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Watch Out for the Early Killers: Imaging Diagnosis of Thoracic Trauma

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Radiologists and trauma surgeons should monitor for early killers among patients with thoracic trauma, such as tension pneumothorax, tracheobronchial injuries, flail chest, aortic injury, mediastinal hematomas, and severe pulmonary parenchymal injury. With the advent of cutting-edge technology, rapid volumetric computed tomography of the chest has become the most definitive diagnostic tool for establishing or excluding thoracic trauma. With the notion of "time is life" at emergency settings, radiologists must find ways to shorten the turnaround time of reports. One way to interpret chest findings is to use a systemic approach, as advocated in this study. Our interpretation of chest findings for thoracic trauma follows the acronym "ABC-Please" in which "A" stands for abnormal air, "B" stands for abnormal bones, "C" stands for abnormal cardiovascular system, and "P" in "Please" stands for abnormal pulmonary parenchyma and vessels. In the future, utilizing an artificial intelligence software can be an alternative, which can highlight significant findings as "warm zones" on the heatmap and can re-prioritize important examinations at the top of the reading list for radiologists to expedite the final reports.

Keywords: Pneumothorax; Rib fractures; Traumatic aortic injury; Pulmonary contusions; Pulmonary lacerations

INTRODUCTION

Thoracic trauma refers to any form of physical injury to the thoracic cage, airway, lung parenchyma, or mediastinal great vessels. It accounts for approximately 20% to 25% of all trauma cases and is the third most common cause of death in all ages [1-3]. Thoracic trauma occurs in approximately two-thirds of patients with polytrauma [1,4-6]. However, early mortality can exceed 50% when the injuries are severe, such as extensive pulmonary parenchymal injury, tension hemopneumothorax, and tracheobronchial and traumatic aortic injuries [5,7]. Consequently, rapid physical and radiographic evaluations play important roles in identifying severe thoracic trauma. Chest radiography is usually performed in patients with trauma to identify primary life-threatening conditions [8]. However, readily available volumetric chest computed tomography (CT) is the best tool for establishing or excluding a definitive diagnosis of thoracic trauma in almost every emergency department if the patient is stable [9-11]. Currently, supervised contrast-enhanced chest CT can serve as an important diagnostic tool if unstable patients are well protected and communication between the trauma bay and CT rooms is unimpeded. Contrast-enhanced chest CT images are not only accurate for characterization of the nature of injuries but also provide us with knowledge of the true extent of thoracic trauma. Moreover, whole-body CT has already become a trend in emergency surveys of trauma patients. The incorporation of chest CT into whole-body CT does not lengthen the examination time or add radiation dose significantly, but it increases the volume of images for radiologists who are already burnt out by heavy workload. With the notion that "time is life" in emergency settings, radiologists must devise ways to shorten the report

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turnaround time. An alternative method is to interpret chest findings using the systemic approach advocated in this article. Our interpretation of chest findings follows the acronym of "ABC-Please" in which "A" stands for air, "B" stands for bones, "C" stands for the cardiovascular system, and "P" stands for pulmonary parenchyma and vessels. Turnaround times of reports at different institutions may have different definitions [12]. In general, this is the sum of the waiting and reading times. Waiting time is defined as the time between the termination of the examination by technicians and a review of the verified images on the picture archiving and communication system by radiologists. Reading time is defined as the period between reviewing the images and finalizing the report. Artificial intelligence can re-prioritize examinations with life-threatening findings at the top of the reading list for radiologists and shorten the report turnaround time by highlighting these findings as "warm zones" on the heatmap [12,13].

Air (Pneumothorax and Pneumomediastinum)

Pulmonary laceration with or without rib fracture can cause visceral pleura disruption and consequent pneumothorax [5,9]. If the pneumothorax is large, it can cause tension pneumothorax (Fig. 1), which can deviate the lung and mediastinum to the contralateral side and compromise systemic venous return [7]. A poor venous return results in poor cardiac output and death. Pneumothorax volume measurement can be accomplished by employing artificial intelligence on radiographs or CT images; undeniably, a three-dimensional measurement model on CT is a better way to calculate the exact volume of the pneumothorax [14,15]. A trivial pneumothorax may progressively enlarge and cause tension pneumothorax in the event of mechanically assisted ventilation. Therefore, chest tube thoracostomy is usually performed irrespective of the amount of pneumothorax if patients have to undergo intubation or general anesthesia.

