TACTICAL COMBAT CASUALTY CARE: TRANSITIONING BATTLEFIELD LESSONS LEARNED TO OTHER AUSTERE ENVIRONMENTS

Treatment of Thoracic Trauma: Lessons From the Battlefield Adapted to All Austere Environments

Lanny F. Littlejohn, MD

From the Naval Hospital Camp Lejeune, Norfolk, VA.

Severe thoracic trauma in the backcountry can be a formidable injury pattern to successfully treat. Traumatic open, pneumo-, and hemothoraces represent some of the most significant patterns for which advanced equipment and procedures may help leverage morbidity and mortality, particularly when evacuation is delayed and environmental conditions are extreme. This paper reviews the development of successful techniques for treating combat casualties with thoracic trauma, including the use of vented chest seals and the technique of needle thoracentesis. Recommendations are then given for applying this knowledge and skill set in the backcountry.

Keywords: chest trauma, chest seals, needle thoracentesis, prehospital, combat trauma, pneumothorax

Introduction

Thoracic injury accounts for 25% of all trauma mortality,¹ and pneumothorax (PTX) is the single most common manifestation of intrathoracic blunt chest injury.² Overall the vast majority of patients with thoracic trauma does not require thoracic surgery but may require other invasive procedures to manage their injury successfully. Traumatic PTX is a leading cause of preventable mortality in multitrauma patients.³ In combat settings, hemopneumothorax is the second leading cause of preventable combat death and the third leading cause of mortality overall.⁴

The presence of PTX reduces the physiologic negative pressure of normal respiratory mechanics and makes spontaneous breathing progressively more difficult and inefficient. In the backcountry, the risk of thoracic trauma is most likely blunt trauma from falls, but penetrating mechanisms such as gunshot wounds and animal attacks also are possible and have been reported.⁵ In civilian settings, most thoracic trauma is managed

with supplemental oxygen, tube thoracostomy, and mechanical ventilation when necessary. None of these are likely to be available or advisable in austere settings. Thus, wilderness medicine providers must look to practical means to treat chest trauma when resources are limited and evacuation is prolonged.

Mechanisms and Patterns of Injury

Both penetrating and blunt mechanisms can lead to air and blood accumulating in the chest. Three conditions that lead to the most morbidity and mortality in the combat setting will be reviewed, framing treatment considerations in all austere settings.

An open PTX entails the collapse of the lung due to an associated chest wall defect that allows air to enter during inspiration and exit during expiration (eg, the “sucking” chest wound). It is possible that an open PTX may lead to respiratory compromise or even failure, depending on the size of the defect.⁶ The larger the defect, the more likely that air will enter the thorax through the wound during inspiration rather than through the trachea.

A hemothorax occurs from bleeding of the chest wall, lung parenchyma, or pulmonary vessels and is more likely than a PTX to occur in the context of blunt trauma from falls.⁷ Rib fractures due to thoracic trauma are in

Corresponding author: Lanny F. Littlejohn, MD, Naval Hospital Camp Lejeune; e-mail: eoddm@gmail.com.

Presented at the Tactical Combat Casualty Care: Transitioning Battlefield Lessons Learned to Other Austere Environments Preconference to the Seventh World Congress of Mountain & Wilderness Medicine, Telluride, Colorado, July 30–31, 2016.

the range of 40 to 80% in blunt thoracic trauma cases.⁸ Decompression of the pleura and re-expansion of the lung may allow for parenchymal bleeding to tamponade and ventilation-perfusion to be matched more closely. Thus, decompression of the pleura is beneficial in the treatment of both hemo- and pneumothoraces.

