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Minimally invasive management of thoracic trauma: current evidence and guidelines

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SUMMARY

Minimally invasive procedures are being increasingly proposed for trauma. Injuries to the chest wall and/or lung have historically been managed by drainage with a large bore thoracostomy tube, while cardiac injuries have mandated sternotomy. These treatments are associated with significant patient discomfort. Percutaneous placement of small 'pigtail' catheters was initially designed for drainage of simple pericardial fluid. Their use subsequently expanded to drainage of the pleural cavity. The role of pigtail catheters for primary treatment of traumatic pneumothorax and hemopneumothorax has increased, while their use for pericardial fluid after trauma remains controversial. Pericardial windows have alternatively been purposed as a minimally invasive treatment option for possible hemopericardium. The aim of this article is to review the current evidence and guidelines for minimally invasive management of chest trauma.

INTRODUCTION

Minimally invasive procedures are being increasingly proposed for trauma. Injuries to the chest wall and/or lung have historically been managed by drainage with a large bore (36–40 Fr) thoracostomy tube, while cardiac injuries have mandated sternotomy. These treatments are associated with significant patient discomfort. Percutaneous placement of small (14 Fr or less) 'pigtail' catheters was initially designed for drainage of simple pericardial fluid.[1] Their use subsequently expanded to drainage of the pleural cavity for simple effusions.[1 2] The role of pigtail catheters for primary treatment of traumatic pneumothorax and hemopneumothorax has increased, while their use for pericardial fluid after trauma remains controversial. Pericardial windows have alternatively been purposed as a minimally invasive treatment option for possible hemopericardium. The aim of this article is to review the current evidence and guidelines for minimally invasive management of chest trauma.

Minimally invasive management of the pleural space

Traumatic injuries to the chest wall and lung often result in pneumothorax or hemopneumothorax. Most of these injuries will heal if managed non-operatively with drains. Traditional teaching has advocated for placement of a large (36–40 Fr) tube to ensure optimal chest drainage. However, in 2012, Inaba *et al* challenged this dogma, demonstrating that smaller chest tubes (28–32 Fr) were equally effective.[3] Since that time, smaller chest tubes have been increasingly used after trauma. Traditional tube thoracostomies are placed by surgical cutdown with finger thoracostomy, to allow for rapid release of a tension pneumothorax and to ensure correct placement in the chest cavity. Use of pigtail catheters for drainage of the pleural cavity, without cutdown, was first described in the 1980s.[2] This alternative procedure for chest drainage was initially used for simple effusions in stable patients. Rivera *et al* first described use of pigtails for primary management of chest trauma, however, placement was with image guidance in the Interventional Radiology Suite.[4] Several studies have reported a learning curve before surgeons have demonstrated proficiency with the procedure at bedside, with many converting to traditional chest tube during their first few attempts.[5] Also, many surgeons have been hesitant to use these drains for traumatic hemothorax, due to concern that blood may not adequately drain through such a small diameter tube. Despite these concerns, pigtail catheters have become increasingly popular over the past two decades, due to their less invasive nature, as well as the ability to use image guidance for precise placement.

Traumatic pneumothorax

Kulvatunyou *et al* retrospectively described the introduction of bedside pigtail catheters placed after trauma at their institution in 2011.[6] They compared patients who had pigtails or chest tubes inserted solely for non-emergent traumatic pneumothorax, and reported no statistical differences in tube days, need for mechanical ventilation, or insertion-related complications. The tube failure rate, defined as requirement for an additional tube or by a pneumothorax recurrence that required intervention, was higher in the pigtail group, but was not statistically significant.

In 2014, the same group published a randomized clinical trial of 40 patients comparing bedside pigtail catheter placement with tube thoracostomy for non-emergent traumatic pneumothorax.[7] Primary outcome measures were pain at the tube site and the daily intravenous pain medication usage. Pigtail catheters were associated with a >50% reduction in tube-site pain compared with 28 Fr chest tubes, both on day of insertion and for the following 2 days, however, there was no significant difference in pain medication usage. Secondary outcomes included success rate (defined as no requirement for a second tube insertion) and tube insertion-related complications, which were similar between the two groups. The authors concluded that pigtail catheters for treatment of non-emergent traumatic pneumothorax were associated with less pain, but no other important differences.