Pneumomediastinum occurs due to various causes of trauma. Tracheobronchial injuries are early killers and can result in massive pneumothorax and pneumomediastinum unresponsive to chest tube thoracostomies [7]. The lungs distal to the tracheobronchial injuries have no structural support and typically manifest as a fallen lung to the thoracic periphery, away from the injury site (Fig. 2). In addition to tracheobronchial injuries, massive pneumomediastinum associated with periesophageal fluid can result from traumatic esophageal rupture, although it is rare [2,9]. Because early intervention for esophageal rupture can reduce morbidity and mortality, emergency esophagography using a water-soluble contrast medium followed by thin barium esophagography [2] is the mainstay for excluding injury (Fig. 3). Most cases of pneumomediastinum are benign and caused by interstitial pulmonary injuries. As a result of the Macklin effect, the air in an alveolar rupture can dissect along the peribronchovascular interstitial sheaths, interlobular septa, and visceral pleura into the mediastinum during respiratory movements [9]. This type of spontaneously resolving pneumomediastinum is usually documented on chest radiography.

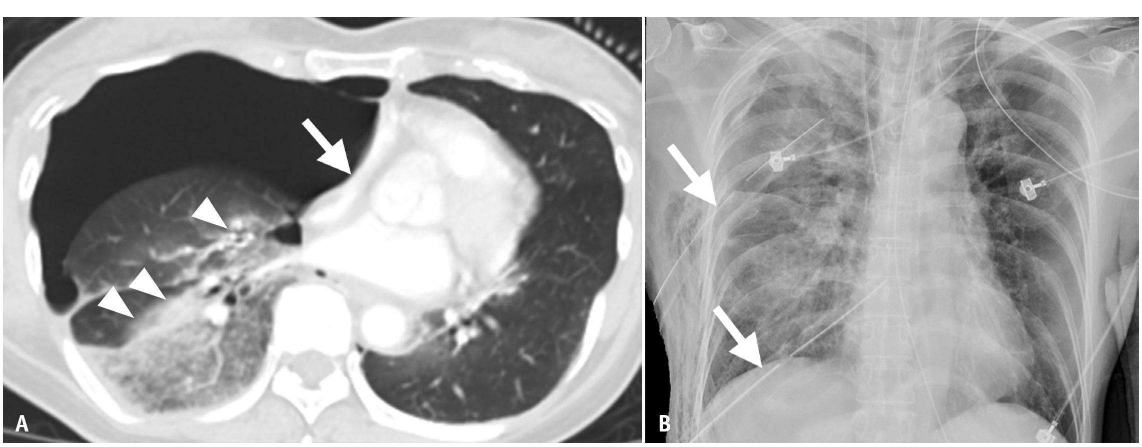

Fig. 1. Images of a patient with tension pneumothorax. **A:** Chest computed tomography shows right pulmonary contusion with ground-glass and air-space filling opacities at the alveolus (arrowheads). The right tension pneumothorax (arrow) has deviated the mediastinum to the left and induced right atrial collapse with a concave curvature. **B:** Chest radiograph demonstrates the return of the mediastinum to the center after two right-sided chest tube thoracostomies (arrows). The patient is endotracheally intubated and subcutaneous emphysema has occurred after thoracostomies indicating parietal pleural disruption.

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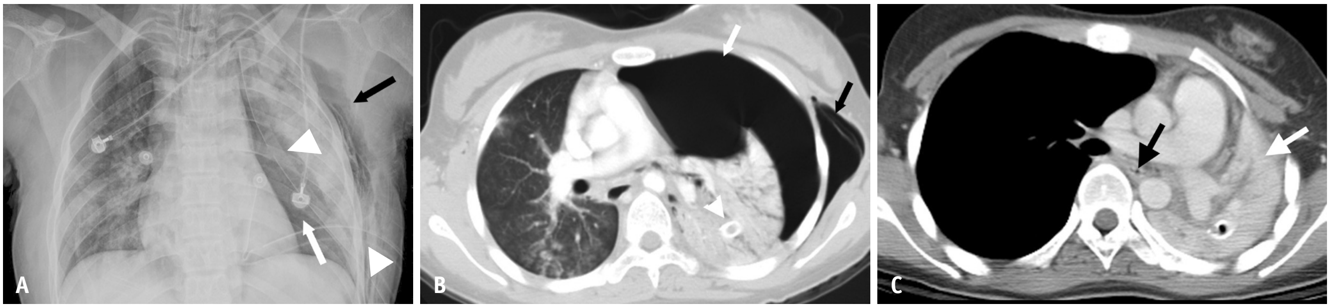

Fig. 2. Images of a patient with persistent pneumothorax caused by a main bronchus-tearing injury. Supine chest radiograph **(A)** and chest computed tomography **(B)** show persistent left pneumothorax (white arrows) and subcutaneous emphysema (black arrows) despite two chest tube thoracostomies (arrowheads), one of which is embedded in the interlobar fissure. **C:** The patient's condition was complicated by a persistent stricture of the left main bronchus (black arrow) and collapse of the left lower lobe (white arrow).

