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Thoracic trauma WSES-AAST guidelines

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Abstract
Chest trauma is a common consequence of traumatic events. It may be blunt or penetrating. A low number of patients with blunt chest trauma require surgical intervention; in contrast, penetrating ones frequently require surgery and are associated with higher mortality. Chest trauma due to its anatomical location and to its potential effects on different systems must be multidisciplinary, and emergency and trauma systems should be organized and prepared to face all aspects. The present paper describes the recommendations provided by World Society of Emergency Surgery (WSES) and the American Association for the Surgery of Trauma (AAST), about comprehensive management of thoracic trauma.

Keywords Chest, Trauma, Physiology, Multidisciplinary, Mortality, Morbidity, Blunt, Penetrating, Children, Elderly, Adult, Classification

Background

Chest trauma is a common event, blunt chest trauma is more common (70–80%) than penetrating and accounts for 20 to 25% of trauma deaths. In many low-middle-income countries (LMIC) penetrating trauma, both stab and gunshot wounds, are at least as common as blunt trauma, and immediately lethal, with over 75% of stab wounds to the heart dying before they can reach the hospital. Motor vehicle collisions are associated with higher morbidity and mortality due to high-speed collisions and particularly with non-use of seat belts. Older patients may have a worse outcome due to frailty and other comorbidities. Despite its higher incidence, less than 10% of patients with blunt chest trauma require surgical intervention. In contrast, up to 30% of patients with penetrating chest trauma require surgery and are associated with higher all-cause mortality [1–3].

The complex lesion pattern, that may involve more than one component of the thorax content and boundaries, need attention and deep knowledge of mechanical and physiological mechanisms. The present paper describes the recommendations provided by World Society of Emergency Surgery (WSES) and the American

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Association for the Surgery of Trauma (AAST), about comprehensive management of thoracic trauma.

Notes on the use of the guidelines

The guidelines are evidence-based, with the grade of recommendation based on the evidence. The guidelines present the methods for optimal management of thoracic trauma patients. The practice guidelines promulgated in this work do not represent a standard of practice. They are suggested plans of care, based on the best available evidence and the consensus of experts, but they do not exclude other approaches as being within the standard of practice. For example, they should not be used to compel adherence to a given method of medical management, which method should be finally determined after taking account of the conditions at the relevant medical institution (staff levels, experience, equipment, etc.) and the characteristics of the individual patient. However, responsibility for the results of treatment rests with those who are directly engaged therein, and not with the consensus group.

Methods

A computerized search was done by a bibliographer in different databases (MEDLINE, Scopus, EMBASE) and citations published between January 2000 and February 2024 were included when satisfying, the primary search strategy: "thorax, trauma, lung, parenchyma, morbidity, mortality, injury, trachea, bronchus, infections, empyema, hemothorax, pneumothorax, vascular, soft tissue, rib, bones, sternum, therapy, surgery, fixation, pleura" combined with AND/OR. No search restrictions were imposed. Expert opinion reviews, narrative reviews, case reports and case series based on less than 30 patients were not considered relevant. The dates were selected to allow comprehensive published abstracts of clinical trials, consensus conference, comparative studies, congresses, guidelines, government publication, multicenter studies, systematic reviews, meta-analysis, large case series, original articles, and randomized controlled trials (RCT). Narrative review articles were only used to determine if other cited studies should be included.

Table 1 Thoracic trauma classification (*Respiratory impairment*: reduced lung function without distress; *Respiratory distress:* an acute diffuse lung injury that occurs within a short period of time and can cause severe hypoxemia leading to hypoxic damage to various organs throughout the body

	Grade	Respiratory function	Haemodynamic
Minor	Grade I	Normal	Stable
Moderate	Grade II	Respiratory impairment	Stable
Severe	Grade III	Respiratory distress	Stable
	Grade IV	Any	Unstable

Level of evidence (LoE) was graded in high, moderate, low, and very low. The grade of recommendation (GoR) was graded as strong, moderate, and weak.

A group of experts from the involved Societies (AAST, WSES) in the field led by a central coordinator was contacted to express their evidence-based opinion. Different issues were discussed in subsequent virtual rounds based through a modified Delphi process. The central coordinator assembled the different answers derived from each round. Each version was then revised and improved. After three rounds the process led to the one hundred percent of agreement about the statements and the text. The present manuscript represents the final version.

Thoracic trauma classification

Thoracic trauma are classified as follow (Table 1).

Respiratory function evaluation

To evaluate the severity of respiratory impairment and respiratory distress, the Berlin definition of acute respiratory distress syndrome (ARDS) can be used [4], but we suggest the application of the more recently published Global definition of ARDS [5], (Table 2), which is more applicable in different settings, including lower resource ones.

In fact, the impairment in oxygenation may be evaluated by the SpO_2/FiO_2 ratio (or, with the classical PaO_2/FiO_2 ratio). In contrast, lung infiltrates may be assessed using ultrasound (or the classical chest x-ray). In this regard, the value of the Lung Ultrasound Score in quantifying the extension of pulmonary contusions in blunt chest trauma has been recently evaluated [6]. Moreover, the definition does not mandate using positive pressure ventilation to diagnose and stratify ARDS severity, but it includes the application of oxygen by high flow nasal cannulas.

The risk of delayed development of ARDS may be predicted by the application of the Thoracic Trauma severity score [7], which includes several factors (Table 3): a value of the score between 13 and 25 predicts a high risk of developing ARDS.

Diagnosis

- Systematic evaluation of the patient is indicated to promptly identify life-threatening thoracic injuries, including lung parenchymal injuries (LoE moderate, GoR strong).
- In unstable penetrating and blunt thoracic trauma patients lesions diagnosis should be pursued with E-FAST and/or chest-x ray (LoE moderate, GoR strong).
- In stable penetrating and blunt thoracic trauma patients contrast enhanced CT-scan (with eventual

Table 2 ARDS definition [5]

Criteria that apply to all ARDS categories			
Risk factors and origin of edema	Precipitated by an acute predisposing risk factor, such as pneumonia, non-pulmonary infection, trauma, transfusion, aspiration, or shock. Pulmonary edema is not exclusively or primarily attributable to cardiogenic pulmonary edema/fluid overload, and hypoxemia/gas exchange abnormalities are not primarily attributable to atelectasis. However, ARDS can be diagnosed		
Timing	Acute onset or worsening of hypoxemic respiratory failure within 1 week of the estimated onset of the predisposing risk factor or new or worsening respiratory symptoms		
Chest imaging	Bilateral opacities on chest radiography and computed tomography or bilateral B lines and/or consolidations on ultrasound not fully explained by effusions, atelectasis, or nodules/masses		
	Criteria That Apply to Specific ARDS Categories		
	Non-intubated ARDS	Intubated ARDS	Modified Definition for Resource-Limited Settings
Oxygenation	PaO_2/ $FiO_2 \leq 300$ mmHg or $SpO_2/FiO_2 \leq 315$ (if $SpO_2 \leq 97\%$) on HFNO with flow of > 30 L/min or NIV/CPAP with at least 5 cmH_2O PEEP	- Mild: $200 < PaO_2/FiO_2 \leq 300$ mmHg or$235 < SpO_2/FiO_2 \leq 315$ - (if $SpO_2 \leq 97\%$) - Moderate: $100 < PaO_2/FiO_2 \leq 200$ mmHg or $148 < SpO_2$: $FiO_2 \leq 235$ - (if $SpO_2 \leq 97\%$) - Severe: $PaO_2/FiO_2 \leq 100$ mmHg or $SpO_2/FiO_2 \leq 148$ - (if $SpO_2 \leq 97\%$)	$SpO_2/FiO2 \leq 315$ (if $SpO_2 \leq 97\%$). Neither PEEP nor a minimum flow rate of oxygen is required for diagnosis in resource-limited settings

Table 3 Thoracic trauma severity score [7]

PaO_2/ FiO_2	Rib fracture	Contusion	Pleural involvement	Age (years)	Points
> 400	0	None	None	< 30	0
300–400	1–3	1 lobe	Pneumothorax	30–41	1
200–300	4–6 unilateral	1 lobe bilateral or 2 lobes unilateral	Unilateral Hemothorax or Hemopneumothorax	42–54	2
150–200	> 3 bilateral	< 2 lobes bilateral	Bilateral Hemothorax or Hemopneumothorax	55–70	3
< 150	Flail chest	≥ 2 lobes bilateral	Tension pneumothorax	> 70	5

Table 4 Key differences between elderly and pediatric patients

Feature	Elderly patients	Pediatric patients
Rib fractures	Common due to osteoporosis	Rare; rib fractures suggest severe force
Pulmonary reserve	Reduced; prone to respiratory failure	Higher reserve but immature mechanisms
Healing	Slower with higher risk of complications	Faster but complications (e.g., ARDS) possible
Mortality risk	Higher even with minor trauma	Lower but depends on associated injuries

3D reconstruction) is strongly indicated to define the type and extent of injuries (LoE moderate, GoR strong).

