The role of video-assisted thoracoscopic surgery in blunt and penetrating chest trauma: timing of intervention and clinical outcomes—a review of the current evidence

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Contributions: (I) Conception and design: AJ Patel; (II) Administrative support: All authors; (III) Provision of study materials or patients: All authors; (IV) Collection and assembly of data: AJ Patel; (V) Data analysis and interpretation: All authors; (VI) Manuscript writing: All authors; (VII) Final approval of manuscript: All authors.

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Abstract: Video-assisted thoracoscopic surgery (VATS) has emerged as a valuable tool in the management of both blunt and penetrating chest trauma. Indications for VATS include retained haemothorax, persistent pneumothorax, and diagnostic clarification of suspected intrathoracic injuries. Compared to open thoracotomy, VATS offers reduced postoperative pain, shorter hospital stay, and decreased infection rates, particularly when performed early, ideally within 72 hours of injury. In cases of blunt trauma, early VATS enables effective evacuation of clotted blood, reduces ventilator days, and minimizes complications such as empyema or fibrothorax. In penetrating trauma, VATS allows for minimally invasive inspection and management of diaphragmatic, pulmonary, and pleural injuries in haemodynamically stable patients, with early intervention showing superior outcomes. The role of VATS in rib fracture stabilization is expanding, with data supporting its feasibility and effectiveness in anatomically challenging cases, such as posterior or subscapular fractures. Thoracoscopic-assisted fixation may offer comparable or superior outcomes to open techniques, particularly when novel devices like memory alloy plates are used. While early surgical stabilization of rib fractures (SSRF) is generally favoured, recent evidence suggests that delayed SSRF does not necessarily worsen clinical outcomes, allowing prioritization of other life-threatening injuries in polytrauma scenarios. Despite promising retrospective and cohort data, there remains a lack of randomized controlled trials (RCTs) to definitively guide timing and patient selection for VATS in trauma. Standardized protocols for integrating VATS into trauma algorithms are needed. This review synthesizes current evidence and proposes pragmatic recommendations for the timing and indications of VATS in modern thoracic trauma care.

Keywords: Video-assisted thoracoscopic surgery (VATS); thoracic trauma; rib fixation; blunt trauma; penetrating trauma

Received: 20 July 2025; Accepted: 06 November 2025; Published online: 19 December 2025.
doi: 10.21037/vats-25-32
View this article at: https://dx.doi.org/10.21037/vats-25-32

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Introduction

Chest trauma accounts for approximately 25% of all trauma-related deaths, making it a significant global health concern (1,2). The primary causes include motor vehicle accidents, falls from height, and other blunt-force injuries, as well as penetrating trauma from gunshot wounds or stab injuries. Chest trauma is broadly classified into blunt and penetrating injuries, each presenting with distinct pathophysiological characteristics. Blunt trauma commonly results from high-impact forces, leading to rib fractures, pulmonary contusions, haemothorax, and pneumothorax. In contrast, penetrating trauma is associated with direct organ or vascular injury, often causing rapid deterioration due to haemorrhage or pneumothorax (1).

Recent advancements in trauma care have highlighted the growing role of video-assisted thoracoscopic surgery (VATS) in managing chest injuries. Compared to traditional open thoracotomy, VATS is associated with faster recovery, reduced postoperative complications, and decreased morbidity. Initially developed for oncologic and pleural disease management, VATS has increasingly been utilized for thoracic trauma cases, particularly in patients presenting with haemothorax, pneumothorax, and retained pleural collections. The minimally invasive nature of VATS makes it an attractive option for trauma surgeons, offering a direct visual assessment of thoracic injuries while minimizing tissue damage (3).

The timing of surgical intervention is crucial in optimizing outcomes for trauma patients. Studies indicate that early VATS intervention (within 72 hours of admission) is associated with higher success rates, shorter hospital stays, and lower postoperative complications, particularly in cases of traumatic haemothorax and pneumothorax. Delayed surgical intervention, on the other hand, increases the risk of fibrothorax formation, pleural infections, and prolonged respiratory impairment. Establishing guidelines for timely VATS application based on injury severity and patient stability remains an essential focus in modern thoracic trauma management (4).