Acute hemothorax or hemopneumothorax

Kulvatunyou *et al* also studied bedside drainage of traumatic hemothorax by pigtail catheters.[8] In 2012, they published 30 months of prospective pigtail data from their center, comparing it with their retrospective chest tube data from the same time period (36 pigtails, 191 chest tubes). The primary outcome was the initial drainage output. Contrary to concerns about the ability of small tubes to adequately drain blood, initial output was higher in the pigtail catheter group (560 mL vs 426 mL in the chest tube group, p=0.13), however, this was not statistically significant. Also, in the pigtail group, the time from trauma to tube insertion was longer than the chest tube group. This longer time period could have allowed for accumulation of a larger hemothorax. Secondary outcomes in the study were tube duration, insertion-related complications, and failure rate, which were all similar.

Bauman *et al* published a prospective series of 496 patients from the same center from 2008 to 2014 comparing bedside pigtail catheters with chest tubes in traumatic hemothorax or hemopneumothorax.[5] Some of these data overlapped with the aforementioned hemothorax study. The primary outcomes included initial drainage output, tube insertion-related complications, and failure rate. The initial output was again higher after placement of a pigtail catheter, suggesting efficacy of the pigtails for drainage of hemothorax. However, pigtails were again placed at a later time, also in older patients, and after blunt trauma. These risk factors may have increased the overall volume of hemothorax at the time of drainage. In addition, insertion-related complications were higher in the pigtail catheter group, although this was not statistically significant. Failure rate, defined as an incompletely drained or retained hemothorax that required a second intervention, was higher in the chest tube group, but this also was not significant. The use of pigtail catheters increased over the study period, and the conversion rate to traditional tube thoracostomy decreased, demonstrating increasing provider comfort with the procedure over time. The authors also did a subanalysis of the 226 patients who had chest drainage emergently, which was defined as placement in the trauma bay shortly after arrival. On subanalysis, output was again higher in the pigtail group. Insertion-related complications were also higher in the pigtail group, although still not statistically significant.

In 2021, Bauman *et al* published a randomized controlled trial comparing 14 Fr pigtail catheters placed at the bedside with large-caliber (28–32 Fr) chest tubes in non-emergent traumatic hemothorax or hemopneumothorax in 43 patients.[9] The primary outcome was failure rate, defined as the need for an additional drainage intervention, which was found to be similar between the two groups. Initial and daily outputs were also similar between the groups, suggesting no difference in efficacy for draining the chest. There was also no difference in tube days between the two groups, however, insertion perception experience (IPE), rated by the patient, favored the pigtail catheter over the traditional chest tube. Interestingly, there were no insertion-related complications.

Finally, in 2021, Kulvatunyou *et al* published a multicenter randomized controlled trial comparing 56 patients with 14 Fr pigtails placed at bedside with 63 patients with 28–32 Fr chest tubes for traumatic hemothorax from 2015 through 2020.[10] They again excluded patients in extremis who required emergent tube placement. The primary outcome was failure rate, which was defined as a retained hemothorax requiring a second intervention. Secondary outcomes included daily drainage output, tube days, intensive care unit (ICU) and hospital length of stay (LOS), and IPE score on a scale of 1–5 (1, tolerable experience; 5, worst experience). Failure rate was similar (11% pigtails vs 13% chest tubes, p=0.74), and all other secondary outcomes were similar. However, pigtail catheter patients reported lower IPE scores (median, 1) than chest tube patients (median, 3; p<0.001). The authors concluded that small caliber pigtails are equally effective as standard chest tubes with no difference in complications and better patient IPE scores.

Delayed hemothorax

In 2020, Orlando, *et al* published a retrospective multicenter trial of patients with 'delayed hemothorax' treated with either large-bore chest tubes (>14 Fr) or small-bore pigtail catheters (</=14 Fr).[11] Patients were included if their initial drainage tube was placed for hemothorax at 36 hours or greater after hospital arrival. The primary outcome was at least one tube complication (including need for a second chest tube, tube dislodgment, clogging of tube, pneumonia, empyema, or retained hemothorax requiring intervention). This occurred in 17% of tubes, with no difference between groups. With regard to specific complications, large-bore chest tubes had a higher rate of need for subsequent video-assisted thoracoscopic surgery (VATS), and small-bore chest tubes were associated with a higher rate of pneumonia. Due to the retrospective nature of the study, these findings may be attributable to a number of factors. The decision to place an additional tube, attempt thrombolytic therapy, or proceed with VATS varies with center and provider. In this study, all of the pigtail catheters were placed at the same center, while the other five centers preferentially placed chest tubes. Practice patterns at the centers therefore likely impacted the VATS numbers. Also, number of rib fractures and number of ventilator days were not evaluated, which would have impacted pneumonia rate. There was no difference between groups in time each chest tube was in place or volume of initial output, however, large-bore tubes drained at a rate 4 times faster than small-bore tubes. The drainage rates, however, may not be accurate, because they were based on a subset of the total study population, and they were calculated dependent on timing of output recording.

