Selective Operative Management of Penetrating Chest Injuries

Andrew John Nicol[1] · Sorin Edu[1] · Pradeep Navsaria[1]

Abstract

Purpose of Review The aim of this review was to review the recent literature with respect to penetrating chest injuries so as to provide an update on the current/changing management of these injuries.

Recent Findings The management of a stable patient following penetrating chest trauma with a hemopericardium on ultrasound has changed from routine sternotomy to a pericardial window and drainage, with a sternotomy reserved for those patients who have active bleeding at the time of the pericardial window. It is imperative to diagnose and repair an occult left-sided diaphragm injury and this can be achieved laparoscopically once a hollow organ injury has been excluded. Small pneumothoraces less than 2 cm may be observed in asymptomatic patients provided the patient is not on positive pressure ventilation, and hemothoraces of less than 300 mL may be managed with observation alone.

Summary There are new management strategies evolving in the patient presenting with penetrating thoracic trauma and it is important that surgeons managing these patients are aware of these changes.

✉ Andrew John Nicol
    andrew.nicol@uct.ac.za

    Sorin Edu
    sorinedu@yahoo.com

    Pradeep Navsaria
    pradeep.navsaria@uct.ac.za

[1] Trauma Centre, Groote Schuur Hospital, University of Cape Town, Cape Town, South Africa

Introduction

The mortality rate from a penetrating chest wound is a major contributor to non-natural deaths. However, the vast majority of these deaths occur in the pre-hospital phase. The in-hospital mortality rate can be as staggering low at 2% of admissions, this obviously being relative to the proportion of gunshot (GSW) to stab wounds (SW) encountered. At Groote Schuur Hospital in Cape Town, South Africa approximately 25% of our penetrating thoracic injuries (PTI) are gunshot related. We have found that 83% of PTI can be managed by observation and/or chest drainage [1]. Selective operative management (SOM) is safe and effective but it is essential to have a clinical algorithm to ensure that patients are appropriately investigated and managed. The trend towards more conservative, non-operative management continues but it must be recognized that patients can deteriorate rapidly and there is a need for very close monitoring.

The failure of SOM is in the region of 7% and predominantly related to retained pleural collections/empyema, and missed penetrating cardiac injuries. This raises the question about how we screen patients for cardiac trauma and the role of early video-assisted thoracoscopic surgery. What is also topical is the best way to exclude a penetrating diaphragm injury following a penetrating thoraco-abdominal wound.

Screening for a Penetrating Cardiac Injury

Penetrating cardiac injuries (PCI) predominantly present with hypovolaemic shock or cardiac tamponade and are fairly easy to diagnose. Approximately one-third of patients of with a PCI present with a penetrating thoracic wound and haemodynamic stability. These patients are classified as "occult cardiac injuries", and in these patients the diagnosis of a PCI may be difficult. The current international practice is to screen for occult cardiac injuries with an ultrasound (US) of the pericardial sac. If the US confirms the presence of fluid in the sac then the patient undergoes a subxiphoid pericardial window (SPW). Early reported sensitivity of the US in diagnosing an occult cardiac injury was reported to be 100%. In our experience, the sensitivity of US is only in the region of 86% and false negative scans are associated with the presence of a hemothorax [2•]. The largest prospective multicentre study, prior to our study, had only 29 patients with confirmed cardiac injuries and the smallest contained 6 patients [3]. What is apparent when looking at the literature with respect to the sensitivity and specificity of ultrasound in detecting pericardial fluid are the small numbers of patients with actual PCI included (Table 1) [4–8].

A problem of false negatives with US has been well documented in the literature. In 2009 Ball et al. published a retrospective series of 228 patients from the USA in which there were 5 false negative scans [9•]. These five patients all had associated left-sided hemothoraces and had normal repeat ultrasounds performed after drainage of the haemothorax. Two of the five patients (40%) with missed cardiac injuries after a negative US died. It was surmised that the pericardial collection had drained into the chest through a pericardial hole and this was the cause of the negative US [9•].