- Contrast-enhanced CT-scan and eventual CT-Angiography are indicated for precise vascular mapping, facilitating a tailored approach, and planning appropriate interventions (LoE moderate, GoR strong).
- Bronchoscopy remains the gold standard for diagnosing specific tracheal and bronchial injuries, providing direct airway visualization (LoE moderate, GoR strong).
- In case of suspected oesophageal perforation, contrast CT-scan or esophagoscopy is recommended (LoE moderate, GoR strong)

Different lesions may be supposed according to the age of the patient (Table 4).

Chest X-ray (CXR) is easy to perform, fast, cheap, and often readily available in many settings. However, its sensitivity for detecting PNX in the supine position ranges from 28 to 75% [8].

CXR is rarely able to diagnose diaphragmatic injuries (DI), unless there is a major herniation into the thoracic cavity.

Sensitivity of US was considered higher than CXR ($p < 0.001$), but the specificities were similar ($p = 0.35$) [9]. In penetrating injuries, it may be useful to detect bullet trajectories or bullet fragments or radiopaque fragments

[10]. CXR associated to bullet markers and clinical assessment can detect deep bullet trajectory.

CXR can rapidly detect pneumothorax (PNX), large hemothorax (HTX), flail chest and mispositioned tubes, which are major death risk factors [10]. In simple PNX, anteroposterior CXR may fail to detect PNX due to the persistence of lung parenchyma masking the air [11].

CXR is strongly suggested in all major trauma patients, especially with chest trauma, but is not mandatory in minor traumas without thoracic involvement and if the patient has no clinical signs or significant distracting injuries or intoxication [11–15].

CXR may not be reliable as a screening tool for blunt thoracic aortic injury (BTAI), even at the highest grades of injury. Enlarged mediastinum (widened more than 8 cm) was found in only 27.7% of all confirmed cases of BTAI and in just 47.4% of the most severe Grade 4 injuries. Specifically, it was detected in grade 1, 2, 3 and 4 injuries in 7.8%, 23.3%, 35.3% and 47.4% respectively [16].

Ultrasound (US), especially if extended focused assessment with sonography in trauma (E-FAST) [14], in skilled hands with linear ultrasound transducer probe (5 to 10 MHz), it may achieve 98% sensitivity and 100% specificity in detecting free fluid [1, 8, 11, 12, 17–21]. US can be performed at the bedside, it may result more useful and effective than CXR in unstable patients to detect PNX [22, 23]. E-FAST may be even performed prior to CXR for rapid detection of PNX [9] and eventual consequent management in emergency situations. However, it is not accurate enough in obese patients and in the presence of subcutaneous emphysema.

US is more sensitive and faster than CXR for traumatic HTX diagnosis (97.5% vs. 92.5%, and 1.3 min. vs. 14.2 min, respectively) [17, 23, 24]. Chest ultrasound has increased the potential for diagnosis of air embolism by visualizing microbubbles within the heart or great vessels [25]. Transesophageal echocardiography can visualize air bubbles in the heart and major vessels, though this requires a skilled sonographer [25]. Doppler ultrasound may be used to detect air emboli in peripheral vessels [26].

In post-traumatic pulmonary artery thrombosis (PTPAT) echocardiography may be used to assess the impact of the thrombus on heart function.

In addition, US is accurate in the diagnosis of hemopericardium and cardiac contractility in peri-arrest or critically unstable patient.

Contrast enhanced computed tomography (CT) is the most specific tool and is useful in hemodynamically stable severe trauma and cases of equivocal findings on CXR and/or US [27, 28]. In fact, missing chest injuries can be identified in 71% of patients with a normal chest X-ray, and in 37.5% the injuries may require life-saving interventions [10]. CT-scan requires hemodynamic stabilization.

In the case of haemodynamic instability and acute respiratory failure with suspected tension PNX, the first useful diagnostic tool is US associated with emergency decompression [2, 22]. Chest X-ray can also be useful if US is equivocal.

In haemodynamically stable patients, ultrasound, chest x-ray and CT scan can be differently combined to refine the diagnosis [27, 29].

CT scan of the chest is essential in the pre-operative planning of surgical stabilization of thoracic wall injuries, especially when associated with 3D reconstructions. In fact, it allows to precisely visualize number, location and degree of displacement of rib fractures. The degree of rib displacement may be underestimate since posterior rib fractures may be partly reduced if the initial CT scan was performed with the patient in supine position. Hence, some authors recommend a CT scans done on inspiration.

Even with some concerns, CT scan appears to be the most reliable and effective tool in diagnosing a diaphragmatic rupture with or without herniation. It allows direct identification of the defect and/or indirect signs that may help in identifying the trajectory in penetrating trauma.

CT is the best tool to diagnose and identify chest hemorrhage with or without active bleeding (fluid collection with a density of 30–45 HU for fluid blood, and 45–70 HU for clot) residual hemothorax or its complications like empyema [15, 22, 28].

CT scans excel in identifying lung parenchymal damage, offering precise insights into the severity and specifics of lung injuries [30]. Early CT scans can accurately predict the risk of Acute Respiratory Distress Syndrome (ARDS), noting that the likelihood of ARDS escalates with the volume of initial lung injury [31].

For a detailed visualization of the trachea and bronchi, and to assess associated injuries, particularly those to the great vessels and oesophagus CT scan represents the best tool [18, 32–34]. It is indispensable for identifying subtle injuries [18].

CT angiography (CTA) emerges as the preferred imaging technique for diagnosing vascular lesions and pulmonary artery thrombosis and planning appropriate treatment strategies whenever needed [35–37].

In pulmonary contusions, a CT scan is the recommended method to measure the extent of the damage. This measurement is important as it correlates with the likelihood and severity of complications. While chest X-ray might initially underestimate the injury, it remains valuable for short-term monitoring [38]. Early quantification of the contusion volume through CT scans is crucial for identifying patients who are at an elevated risk for delayed respiratory issues (i.e. pneumonia and ARDS) [38, 39].

In suspected pulmonary embolism (gas and fat) CT angiography is the definitive diagnostic tool, complemented by echocardiography for immediate clinical decisions. Head CT is often necessary to rule out intracranial pathology [40]. CT scan can detect air in the vascular system, particularly in the heart and lungs, but it is not sensitive enough to exclude the diagnosis [41].

A comprehensive strategy integrating vital signs, scores, biomarkers, and imaging for precise risk prediction, with pulmonary embolism response teams enhancing care for severe cases [42–45]

Bronchoscopy represents the gold standard to evaluate tracheal and bronchial injuries. Fiberoptic bronchoscopy reaches 90% sensitivity. Moreover, bronchoscopy may hold a pivotal role in the diagnosis of airway trauma, potentially influencing the therapeutic approach, especially in emergency settings and during surgical management of lung injuries [46].

Diagnostic laparoscopy/thoracoscopy is an accurate, safe and minimally invasive method to evaluate the entire abdominal and diaphragmatic dome, allowing to diagnose and repair injuries. Diagnostic laparoscopy/thoracoscopy should be considered in hemodynamically stable patient that sustained a penetrating thoraco-abdominal trauma or a blunt trauma with high suspicion of a DI non detectable at the CT scan.

Artificial intelligence (AI) tools have demonstrated promising potential. By rapidly analyzing imaging data in real-time, AI can provide clinicians with actionable insights to triage patients, prioritize interventions, and reduce diagnostic delays. By integrating data from imaging, vital signs, and trauma scores, these systems can stratify patients based on injury severity and predict complications such as acute respiratory distress syndrome. AI may in the future enable clinicians to make more informed decisions about appropriate treatment plans and resource allocation.

Thoracic wall injuries

Hemodynamic instability is a contraindication to surgical stabilization of rib fractures (LoE Moderate, GoR Strong).

Surgical stabilization of rib fractures should be considered in all hemodynamically stable patients presenting with a flail chest (LoE Moderate, GoR Moderate).

Surgical stabilization of rib fractures should be considered in patients presenting multiple (≥ *3) rib fractures (in ribs from 3rd to 10th) if they are ipsilateral and severely displaced and/or in presence of poor response to or impossibility to wean from mechanical ventilation (LoE Moderate, GoR Moderate).*

Surgical stabilization of rib fractures should be performed within 48–72 h after injury (LoE High, GoR Strong)

If early intervention is contraindicated, surgical stabilization of rib fractures should be performed as soon as possible within 3 to 7 days after injury (LoE Moderate, GoR Moderate).