A tension PTX occurs when an injury to the lung, bronchi, or trachea allows a continuous leakage of air into the pleural space and progressively collapses the lung when air cannot escape. This is a disease entity that is different in the awake patient versus the ventilated patient and should be taught in this manner. When a casualty is under positive pressure ventilation, development of a tension PTX can be rapid. With normal pulmonary mechanics (relative negative pressure), the development takes much longer. In spontaneously breathing animal models and human case reports, the pathophysiology is hypoxia from pulmonary shunting and parenchymal collapse,⁹ with decompensation occurring from progressive respiratory failure and respiratory arrest.^{10,11} The disease in awake, spontaneously breathing patients is progressive and primarily respiratory in clinical appearance, with hypoxemia predominating over hypotension.¹² In ventilated patients, the fall in hemoglobin saturation indicated by pulse oximetry (SpO₂) happens abruptly and is followed quickly by hypotension.¹³ Thus, hypotension from a tension PTX in the spontaneously breathing patient is a rare but ominous finding.

Diagnosis

Any patient who presents with penetrating inferior neck or thoracoabdominal trauma could have wounds that result in an open, pneumo-, or hemothorax. Those with blunt trauma with obvious rib fractures or signs of significant trauma to the thorax (abrasions, ecchymosis) also may have a pneumo- or hemothorax. Usually a patient will report pain and progressive dyspnea. Asymmetric chest movement with respirations, decreased breath sounds, subcutaneous emphysema, or paradoxical movement of a flail chest segment may be seen. Application of a portable pulse oximeter may show hypoxia and tachycardia well before a fall in blood pressure in the spontaneously breathing patient. Hypotension is not common in awake patients, and its presence should signal the hunt for other causes. Tracheal deviation and jugular venous distension are rare findings and indicate imminent circulatory collapse.

Treatment

A small PTX may not require treatment but is important to recognize in the context of positive pressure ventilation or air transport requirements, in which there will be

changes in ambient pressure. Under those conditions, a simple PTX can develop tension. For an open PTX, chest seals are recommended. These are manufactured as occlusive or ventilated (one-way valve) seals. For hemo- or pneumothoraces, decompression of the pleural space must be performed to maximize oxygenation and cardiac output. This can be accomplished with needle thoracentesis (NT) or via simple thoracostomy.

CHEST SEALS

Recently, a 3-sided occlusive dressing was advocated by the Advanced Trauma Life Support Curriculum.¹⁴ This fell out of favor after a thorough review of the literature found no evidence for, or against, this practice. At that time, occlusive chest seals were recommended for the treatment of open PTX.

Legitimate concerns were raised that chest seals might fail due to coagulation, vent malfunction, or poor skin adherence. Thus the 2 most common chest seals at the time, the Bolin (H&H Medical, Williamsburg, VA) and the Asherman (Teleflex Medical, Morrisville, NC), were tested by Arnaud et al at the US Navy Medical Research Center. In a spontaneously breathing swine model, a 1.5-cm hole was made (held open with a cut portion of a 10-mL syringe) and air was introduced to obtain a 20% fall in mean arterial pressure (average, 372 mL). A total of 1500 mL of air was introduced unilaterally with no fall in mean arterial pressure when the seals were applied. Both vented CS worked well as described and adherence was good on dry skin, but on wet/soiled skin the Bolin profoundly outperformed the Asherman.¹⁵ The Bolin's hydrogel, layered on a rugged polyurethane disc, not only adhered well but allowed for easier relocation and "burping" of the seal if it failed to vent.

In 2012, the Committee on Tactical Combat Casualty Care (CoTCCC) began to question the practice of treating a usually nonlethal condition (open PTX) in a manner predisposed to a lethal condition (tension PTX). Kheirabadi et al looked at this question by comparing the use of vented and nonvented chest seals¹⁶ using a model similar to that of Arnaud et al.¹⁵ They compared the unvented HALO (Progressive Medical, Fenton, MO) to the vented Bolin. In all instances, the HALO led to a tension PTX after injection of air, whereas the Bolin did not. For both seal types, application to an open PTX led to immediate improvement in respiratory function and oxygenation. This model did not test a hemopneumothorax, however, and concerns over clotting remained.