Early surgical intervention significantly reduces the need for open thoracotomy and improves patient recovery. VATS is not only an effective diagnostic tool but also serves a therapeutic role, particularly in stable patients with retained haemothorax or persistent pneumothorax (5). Additional studies further support VATS as a safe and effective alternative to more invasive procedures, provided that appropriate patient selection and timely intervention are maintained.

Methods

We conducted a comprehensive review of the literature in PubMed examining the use of VATS for blunt and penetrating thoracic trauma, with a particular focus on the timing of intervention. The search was restricted to articles published in English. Titles and abstracts were initially screened for relevance. Eligible study types included meta-analyses, randomized controlled trials (RCTs), prospective observational studies, and retrospective cohort studies, with no restrictions on publication date. Each manuscript was reviewed in detail by the authors to assess its relevance to VATS indications, outcomes, and timing. Formal quantitative synthesis or meta-analysis was not performed. Additional studies providing background context or addressing specific injury patterns were reviewed and incorporated as needed.

Pathophysiology of blunt and penetrating chest trauma

Chest trauma is classified into blunt and penetrating injuries, each with distinct mechanisms and clinical implications (6). Blunt trauma occurs when high-energy forces compress the thoracic cavity, leading to rib fractures, pulmonary contusions, haemothorax, pneumothorax, and diaphragmatic rupture. It is commonly caused by motor vehicle accidents, falls, or direct impact and often develops progressively due to internal haemorrhage or inflammation (6).

In contrast, penetrating trauma results from sharp or high-velocity objects breaching the chest wall, directly injuring underlying structures. Stab wounds, gunshot wounds, and impalements can cause severe vascular, pulmonary, or cardiac injuries, leading to exsanguination, pneumothorax, or pericardial tamponade. Unlike blunt trauma, penetrating injuries usually present acutely, with immediate signs of haemorrhage or respiratory distress (6).

Chest trauma can lead to several complications, each with distinct pathophysiological consequences and clinical implications. The most common sequelae include haemothorax, pneumothorax, lung contusions, rib fractures, and diaphragmatic injuries, all of which require careful assessment and management (7).

Haemothorax refers to the accumulation of blood within the pleural cavity, typically resulting from vascular injury due to blunt or penetrating trauma. The presence of blood in the pleural space can lead to respiratory compromise, reduced lung expansion, and hypoxia. Clinically, patients may present with dyspnoea, tachypnoea, hypotension, and diminished breath sounds on the affected side. Management depends on the severity of the haemothorax, ranging from conservative observation for small collections to chest tube drainage or surgical intervention (e.g., VATS or thoracotomy) for larger volumes or persistent bleeding (6).

Pneumothorax occurs when air enters the pleural space, leading to lung collapse and impaired ventilation. It can result from rib fractures, penetrating injuries, or barotrauma. Symptoms include sudden onset dyspnoea, pleuritic chest pain, and decreased breath sounds on auscultation. In severe cases, tension pneumothorax may develop, characterized by tracheal deviation, hypotension, and jugular venous distension, necessitating emergency decompression via needle thoracostomy followed by chest tube placement.

Lung contusions represent parenchymal injury caused by direct trauma, leading to alveolar haemorrhage, oedema, and impaired gas exchange. Unlike haemothorax or pneumothorax, lung contusions may not be immediately apparent on imaging but can progressively worsen, resulting in hypoxia and respiratory distress. Patients may exhibit tachypnoea, hypoxemia, and haemoptysis. Management is primarily supportive, including oxygen therapy, pulmonary hygiene, and mechanical ventilation in severe cases (7).