Surgical stabilization of rib fractures may be considered in severe pain unresponsive to other treatments (LoE Low, GoR Weak).

Traumatic brain injury and pulmonary contusion are not absolute contraindications to surgical stabilization of rib fractures (LoE Moderate, GoR Moderate).

Advanced age, significant cardiopulmonary comorbidities, active malignancy or other terminal illnesses represent relative contraindications to surgical stabilization of rib fractures; case-by-case evaluation is mandatory (LoE Low, GoR Strong).

In patients with empyema or prior chest radiation surgical stabilization of rib fractures mandates a careful evaluation of the risk/benefit ratio (LoE Low, GoR Strong).

If intrathoracic organ injury is suspected or significant haemothorax or pneumothorax is present despite chest tube, video assisted thoracoscopy should be considered at the time of rib fractures surgical stabilization (LoE Moderate, GoR Moderate).

If pleural cavity is open at the time of rib fractures surgical stabilization, chest tube should be placed (LoE Moderate, GoR Moderate).

Significant chest wall defects with lung herniation or at risk of hernia development should be repaired (LoE Moderate, GoR Moderate).

Hemodynamic instability is an absolute contraindication to surgical stabilization of rib fractures [47, 48]. Severe bleeding from thoracic wall injuries can be controlled by horizontal mattress sutures, packing or angioembolization of intercostal arteries. There have been some comparative studies, as well as several randomized clinical trials, meta-analysis and systematic reviews all over the years, that showed significantly superior clinical outcomes in patients with flail chest (FC) treated with surgical stabilization (SS), compared to non-operative management (NOM) [30, 32, 34–36, 38, 40, 43, 44]. Improved outcomes included lower incidence of tracheostomies, pneumonia, respiratory failure and ARDS, shorter time on mechanical ventilation, decreased ICU LOS. Patients treated surgically also experienced lower rates of long-term respiratory dysfunction, chronic pain and persistent chest tightness. Moreover, surgical fixation proved itself to be the most cost-effective strategy in patients with flail chest, showing decreased hospital length of stay, reduced ventilator days and earlier return to previous employment, resulting in an overall reduction of costs and better quality of life [30, 33].

From the reported evidence, patients who have antero-lateral flail chest and respiratory failure (without severe pulmonary contusion), patients with pulmonary contusion and persistent instability of the chest wall or unable to be weaned from the ventilator and non-intubated patients with deteriorating pulmonary function in the setting of flail chest are the ones who appeared to benefit the most from surgical rib fixation [37, 45–49].

Case–control studies, RCT and metanalysis showed results favoring surgical stabilization of rib fractures (decreased mortality, hospital LOS, higher ventilator-free days) in ventilated patient's presenting with severe chest wall injury with multiple rib fracture without FC (> = 3 fractures with a severe displacement or overriding (by minimum 15 mm each) or protrusion into lung parenchyma or > = 25% loss of thoracic volume) [22, 55–59, 62, 63, 67, 76]. Lower rate of pleural space complications, lower pain score and better quality of life, and a shortened time of disability with an earlier return to work were reported for the non-mechanically ventilated patients.

Fractures located on higher ribs (1st and 2nd) or lower ribs (11th and 12th) do not impact ventilation. Unless these ribs are significantly displaced and are causing damage to surroundings structures their surgical fixation is not recommended.

Fractured ribs from 3 to 10 should be strongly considered for surgical stabilization [48, 49]. Ribs 3 to 8 mainly affect the mechanics of respirations, and ribs 6 to 8 warrant an even stronger consideration for surgical stabilization being strongly related to an impairing decrease in thoracic volume if severely displaced.

Early fixation (within 72 h from injury) has the benefit of potentially mitigating factors such as inflammation, hematoma, clotted HTX, empyema, rigidity with deformities of the chest wall, and early callous formation that makes surgical reduction of the fractures difficult [48]. Moreover, it maximizes the chances of avoiding ventilator-associated complications [47]. Early surgical stabilization showed reduced mechanical ventilation duration, intensive care unit (ICU) and hospital length of stay (LOS) and lower risk of tracheostomy [30, 50] without affecting mortality. On the other hand, late stabilization (within 3 to 7 days after the injury) may allow to correctly identify patients prone to failing of NOM and requiring operative management. Late stabilization was associated with prolonged operative time and increased likelihood of prolonged mechanical ventilation and pneumonia development.

Pulmonary contusion and severe traumatic brain injury (TBI) were historically considered an absolute contraindication to SS especially in severe cases (GCS lower than 9) [54]. Some recent studies compared outcomes of patients with moderate to severe TBI and chest wall injuries managed operatively and non-operatively and showed lower risk of pneumonia, shorter ICU LOS and ventilator-dependence time is chest wall injuries were surgically stabilized. Patients with TBI should be evaluated for surgical stabilization of rib fractures on an individual case basis.

Patients with rib fractures and mild to moderate PC who underwent surgical stabilization had lower risk of respiratory failure and tracheostomy, lower mechanical ventilation time, improved respiratory function and lower HLOS. Similar benefits seem to exist also in severe PC, showing that early rib stabilization could be beneficial regardless the PC severity.

Significant cardiopulmonary comorbidities, active malignancy, presence of empyema and history of chest wall irradiation represents relative contra-indications and risks and benefits must be evaluated. Few evidence showed as surgical stabilization in elderly is safe, reduces mortality and respiratory complications, and improves respiratory mechanics.

In presence of concomitant spine fractures, management prioritization depends on their stability. In case of unstable vertebral injuries, these should be addressed first. Nevertheless, prolonged prone position may exacerbate the severity of an associated chest wall injury (increasing intra-thoracic pressure and cardio-pulmonary complications): thus, in case of stable neurological status and spinal fractures, surgical stabilization of rib fractures may be considered prior to spinal stabilization [47].

Video assisted thoracoscopy (VATS) may offer multiple advantages at the time of SS of rib fractures.

Nevertheless, there are no definitive data in favor of routine-VATS compared to selective-VATS. Therefore, the routine addition of thoracoscopy during surgical stabilization cannot be recommended [47] and should be defined case by case. In the event of suspected intra-thoracic organ damage or persistent hemothorax despite chest tube (established risk factor for empyema development), VATS should be considered.

Patients who undergo chest tube drainage after surgical stabilization, either via the incision itself or via VATS, have decreased likelihood of both retained hemothorax and empyema. For this reason, chest tube should be placed if the pleural cavity has been violated. On the other hand, chest tube is not necessary if the pleural cavity remains closed and there is no hemothorax or pneumothorax [47].

Lung herniation is a rare but severe sequalae of chest injury; visible lung herniation or large defects with concern for future lung herniation (and unlikely spontaneous resolution), should be considered for surgical repair [46, 47] either with direct suture or with prosthesis implantation.

Diaphragmatic injuries

- Diaphragmatic injuries must always be repaired as soon as the patient condition permit (LoE Moderate, GoR Strong).
- After diaphragmatic injury repair, chest tube is indicated (LoE Moderate, GoR Strong).

Diaphragmatic injuries (DI) happen in almost 0.4% of all trauma cases. 63% of DI are caused by penetrating trauma. In thoracoabdominal trauma DI incidence may reach 42%. In general penetrating trauma results in small diaphragmatic tears and blunt in much larger ones. Moreover, it should be evaluated the potential association of DI with abdominal injuries (i.e. spleen lesions, etc.). If a diaphragmatic injury is suspected, an early thoracoscopy or laparoscopy should be performed within 24 h according to the traumatic mechanisms and local expertise. Leaving an undetected injury untreated can result in the development of a post-traumatic diaphragmatic hernia.

Management surgical repair of DI is mandatory on both sides and repair strategies depend on the extent of the damage. After reduction of herniated organs back into the abdominal cavity is usually suggested to inspect and irrigate the ipsilateral pleural cavity. The diaphragm may be repaired with interrupted or continuous slowly absorbable or non-absorbable monofilament. No differences exist between the different techniques (i.e. interrupted figure of eight suture, horizontal mattress suture, running suture or double layer repair) [1, 24]. The use of meshes may help but it is rarely needed in the acute setting. After repair, a chest tube should always be placed. During laparoscopy for DI, the surgeon and the anaesthesiologist should be aware of the risk of developing tension pneumothorax due to abdominal insufflation: this complication may anticipate the need of a chest tube or may even require conversion to open surgery.