As a general rule, one has to be aware of other screening modalities to exclude a hemopericardium. Such modalities include the presence of a J wave on the electrocardiogram [10] and a straight left heart border [11]. The presence of either of these findings should prompt the surgeon to perform a SXW even in the face of a negative US report.

It is important to realize a gunshot wound to the chest can result in a PCI even if outside the cardiac box and a cardiac injury should be suspected in all gunshot wounds [12].

Pericardial Drainage for a Hemopericardium on Ultrasound After Penetrating Chest Trauma in the Stable Patient

A RCT published in 2014 confirmed that hemodynamically stable patients with a hemopericardium detected on US can be successfully managed with a subxiphoid pericardial window (PCW). Unstable patients with evidence of bleeding, cardiac tamponade, a murmur suggestive of a traumatic septal defect or valvular injury are not considered to be candidates for this minimal surgical approach. The PCW will confirm the presence of a hemopericardium and allows for irrigation of the pericardial sac. Approximately 4% of stable patients will have active bleeding at PCW and require a median sternotomy. The remainder can be successfully managed with this procedure alone thereby avoiding a median sternotomy. Pericardial lavage is an important component of this management as the aim is to dispel any unstable clot that may precipitate a delayed bleed. The patient should be managed in a high care unit pre-and post-operatively and a soft drain should be left in the pericardial sac if a hemopericardium is confirmed. This allows for the monitoring of any post-operative bleed [13••].

Penetrating Thoraco-Abdominal Trauma

The thoraco-abdominal region is defined as the region between the sternum and fourth intercostal space anteriorly, the vertebra and lower tip of scapula posteriorly and

Table 1 Prospective series in the literature dealing with the detection of a haemopericardium on ultrasound in stable patients after penetrating chest trauma

Study	Design	Number of patients with penetrating chest injuries	Number of cardiac injuries confirmed at surgery	Sensitivity (%)	Specificity (%)	False −	False +
Ma et al. [4]	Prospective	Not stated	6	100	99	0	1
Rozycki et al. [6]	Prospective	247	10	100	100	0	0
Rozycki et al. [5]	Prospective	313	22	100	99	0	2
Rozycki et al. [3]	Prospective	261	29	100	97	0	7
Bokhari et al. [7]	Prospective	49	Not stated	100	50	0	20
Tayal et al. [8]	Prospective	32	8	100	100	0	0
Nicol et al. [2•]	Prospective	172	135	86	77 (PPV)	18	19

PPV positive predictive value

the costal margin inferiorly. Penetrating injuries in this region are frequently associated with multi-cavity injury (both thorax and abdomen), and multiple per cavity injuries that may require operative intervention. This may cause both diagnostic and therapeutic dilemmas.

Depending on the trajectory, *cardiac injuries* need to be excluded [14] and *diaphragmatic injuries* maybe seen in as high as 60% of patients [15]. Furthermore, there is a high rate of negative thoracotomies (22%) or laparotomies (11%) and inappropriate sequencing is found in 44% of patients undergoing thoracotomy and laparotomy [16].

Cardiac injuries with arrest, hypovolaemic shock, tamponade, chest drain output (1500 mL immediately or > 150–200 mL/h), peritonitis or haemodynamic instability due to intra-abdominal haemorrhage are clear indications to proceed with *surgery*.

Which injury is bleeding more, and needs to be addressed first, is not always clear. The chest drain output maybe from an intra-abdominal source through a diaphragm laceration. Ultrasound is of benefit, especially to search for hemopericardium, but may result in a false-positive in the presence of a moderate haemothorax [16]. The burden of both a thoracotomy and laparotomy are immense for the patient, and unnecessary surgery should be avoided as the mortality is doubled in these patients.

In a cohort of patients with thoraco-abdominal stab injuries, half of all patients (53%) required a laparotomy only, the indications being a hollow viscus perforation, a diaphragm injury or a bleeding solid organ [17]. No surgery was required in 40% of patients. The remainder had a thoracotomy/sternotomy, nearly always because of a cardiac injury. The authors in this study concluded that in unstable patients, a cardiac injury must be ruled out first. If clear signs of a cardiac injury are absent, the best approach is to start with a laparotomy, and if there remains a concern regarding a cardiac injury, then a *diagnostic transdiaphragmatic pericardial* window can be made (through an existing diaphragm laceration that can be extended). If the pericardial window reveals blood, then a cardiac injury needs to be excluded and the chest needs to be opened (thoracotomy or sternotomy).