Rib fractures are the most common thoracic injury following blunt trauma, often associated with significant pain and respiratory compromise. Multiple rib fractures can lead to flail chest, a condition where a segment of the chest wall moves paradoxically during respiration, exacerbating ventilatory insufficiency. Pain control is crucial to prevent atelectasis and pneumonia, with options including regional anaesthesia (e.g., epidural or intercostal nerve blocks), multimodal analgesia, and surgical rib fixation in severe cases (6).

Diaphragmatic injuries are frequently underdiagnosed due to their subtle presentation and delayed onset of symptoms. They occur due to blunt or penetrating trauma, leading to diaphragmatic rupture and potential herniation of abdominal organs into the thoracic cavity. It is these injuries which very often escape pre-operative CT diagnosis. Clinical signs include respiratory distress, bowel sounds in the thorax, and paradoxical diaphragmatic movement. Definitive management requires surgical repair, often via laparotomy or thoracotomy, depending on the extent of the injury (6,7).

The management of chest trauma is broadly categorized into conservative and surgical approaches, with treatment strategies determined based on the patient's clinical stability, the severity of injury, and the presence of complications.

Conservative management is frequently employed in cases of mild to moderate chest trauma, including minor haemothorax, limited pneumothorax, isolated rib fractures, and pulmonary contusions. This approach encompasses oxygen therapy to mitigate hypoxia, analgesic administration such as non-steroidal anti-inflammatory drugs (NSAIDs) or opioids for pain control, chest tube drainage in cases of moderate haemothorax or pneumothorax, and serial imaging studies to monitor disease progression. The advantages of conservative management include reduced invasiveness, a lower risk of complications, and shorter hospitalization durations. It is particularly suitable for elderly patients and those with significant comorbidities. However, its limitations include the potential for progression of haemothorax or pneumothorax, necessitating surgical intervention, and inadequate pain control, which may impair pulmonary function and increase the risk of pneumonia (8-10).

Conversely, surgical management is warranted for severe chest trauma or when conservative therapy fails. Indications include massive haemothorax, persistent pneumothorax, multiple rib fractures leading to flail chest, and diaphragmatic injuries with visceral herniation. Surgical interventions include VATS, which is minimally invasive and effective in managing haemothorax and pneumothorax, as well as thoracotomy for extensive injuries requiring direct repair. Rib fixation procedures are employed to stabilize flail chest, and diaphragmatic repair is necessary in cases of herniation. Surgical management offers the benefit of rapid symptom resolution, a lower likelihood of long-term complications such as chronic pain or respiratory dysfunction, and improved survival rates among critically injured patients. Nonetheless, drawbacks include increased procedural invasiveness, prolonged hospital stays, and heightened perioperative risk, particularly among elderly individuals and those with comorbid conditions (10).

The selection of the appropriate therapeutic strategy is contingent on a comprehensive assessment of the patient's hemodynamic stability, injury severity, complication profile, and individual risk factors such as age and comorbidities. A multidisciplinary approach, integrating clinical evaluation, radiographic findings, and patient-specific factors, is essential to optimize treatment outcomes in chest trauma management.

VATS in chest trauma

The pathologies discussed above, can all be surgically managed using a VATS approach and indeed early data has demonstrated its utility and superiority over the open approach in uncomplicated, stable patients (11,12). In combination with palpation of the chest wall, thoracoscopy allows relevant fractures or injuries, the degree of rib dislocation, and any instability to be identified clearly and precisely which allows for a focused management plan to be exacted such that there is proper restoration of the chest wall. This means that the "open" access route to the fractures can be kept "minimally invasive" and muscle sparing (13).

Other than severe haemodynamic instability or massive haemorrhage, there are no set absolute contraindications to the use of VATS in the trauma setting, but there are a set of relative contraindications or considerations to bear in mind when operating for thoracic trauma. Relative contra-indications for the use of VATS in the trauma setting include previous thoracic surgery, previous pleurodesis or radiological signs of dense adhesions. VATS can certainly still be adopted in these settings however there should be a low threshold to convert to thoracotomy if access is challenging, especially in an acute setting. Traumatic lung contusions or pneumatoceles can pose challenges with maintaining effective alveolar ventilation and VATS should be considered a relative contraindication in patients who are unable to maintain effective gas exchange especially in centres without direct access to veno-venous ECMO. The presence of tracheobronchial injury can also pose unique surgical and anaesthetic challenges and should not be considered for VATS (14).