Kotora et al would next compare 3 vented CS in a model that tested the decompression of a tension PTX and then a hemopneumothorax with a 10% autologous

injection of blood volume into the thoracic cavity in a similar swine model. They found that the SAM (SAM Medical, Wilsonville, OR), Hyfin (North American Rescue, Greer, SC), and Sentinel (Combat Medical Systems, Harrisburg, NC) chest seals all adhered well and vented both blood and air without the feared complication of clotted blood occluding the vent.¹⁷

Finally, Arnaud et al again compared several commercial vented CS for adhesive properties and found that 4 demonstrated superior performance in soiled, wet, hot, and cold conditions: the SAM, Hyfin, Russell (Tactical Medical Solutions, Anderson, SC), and Fast Breathe (Fasttrack Medical Solutions, Eden Prairie, NM).¹⁸ It was noted that the efficacy of the different valves in these seals needed to be further tested.

Thus, the CoTCCC currently recommends vented chest seals as the first line treatment of open pneumothoraces with occlusive chest seals used as a last resort and with attention paid to the patient for development of tension PTX if an occlusive seal is applied.¹⁹ Given the existing literature, it appears that any of the 4 vented chest seals in the most recent Arnaud et al¹⁸ article can be recommended for use in austere environments.

PLEURAL DECOMPRESSION

NT initially was taught as a life-saving intervention, primarily based on consensus and expert opinion. In the past few years, its safety and efficacy have been called into question.

NT is the most rapid and simple method of relieving high pressure air from the thorax if tension is present. If successful, there should be an audible rush of air and gradual improvement in clinical signs and symptoms.^{20,21} The Advanced Trauma Life Support Curriculum recommended decompression in the second intercostal space (ICS) with a needle that is at least 5 cm long.²² The TCCC guidelines recommended an 8.25 cm needle (3.25 in).²³ The decision to perform this maneuver is different in the context of austere environments. Field challenges often include inadequate sedation, altitude, temperature, wind, precipitation, sterility, and vital sign monitoring.

NT may fail to decompress the thorax through several mechanisms: poor technique, catheter kinking or obstruction, and inadequate diameter and catheter length. NT catheters may be more prone to kinking when placed in the midaxillary line due to the position of the patient during transport.²⁴ The midclavicular approach has problems as well. Jones and Hollingsworth reviewed 3 cases of failure attributed to kinking in the second ICS/midclavicular line and recommend a more rigid device.²⁵ Although use of the midaxillary approach may be safer

because it does not endanger the “cardiac box,”²⁶ one study showed that lateral chest wall thickness was greater, on average, than the anterior approach.²⁷

When one emergency medical services (EMS) system compared a 4.5 cm vs 3.2 cm catheter, there was a 65% failure rate in the shorter length vs 4% failure rate with the longer. Stevens et al retrospectively evaluated chest CT studies and found that the average chest wall thickness at the second ICS was 41 to 45 mm and that a 4.5 cm needle would be unsuccessful in 50% of patients based on body habitus alone. Thus, the TCCC recommendation of an 8.25 cm catheter is critical to successful decompression.

Martin et al showed that, in a porcine model, a 14 gauge angiocatheter would not be expected to decompress the chest and relieve a tension PTX because the air leak leading to tension physiology cannot be drained effectively with a tube of that diameter.²⁸ The Israeli Defense Force has now moved to a NT catheter that is more rigid, longer, and wider in diameter. They studied the Vygon TT, a 10 French drain 8 cm long. They report their initial experience in only 6 casualties and noted no complications when compared with 88 casualties receiving standard NT.²⁹

Eckstein and Suyehara reviewed 108 NTs by paramedics and found that only 5% showed objective improvement in field vital signs.³⁰ Barton³¹ compared 169 NT vs 106 TT (tube thoracostomy) and found that 19% of NT patients were deceased on arrival vs 7% TT patients, leading them to conclude that, at least for air transport, TT is preferable. In this study, 38% of the patients who received TT did so because they showed no clinical improvement after NT. In the author's anecdotal experience, most patients do report subjective improvement and, when faced with a second NT, it is understandable why. Thus, subjective patient reports of improvement are not reliable in the austere setting.

Complications with NT placement may include cardiac tamponade, life-threatening bleeding from pulmonary and intercostal vessels, and nerve injury.³² Errors identifying the midclavicular line and second ICS are common, with 60% of emergency physicians misidentifying the correct site.³³ The use of the hemithoracic line versus the midclavicular line is recommended so that practitioners stay out of the cardiac box. TCCC recommendations are to decompress on or lateral to the nipple line in males.