Antibiotic prophylaxis is indicated in penetrating injuries and in all cases undergoing surgical exploration (thoracotomy/thoracoscopy) [61].

Follow up Diaphragmatic injuries and hernias outcomes are usually related to associated injuries severity and pattern. Reported mortality and morbidity rates ranges between 18–40% and 40–60% respectively. Complications directly related to diaphragmatic repair may be empyema and subphrenic abscess, suture dehiscence and hemidiaphragm paralysis (due to phrenic nerve damage).

Pleural injuries

Pneumothorax and hemothorax

- Tension pneumothorax and massive hemothorax are a life-threatening condition requiring immediate recognition and treatment (LoE moderate, GoR strong)
- Chest tube is the treatment of choice for simple and tension pneumothorax and haemothorax (LoE moderate, GoR strong)
- Hemothorax ≥ 500 ml, in stable patients, should be drained (LoE low, GoR moderate)
- Hemothorax, in traumatic unstable patients, should be drained with large chest tube regardless of the dimension (LoE low, GoR moderate)
- Small pneumothorax (≤ 2 cm) in stable patients can be managed conservatively with at least 24 h of observation (LoE low, GoR moderate)
- Small hemothorax (< 300 ml), in stable patients, can be managed conservatively (LoE low, GoR moderate).
- Operative management is indicated in case of hemodynamic instability from thoracic bleeding or in presence of a blood loss from the chest tube of more than 1,500 cc in 24 h, or more than 200 mL/h over 3 consecutive hours in the absence of other cause(s) of bleeding (LoE low, GoR strong)

Etiology and definition

Pneumothorax (PNX) and Hemothorax (HTX) are respectively an accumulation of air or blood in the pleural cavity. PNX and HTX may be classified into simple, tension or open ones [52]. Post-traumatic pneumomediastinum (PNM) means the accumulation of air within the mediastinum.

In blunt trauma, PNX can occur with rib fracture or dislocation that lacerates the visceral pleura, or with increased alveolar pressure that can cause alveolar rupture [51, 52].

The overall risk of simple or tension PNX in polytrauma patients is 20% and can increase up to 50% in severe chest trauma [22, 27].

HTX is more frequent in penetrating and high energy trauma, injuries to ribs and sternum or flail chest. In modern war setting the HTX can occur in 30% of thoracic trauma [10].

The clinical presentation can be variable. The most important life-threatening emergencies are tension PNX or tension HTX. If suspected they requires emergent management (decompression) even in the prehospital setting [22, 24, 53]. Tension PNX or HTX clinical findings include hemodynamic instability, hypotension, tachycardia, trachea deviation, jugular venous distension, cyanosis, respiratory failure up to cardiac arrest [27].

In other presentations of PNX and HTX, in conscious patient, clinical findings may include dyspnea, sharp pleuritic pain that may radiate to the ipsilateral back or shoulder, increased respiratory rate, pain, but also asymmetric lung expansion, decreased tactile fremitus, hyper or hypo resonant percussion sound, decreased intensity of breath sounds or absent breath sounds [53].

Irrespective of the size/volume, PNX and HTX clinical presentation should drive the diagnostic and therapeutic approach. This concept remains important in cases of occult PNX (OPNX). OPNXs are known to be occult to supine CXR but subsequently detected on cross sectional imaging and/or ultrasonography (EFAST examination). Once diagnosed, OPNX-targeted interventions should be pursued based on the patient's clinical condition, rather than size of the OPNX.

Treatment

Management of PNX is chest tube placement (small bore tubes or a range of pleural catheters (8.5Y16 Fr or 18 Fr to 24 Fr) are acceptable) and it is almost mandatory in the case of positive pressure ventilation, respiratory and/or hemodynamic impairment [2, 22, 24, 53]. Lateral chest tube insertion (4th-6th intercostal space on the anterior or mid axillary line) is the best approach [24, 53]. The use of a small "pigtail" can be feasible in case of small isolated PNX [53]. In urgent situation in absence of available chest tube or in the prehospital care, needle decompression in the 2nd intercostal space midclavicular line or – alternatively – in the 5th intercostal space midaxillary line may represent a treatment option. However, as the needle may displace or not remain effective up to the arrive to the hospital, simple finger thoracostomy may also work effectively to decompress the thoracic cavity in an emergency scenario.

No antibiotics prophylaxis is suggested during this procedure and only patients with penetrating injuries can benefit from antibiotic prophylaxis [55, 57, 58, 61].

No differences exist in the use of negative pleural suction compared with a non-suction drainage system in patients with uncomplicated traumatic pneumothorax, hemothorax or hemo-pneumothorax [52]. A low-pressure suction seems useful in reducing hospital stay and duration of chest tube [24].

Stable patients with previous thoracic surgery or chronic lung disease (i.e. emphysema, pleural inflammation, chronic bronchitis) may be better managed with image-guided catheter drainage to avoid areas of adhesions [22]. If a chest tube is inadvertently placed within an unintended organ (lung, spleen, liver, diaphragm), it should not be immediately removed. Urgent cross-sectional imaging and subsequent multidisciplinary management is essential.

Open PNX should be initially managed with a three-sided occlusive dressing then tube thoracostomy and chest wall defect repair should be performed.

Small (rim up to 3.5 cm at the pulmonary apex) or lately diagnosed small occult PNX can be observed and may not require drainage. However, at least 24 h of observation are required [2, 22, 53].

In patients with spinal cord injury associated with chest trauma and PNX, early chest tube placement is suggested due to the increased risk of respiratory failure, however, multidisciplinary consultation should be always performed [2].

Antibiotic prophylaxis is not indicated in chest tube insertion for blunt or spontaneous PNX, but it is indicated open PNX.

Management of HTX ≥ 500 ml should be considered for drainage and the optimal timing for drainage is within 72 h [1, 22, 24, 53]. Hemothorax need for a large bore intercostal catheter (28Fr-40Fr, no differences were found in catheter larger than 32Fr) [24]. Massive HTX (rapid blood loss greater than 1500mLs into the chest cavity) needs for an early recognition, decompression, and blood restoration. Smaller bore tube can give less pain but can leave residual hemothorax with increased risk factor for development of empyema for blood infection, especially in case of residual hemothorax > 300 cc [22, 28]. No data exist about the safe quantity of residual blood, patient and pulmonary conditions should be always considered in directing the subsequent actions. As a result, complete evacuation of any HTX should be ensured. In cases of penetrating trauma to the central chest with residual HTX despite chest tube drainage, the clinician must rule out a concurrent cardiac (typically right sided) injury with associated pericardium laceration and decompression into the ipsilateral hemithorax.

Small HTX could be managed without drainage initially in a stable patient with a repeat CXR to monitor progression for up to 24 h [2, 22].

Few data exist about the use of thrombolytic agents in pleural cavity; however, it seems related with a delay in resolution, increased cost, and increased complications in trauma patients [22, 55, 56].

Continuous low-pressure suction, after penetrating chest trauma, can helps to evacuate blood, increase lung expansion, reduce empyema, and prevent clotted hemothorax [59, 60].

Antibiotic prophylaxis is indicated in draining retained HTX [60]

In persistent thoracic hemorrhage with hemodynamic stability endovascular procedures should be considered. Video-assisted thoracic surgery or occasionally open surgery may be required in treating residual HTX or bleedings in stable patients [22].

Surgery should be considered in case of hemodynamic instability and active intrathoracic bleeding (more than 1500 mL of blood or more than 200 mL/h over 3 consecutive hours without other causes of bleeding) [1, 22, 24, 53]. However, chest tube output alone can be misleading so close clinical monitoring is mandatory [22, 53]. Other indications for operative management are large retained hemothorax, air leak and suspicion of relevant injuries such as diaphragm [22].

In case of massive torso hemorrhage resuscitative endovascular balloon occlusion of the aorta (REBOA) may be indicated before opening the chest for damage control surgery (DCS) [2, 53]. However, REBOA use is generally not indicated in the presence of chest trauma with major intrathoracic hemorrhage and/or pericardial tamponade.

Antibiotic prophylaxis is indicated in all patients undergone to operative management and in drainage of retained HTX.

Management of post-traumatic PNM is generally non-operative whenever not associated to other lesions. Its treatment generally derives from the management of the eventual underlying causative event. Whenever PNM is due to airway or esophageal injuries its treatment is the treatment of the originating lesions.