Gunshot wounds producing thoraco-abdominal injuries are more complex and most of these patients (66%) require a laparotomy, with 14% requiring a laparotomy and thoracotomy/sternotomy [18]. In this series, 14% of patients had no surgery. In total one-third needed a thoracotomy; however, most of these patients were in extremis with either experiencing a cardiac arrest or an agonal rhythm and had an emergency department thoracotomy (EDT) with poor outcomes. The authors concluded that patients either have clear signs of cardiac or major thoracic vascular injuries requiring EDT or have hemodynamic instability requiring a laparotomy. If patients have a clear indication to proceed with a laparotomy but no clear indication to proceed with a thoracotomy, these patients ideally have a transdiaphragmatic pericardial window first to rule out a cardiac injury if the trajectory is close to the heart. Some authors recommend a subxyphoid approach instead. A subxyphoid pericardial window (PCW) has a lower risk of pericardial contamination with gastrointestinal contents and can diminish the rate of negative sternotomies and mortality.

In thoraco-abdominal injuries there is a general increased risk of pleural empyema due to the spillage of gastrointestinal contents through the diaphragmatic injury into the chest. One safe way to reduce the risk of intrathoracic septic complications is to enlarge the diaphragmatic injury for a thorough transpleural lavage before closure of the diaphragm defect [19].

Occult Diaphragm Injury

Up to two-thirds of patients with a penetrating thoraco-abdominal trajectory have a diaphragmatic injury [15]. Complications include herniation, incarceration and strangulation of bowel into the chest with a morbidity and mortality of 30% and 10%, respectively [20]. Delayed or missed diagnosis must be avoided and left-sided diaphragmatic injuries particularly should be addressed as these have a much higher rate of subsequent hernia formation. Some patients present with a clear indication for surgery, other than the diaphragmatic injury, and proceed to laparotomy or thoracotomy/sternotomy, at which a thorough examination of the diaphragm must be performed and an injury repaired. In stable, asymptomatic patients, the algorithm is more ambiguous. Clinical examination cannot clearly establish the diagnosis. Hemo- and/or pneumothorax are most often seen on a chest X-ray; however, one-third have a normal chest X-ray [21]. The overall CT accuracy and sensitivity is low. Although thoracoscopy and laparoscopy have a high accuracy; they are, however, invasive. In a report of 24 highly selected patients with possible diaphragmatic injuries, the patients underwent diagnostic and therapeutic laparoscopy *after* 24–36 h of uneventful clinical observation (hence precluding any hollow viscus injury). The asymptomatic stable patient, who completes a trial of abdominal observations successfully, should undergo a delayed diagnostic laparoscopy to exclude a diaphragm injury, as early laparoscopy tends to be associated with a high conversion rate to laparotomy [22].

Managing a hemo- pneumothorax

Stable *pneumothoraxes*, *hemothoraces* and a combination thereof, are the most common injuries sustained in PTI. Thoracostomy tube drainage has been the mainstay of

treatment, for these conditions for the last half century. More recently, there has been a differentiated approach, in the management of pnemothoraxes and haemothoraxes, which takes into account, size, mechanism of injury, clinical impact of the pneumo/haemo as well as complications.