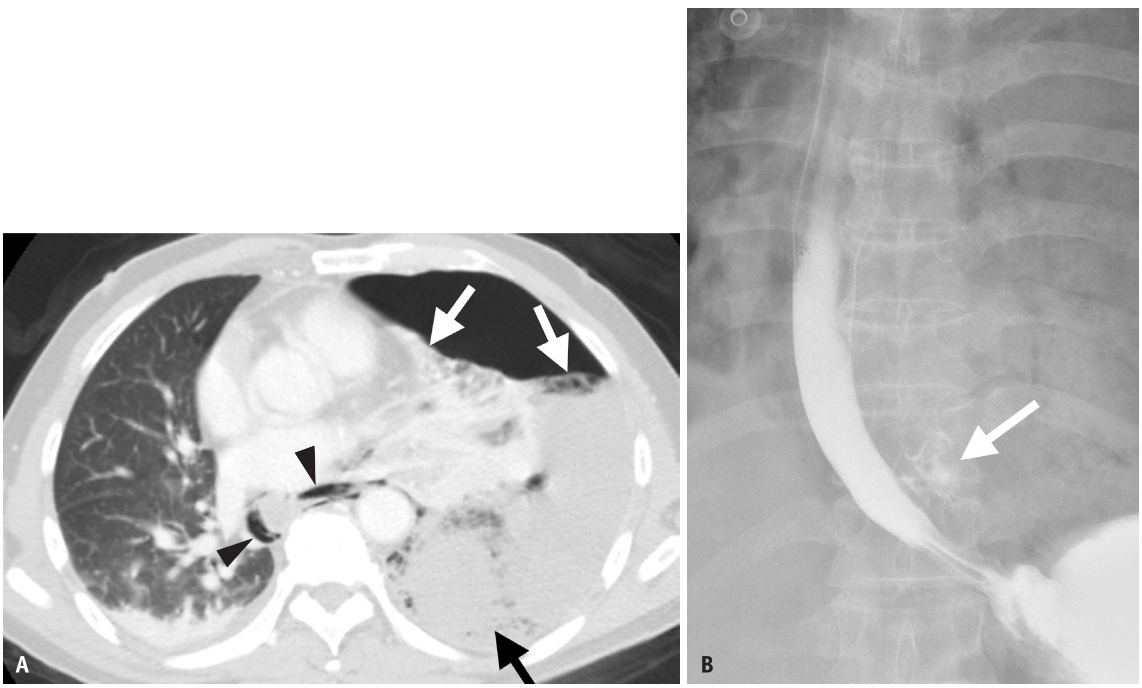

Fig. 3. Images of a patient with pneumothorax and pneumomediastinum caused by traumatic esophageal rupture. **A:** Chest computed tomography shows pneumomediastinum (black arrowheads), massive hydropneumothorax (white arrows), and left lung air space opacities (black arrow). **B:** Emergency esophagogram using water-soluble oral contrast medium showing a distal esophageal rupture (arrow).

Bones (Thoracic Cage and Vertebral Injuries)

Approximately 10%–70% of patients undergoing whole-body CT examinations have rib fractures [16,17]. The detection rates vary greatly because of the limitations in identifying fractures using different imaging modalities [17]. The identification of rib fractures in the thoracic cage can be assisted by a three-dimensional multiplanar reconstructed CT (Fig. 4) [17,18] or by the unfolded rib technique on curved planar reconstructed CT [19]. Using artificial intelligence, convolution neural networks have been viewed as the method of choice for the detection and characterization of rib fractures and provide radiologists with the opportunity to focus on the most important thoracic organ injuries [20]. Multiple rib fractures (≥ 3) can be associated with flail chest if the fractures involve three or more contiguous ribs with two or more breaks per rib. A flail chest resulting from a rib fracture can cause paradoxical respiratory movement of the chest wall. These unwanted paradoxical movements and severe chest pain can cause respiratory difficulties and failure. To avoid paradoxical movements during respiration, patients must be intubated and aided with positive end-expiratory pressure mechanical respiration. Therefore, early surgical fixation of multiple rib fractures is recommended to