Aggregate data

Beeton *et al* performed a meta-analysis of the previously published literature comparing bedside pigtail catheters with traditional chest tubes after traumatic injury. A total of seven studies (two randomized controlled trials, three prospective studies, and two retrospective studies) met inclusion criteria, six of which came from the same institution.[12] The study aimed to compare failure rate (requirement of an additional intervention), initial drainage output (within 30 min), ICU LOS, hospital LOS, ventilator days, and tube duration in adult trauma patients with thoracic injuries who received either a pigtail catheter (≤14 Fr) or chest tube (>16 Fr). Failure rates were compared between 750 patients (6 studies) with chest tubes and 393 patients with pigtail catheters. The relative risk of failure rate of chest tubes compared with pigtail catheters was found to be 1.13 (95% CI 0.85 to 1.51). Patients in the chest tube group had a higher risk of requiring VATS versus the pigtail group (subanalysis of five studies), with a relative risk of 2.77 (95% CI 1.50 to 5.11). However, as previously mentioned, VATS is not always the first or only intervention for failure of chest drainage. It is possible that patients in the pigtail group received placement of a larger chest tube or thrombolysis for failure. Out of 5 studies, the pigtail group (461 patients) had higher initial output volumes compared with the chest tube group (644 patients), with a mean difference of 114.7 mL (95% CI 70.6 to 158.8 mL). Tube duration was also compared in all seven studies and was found to be significantly lower in the pigtail group, but by a difference of only 0.8 days. ICU LOS, hospital LOS, and ventilator days were no different between the groups.

Commentary

Taken in aggregate, the aforementioned studies have established pigtail catheters as an acceptable alternative to standard chest tubes for traumatic pneumothorax and hemopneumothorax. However, there have been important criticisms of the existing literature. First, regarding the advantage of pigtail catheters over traditional chest tubes. Pigtails have been associated with decreased pain at the tube site. However, pain scores after trauma are subjective, and it is difficult to isolate the pain associated with thoracic soft tissue, lung, or bone injury from that due to the tube itself. Pigtails have also been associated with a significantly improved IPE, as rated by patients. It should be noted that the scale used has not been previously validated in the literature.[5]

Regarding the safety of bedside percutaneous pigtail placement in comparison with traditional cutdown for chest tube placement, the most important limitation is that emergency placements have almost always been excluded from these studies. Alhough one subanalysis evaluated 'emergency' drainage tubes, this was defined by placement in the trauma bay on the day of presentation, not by hemodynamic or respiratory instability.[9] The majority of complications from drainage tubes occur during emergency placement. If pigtail catheters were to be adopted for emergency placement, further comparison of complications would be appropriate. In addition, there are different techniques and different locations for placement of pigtails, with variable complications. Most of the studies have evaluated lateral pigtails placed by Seldinger technique, so the complication rates cannot necessarily be extrapolated to other techniques. Also not addressed in the studies was bedside placement of pigtail catheters using ultrasound guidance. This practice likely improves the safety of the procedure, although also requires additional training/expertise, equipment, and time for placement.

Regarding the efficacy of pigtails for chest drainage after trauma, the existing studies come largely from the same center, and with some overlapping data. Although the results have demonstrated that pigtail catheters drain traumatic pneumothorax and hemopneumothorax as effectively as standard chest tubes, this is at a center where the practice has been adopted and providers have progressed through the learning curve.