Some authors suggest observation only, for all pneumothoraxes of less than 2 cm (as measured from the apex of the lung to the highest point of the cupula) in asymptomatic patients. They report successful management with observation, only, in 97% of patients [23]. Others venture so far as to advise observation for small pneumothoraxes even for patients on Positive Pressure Ventilation [24]. This conservative approach has been advocated also for CT detected pneumothoraxes, for sizes of up to 35 mm (measured from chest wall to edge of lung) [28]. These publications raise the question of what pneumothoraxes should we drain? The short answer to that question is: all symptomatic pneumothoraxes. A special mention should be made of Tension Pneumothorax, which remains a surgical emergency, is diagnosed clinically and requires immediate needle decompression. However, the site of needle decompression, in adults, has changed, and the third intercostal space, midclavicular line is no longer recommended, being replaced by the traditional site of thoracostomy tube insertion, in the fifth intercostal space midaxillary line (ATLS 10th Edition). Another perennial question is what size catheter should one use, and that applies to both pneumo- and hemothoraxes. Traditionally we used a size 18–32 Fr for either, but in recent years changed to using a 14 Fr Percutaneous Cavity Drainage Catheter (Arrow International®) for drainage of pneumothoraxes with good results. Small size catheter usage via a Seldinger technique for traumatic pneumothoraxes is a validated method in the literature [25] and has proven useful in our centre. Failure of resolution of a pneumothorax after thoracostomy tube insertion, the presence of a large air leak, increase in size of a pneumothorax in spite of appropriate sitting of the tube, mandates the use of negative pressure suction. We use 20 cm of water (2 kPa) negative pressure to this effect. Large pneumothoraxes, large air leaks, bronchopleural fistula mandate the use of larger drains 22–28 Fr, and if the first drain is ineffectual, a second is inserted and both are put on negative pressure suction. If all fails the patient is referred for a bronchoscopy and surgery. Surgery consists of VATS or thoracotomy depending on the pathology and surgeon's preference. VATS (Video-Assisted Thoracosocpic Surgery) can accomplish most of the desired procedures, from simple oversewing of visceral pleura, to non-anatomic lung resection to lobectomy, depending on the surgeon's expertise and available instrumentation.

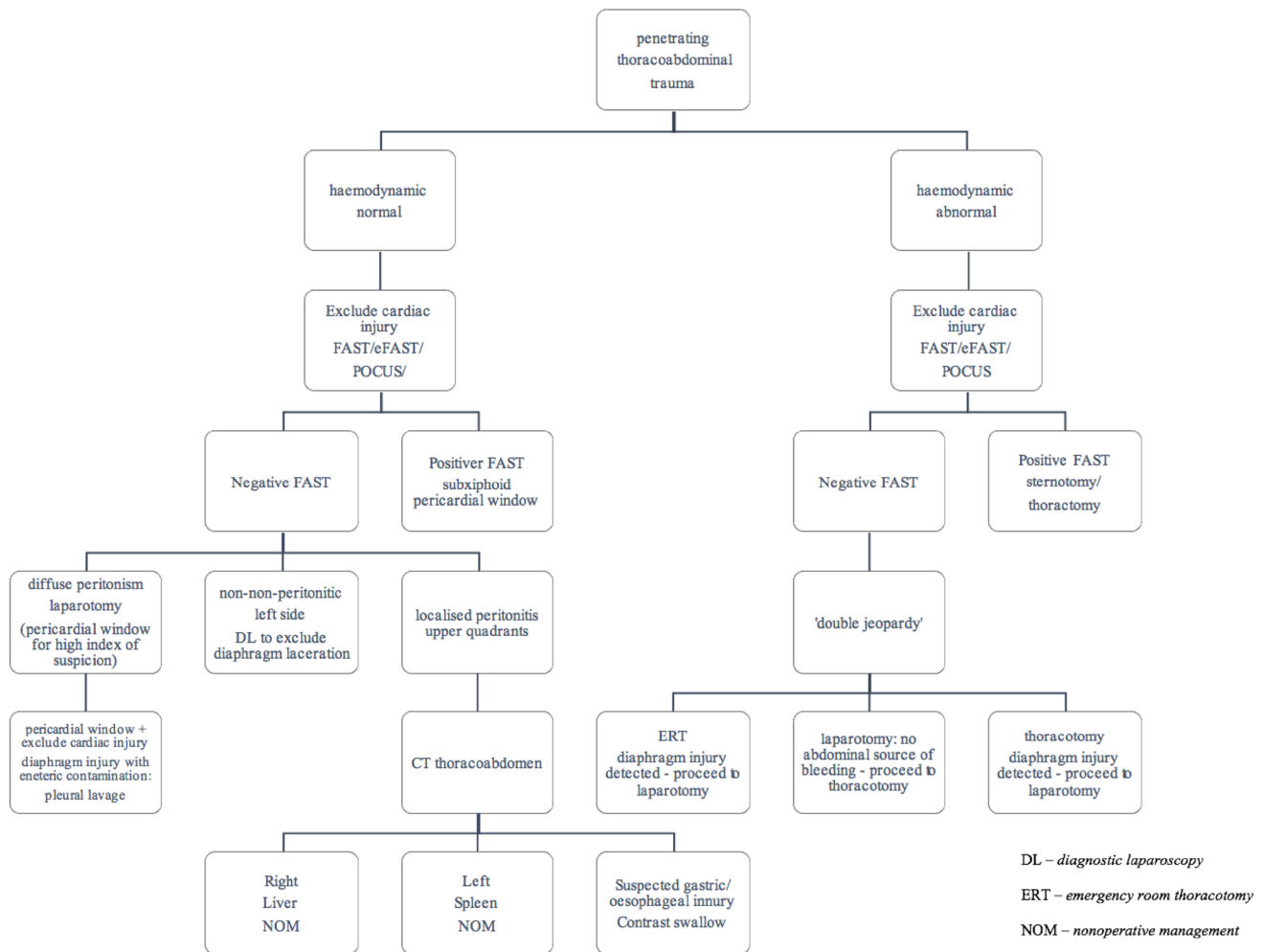Hemothoraxes after penetrating thoracic trauma require a more aggressive, interventional approach. While some surgeons would drain all hemothoraxes (EAST guidelines, level III recommendation), the majority view of Trauma Surgeons is that small hemothoraxes, of less than 300 mL can be managed conservatively, with observation alone [26, 27].