Optimal timing of VATS in blunt chest trauma

VATS is an appropriate and safe way to deal with the sequelae of blunt thoracic trauma injuries, most commonly pneumothorax and haemothorax and rarely burst injuries of the diaphragm which range in their degree of complexity. The timing of intervention in blunt trauma cases, is not unanimously agreed upon and the consensus regarding the relationship between timing of intervention and clinical outcome is mixed (15).

Lin *et al.* (16) retrospectively analysed a cohort of patients (n=136) who underwent VATS for retained haemothorax following blunt chest trauma between 2003 and 2011. All patients had multi-trauma, with over 90% sustaining injuries at more than two anatomical sites. Patients were stratified based on timing of VATS from injury: 2–3 days (Group 1), 4–6 days (Group 2), and ≥7 days (Group 3). Key outcomes assessed included duration of chest tube placement, ventilator dependence, ICU and hospital length of stay (LOS), and microbiological findings from pleural collections. Although baseline characteristics were comparable across groups, delayed VATS (≥7 days) was associated with increased rates of pleural and sputum infection, prolonged chest tube and ventilator use, and longer ICU and hospital stays. Notably, patients who underwent VATS within 3 days experienced significantly fewer infectious complications and shorter ventilator duration, though the need for repeat VATS did not differ significantly across groups. This supports the idea of early VATS (<72 h) post injury to optimise outcomes and mitigate pulmonary infective sequelae such as complex empyema and fibrothorax, which can in turn reduce ICU burden. Some groups have advocated for intervention within 24h even in the haemodynamically stable patients with the rationale being to identify rare or subtle injuries that would otherwise have been missed on simple 3-D trauma scanning (17). In the current era, this is not always possible due to prioritisation of competing injuries but improvements in the trauma pathway and delineation of intrathoracic structures with modern day imaging techniques may obviate the need for emergency chest exploration in an otherwise stable patient.

Further retrospective data has supported early intervention in this cohort; a total of 83 patients underwent VATS for post-traumatic thoracic complications, predominantly for retained haemothorax (73%), empyema (18%), and persistent air leak (10%) (18). Multivariate analysis identified both delayed VATS (>5 days) and the diagnosis of empyema as independent predictors of increased LOS and conversion to thoracotomy. Randomised data (19) compared outcomes between second tube thoracostomy (Group 1, n=24) and early VATS (Group 2, n=15) in patients with retained haemothorax. Patients in whom repeat tube drainage failed were further randomized to VATS or thoracotomy. Patients undergoing VATS had significantly shorter durations of chest tube drainage (2.5 *vs.* 4.5 days), reduced post-procedure hospital stay (3.6 *vs.* 7.2 days), and shorter overall hospitalization (5.4 *vs.* 8.1 days; $P<0.02$ for all). Hospital costs were also significantly lower in the VATS group ($7,689 *vs.* $13,273; $P<0.02$), with no conversions to thoracotomy and no mortality in either group. Among patients in whom second chest tube placement failed, outcomes between salvage VATS and thoracotomy were comparable. However, initial treatment with VATS avoided treatment delays and repeat interventions.

The Eastern Association for the Surgery of Trauma (EAST) (20) conclude that for stable trauma patients with haemothorax or suspected retained collections, early VATS (ideally within 72 h) is preferred over repeated chest tubes or delayed intervention. It is associated with improved outcomes, especially reduced hospital stay, infection rates, and need for thoracotomy, as long as performed by skilled surgeons in a setting equipped for conversion if needed. The evidence further suggests that interventions earlier than this window may further enhance outcomes.