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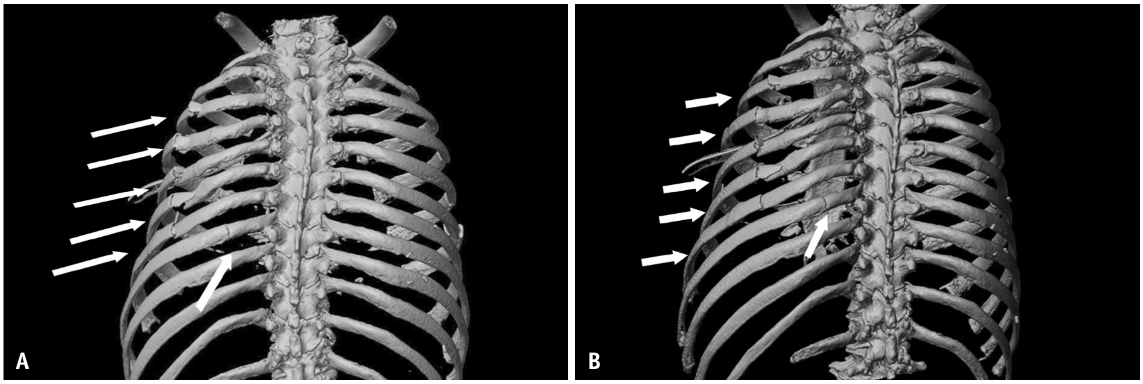

Fig. 4. Images of a patient with multiple rib fractures. The posterior **(A)** and left posterior oblique projections **(B)** of the thoracic cage clearly show multiple fractures from the left 3rd rib to 8th rib (arrows).

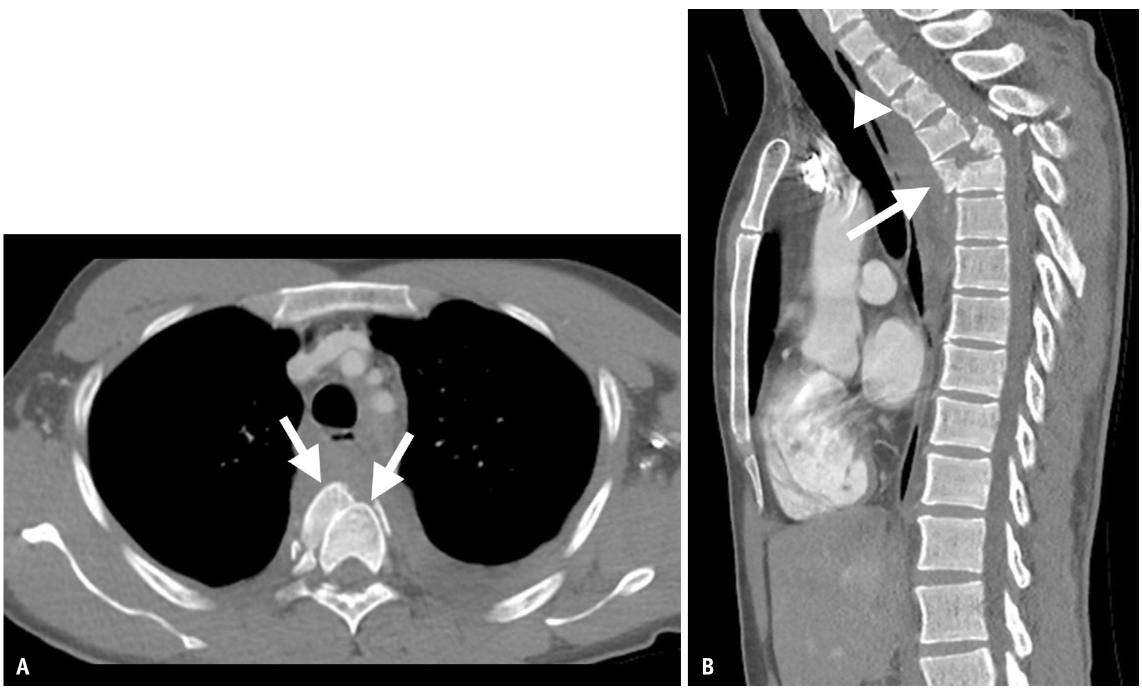

Fig. 5. Images of a patient with an unstable thoracic spine fracture. **A:** Axial chest computed tomography (CT) shows a double vertebrae sign (arrows), posterior mediastinal hematoma, and left hemothorax. **B:** Sagittal reconstructed CT demonstrates a flexion-distraction injury of the upper thoracic spine with a T4 vertebral body burst fracture (arrow). A fracture at the anterosuperior corner of the T2 vertebral body was also noted (arrowhead).

prevent considerable morbidity and mortality [21].