Guidelines

Recent guidelines in 2020 by the Eastern Association for the Surgery of Trauma *conditionally* recommend the use of pigtail catheters in patients that are hemodynamically stable over a standard large-bore chest tube to decrease the rate of retained hemothorax and the need for additional intervention.[13] Western Trauma Association Guidelines recommend pigtail catheters or small-bore chest tubes for traumatic pneumothorax, chest tubes for emergent hemothorax, and either for non-emergent hemothorax.[14 15]

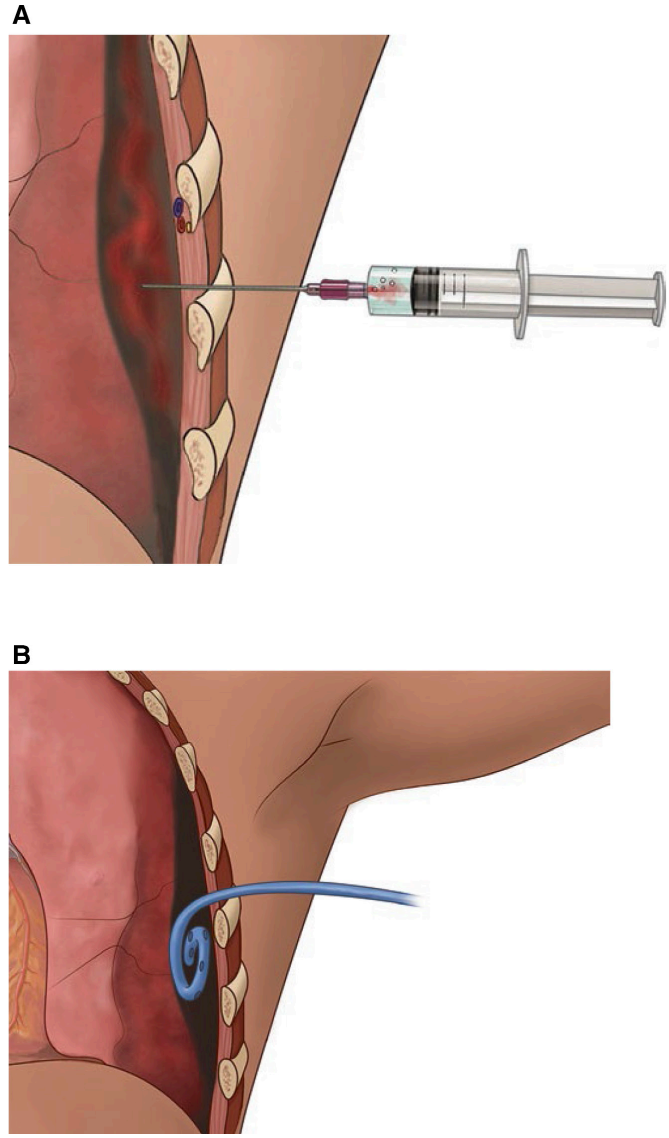

Figure 1 (A) Aspirate air or fluid from the chest cavity into a hollow needle. (B) Removal of the trocar and wire to allow curling of the catheter. Adapted from Demetriades *et al*.[16]

Pigtail catheter technique

Multiple techniques exist for placement of pigtail catheters. The most common is to use Seldinger technique[16]:

1. Aspirate air or fluid from the chest cavity into a hollow needle (figure 1A).
2. Placement of a wire through the needle.
3. Dilation of the tract.
4. Placement of the catheter using a straight hollow trocar over the wire.
5. Removal of the trocar and wire to allow curling of the catheter (figure 1B).

Placement of pigtail catheters for pleural drainage has been described in two locations[7]:

1. At the second or third intercostal space anteriorly.
2. In the fourth or fifth intercostal space laterally (more popular location).

Rarely, percutaneous drainage of traumatic pericardial fluid may be considered. Placement of pigtail catheters for pericardial drainage should be performed in the semi-recumbent position with head of bed elevated 30°–45°, if possible, because it

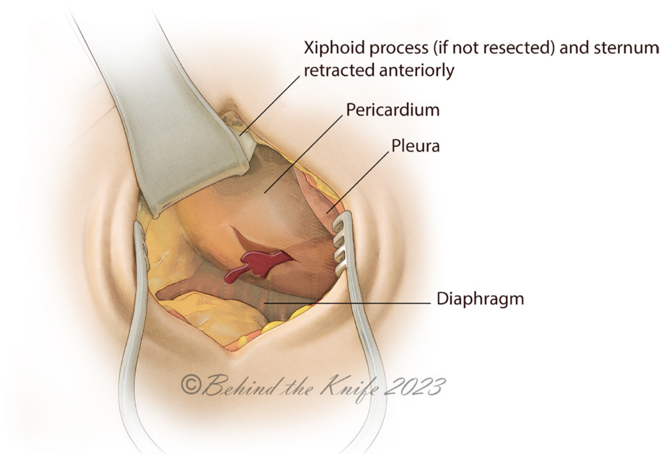

Figure 2 Pericardial window.