SIMPLE THORACOSTOMY

It is evident that NT in both recommended locations has some significant problems. In a helicopter EMS service, NT was found to be associated with the complications of

malpositioning, catheter obstruction, and insufficient drainage. This system conducted a prospective observational study of simple thoracostomy in a mountainous region with average one-way flight times of 40 minutes coupled with an average 38-minute extraction time. Their technique was a 5 cm incision in the fifth ICS. They report an experience with 55 blunt trauma patients with mechanisms being predominantly motor vehicle crashes (75%) and falls (16%). Among 28 patients with multiple rib fractures, 93% had a PTX or hemopneumothorax and the remainder had a hemothorax. No case of recurrent tension PTX was observed. No complications or infections were observed.³⁴ It should be noted that these patients were intubated and under positive pressure ventilation. In a recent review of pleural decompression in the immediate hospital setting by Fitzgerald et al,³⁵ NT was recommended as a last resort. The aim should be to perform a simple thoracostomy first, with tube thoracostomy as a secondary priority. In the backcountry, there are concerns about the known complications of retension from a kinked tube, hematoma, infection, subcutaneous placement.³¹ Thus, tube thoracostomy would likely not prove beneficial when compared with simple thoracostomy and vented chest seal use in the austere environment.

Implications for Other Austere Environments

Given the current evidence from preclinical animal studies, EMS systems, and combat theatre experience with TCCC guideline use, the following recommendations can be made for the prehospital treatment of chest injuries in other austere environments:

1. All open chest wounds should be covered with a vented chest seal. If a vented chest seal is not available, then an occlusive dressing may be used. The patient should be monitored for the development of a tension PTX.
2. If a patient with significant chest trauma develops signs and symptoms of a tension PTX (hypoxia, respiratory distress, or hypotension), then NT with a 14 gauge, 8.25 cm (3.25 in) needle/catheter in the second ICS at the midclavicular line should be performed on the side of the injury. Ensure that the insertion point is not medial to the nipple line or to the hemithoracic line. An alternative site is the fourth or fifth ICS, anterior axillary line. Occlusive chest seals may also be "burped" in this situation.
3. If the initial NT is unsuccessful and/or the patient is in extremis, then advanced trauma practitioners should strongly consider simple thoracostomy coupled with vented chest seal application to ensure adequate pleural decompression of both air and blood.

Conclusions

The past 2 decades of conflict have seen remarkable advances in the prehospital treatment of severe trauma in combat settings, drawing close parallels to austere wilderness settings. Wilderness medicine practitioners should be prepared to translate these lessons learned to care for injuries in the backcountry. For significant thoracic trauma, the equipment and training necessary to apply vented chest seals and perform NT, and possibly simple thoracostomy coupled with a vented chest seal, may be lifesaving.

Financial/Material Support: There was partial funding from the Wellcome Trust for this study.

Disclosures: None.

Disclaimer: The views expressed in this article are those of the author and do not necessarily reflect the official policy or position of the United States Department of the Navy, United States Department of Defense, or the United States Government.