In our Unit, small hemothoraxes are managed expectantly, through observation with good results. Large hemothoraxes, more than 500 mL, we drain via a thoracostomy tube. We use a size 28–32 Fr catheter, placed in sterile conditions in the 4th–5th intercostal space mid to anterior axillary Line. The vast majority of patients arrive to our Unit with the thoracostomy tube in situ, having been inserted at the referring hospital.

The incidence of retained Haemothorax, after thoracostomy tube insertion, is between 4 and 5%. We identified the following as contributors to drainage failure: tube misplacement, displacement, blockage, kinking, large initial hemothorax, polytrauma, need for mechanical ventilation and *failure to mobilize*. Retained hemothorax remains a management problem because of the associated complication rate (up to 50%, in some series), and particularly the high incidence of empyema, which can be 15 times higher than in those without a retained haemothorax [29].

Considerable effort has been put in preventing retained hemothoraxes after trauma, with some authors suggesting suction before insertion of the thoracostomy tube [30], others suggesting irrigation with 1 L of warm saline immediately after placement of the tube [31], or VATS as the initial management tool for all traumatic hemothoraxes. There is no consensus as to an alternative to simple thoracostomy tube insertion for the acute traumatic haemothorax. The same can be said for the retained hemothorax. Management varies with institution and surgeons. Most surgeons agree, however, that thoracostomy tube reinsertion is the least effective treatment modality and prefer other: VATS (multiport/uniport) [33, 34], intrapleural fybrinolitics [32] or a combination of the two leaving thoracotomy as a "salvage" procedure, when everything else fails.

In our series, part of a prospective randomized controlled study (in progress), VATS has proven effective, with a technical success rate of 85% (23/27 patients), the other 15% ($n = 4$) required a thoracotomy due to a thick cortex. We have not used intrapleural fybrinolitics, though some authors describe equal results to VATS by using either streptokinase, urokinase or tPA [32]. For our Video-Assisted Thoracoscopic Surgery we use a 2(+ 1) port technique. There is however an ever-growing volume of literature that suggests equal outcomes with uniportal VATS, with the added bonus of less post-operative pain [33]. Indeed, the future might belong to uniportal VATS, but at this moment there is a lack of large randomized prospective trials to compare uniportal to multiport VATS.