Thoracic spinal fractures are concomitant injuries associated with rib fractures [22]. They are often obscured by mediastinal shadows on radiographs but easily detected on multiplanar reconstructed CT images. Spinal anatomy and fractures are best described by the three-column theory [23]. All spinal fractures, including transverse chance and unstable burst fractures, are considered unstable if the posterior and middle columns are disrupted. Contrastingly, compression fracture where only the anterior column is involved is often called a stable spinal fracture. Disruption of spinal alignment, especially lateral alignment, is indicative of an unstable dislocation injury. Double vertebral signs and fractures of the posterior column in the axial view are important indicators of unstable spine fractures. These can be rapidly confirmed on reconstructed sagittal CT images (Fig. 5). Secondary injuries resulting from unstable vertebral fractures can cause irreparable neurological deficits if not identified. Therefore, multiplanar reconstructed CT images should be viewed in patients with trauma.

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Cardiovascular System (Hemothorax and Mediastinal Hematoma)

Contrast medium extravasation on contrast-enhanced chest CT is indicative of active bleeding, which is life-threatening, such as in traumatic aortic injury [8,24,25]. In lethal traumatic aortic injuries, up to 80% of patients die at the scene or during transfer to a medical facility [24-26]. Of those who reach the hospital alive, 50% die before aortic repair can be performed (Fig. 6) [24-26].

Chest radiography is widely performed in patients with thoracic trauma. A widened mediastinum > 8 cm was considered a positive screening criterion for thoracic aortic injury [27]. However, the positive predictive value of the mediastinal width (> 8 cm) did not exceed 20%. Most thoracic aortic injuries occur at the aortic isthmus; therefore, an aortic pseudoaneurysm or periaortic hematoma in proximity to the aortic isthmus would exert a mass effect on the trachea, resulting in the widening of the left mediastinal width (> 6 cm) from the center of the trachea to the left mediastinal border [8]. To cancel the effect of mediastinal accentuation on supine radiography obtained at emergency settings, the ratio of the left mediastinal width to that of the general mediastinal width of > 0.6 is a criterion for high-risk chest radiograph which is more specific than a mediastinal width of > 8 cm [8]. Further chest CT examinations for patients with high-risk chest radiograph are therefore warranted. Chest CT with any direct signs of aortic injury, including an abnormal intimal flap and pseudoaneurysm, can indicate aortic injury [24,25]. Diagnostic aortogram is reserved for patients whose CT show indirect signs such as periaortic hematoma [24,25]. Previously, it was controversial to treat patients with aortic injuries immediately or later in the course of the disease because of the potential risks of bleeding during surgical repair. Fortunately, thoracic endovascular aortic repair has become the mainstay of management and has significantly reduced the mortality rate of traumatic aortic injuries [26].

Other well-contained mediastinal contrast extravasation such as those originating from smaller vessels can also be obliterated using endovascular techniques [28]. Mediastinal contrast extravasation from the internal mammary artery or thyrocervical trunk usually occurs in the mediastinal space and can be successfully managed using endovascular techniques (Fig. 7). In contrast to contained mediastinal hematoma, pleural space hemorrhages are usually uncontained and can originate from the pleura, lacerated lung surface, intercostal vessels, or mediastinal vessels. Massive hemothorax can result from uncontrolled arterial hemorrhage, detected on contrast-enhanced chest CT as foci of contrast medium extravasation [29]. If patients are hemodynamically stable, interventional radiologists can perform embolization to arrest arterial hemorrhage [28]. However, surgeons must perform emergency surgeries if patients are unstable.

Pulmonary Parenchyma and Vessels

Pulmonary parenchymal injuries occur in up to 75% of blunt thoracic trauma cases [6,9,30,31]. The most common forms of pulmonary parenchymal injury include contusions and lacerations. Pulmonary contusions may not be visible on radiographs in the first 6 h following trauma but may peak in conspicuity and extent within 2 to 3 days [9,31].