Airway/lung injuries

Lung parenchymal injuries

- Initial management should focus on stabilizing the patient's respiratory and circulatory status, including oxygen supplementation and, if necessary, mechanical ventilation (LoE moderate, GoR strong).
- Effective analgesia facilitates breathing and coughing efforts, reducing the risk of pneumonia and atelectasis (LoE moderate, GoR strong).
- Most lung parenchymal injuries can be managed conservatively, with surgery reserved for cases of persistent air leak, hemodynamic instability due to haemorrhage, or associated thoracic injuries requiring operative intervention (LoE moderate, GoR moderate).
- Provide supplemental oxygen and/or mechanical ventilation whenever required, minimizing ventilation-related airway or lung injury (LoE moderate, GoR moderate).
- Lung-sparing surgical technique to preserve pulmonary tissue and function should be implemented whenever surgical intervention is necessary (LoE moderate, GoR moderate).
- Early respiratory physiotherapy and mobilization should be encouraged to enhance lung recovery and prevent complications (LoE moderate, GoR strong).
- Scheduled follow-up should be recommended with chest imaging to evaluate the resolution of parenchymal moderate to severe injuries and evaluate eventual chronic complications (LoE moderate, GoR moderate).
- Pulmonary function tests (PFTs) are suggested to assess long-term respiratory status and guide rehabilitation efforts, particularly for patients with extensive injuries or those experiencing prolonged recovery (LoE moderate, GoR moderate).

Management: The primary aim in managing lung injuries in trauma patients is to ensure sufficient oxygenation, ventilation, and airway safety, particularly during the initial treatment phases [64]. Research indicates that adding sigh breaths to mechanical ventilation for trauma patients doesn't significantly extend ventilator-free days, though it may enhance clinical outcomes and is generally well-tolerated [65].

In the management of patients requiring supplemental oxygen and mechanical ventilation, careful monitoring is necessary to optimize patient outcomes. The use of a high fraction of inspired oxygen (FiO2) can lead to oxygen toxicity, which may also damage the lung parenchyma during the acute phase of lung injury [94]. Therefore, the application of supplemental oxygen should carefully balance the objectives of ensuring optimal oxygenation against the risk of ventilator-induced lung injury. In the realm of mechanical ventilation, particularly for patients with ARDS, protective ventilation strategies such as low tidal volume and pressure limitation are beneficial [47, 94]. Achieving personalized and lung-protective ventilation is possible through a physiological closed-loop control structure for mechanical ventilation, which supports adequate gas exchange while adhering to evidence-based components of lung protective ventilation [95]. However, it's important to note that spontaneous respiratory effort during mechanical ventilation can potentially cause or exacerbate acute lung injury, especially in severe ARDS cases [95, 96]. Therefore, the prompt adjustment of ventilator settings to meet the variable needs of patients is crucial in ensuring the provision of personalized and protective ventilation [95].

For severe traumatic lung injuries, veno-venous extracorporeal membrane oxygenation (ECMO) presents a viable option for cases where traditional ventilation methods fail, with a reported survival rate of 68.4% [66, 67]. The impact of non-invasive ventilation on adults with blunt chest injuries remains uncertain, highlighting a need for more studies to find the best approach for respiratory care [67, 68]. Protective ventilation can lead to better outcomes in thoracic trauma with ARDS, decreasing the duration of mechanical ventilation and improving the oxygenation index [69]. A proactive respiratory protocol for trauma patients showed to reduce hospital stays and prevent unplanned ICU admissions [70]. Effective analgesia plays a crucial role in the management of trauma patients, particularly those with significant thoracic injuries, as it is essential for maintaining efficient respiratory function [71] with improvement in respiratory rates, oxygen saturation, and peak expiratory flow rate [72]. Severe pain, in fact, may hinder deep breathing and coughing, contributing to the retention of secretions, atelectasis, and infections. Conversely, the overuse of opiates may worsen respiration [73]. Proper analgesic treatment has been proven to mitigate or prevent pulmonary complications such as pneumonia, atelectasis, and ARDS, with a reduction in ICU and hospital stays and mortality [72, 74]. Despite some limitations, epidural analgesia and multimodal analgesia are conditionally recommended for patients with blunt thoracic trauma, with specific attention to patient preferences for pain management [75].

Conservative management of lung parenchymal injuries primarily relies on supportive care, addressing potential acute or delayed respiratory complications such as pneumonia or ARDS [74, 75]. Key strategies to enhance pulmonary function and facilitate gas exchange encompass balanced fluid resuscitation, positioning therapy, and effective pain management [77]. Surgical intervention is warranted in situations of active hemorrhage and significant air leaks, often resulting from penetrating injuries, or to re-establish hemodynamic stability in cases of massive hemothorax or to remove retained HTX blood clots [74, 75, 77, 78]. Additionally, damage control techniques, including temporary hilar clamping and chest packing, have been recognized as effective methods to enhance survival in patients suffering from severe chest trauma [79, 80].

The management of traumatic pulmonary injuries in damage control focuses on achieving hemodynamic stability, controlling hemorrhage, and preserving lung tissue. Aortic occlusion is critical for hemodynamic support. This can be accomplished through emergency thoracotomy for aortic clamping or by using REBOA in Zone I. These interventions should be performed swiftly, alongside massive transfusion protocols and tranexamic acid administration, without delaying immediate surgical action.

Surgical access is determined by the injury's location and the surgeon's experience. Anterolateral thoracotomy or median sternotomy are common approaches to the thoracic cavity and major vascular structures.

Once hemorrhage is controlled peripheral injuries can be managed with less invasive techniques like tractotomy, which opens the wound tract to control bleeding and minimize lung damage. More severe central injuries may necessitate lobectomy or pneumonectomy. However, these procedures are typically deferred in damage control settings due to the high risk of mortality. In such cases, temporary clamping of the pulmonary hilum allows for stabilization before definitive resection. Selective ligation of the bleeding vessel should be prioritized over block ligation.

After initial damage control, the thoracic cavity may be temporarily closed using thoracic wall packing or negative pressure systems to ensure hemostasis and allow for ongoing monitoring. Thoracostomy tubes are indicated to early detect any recurrent bleeding or respiratory complications. Lung sparing surgical efforts are linked to improved survival rates [74]. Moreover major lung resections (i.e. lobectomies and pneumonectomies), are associated with prolonged hospital stays, increased morbidity, and mortality, if compared to less extensive procedures like wedge resections [78, 81]. Reported mortality after trauma pneumonectomy is to be as high as 100%.

Pulmonary hilum injuries: Lesions involving the pulmonary hilum are rare but represent a critical challenge due to the potential for massive hemorrhage and rapid hemodynamic deterioration. Prompt surgical intervention is typically required, with median sternotomy as the preferred approach for exposure.

Surgical Access: Proximal vascular control should be achieved. In cases where primary repair is not feasible, ligation of the hilum may be necessary, although this carries a significant risk of morbidity and mortality.

Techniques for Repair: Injuries to the pulmonary arteries or veins within the hilum often require meticulous dissection to isolate the vessels for repair. Primary suturing is the preferred method when feasible. If vessel repair is not achievable, a pneumonectomy may be indicated, acknowledging the associated high mortality rate.

Damage control approach: For unstable patients, temporary packing of the mediastinum with/without negative pressure dressing may be necessary to control hemorrhage and stabilize the patient before definitive repair. A staged approach with subsequent re-exploration is often employed.

Postoperative monitoring: Close monitoring in the intensive care unit is essential. Follow-up imaging with contrast-enhanced CT is recommended to evaluate the integrity of the repair and identify any residual or recurrent bleeding. A multidisciplinary approach involving trauma, thoracic, and vascular specialists is crucial for managing these complex injuries.

Antibiotic prophylaxis is indicated in penetrating injuries and in all cases undergoing surgical exploration (thoracotomy/thoracoscopy) [61].

Rehabilitation and Follow-Up: The significance of early mobilization in both preventing complications and fostering lung recovery following lung parenchymal trauma is well-documented. Physiotherapists globally employ strategies such as active coughing, body positioning, deep breathing exercises, and, notably, early mobilization to mitigate the adverse effects associated with major chest trauma [82]. Research further underscores the benefits of admitting patients to early pulmonary rehabilitation units, where outcomes are favorable across the board, irrespective of breathing status, highlighting the positive influence of early rehabilitation on patient recovery. This approach is not only beneficial in the context of lung trauma but extends to enhancing functional parameters like the FAM-Index, Barthel-Index, and six-minute walking distance in those severely affected by lung injuries. [82, 83].