Optimal timing of rib fixation in blunt chest trauma

Rib fractures are present in approximately 10% of all traumatic injuries and are a significant contributor to both morbidity and mortality (21). Mortality associated with rib fractures remains high and although an expanding body of evidence supports the benefits of surgical stabilization of rib fractures (SSRF), its widespread adoption as a standard of care across trauma centres is yet to be fully realised.

The Chest Wall Injury Society (CWIS) consensus (22,23) outlines clear criteria for SSRF, emphasizing both indications and contraindications, as well as the timing of intervention. The major indications are primarily chest wall instability: flail chest (≥3 consecutive ribs fractured in ≥2 places), or ≥3 ipsilateral bi-cortically-displaced/offset ribs; clinically seen as paradoxical movement, instability, or palpable "clicking", and non-flail, displaced fractures: ≥3 ribs with ≥50% displacement plus ≥2 physiological impairments [e.g., respiratory rate (RR) ≥20 bpm, incentive spirometry <50%, pain >5/10, poor cough]. These criteria equally apply to ventilated and non-ventilated patients, with ventilator-dependent individuals also eligible if they fail to wean due to rib fractures.

Absolute contraindications include persistent hemodynamic instability requiring resuscitation, severe traumatic brain injury (TBI), fractures outside ribs 3–10 and acute myocardial infarction. Relative contraindications include age <18 years, significant comorbidities, mild/moderate TBI, unstable spine injury, existing empyema and prior chest wall radiation.

The recommendations on timing are as early as feasible, ideally within 24 hours, and no later than 72 hours after injury, especially for unstable rib patterns or ventilator-dependent patients. When other life-threatening injuries take precedence, SSRF may be postponed until resources and patient stability permit. A position paper from the CWIS (23) supported this timing guidance, and in the case of concomitant conditions contraindicating early SSRF, it should be performed as soon as possible, within 3–7 days after injury. There is a large body of data, primarily retrospective and non-randomised supporting the early intervention for complex rib trauma (24,25). Prospective clinical trial data from the NONFLAIL study (26) compared SSRF to non-operative management for non-ventilator dependent trauma patients with non-flail displaced rib fractures. Lower morbidity rate and decreased pain levels were reported in the surgical group, undergoing SSRF within 72h from admission.

Groups have conversely made an argument for delayed SSRF; Belaroussi *et al.* (27) investigated whether delay to surgery influences postoperative pulmonary outcomes, including pneumonia and failure to extubate. Data from 159 patients undergoing SSRF between 2010 and 2020 were analysed, with timing stratified into early (<48 hours), mid (48 hours–7 days), and late (>7 days) groups. Outcomes were evaluated in relation to trauma characteristics, ventilatory status, associated injuries, and post-operative care.

Pulmonary infections occurred in 42.2% of patients, with most early pneumonias occurring within the first 5 days. However, delay to surgery was not significantly associated with increased rates of pneumonia or failure to wean from mechanical ventilation ($P>0.05$). The overall 1-month mortality was low (1.9%). The authors concluded that clinical stabilization and comprehensive assessment of injury severity and pulmonary function should guide surgical timing rather than rigid time thresholds.

There is a large amount of data supporting early SSRF and although the findings from Belaroussi *et al.* are interesting and the conclusions logical, less is known about the relationship between delayed SSRF and clinical outcomes. The study highlights the complexity of managing patients with severe chest trauma, where prioritization of life-threatening injuries may necessitate delay in SSRF. Despite a trend toward higher complication rates in delayed cases, these did not reach statistical significance potentially due to limited sample size and study power. Importantly, delayed SSRF did not worsen overall outcomes, contradicting some prior studies that associated late surgery with increased ICU stay and ventilator days (28,29).

While early SSRF remains ideal, delayed fixation should not be dismissed, particularly in polytrauma patients requiring stabilization of other critical injuries first. Future prospective studies are needed to define the optimal timing of SSRF and clarify its benefits across various clinical scenarios.