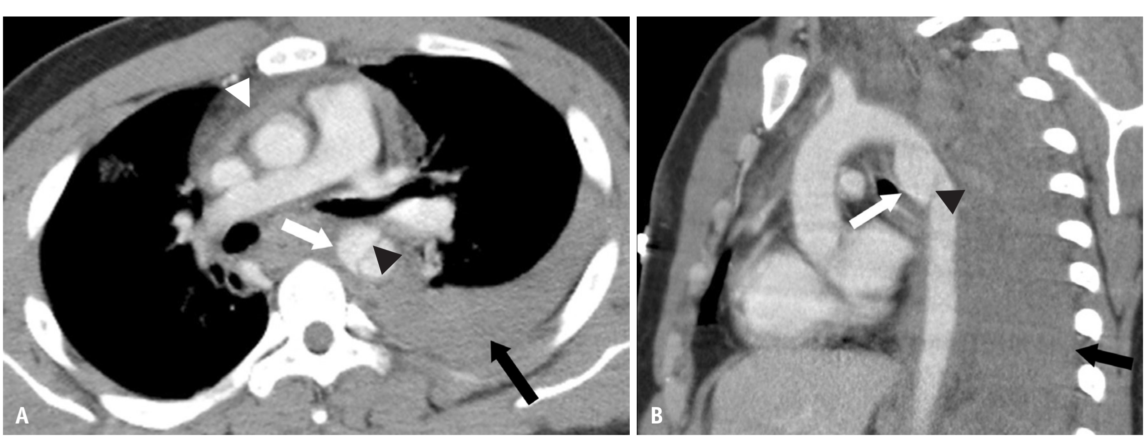

Fig. 6. Images of a patient with traumatic aortic injury. Axial computed tomography (CT) **(A)** and coronal oblique reconstructed CT **(B)** shows a traumatic aortic pseudoaneurysm (white arrows) typically developing at the aortic isthmus and a short intimal flap sign (black arrowheads). Mediastinal hematoma (white arrowhead) and left hemothorax (black arrows) are also present.

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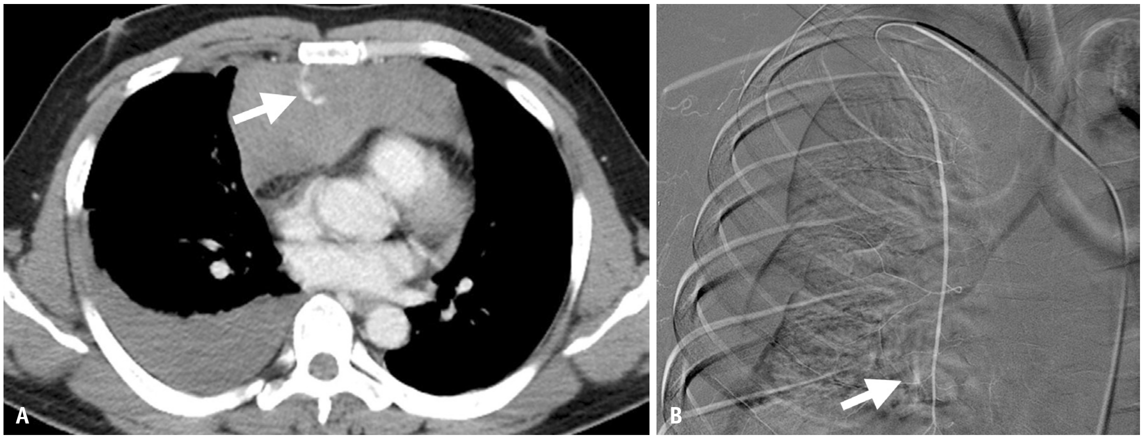

Fig. 7. Images of a patient with mediastinal hematoma and retrosternal contrast medium extravasation. **A:** Contrast-enhanced computed tomography shows retrosternal extravasation of the contrast medium (arrow) and a large anterior mediastinal hematoma. **B:** Selective angiography of the right internal mammary artery shows active bleeding (arrow). Subsequent segmental embolization successfully arrested active bleeding.