Long-Term Management: Advancements in long-term imaging techniques, such as the routine use of CT-scan, have led to changes in patient management, potentially improving patient outcomes [84–86]. Pulmonary Function Tests (PFTs) are indispensable in the diagnosis and assessment of respiratory diseases in patients who have suffered thoracic injuries due to trauma, offering critical insights into the extent and nature of the damage [87]. Notably, research focusing on active duty service members with thoracic injuries reveals a pronounced increase in the incidence of abnormal PFT results when compared to a representative population, underscoring the lasting impact of thoracic injuries on lung functionality [87]. Pulmonary rehabilitation (PR) has been associated with improved peak cough flow, maximal inspiratory pressure, and diaphragmatic mobility, thereby affirming the role of PR in enhancing respiratory function among trauma patients [88]. Moreover, the geriatric demographic, after blunt thoracic trauma, exhibits a higher propensity for developing lung failure, highlighting the critical need for specialized respiratory assessments and rehabilitative strategies tailored to older patients [89].

Airways (tracheal and bronchial injuries)

- In cases of significant tracheal or bronchial injury, the main initial focus should be on securing the compromised airway (LoE moderate, GoR strong).
- Careful intubation, potentially under bronchoscopy guidance, is necessary to ensure ventilation without exacerbating the underlying injury (LoE moderate, GoR strong).
- Small, uncomplicated tracheobronchial injuries may heal with conservative management, including close monitoring and infection control (LoE moderate, GoR moderate).
- Surgical repair should be Indicated for large ruptures, significant air leaks, or injuries associated with oesophageal injury, vascular damage, or persistent pneumothorax despite chest tube drainage. The timing of surgery should be based on the patient's overall stability and presence of concomitant injuries (LoE moderate, GoR strong).
- Continued ventilatory support may be necessary post-operatively. Weaning protocols should be initiated as soon as clinically feasible (LoE moderate, GoR moderate).
- Prophylactic antibiotics may be considered to prevent infection, particularly in the setting of surgical repair or delayed drainage of haemothorax (LoE moderate, GoR moderate).
- Scheduled follow-up is essential for monitoring healing and identifying any delayed complications (LoE moderate, GoR strong).

Initial management: airway management plays a pivotal role in ensuring patient safety [90, 91]. Tracheal and bronchial injury are associated with high mortality rates. Prompt diagnosis and careful securing of the airway are mandatory [92, 93].

Non-operative management: In the management of tracheobronchial injuries conservative management compared to surgical intervention revealed that, despite surgical treatment enabling shorter stays in both the ICU and hospital, the outcomes of the two approaches are largely comparable. Furthermore, minimally invasive techniques, such as stent placement, showed good results. These techniques have showed to be effective also in those patients considered poor surgical candidates [97–99].

Surgical management: The management of tracheobronchial injuries requires surgical approach in presence of large ruptures, significant and persistent air leaks, or injuries associated with esophageal injury, vascular damage, or persistent pneumothorax despite chest tube drainage. Key surgical strategies emphasize minimal debridement, maintaining tension-free connections, blood supply preservation, and tracheostomy. Early primary repair, ideally within the first 24 h, is essential to ensure airway patency, minimize scarring, and reduce complications such as stenosis or fistula formation. For concurrent esophageal and airway damage, employing an interposition muscle flap is essential, with early repair critical to avoid airway stenosis [34, 100]. Early diagnosis and intervention are vital [101]. Tracheostomy is reserved for severe laryngeal injuries or destructive tracheal injuries where early reconstruction is not feasible. Multidisciplinary approach in specialized centers may warrant better outcomes [46].

Antibiotic prophylaxis is indicated in penetrating injuries and in all cases undergoing surgical exploration (thoracotomy/thoracoscopy) [61].

Rehabilitation and Follow-Up: Continued ventilatory support may be necessary post-operatively, where tracheostomy plays a crucial role in facilitating respiratory care and the process of weaning from mechanical ventilatory support [46, 102]. This is especially pertinent for patients with severe brain injury, who may require long-term mechanical ventilation; in such cases, flexible bronchoscopy can guide successful tracheostomy weaning in the presence of late tracheostomy complications [103].

Additionally, early tracheotomy has been shown to lead to improved outcomes for patients who may require prolonged intubation [104]. As such, it is recommended that weaning protocols be initiated as soon as clinically feasible. A nurse-led weaning protocol from tracheostomy has been proven to be feasible and safe, offering a high rate of successful weaning from tracheostomy [104, 105]. Moreover, an early tracheostomy may facilitate a shorter weaning process by reducing the work of breathing and decreasing the risks associated with prolonged intubation [106].

Long-Term Management: airway endoscopies are indicated for evaluate injuries healing, particularly those managed conservatively. They are crucial in the discovering and planning the eventual treatment of late sequelae as stenosis needing planned delayed surgical treatments [107].

Vascular

- Hemodynamically unstable patients with suspected vascular injuries should be transported to the OR immediately for open exploration. Hybrid OR is a viable alternative where both open and endovascular techniques can be implemented at once (LoE moderate, GoR strong).
- In hemodynamically stable patients the initial approach to thoracic arterial injuries, should be minimally invasive endovascular, whenever feasible (LoE strong, GoR moderate).
- Traditional surgical approaches should be reserved for those scenarios, such as ongoing haemorrhage unresponsive to conservative measures, necessitating immediate intervention (LoE strong, GoR strong).
- A structured follow-up regimen, incorporating surveillance imaging to monitor repair durability and identify late-onset complications is suggested (LoE moderate, GoR moderate).

Minimally invasive management: endovascular management of thoracic vascular lesions is highly preferrable and effective for their reduced morbidity, smaller incisions and decreased operating times [109–111]. Thoracic endovascular aortic repair (TEVAR) is now the recommended first-line treatment for more severe traumatic aortic injuries (grades II–IV), largely supplanting open surgery due to its minimally invasive nature and superior outcomes [108].

Surgical management: in presence of hemodynamic instability or in facing severe venous injuries not amenable of conservative or endovascular repair, open surgical approach should be attempted even if it brings higher morbidity and mortality.

Antibiotic prophylaxis is indicated in penetrating injuries and in all cases undergoing surgical exploration (thoracotomy/thoracoscopy). Endovascular access is not an indication to antibiotic prophylaxis.

Follow-Up: Evidence-based follow-up regimens are not yet described and universally defined. Each facility based on local resources and protocol should set up a follow-up for traumatic vascular injuries, relying on CT and CTA. A suggested protocol may be to follow-up with a contrast enhanced CT scan at 24 h, after 1 week and after 3, 6 and 12 months. Literature reports a significant issue with loss to follow-up. In fact, there is a scarcity of follow-up data available to forecast the long-term outcomes of employing thoracic endovascular aortic repair (TEVAR) for these injuries [114, 115]. The early involvement of specialized surgeons can be a potential solution to overcome the reported discrepancies.

Notes on venous injuries:

Venous injuries to the thoracic vessels are rare, in blunt trauma but are very common in penetrating trauma, especially stab wounds and often necessitate open surgical repair. Every care must be made to avoid air embolism. Mediastinal hematomas, indicative of possible vascular injuries, should be radiologically assessed from multiple angles to identify any vascular injuries.

Azygos vein injuries, although rare, should be considered in presence of spinal fractures. Access for repair typically involves a right thoracotomy.

Superior vena cava injuries are exceptionally rare and often fatal, largely occurring in cases of penetrating trauma. Blunt trauma-related SVC injuries typically occur near its entry into the right atrium, often accompanied by right atrium injuries. Proximal injuries often necessitate sternotomy for access, while distal injuries may be approached via a cervical incision.

Pulmonary vein injuries due to blunt trauma are rare, usually presenting alongside severe injuries to the heart, bronchi, pericardium, and aorta. These injuries can lead to significant clinical signs such as hypotension and massive hemothorax. Depending on their location relative to the pericardium, pulmonary vein injuries may even cause hemopericardium, potentially with cardiac tamponade, or hemothorax [112, 113]

Lung post-traumatic disease / dysfunction

Lung contusion

- Focus on oxygen supplementation to maintain adequate oxygenation and analgesia to facilitate deep breathing and coughing (LoE strong, GoR strong).
- Apply non-invasive (NIV) or mechanical ventilation in cases of respiratory failure with careful monitoring

to avoid further lung injury (LoE moderate, GoR strong).

Initial management: Oxygen supplementation plays a vital role in ensuring sufficient oxygen levels in patients suffering from pulmonary contusions [116–118]. However, it's critical to avoid excessive oxygen use to prevent hyperoxia, which can increase the risk of lung complications and death [119]. Effective pain management is crucial to enable patients to breathe deeply and cough, which helps prevent pneumonia and ARDS. Careful fluid administration is indicated in the event of lung contusion.