Advancements in complete VATS for rib fixation have demonstrated feasibility and safety in treating multiple rib fractures and flail chest. This approach has been shown to be a safe and effective alternative to open surgery in selected patients with multiple rib fractures or flail chest, offering comparable clinical outcomes with reduced postoperative pain and fewer pleural complications (30). Single port VATS has further demonstrated superior comparative outcomes based on a series of 73 patients, in terms of intra-operative blood loss, chest tube drainage amount, chest tube duration, length of post-operative stay and the incidence of post-operative complications (31). For certain complex fracture patterns, VATS may even be superior to a traditional open approach, particularly in anatomically challenging areas, such as beneath the scapula. This technique is particularly effective for stabilizing complex segmental fractures, as the bridging plate can span multiple fracture sites using a single fixation point on each end. It is also well-suited for posterior rib fractures, where limited access may preclude placement of multiple screws (32). Novel use of memory alloy fixation for internal stabilization of rib fractures and flail chest has been described in a retrospective study of 35 patients, including those with anterior, lateral, scapular, and paravertebral rib fractures (33). All procedures were successfully performed via thoracoscopy without additional chest wall incisions. The technique demonstrated excellent functional and cosmetic outcomes, rapid recovery, and no perioperative complications. Follow-up (6–24 months) confirmed stable fixation with no hardware detachment, supporting this method as a promising alternative to conventional open fixation.

VATS in haemodynamically stable penetrating chest trauma

Penetrating thoracic trauma accounts for a significant proportion of emergency surgical interventions, with approximately 15% of patients requiring immediate thoracotomy for resuscitation due to haemodynamic instability or massive haemorrhage. The remaining 85% can often be managed initially with tube thoracostomy, analgesia, pulmonary toilet, and observation (34). Conservative measures, however, are associated with risks such as retained haemothorax, empyema, fibrothorax, and missed injuries, which may necessitate delayed surgical intervention (35).

The advent of VATS has transformed thoracic trauma management, providing a minimally invasive alternative to thoracotomy for select patients. VATS facilitates diagnostic evaluation, enables evacuation of retained haemothorax, and allows for definitive management of diaphragmatic, pulmonary, and pleural injuries as well as removal of retained foreign bodies. Despite these advantages, the optimal timing or indeed the use for VATS in haemodynamically stable penetrating chest trauma remains a subject of debate (36). A narrative review highlighted the role of VATS in addressing persistent air leaks following traumatic pneumothorax. In a small series, VATS demonstrated superiority over non-operative management, reducing chest tube duration (8.1 *vs.* 11.8 days) and hospital LOS (9.7 *vs.* 16.5 days) (37). Although this study focused on pneumothorax, the findings underscore VATS's potential in managing specific post-traumatic complications. In the context of retained haemothorax, early VATS intervention within 7 days post-injury has been associated with decreased post-traumatic infection rates and shorter hospital stays (38).

Several studies have assessed the efficacy and timing of VATS in this patient cohort and indeed demonstrated diagnostic accuracy and therapeutic efficacy in the haemodynamically stable patient (39). A retrospective analysis by Abolhoda *et al.* evaluated 16 patients undergoing VATS for penetrating thoracic trauma, reporting a 75% success rate. In this study, evacuation of clotted haemothorax was successfully performed up to 7 days post-injury, whereas two failures occurred when VATS was attempted beyond one week, suggesting a time-dependent decline in efficacy (36). Similarly, Ahmed *et al.* assessed 88 patients with retained haemothorax beyond 48 hours post-chest tube insertion, comparing outcomes between early VATS (n=27) and observation (n=55). Early VATS significantly reduced hospital LOS (4.3 *vs.* 9.4 days, $P<0.05$), ICU duration (1.3 *vs.* 3.2 days, $P<0.05$), and the need for conversion to thoracotomy (0% *vs.* 12.7%) (40).