Fig. 1 Management algorithm for penetrating thoracoabdonimal trauma

Conclusion

Selective operative management (SOM) is safe and effective in the management of penetrating thoracic trauma with an anticipated failure rate of around 7% that is primarily caused by the development of complications. A management algorithm for the management of these injuries is presented in Fig. 1.

Compliance with Ethical Guidelines

Conflicts of interest Andrew John Nicol, Sorin Edu, and Pradeep Navsaria declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

References

Papers of particular interest, published recently, have been highlighted as:
• Of importance
•• Of major importance

1. Van Waes OJ, Halm JA, Van Imhoff DI, et al. Selective non-operative management of penetrating thoracic injury. Eur J Emerg Med. 2018;25(1):32–8.
2. • Nicol AJ, Navsaria PH, Beningfield S, Hommes M, Kahn D. Screening for occult penetrating cardiac injuries. Ann Surg. 2015;261(3):573–8. *Ultrasound screening for a pericardial effusion after penetrating trauma can result in false positives and false negatives particularly if there is an associated hemothorax.*
3. Rozycki GS, Feliciano DV, Ochsner MG, et al. The role of ultrasound in patients with possible penetrating cardiac wounds: a prospective multicenter study. J Trauma. 1999;46:543–52.
4. Ma OJ, Mateer JR, Ogata M, et al. Prospective analysis of a rapid ultrasound examination performed by emergency physicians. J Trauma. 1995;38:879–85.

5. Rozycki GS, Balllard RB, Feliciano DV, et al. Surgeon performed ultrasound for the assessment of truncal injuries: lessons learned from 1540 patients. Ann Surg. 1998;228:557–67.

6. Rozycki GS, Feliciano DV, Ochsner MG, et al. The role of ultrasound in patients with possible penetrating cardiac wounds: a prospective multicenter study. J Trauma. 1999;46:543–52.

7. Bokhari F, Nagy K, Roberts R, et al. The ultrasound screen for penetrating truncal trauma. Am Surg. 2004;70:316–21.

8. Tayal VS, Beatty MA, Marz JA, et al. FAST (focused assessment with sonography in trauma) accurate for cardiac and intraperitoneal injury in penetrating anterior chest trauma. J Ultrasound Med. 2004;23:467–72.

9. • Ball CG, Williams BH, Wyrzykowski AD, et al. A caveat to the performance of pericardial ultrasound in patients with penetrating cardiac wounds. J Trauma. 2009;67:1123–4. *Ultrasound screening may result in false negatives*.

10. Nicol AJ, Navsaria PH. The J wave: a new electrocardiographic sign of an occult cardiac injury. Injury. 2014;45:112–5.

11. Nicol AJ, Navsaria PH, Beningfield S, et al. A straight left heart border: a new radiological sign of a hemopericardium. World J Surg. 2014;38:211–4.

12. Jhunjhunwala R, Mina MJ, Roger EI, et al. Reassessing the cardiac box: a comprehensive evaluation of the relationship between thoracic gunshot wounds and cardiac injury. J Trauma Acute Care Surg. 2017;83:349–55.

13. •• Nicol AJ, Navsaria PH, Hommes M, et al. Sternotomy or drainage for a hemopericardium after penetrating trauma. A randomized controlled trial. Ann Surg. 2014;259:438–42. *This is the first randomized trial on stable patients with a hemopericardium after penetrating trauma and showed that simple drainage is sufficient if there is no active bleeding at the time of the procedure*.

14. Hommes M, Nicol AJ, van der Stok J, et al. Subxiphoid pericardial window to exclude occult cardiac injury after penetrating thoracoabdominal trauma. Br J Surg. 2013;100(11):1454–8.

15. D'Souza N, Clarke D, Laing G. Prevalence, management and outcome of traumatic diaphragm injuries managed by the pietermaritzburg metropolitan trauma service. Ann R Coll Surg Eng. 2017;99:394–401.

16. Matushima K, Khor D, Berona K, Antoku D, Dollbaum R, Kahn M, Demetriades D. Double jeopardy for penetrating trauma: get FAST, get it right. World J Surg. 2018;42:99–106.