increases dependent pooling of fluid and brings the heart closer to the chest wall. However, it can also be performed supine if required to maintain spinal precautions. Two common locations for needle insertion include:

1. Subxiphoid just to the left of midline.
2. Apical (at the point of maximal cardiac impulse in the left chest).

Ultrasound can be used at the bedside for guidance for either procedure and likely has the advantage of decreased complications and increased first attempt success rates.[17]

Complications of pigtail catheters

Complications due to placement of pigtail catheters are well described.[18 19] Although a less-invasive intervention, some studies have demonstrated that small-caliber tubes have a high complication rate, including infection (cellulitis 3%, empyema 3%), catheter dislodgment (2%), catheter malfunction (4%), pneumothorax (6%), and, more rarely, bleeding and injury to adjacent organs.

Early complications of pigtail catheters involve organ injury (eg, spleen, liver, lung, diaphragm, heart, major blood vessels, esophagus, stomach, bowel) during placement, equipment malfunction (eg, kinking of the wire during placement), re-expansion pulmonary edema, and bleeding. This can include major bleeding, requiring surgical control, due to an injury of an intercostal vessel, coronary vessel, pulmonary artery branch, or the heart or lung. Errors in placement technique can also occur (eg, subcutaneous placement or retained obturator).[20]

Late complications encompass infection (eg, cellulitis or empyema), pneumothorax, bronchopleural fistula, non-functioning tube, premature removal or dislodgment, nerve irritation, arteriovenous fistula, and cardiac arrythmias.[20]

Minimally invasive management of the pericardium

Cardiac injuries are highly lethal and require rapid treatment. The standard of care for hemodynamically unstable patients with pericardial tamponade is median sternotomy. However, in hemodynamically stable trauma patients, a pericardial window can be considered (figure 2). It is important to recognize that a pericardial window does not allow for cardiac repair, so the surgeon must be prepared to perform a median sternotomy should the pericardial window demonstrate blood that does not clear with irrigation.

In hemodynamically stable patients presenting with penetrating injuries *without* pericardial tamponade, a pericardial window should be considered if (1) the trajectory of the injury is concerning and (2) there is pericardial fluid present, ultrasound and/or CT scan are unavailable or difficult to interpret, and/or the patient has a hemothorax (ie, the injury could be decompressing into the chest).

The available data suggest that most hemodynamically stable blunt trauma patients with pericardial fluid seen on imaging can be managed non-operatively. Witt *et al* identified 75 blunt

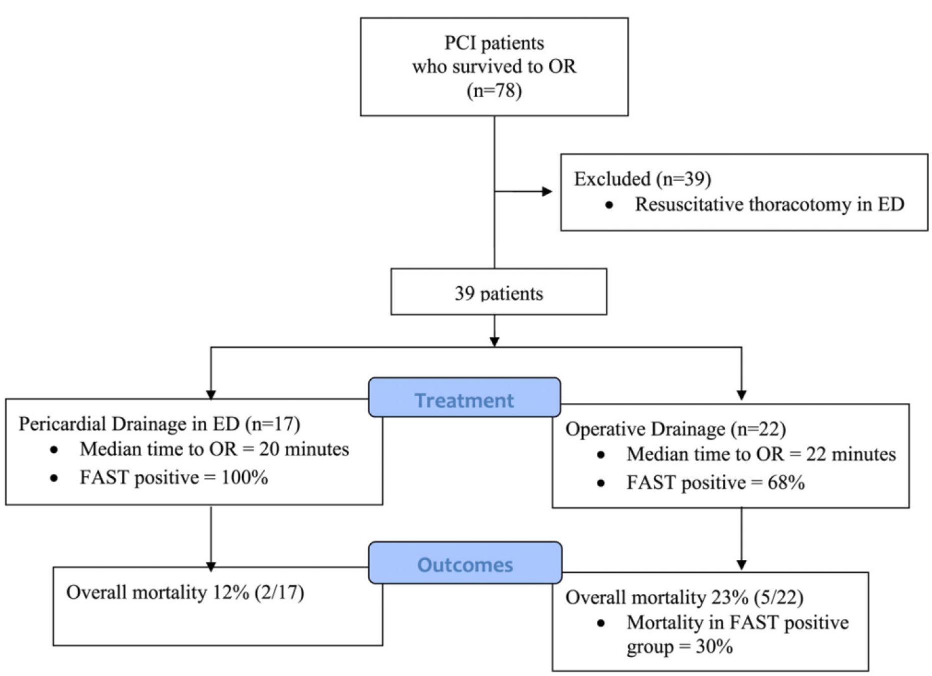

Figure 3 Algorithm for treatment after penetrating cardiac njury (PCI). ED, emergency department; FAST, focused abdominal sonography for trauma.