Non-invasive ventilation (NIV) has proven more effective for patients with blunt chest trauma and pulmonary contusions than traditional respiratory support methods. Lastly lung-protective ventilation techniques and optimal patient positioning are also key in managing pulmonary contusions [68, 119].

Antibiotic prophylaxis: Antibiotic prophylaxis in lung contusion has been a topic of debate over the years. The routine use of antibiotics prophylaxis is not indicated for lung contusions in healthy patients without other penetrating injuries requiring chest tube placement [61].

Necrotizing lung infections

- High-resolution CT scan is indicated for detailed assessment (LoE strong, GoR strong).
- Blood, sputum, and, if accessible, pleural samples should be obtained to identify causative organisms (LoE strong, GoR strong).
- Broad-spectrum antibiotics should be started as soon as possible and refined based on culture results (LoE moderate, GoR strong).
- Surgical debridement is indicated in case of medical management failure, to remove necrotic tissue and to control infection source (LoE moderate, GoR strong).

Initial management: high-resolution CT scans are crucial for diagnosing necrotizing pneumonia, revealing key signs such as pleural effusions, necrosis, and detecting complications like bronchopleural fistulae [120]. Cultures from blood, sputum, and pleural fluid, along with CT-guided percutaneous transthoracic needle biopsies (PTNBs), identify the causative pathogens in 30–40% of cases, guiding treatment [121]. Despite lung ultrasound's usefulness, CT is indispensable for spotting complex issues PTNBs have a low complication rate and are crucial for diagnosis and treatment, with bronchoscopy used for further clarification in uncertain cases [120–122].

Antibiotic therapy: pathogens like Hemophilus influenzae, Klebsiella pneumoniae, and multidrug resistant staphylococcus aureus (MRSA) are common culprits of post-traumatic necrotizing lung infections [123, 124]. Early administration of adequate antibiotics is generally effective in resolving the disease [124]. Culture-based treatment approaches may match the efficacy of immediate treatments with targeted use of culture results enhancing treatment accuracy and combating antibiotic resistance [124–127]. Nebulized antibiotics may offer benefits without increased renal toxicity in severe cases [128].

Surgical management: recent findings highlight that optimal medical management may suffice for severe necrotizing pneumonia, with surgical debridement reserved only for specific cases whenever the infection evolves into abscesses/extended tissue necrosis or empyema not amenable of conservative treatment. Post-surgery antibiotic therapy duration of at least three to seven days is recommended according to clinical, laboratory and radiological evaluation [129–131].

Pseudocyst

- Post-traumatic lung cysts and pseudocysts should be managed conservatively with attention in monitoring for changes in size or symptoms (LoE strong, GoR strong).
- Surgical management is indicated in the case of infection or severe bleeding or conservative management failure (LoE strong, GoR strong).
- Radiological follow-up is suggested until the complete resolution of the lung cysts and pseudocysts (LoE moderate, GoR moderate).

Initial management: Traumatic pulmonary pseudocysts, a rare complication of blunt chest trauma primarily seen in children and young adults, manifest symptoms such as hemoptysis and persistent pain. Diagnosis hinges on a history of trauma and radiological assessments, including chest radiographs and CT scans, with the latter being particularly advantageous for early detection and differential diagnosis due to its higher sensitivity [132, 133].

Non-operative management: Conservative treatment generally suffices for managing these pseudocysts, as they often resolve spontaneously without complications. Nevertheless, vigilant monitoring is imperative to identify and address potential life-threatening complications from cyst rupture.

Surgical management: Surgical intervention might be required in exceptional cases, particularly when complications like infection or severe bleeding occur, or if the patient is already undergoing a thoracotomy for another reason [134, 135].

Antibiotic prophylaxis: is indicated only in case of surgical intervention (thoracotomy/thoracoscopy).

Follow-Up: It's recommended that follow-up imaging is continued until the pseudocyst has completely resolved, which typically happens within a few weeks to months, to closely watch for any complications that may arise [132, 133].

Empyema

- Pleural fluid analysis is suggested to confirm diagnosis with pH, glucose, LDH and cultures evaluation (LoE strong, GoR strong).
- Broad spectrum antimicrobial therapy must be initiate as soon as possible with subsequent adjustment based on the cultures results (LoE strong, GoR strong).
- Chest tube insertion is indicated for fluid drainage (LoE strong, GoR strong).
- Operative management is indicated in case of conservative treatment failure or whenever the clinical conditions are critical due to the intra-thoracic infection (LoE moderate, GoR strong).

Initial management: Post-traumatic pulmonary empyema has a 32.8% cumulative incidence among trauma patients. Diagnosis should be based on clinical suspicion, confirmed by imaging techniques like CT pulmonary angiogram (CTPA). Samples collection should be performed through thoracentesis, to confirm the diagnosis and guide antimicrobial therapy [136].

Non-operative management: Initial management is critical, involving appropriate antibiotic therapy and drainage with tube thoracostomy and eventual endoscopic conservative treatment. Intra-pleural fibrinolytic therapy may help in treating loculated empyema.

Surgical management: video-assisted thoracoscopy, emergency open window thoracostomy or thoracotomy with decortication are indicated in the case of conservative management failure of in patients where clinical conditions are critical due to the thoracic infection.

Antibiotic therapy: For community-acquired empyema should be performed a therapy with a parenteral second or third generation cephalosporin (ceftriaxone) with metronidazole or parenteral aminopenicillin with β-lactamase inhibitor (ampicillin/sulbactam). For hospital-acquired or postprocedural empyema antibiotics active against methicillin-resistant Staphylococcus aureus and Pseudomonas aeruginosa. Consider continuing anaerobic coverage empirically when the anaerobic cultures are negative. There is no role for intrapleural administration of antibiotics [137].

Rehabilitation and Follow-Up: Follow-up care, essential for managing complications, it includes dedicated pulmonary function monitoring after discharge [138–141]

Pulmonary embolism, gas and fat embolism and Post-traumatic pulmonary artery thrombosis

*Pulmonary embolism (*PE) is a known complication following major trauma, including thoracic injuries, often leading to severe morbidity and mortality. It incidence in trauma patients ranges from 0.27% to 0.619%, with thoracic trauma being a significant contributing factor [142, 143]. PE may occur as early as within a few hours post-injury. Early PE is often due to hypercoagulable states induced by trauma [144, 145].

Key risk factors for PE after trauma include obesity, advanced age, severe trauma (high Injury Severity Score), lower extremity fractures, pelvic fractures, and the need for ICU admission [146].

Early detection and treatment are critical in improving outcomes. Systematic screening in ICU settings can help in early diagnosis and better management of PE in trauma patients [147].

Gas embolism (GE) is a rare but potentially fatal complication of thoracic trauma, characterized by the entry of air or gas into the vascular system, which can lead to severe circulatory and cerebral events [148, 149]. Air into circulatory bloodstream may derive from direct thoracic organs injuries: alveolar rupture, allowing air to enter the pulmonary veins and then the systemic circulation, tracheobronchial injuries that can directly introduce air into the bloodstream, and pneumothorax especially in presence of concomitant lung injury. GE may also derive from iatrogenic causes as central line insertion, positive pressure ventilation, and chest tube placement can inadvertently introduce air into the vascular system.

The symptoms of GE can vary depending on the size and location of the emboli. It presents most commonly as catastrophic circulatory failure as a result of air emboli within the chambers of the heart and coronary arteries, though isolated neurological sequalae has been reported.

Other presentation may include respiratory, cardiovascular and neurological symptoms.

Fat embolism syndrome (FES) is rare, occurring in 0.5–11% of cases [150]. Thoracic trauma often occurs in conjunction with bone fractures and soft tissue injury that represent common sources of fat globules releasing into the bloodstream [151].

FES typically occurs within 24–72 h after the trauma and includes a triad of symptoms: Respiratory distress, Neurological symptoms (confusion, drowsiness, seizures, and focal neurological deficits), Petechial rash that typically appears on the upper body, including the neck, shoulders, and conjunctiva, due to emboli traveling to the skin [152].

Post-traumatic pulmonary artery thrombosis is a rare but serious condition where a blood clot forms in the pulmonary artery following a traumatic injury. This condition can be life-threatening. The development of clots in situ in the pulmonary arteries, rather than as emboli from elsewhere, suggests a distinct pathophysiological process involving local thrombosis due to trauma-induced endothelial damage [153].

Symptoms and signs may be shortness of breath, chest pain that may be exacerbated by deep breathing or coughing, cyanosis, tachycardia and hypotension.

Management:

To prevent Pulmonary embolism early initiation of venous thromboembolism (VTE) prophylaxis is crucial. VTE prophylaxis initiation within 48 h post-injury is safe and effectively reduces thromboembolic events without increasing the risk of bleeding.