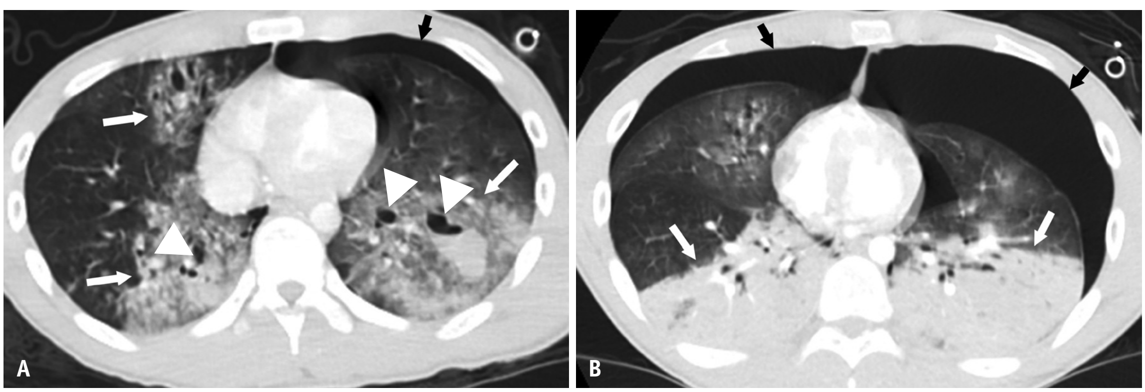

Fig. 8. Images of a patient with severe pulmonary parenchymal injury. Lung window settings of the initial computed tomography (CT) **(A)** and CT obtained half an hour later **(B)** show the progression of bilateral pulmonary contusions represented by ground-glass and airspace opacities (white arrows) and pulmonary lacerations represented by cavities (arrowheads). Progression of the bilateral pneumothorax was also observed (black arrows).

On chest CT, lung contusions typically appear as regions of ground-glass attenuation or airspace opacities, with 1 to 3 mm of subpleural sparing [6,9,31]. The resolution periods of lung contusions vary, but most lung contusions resolve within 3–7 days and no more than 2 weeks.

Conversely, pulmonary lacerations typically appear as spherical or elliptical cavities in pneumatoceles and hematoceles. These cavities result from the unique elastic recoil properties of normal lung tissue from pulmonary lacerations. Although pulmonary lacerations occur simultaneously with pulmonary contusions, they are not visible on initial chest radiographs because they are obscured by airspace-filling contusion opacities. They become more conspicuous when obscuring pulmonary contusions regress. However, in the chest CT era, cystic cavities of pulmonary lacerations can now be identified easily even on initial CT examinations (Fig. 8) [10,11]. Pulmonary lacerations can produce a Swiss cheese appearance when the cavities are numerous and partially filled with hematoma [4,11]. According to Wagner et al. [11], pulmonary lacerations can be classified into four types: compression rupture type that occurs at the central lung, compression shearing type that occurs at the paraspinal lung, rib-penetrating type that occurs at the sites of inwardly displaced fractured ribs, and adhesive lung tear type that occurs randomly at any site of lung adhesion.

Resolution of most pulmonary lacerations on chest CT will take longer than that of pulmonary contusions. If pulmonary contusions or lacerations increase in size and extent instead of spontaneously resolving within 2 weeks and tend to progress in terms of lung cavities, airspace-filling process, or pneumothorax, complications can occur (Fig. 9). These

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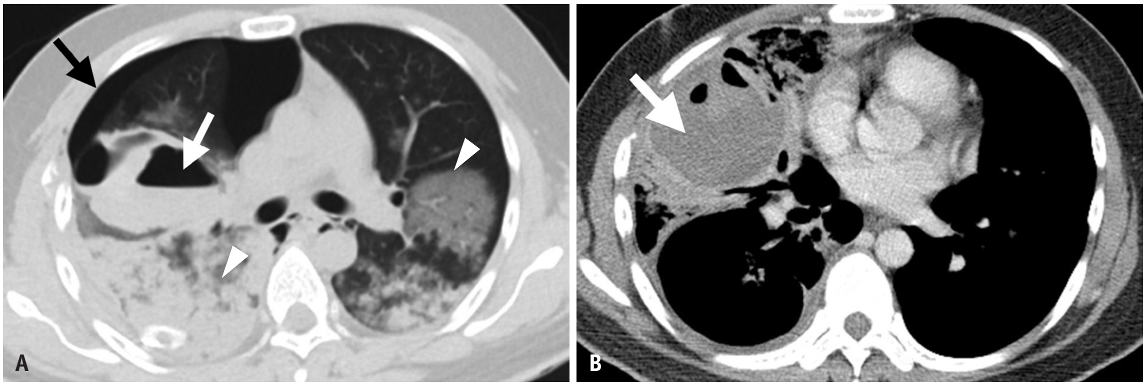

Fig. 9. Images of a patient with pulmonary injury complicated by a lung abscess. **A:** Chest computed tomography (CT) with a lung window shows bilateral lung contusions (arrowheads), large right lung laceration (white arrow), and right pneumothorax (black arrow). **B:** Contrast-enhanced chest CT 20 days later demonstrates persistent loculated opacity of the fluid and air bubbles in the right middle lobe (white arrow). A lung abscess was suspected because of the spiking fever. The complicated lung laceration was successfully drained using a pigtail catheter.