Goodman *et al.* examined outcomes in 23 trauma patients (20 penetrating injuries) who underwent VATS within 24 hours of admission. The study reported no conversions to thoracotomy and no need for reoperation, with a mean post-operative chest tube duration of 2.9 days and an average hospital stay of 5.6±0.9 days (41). Lang-Lazdunski *et al.* analysed 42 thoracic trauma patients (21 penetrating injuries), finding that patients undergoing VATS within 24 hours had superior outcomes compared to those with delayed intervention (mean postoperative LOS: 13 days for penetrating trauma *vs.* 21 days for blunt trauma) (42).

Additional studies support the role of early intervention. Manlulu *et al.* reported a cohort of 11 patients with penetrating thoracic trauma who underwent VATS within 24 hours, demonstrating a 100% success rate without morbidity or conversion to thoracotomy. The median length of hospital stay was 4.7 days (12). In a prospective randomized trial, Meyer *et al.* compared early VATS (n=15) to a second tube thoracostomy (n=24) for retained haemothorax. Patients in the VATS group had a significantly shorter hospital stay (5.4±2.16 *vs.* 8.13±4.62 days, P<0.02), with none requiring conversion to thoracotomy, whereas 10 patients in the tube thoracostomy group failed and required subsequent surgical intervention (19).

Paci *et al.* assessed 13 patients with penetrating thoracic injuries, with 12 undergoing VATS within 6 hours post-injury. The study found no in-hospital mortality and an average hospital stay of 5 days (43). Similarly, Pons *et al.* reported outcomes in 13 patients, 11 of whom underwent VATS within 8 hours of injury. Although 4 patients required conversion to thoracotomy, the cohort had no in-hospital mortality and a mean hospital stay of 10±4 days (44).

The accumulated evidence suggests that early VATS, particularly within 24–48 hours, offers significant advantages in haemodynamically stable penetrating thoracic trauma patients, reducing hospital stay, ICU duration, and the need for conversion to thoracotomy. Consensus data from the Eastern Association for the Surgery of Trauma (EAST) recommends early VATS (within 4 days) over intrapleural fibrinolysis for traumatic haemothorax in stable patients (45). Randomised data has also supported this recommendation, where VATS proved to be the better treatment modality for retained haemothorax with fewer complications and less need for additional procedures, while the length of hospital stay between the two groups was not statistically different (46). Reports have also been published in the setting of penetrating cardiac injury (contained) that have utilised a VATS approach for both diagnostic and therapeutic purposes (47). Despite these promising findings, current data are largely retrospective and observational, necessitating further prospective randomized trials to delineate optimal timing and refine clinical guidelines. Additionally, emerging data on robotic-assisted thoracic surgery (RATS) may provide new insights into the future of minimally invasive management in thoracic trauma (18,48,49).

Future perspectives and research gaps

Despite mounting evidence supporting the use of VATS in chest trauma, prospective RCTs remain scarce. Current literature is largely retrospective, limiting the ability to establish definitive timing guidelines or stratify patients based on injury severity. Ongoing and future trials, including the NONFLAIL trial and other studies championed by the CWIS (22,23), are beginning to provide data on outcomes of SSRF in both flail and non-flail rib fractures. These initiatives underscore the need for high-quality evidence to validate early operative strategies, evaluate optimal timing, and standardize patient selection criteria. The CWIS algorithms and consensus statements provide a foundational framework for SSRF, but similar efforts are needed for the application of VATS in trauma. Incorporating clear VATS indications and timing benchmarks into major trauma protocols, especially for haemodynamically stable patients with retained haemothorax or persistent pneumothorax, could improve consistency in care delivery and outcomes.