Anticoagulation is the mainstay of treatment for PE. Low-molecular-weight heparin, unfractionated heparin, or fondaparinux are commonly used [154].

For massive PE, thrombolytic therapy or rarely surgical embolectomy may be required. Thrombolytic therapy however is associated with increased bleeding risks. For massive PE, surgical embolectomy or catheter-directed thrombolysis may considered in those cases where anticoagulation is contraindicated [155]. In cases where anticoagulants are contraindicated, mechanical prophylaxis techniques such as compression devices or inferior vena cava (IVC) filters may help in preventing thrombosis formation or migration.

Gas embolism management is aimed at removing the air bubbles and supporting vital organ function. Positioning the patient in the left lateral decubitus and Trendelenburg position may trap air in the right heart and prevent it from entering the pulmonary circulation. Animal studies, however, suggest that body positioning does not alter the hemodynamic status of a patient with an air embolus [25, 156]. Administering 100% oxygen to promote nitrogen washout and reduce bubble size. Intravenous fluids and vasopressors may be needed to maintain blood pressure and cardiac output Any source of ongoing air entry should be identified and controlled, such as sealing chest wounds or correcting line placements.

Historically immediate thoracotomy and hilar clamping of the affected side has been suggested to remove the source of further air entrapment, but selective lung isolation and differential ventilation may preclude the necessity for thoracotomy in those settings allowing for it. [25, 149]

Hyperbaric oxygen therapy is recommended for managing cerebral air embolism due to its effectiveness in reducing air emboli and improving neurological patient outcomes [149].

The positive effects of hyperbaric oxygen therapy in trauma are limited to case reports and are most apparent within therapy is initiated 6 h though there is evidence of some benefit if initiated within 30 h [157].

Fat embolism syndrome (FES) is primarily supportive as specific medical therapy for fat embolism and FES does not exist. Current care is directed at controlling and supporting respiratory and hemodynamic derangements. Management consists in oxygen therapy to address hypoxia, ventilatory support for severe respiratory distress or failure, Fluid Management to maintain hemodynamic stability and prevent hypovolemia. Corticosteroids have been used, though their efficacy is still debated even if they seem to reduce mortality [158]. Preventive measures focus on early stabilization of fractures of long-bone fractures is recommended to minimize bone marrow embolization into the venous system [159]. Rigid fixation within 24 h has been shown to yield a fivefold reduction in the incidence of FES [160].

Post-traumatic pulmonary artery thrombosis (PTPAT) Effective management involves a combination of anticoagulation (commonly heparin and warfarin), thrombolytic therapy (plasminogen activator (tPA)), and sometimes surgical intervention, alongside supportive measures management includes Endovascular techniques are increasingly used for managing traumatic vascular injuries, including PTPAT. These techniques are associated with reduced operative blood loss and are feasible with commonly available tools [161].

Cardiorespiratory failure or severe respiratory dysfunction

- Severe Hemodynamic instability and/or severe respiratory dysfunction should be promptly identified and treated according to the patient's general conditions and available life support facilities (LoE strong, GoR strong).
- When conventional treatment is ineffective in treating cardiorespiratory failure, extracorporeal membrane oxygenation (ECMO) may be considered (LoE strong, GoR strong).
- ECMO use is individualized to the patient's needs; veno-arterial (VA) ECMO suppports both heart and lungs function, veno-venous (VV) ECMO is used to support acute respiratory distress/failure (LoE strong, GoR strong).
- Anticoagulation may be omitted for some hours or days only if strictly needed (LoE moderate, GoR strong).

Please remember the following information regarding ECMO:

Initial management: Pulmonary dysfunction resulting from thoracic trauma is the most common reason for utilizing extracorporeal membrane oxygenation (ECMO). The choice of ECMO mode should be based on the patient's condition. Patients with respiratory failure due to severe hypoxia should be considered for venovenous

(VV) ECMO. Those with refractory cardiac dysfunction or cardiogenic shock should receive venous-arterial (VA) ECMO. Starting ECMO early (within 7 days of mechanical ventilation) is favored. Before initiating ECMO, conventional treatments for pulmonary failure and/or cardiac failure should be attempted. ECMO should be initiated before the patient's illness becomes irreversible to avoid futility. [64, 162–167]

Surgical management: VV-ECMO can be performed using a dual-lumen single cannula or two separate cannulas. A single dual-lumen cannula is placed in the right internal jugular vein. In contrast, dual cannulas are typically placed in the jugular and femoral veins, with the jugular cannula mainly used as the return line. The placement of cannulas should be guided by peripheral ultrasound and echocardiography. The return port should be directed toward the tricuspid valve in the right atrium for single dual-lumen cannulation. In the case of dual cannulation, the cannulas should be positioned far enough to avoid recirculation (i.e., oxygenated blood returning directly to the ECMO circuit rather than to the patient). In the case of VA ECMO, cannulation is achieved through the femoral vein and artery. The venous cannula is directed to the vena cava, and the arterial cannula is guided up to the proximal iliac artery. If there is a severely depressed left ventricular function with no opening of the aortic valve and no pulsatile arterial pressure line, care must be taken to avoid blood stasis and increased afterload. In such cases, another device, such as Impella or an intra-aortic balloon pump, is needed to unload the left ventricle and prevent thrombosis [168].

Contraindications: Absolute contraindications include irreversible injury or comorbid conditions such as terminal malignancy and vascular disease or injury that prevents successful ECMO placement. Relative contraindications include mechanical ventilation lasting over 7 days before initiating therapy, chronic end-stage organ dysfunction without transplant eligibility, advanced age, or severe frailty. Relative contraindications also include brain injury, bleeding, and intolerance to anticoagulation [166, 168]

*Anticoagulation Management:*During ECMO, systemic anticoagulation is used. Different monitoring tests, such as partial thromboplastin time, activated clotting time, and anti-Xa, are used with varying therapeutic targets across different centers. Anticoagulation may be stopped temporarily while monitoring for clot formation in the oxygenator [166, 168]

*Follow-Up:*Physicians should focus on preventing complications related to ECMO. Approximately 80% of trauma patients requiring ECMO will experience at least one complication, such as self-limiting arrhythmia, bleeding at the cannulation site, brain or gastrointestinal hemorrhages, embolic events, or sepsis. For patients on VA ECMO, it is crucial to prevent arterial limb ischemia. Providing distal perfusion using an antegrade arterial catheter and, in suitable patients, surgical cannulation of the arterial site through the interposition of a dacron graft can help prevent limb ischemia. Daily ECMO monitoring should involve radiographic assessment of the cannulae position and direct inspection to detect early fibrin deposition in the oxygenator, tubing, and cannulas [67].

Conclusion

Chest trauma management must be multidisciplinary. Emergency and trauma systems should be organized and prepared to face all its aspects to prevent underestimation of its evolution. Patients should be strictly monitored and followed to prevent delayed deterioration and complications. Secondary centralization algorithms must be defined and implemented to warrant the best treatment for all patients that may be initially admitted in spoke hospitals with reduced resource level.

Abbreviations

WSES	World Society of Emergency Surgery
AASz	American Association for the Surgery of Trauma
RCT	Randomized controlled trials
LoE	Level of evidence
GoR	Grade of recommendation ()
ARDS	Acute respiratory distress syndrome ()
CXR	Chest X-ray ()
DI	Diaphragmatic injuries ()
PNX	Pneumothorax
HTX	Hemothorax
BTAI	Blunt thoracic aortic injury
US	Ultrasound
CT	Contrast enhanced computed tomography
CTA	CT angiography
AI	Artificial intelligence
FC	Flail chest
NOM	Non-operative management
ICU	Intensive care unit
LOS	Length of stay
TBI	Traumatic brain injury
SS	Surgical stabilization
VATS	Video assisted thoracoscopy
PNM	Pneumomediastinum
OPNX	Occult PNX
DCS	Damage control surgery
REBOA	Resuscitative endovascular balloon occlusion of the aorta
FiO2	Fraction of inspired oxygen
ECMO	Extracorporeal membrane oxygenation
PFTs	Pulmonary Function Tests
PR	Pulmonary rehabilitation
TEVAR	Thoracic endovascular aortic repair
MRSA	Multidrug resistant staphylococcus aureus
CTPA	CT pulmonary angiogram
PE	Pulmonary embolism
GE	Gas embolism
FES	Fat embolism syndrome
VTE	Venous thromboembolism
FES	Fat embolism syndrome
PTPATT	Post-traumatic pulmonary artery thrombosis
VV	Venovenous
VA	Venous-arterial

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