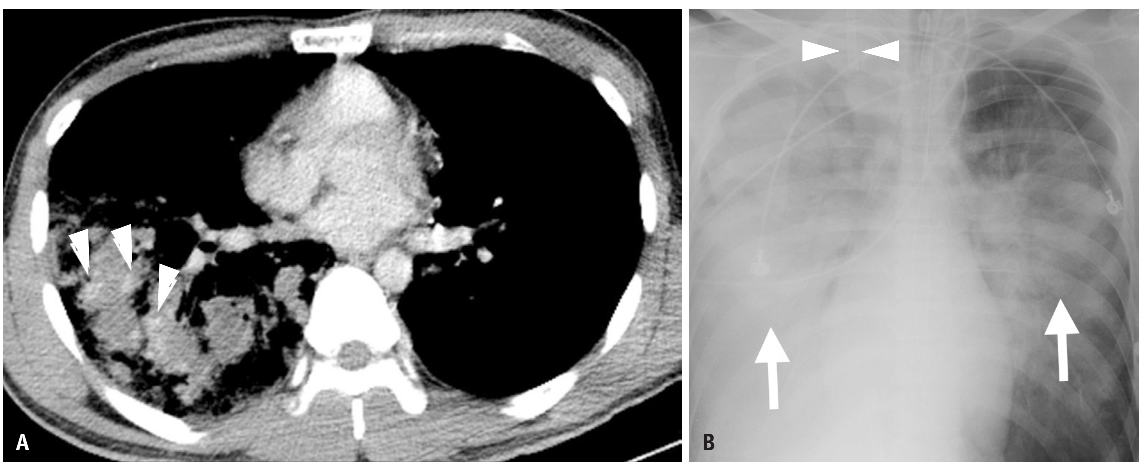

Fig. 10. Images of a patient with severe pulmonary injury and parenchymal contrast medium extravasation. **A:** Initial contrast-enhanced chest computed tomography demonstrates a right lower lung contusion and laceration. Multiple tiny lung pseudoaneurysms are present in the hematoceles (arrowheads). **B:** Rapid progression of the lung hemorrhage is observed as a bilateral confluent air space-filling pattern (arrows). Venovenous extracorporeal membrane oxygenation (arrowheads) is performed. The patient's condition deteriorated rapidly, and he succumbed to suffocation and hypoxemia before double-lumen intubation.

complications include pneumonia, lung abscess, bronchopleural fistula, acute respiratory distress syndrome (ARDS), and pseudoaneurysm [2,10,11,31]. Sayed et al. [3] went a step further and concluded that the lung ultrasound score, which is as good as the CT score, can quantify the extent of lung contusion and detect high-risk patients for developing ARDS within 72 h.

If pulmonary arterial pseudoaneurysms are confined and patients are stable, most vascular injuries recover spontaneously because of the low pulmonary arterial pressure, which is an avenue for thrombosis formation. Unfortunately, some pseudoaneurysms may rupture if the tamponade effect is inadequate, leading to active bleeding from the lungs (Fig. 10). This unfavorable condition manifests as massive hemoptysis, hypoxia, dyspnea, or tachycardia caused by an abnormal airspace-filling process and consequently impaired alveolar gas exchange [6,30]. Surgical lobectomy is the most urgent treatment for arresting active lung bleeding. Some centers may advocate the use of extracorporeal membrane oxygenation (ECMO) [32,33]. Venovenous ECMO is the most appropriate type for severe lung parenchymal injuries. This is also performed more reasonably on heparin-free devices for fear of continuous bleeding from injured sites because of routine application of anticoagulants in ECMO cases [32,33].

CONCLUSION

Radiologists and trauma surgeons must monitor for early killers among patients with thoracic trauma. When interpreting chest imaging irrespective of either radiographs or CT with multiple reconstruction, we have to follow the acronym "ABC-Please" even with the help of artificial intelligence to expedite our report turnaround time to save patients from preventable death.

Conflicts of Interest

The authors have no potential conflicts of interest to disclose.

Author Contributions

Conceptualization: Yon-Cheong Wong, Li-Jen Wang, Rathachai Kaewlai. Supervision: Yon-Cheong Wong. Validation: Yon-Cheong Wong. Writing—original draft: Yon-Cheong Wong, Cheng-Hsien Wu. Writing—review & editing: Yon-Cheong Wong, Cheng-Hsien Wu.

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