Emerging technologies such as RATS represent a promising frontier in trauma surgery. RATS may offer enhanced dexterity and visualization for rib fixation or complex injury repair, particularly in posterior or difficult-to-access thoracic zones. Its potential utility in trauma requires investigation through clinical registries and prospective trials. Standardized protocols, multi-institutional registries, and future prospective studies will be essential to refine the role of minimally invasive thoracic surgery in trauma. Ultimately, integrating VATS and potentially RATS into trauma care algorithms can offer safer, more efficient, and cost-effective management of select chest trauma patients. Implementing early VATS or indeed RATS protocols will be a challenge in a lot of units which lack the expertise and infrastructure to support "minimally invasive" (MiS) programmes and as such this is a key limiting factor which warrants due process. The evidence presented in this paper also is predominantly retrospective, prone to selection bias and concentrated to large MiS programmes which skew the outcomes reporting, again a feature inherent to the nature of the specialty and concentration of service delivery.

Future directions may involve integrating percutaneous cryoablation of the intercostal nerves as a standalone component of conservative management, alongside advancements in surgical care such as the utilization of three-dimensional (3D) printing and bioabsorbable materials for rib fracture fixation (50-53).

Limitations

This review has several limitations. First, it is a narrative synthesis rather than a formal systematic review or meta-analysis, and no quantitative pooling of outcomes was performed. Second, the included studies are heterogeneous with respect to patient populations, trauma mechanisms, injury severity, and VATS techniques, which limits direct comparisons and generalizability. Third, most evidence derives from retrospective observational studies, small prospective cohorts, or single-centre experiences, introducing potential selection and reporting bias. Fourth, there is a lack of high-quality RCTs, particularly regarding the timing of intervention in both blunt and penetrating trauma, limiting the ability to draw strong causal conclusions. Finally, restricting the search to English-language publications may have led to the exclusion of relevant studies from non-English journals. Despite these limitations, the review provides a focused synthesis of current evidence and highlights practical considerations for timing and utilization of VATS in thoracic trauma.

Conclusions

VATS is a safe, effective, and increasingly utilized approach in the management of both blunt and penetrating chest trauma. This review highlights several key findings: (I) early VATS, preferably within 72 hours significantly reduces complications such as retained haemothorax, empyema, and prolonged ventilatory support; (II) in penetrating trauma, VATS provides a minimally invasive diagnostic and therapeutic option in haemodynamically stable patients, with early intervention associated with better outcomes; and (III) thoracoscopic-assisted rib fixation, including novel techniques using memory alloys, shows promise in managing complex fracture patterns with reduced postoperative pain and shorter hospital stays.

Based on current evidence, we propose a practical algorithm:

- ❖ Blunt trauma: perform VATS within 72 hours in stable patients with retained haemothorax, persistent pneumothorax, or diagnostic uncertainty;
- ❖ Penetrating trauma: consider VATS within 24–48 hours for haemodynamically stable patients to evacuate clots, assess diaphragmatic or pulmonary injury, and retrieve foreign bodies;
- ❖ Rib fixation: aim for surgical stabilization within 72 hours in appropriate candidates, while accepting that delayed SSRF may be safe and effective when prioritizing management of other life-threatening injuries.

Despite these advances, the field lacks high-quality RCTs to define optimal timing, patient selection, and long-term outcomes for VATS in trauma care. We call for prospective, multi-centre studies and robust clinical registries to validate these recommendations, standardize timing protocols, and explore the emerging role of RATS in trauma management.

Acknowledgments

None.

Footnote

Provenance and Peer Review: This article was commissioned by the Guest Editors (Savvas Lampridis and Andrea Bille) for the series "The Role of VATS in Thoracic Trauma Management" published in *Video-Assisted Thoracic Surgery*. The article has undergone external peer review.

Peer Review File: Available at https://vats.amegroups.com/article/view/10.21037/vats-25-32/prf

Funding: None.

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://vats.amegroups.com/article/view/10.21037/vats-25-32/coif). The series "The Role of VATS in Thoracic Trauma Management" was commissioned by the editorial office without any sponsorship or funding. The authors have no other conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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doi: 10.21037/vats-25-32
Cite this article as: Patel AJ, Domjan M, Yamamoto H. The role of video-assisted thoracoscopic surgery in blunt and penetrating chest trauma: timing of intervention and clinical outcomes—a review of the current evidence. Video-assist Thorac Surg 2025;10:33.