trauma patients with pericardial fluid on admission CT scan over a 6-year period at a busy level 1 trauma center. Seven patients underwent operative management, six of whom had hypotension and/or EKG changes. Interestingly, none had cardiac injuries that required repair. Of the patients managed non-operatively, none went on to need surgery and none died.[21] These findings are supported by another study of 30 patients.[22]

Cardiac injury is effectively ruled out when pericardial fluid is found to be non-bloody. However, if the fluid does appear bloody, blood and clot should be cleared with suction and irrigation. If the bleeding stops and the drainage clears, then the wound may have sealed, or the injury may be only partial thickness. In these situations, sternotomy can be deferred in favor of pericardial drain placement and close observation in select patients. If bloody drainage continues to accumulate despite irrigation, then exploration is required. This recommendation is supported by literature from South Africa. A pilot study completed by Navsaria and Nicol found that 71% (10 out of 14) patients with penetrating chest trauma had a non-therapeutic sternotomy performed for bloody drainage identified during pericardial window.[23] The same group went on to perform a randomized controlled trial in which hemodynamically stable patients with penetrating chest trauma resulting in hemopericardium, pneumopericardium, or clinical suspicion and equivocal imaging underwent pericardial window. Importantly, the window was performed *after* 24 hours of observation. The pericardial sac was 'irrigated vigorously' with 500 cc of warm saline and if active bleeding was identified a median sternotomy was performed. If the bloody drainage cleared, then the patient was randomized to sternotomy or observation with drain placement. A total of 111 patients were randomized, 109 of which suffered stab wounds. Of the 55 patients who underwent sternotomy, 51 (93%) had either no cardiac injury (13) or a tangential/partial thickness wound (38). In all four patients with full thickness injuries, the wound had sealed by the time of surgery. Ultimately, no patients required surgery in the observation group. It should be emphasized that most patients were stabbed and all of them were observed for 24 hours before the pericardial window was performed.[13] Similarly, Thorson *et al* reviewed data from patients with chest trauma who underwent pericardial window (377 patients) and/or median sternotomy (110 patients). They found that 21 (38%) patients with hemopericardium identified on pericardial window went on to have a non-therapeutic sternotomy.[24]

Pigtail catheters have been used sparingly in the management of potential cardiac injuries. There is extremely limited data to support a drainage-first approach for hemopericardium. In fact, there is only one contemporary study that reports on its usage. Jones *et al* shared their experience at Denver Health over a 16-year period, where 17 patients with pericardial fluid on ultrasound underwent percutaneous pericardial drainage in the ED before going to the OR. Drainage was successful in all but one patient. Drainage volume ranged from 15 to 200 cc of fluid, there were no drain-related complications, and blood pressure improved in over half of the patients. There was also no delay in time to the OR (figure 3).[25]

Summary

Placement of a pigtail catheter at bedside or creation of a pericardial window are minimally invasive options available in the management of chest trauma. Placement of a pigtail catheter requires a learning curve for safety and success. Based on current data, in the hands of experienced users, the safety and efficacy appear comparable to that of a traditional chest tube for non-emergent pneumothorax, hemothorax, or hemopneumothorax. Compared with large bore thoracostomy tubes, pigtails are associated with improved pain at the tube site, and improved IPE, as rated by the patient. There may also be a difference in tube duration of <1 day in favor of pigtail catheters, although this is based on low-quality evidence. Most providers remain hesitant to use pigtail catheters for hemodynamically or respiratory unstable trauma patients, and professional guidelines do not currently support the practice in hemodynamically unstable patients with hemothorax.

Definitive treatment for cardiac injuries remains median sternotomy, although a pericardial window can be considered for hemodynamically stable patients without cardiac tamponade. If the pericardial fluid is not bloody, or if it clears after irrigation, the pericardium can be drained without proceeding to sternotomy. Finally, using a percutaneous drainage-first approach for hemopericardium has been described by a single center but remains outside the standard of care in trauma.

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