM identified on chest CT, we found that although the size of the PNM had a linear association with mortality, this relationship was not statistically significant, which may be the result of a relatively small sample size. Location of PNM posterior to the heart and having PNM in all 3 locations (superior, anterior, and posterior to the heart) were associated with increased mortality. It may be counterintuitive that the location of the PNM seemed to predict worse outcomes as opposed to the amount of air that is seen. One theory is that the size of the PNM may be associated with the time from injury to the arrival at the trauma center and ultimately obtaining CT imaging; however, the location of the PNM may be more closely related to the amount of blunt force energy and mechanism of impact.

We found that CT findings of PNM in the posterior location in predicting in-hospital mortality has a sensitivity of 88% and a specificity of 63%, and air in all 3 mediastinal locations has a sensitivity of 50% and specificity of 90%. The sensitivity and specificity of these 2 CT findings in predicting in-hospital mortality are comparable to those of other quantitative scoring systems developed to predict disease severity and mortality, including Acute Physiology and Chronic Health Evaluation II (sensitivity 38%, specificity 99%), Trauma and Injury Severity Score (sensitivity 52%, specificity 94%), Acute Physiology and Chronic Health Evaluation III (sensitivity 60%, specificity 98%), and 24-hour ICU point system (sensitivity 51%, specificity 98%).[21] However, these quantitative scoring systems are all calculated retrospectively and are not available to the trauma surgeon on the day of admission. The finding of PNM in certain locations on the admission chest CT image provides the trauma team with a risk stratification tool to aid in the management of care for this trauma patient population early in their hospital course.

The negative predictive value for mortality was relatively high for mediastinal air in the posterior location as well as in all 3 locations, since a patient with blunt trauma with an absence of these findings may have a lower mortality risk. Although the positive predictive value was relatively low, which may be because of the low mortality rates, the significant association between these CT findings and mortality may be an indication that further workup is warranted. For a patient with any one of these CT findings, we recommend that the trauma team consider ICU admission, goal-directed resuscitation with serial serum lactate monitoring, indwelling urinary catheterization, and central venous pressure monitoring.

The presence of hemothorax with PNM may also portend a worse outcome in patients with blunt trauma. In patients with PNM, concurrent hemothorax increased the risk of mortality from 3% to 22%. These associations are likely related to injury severity, since the presence of mediastinal air and bleeding into the pleural space are likely a result of a significant blunt force mechanism. However, these characteristics of PNM noted on CT could be easily and immediately assessed on admission, which could predict a higher mortality risk and alert the physician to a potentially complicated hospital course.

In addition to being a single-center retrospective series, a limitation of this study is that most patients did not undergo further imaging or endoscopic evaluation. This lack of further testing may have contributed to the underdiagnosis of occult aerodigestive tract injuries. However, despite the implications of missed detection of an aerodigestive tract injury, the care of these patients was managed successfully with nonoperative interventions, and the patients were discharged without clinical evidence of a tracheal injury or esophageal leak.

Conclusions

Our study has demonstrated that certain patterns of PNM seen on the initial CT image may be a warning sign for patients with blunt trauma injuries. Pneumomediastinum was uncommon—found in only 2.2% of initial chest CT images. Patients with PNM were more severely injured compared with their non-PNM counterparts, with higher rates of mortality and longer lengths of ICU stay, hospital stay, and ventilator days. The size of the PNM was not associated with increased mortality; however, patients were more likely to die if PNM was identified posterior to the heart, was identified in all 3 mediastinal compartments, or was associated with a hemothorax. These findings on CT should alert the trauma surgeon that the patient has an increased risk of a lethal injury of up to 40%. When detected early on initial chest CT, these ominous signs of a potentially lethal injury are an easy way to warn the trauma surgeon to consider close monitoring in the ICU, aggressive resuscitation, and the possibility of additional diagnostic studies.

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Study concept and design: All authors.
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