17. Berg RJ, Karamanos E, Inaba K, et al. The persistent diagnostic challenge of thoracoabdominal stab wounds. J Trauma Acute Care Surg. 2014;76(2):418–23.

18. Berg RJ, Inaba K, Okoye O, et al. The peril of thoracoabdominal firearm trauma: 984 civilian injuries reviewed. J Trauma Acute Care Surg. 2014;77(5):684–91.

19. Zellweger R, Navsaria PH, Hess F, et al. Transdiaphragmatic pleural lavage in penetrating thoracoabdominal trauma. Br J Surg. 2004;91(12):1619–23.

20. Petrone P, Asensio JA, Marini CP. Diaphragmatic injuries and post-traumatic diaphragm hernias. Curr Probl Surg. 2017;54(11–32):88.

21. Shaw JM, Navsaria PH, Nicol AJ. Laparoscopy-assisted repair of diaphragm injuries. World J Surg. 2003;27(6):671–4.

22. McDonald AA, Robinson BRH, Alarcon L, Dorion H, Haut ER, Juern J, Madbak F, Reddy S, Weiss P, Como JJ. Evaluation and management of traumatic diaphragmatic injuries: a practice management guideline from the East Association for the Surgery of Trauma. J Trauma Acute Care Surg. 2018;85(1):198–207.

23. Kong VY, Oosthuizen GV, Clarke DL. The selective conservative management of small traumatic pneumothoraces following stab injuries is safe: experience from a high-volume trauma service in South Africa. Eur J Trauma Emerg Surg. 2015;41(1):75–9.

24. Walker SP, Barratt SL, Thompson J, et al. Conservative management in traumatic pneumothoraces: an observational study. Chest. 2018;153(4):946–53. https://doi.org/10.1016/j.chest.2017.10.015.

25. Kulvatunyou N, Erickson L, Vijayasekaran A, et al. Randomized clinical trial of pigtail catheter versus chest tube in injured patients with uncomplicated traumatic pneumothorax. Br J Surg. 2014;101(2):17–22. https://doi.org/10.1002/bjs.9377.

26. Wells BJ, Roberts DJ, Grondin S, et al. To drain or not to drain? Predictors of tube thoracostomy insertion and outcomes associated with drainage of traumatic hemothoraces. Injury. 2015;46(9):1743–8. https://doi.org/10.1016/j.injury.2015.04.032.

27. Demetri L, Martinez Aguilar MM, Bohnen JD, et al. Is observation for traumatic hemothorax safe? J Trauma Acute Care Surg. 2018;84(3):454–8.

28. Eddine SBZ, Boyle KA, Dodgion CM, et al. Observing pneumothoraces: the 35 millimeter rule is safe for both blunt and penetrating chest trauma. J Trauma Acute Care Surg. 2019;86:557–64.

29. Karmy-Jones R, Holevar M, Sullivan RJ, Fleisig A, Jurkovich GJ. Residual hemothorax after chest tube placement correlates with increased risk of empyema following traumatic injury. Can Respir J. 2008;15(5):255–8.

30. Ramanathan R, Wolfe LG, Duane TM. Initial suction evacuation of traumatic hemothoraces: a novel approach to decreasing chest tube duration and complications. Am Surg. 2012;78(8):883–7.

31. Kugler NW, Carver TW, Milia D, et al. Thoracic irrigation prevents retained hemothorax: a prospective propensity scored analysis. J Trauma Acute Care Surg. 2017;83(6):1136–41.

32. Hendriksen BS, Kuroki MT, Armen SB, et al. Lytic therapy for retained traumatic hemothorax: a systematic review and meta-analysis. Chest. 2019;155:805–15.

33. Sanna S, Bertolaccini L, Brandolini J, et al. Uniportal video-assisted thoracoscopic surgery in hemothorax. J Vis Surg. 2017;14(3):126. https://doi.org/10.21037/jovs.2017.08.06.

34. Billeter AT, Druen D, Franklin GA, et al. Video-assisted thoracoscopy as an important tool for trauma surgeons: a systematic review. Langenbecks Arch Surg. 2013;398:515–23.