References

1. Livingston DH, Hauser CJ. Trauma to the chest wall and lung. In: Moore EE, Feliciano DV, Mattox KI, eds. *Trauma*. 5th ed. New York, NY: McGraw-Hill Medical; 2003:507–537.
2. Brasel KJ, Stafford RE, Weigelt JA, Tenquist JE, Borgstrom DC. Treatment of occult pneumothoraces from blunt trauma. *J Trauma*. 1999;46:987–991.
3. Rommens PM, Carlier H, Deloos HH. Early mortality following multiple trauma: a retrospective study. *Acta Chir Belg*. 1988;88:374–379.
4. McPherson JJ, Feigin DS, Bellamy RF. Prevalence of tension pneumothorax in fatally wounded combat casualties. *J Trauma*. 2006;60:573–578.
5. Rasool A, Wani AH, Darzi MA, Zaroo MI, Iqbal S, Bashir SA, et al. Incidence and pattern of bear maul injuries in Kashmir. *Injury*. 2010;41:116–119.
6. Hodgetts TJ, Hanlan CG, Newey CG. Battlefield first aid: a simple, systematic approach for every soldier. *J R Army Med Corps*. 1999;145:55–59.
7. Kong VY, Oosthuizen GV, Clarke DL. Selective conservatism in the management of thoracic trauma remains appropriate in the 21st century. *Ann R Coll Surg Engl*. 2015;97:224–228.
8. Lin FC, Li RY, Tung YW, Jeng KC, Tsai SCW. Morbidity, mortality, associated injuries, and management of traumatic rib fractures. *J Chin Med Assoc*. 2016;79:329–334.
9. Carvalho P, Hilderbrandt J, Charan NB. Changes in bronchial and pulmonary arterial blood flow with progressive tension pneumothorax. *J Appl Physiol*. 1996;81:1664–1669.
10. Rutherford B, Hurt HH Jr, Brickman RD, Tubb JM. The pathophysiology of progressive, tension pneumothorax. *J Trauma*. 1968;8:212–227.
11. Gustman P, Yerger L, Wanner A. Immediate cardiovascular effects of tension pneumothorax. *Am Rev Respir Dis*. 1983;127:171–174.

12. Barton ED. Tension pneumothorax. *Curr Opin Pulm Med*. 1999;5:269–274.
13. Coats TJ, Wilson AW, Xeropotamous N. Pre-hospital management of patients with severe thoracic injury. *Injury*. 1995;2:581–585.
14. American College of Surgeons, Committee on Trauma. *Advanced Trauma Life Support*. 7th ed. American College of Surgeons; 2004.
15. Arnaud F, Tomori T, Teranishi K, Yun J, McCarron R, Mahon R. Evaluation of chest seal performance in a swine model: comparison of Asherman vs Bolin seal. *Injury*. 2008;39:1082–1088.
16. Kheirabadi BS, Terrazas MS, Alexandra Koller, Allen PB, Klemcke HG, Convertino VA, et al. Vented versus unvented chest seals for treatment of pneumothorax and prevention of tension pneumothorax in a swine model. *J Trauma Acute Care Surg*. 2013;75:150–156.
17. Kotora JG Jr, Henao J, Littlejohn LF, Kircher S. Vented chest seals for prevention of tension pneumothorax in a communicating pneumothorax. *J Emerg Med*. 2013;45:686–694.
18. Arnaud F, Maudlin-Jeronimo E, Higgins A, Kheirabadi BS, McCarron R, Kennedy D, et al. Adherence evaluation of vented chest seals in a swine skin model. *Injury*. 2016;47:2097–2104.
19. Butler FK, Dubose JJ, Otten EJ, Bennett DR, Gerhardt RT, Kheirabadi BS, et al. Management of open pneumothorax in tactical combat casualty care: TCCC guidelines change 13-02. *J Spec Oper Med*. 2013;13:81–86.
20. Salomone JP, Pons PT, McSwain NE, eds. *PHTLS: Prehospital Trauma Life Support*. 6th ed. St Louis, MO: Mosby; 2007.
21. Leigh-Smith S, Harris T. Tension pneumothorax: time for a re-think? *Emerg Med J*. 2005;22:8–16.
22. American College of Surgeons. *Advanced Trauma Life Support for Doctors*. 8th ed. American College of Surgeons; 2008.
23. TCCC Guidelines for Medical Personnel. 2016. Available at: <http://www.naemt.org/docs/default-source/education-documents/tccc/072016-updates/tccc-guidelines-for-medical-personnel-160603.docx?sfvrsn=2>. Accessed March 9, 2017.
24. Beckett A, Savage E, Pannell D, Acharya S, Kirkpatrick A, Tien HC. Needle decompression for tension pneumothorax in tactical combat casualty care: do catheters placed in the midaxillary line kink more often than those in the mid-clavicular line? *J Trauma*. 2011;71(Suppl 1):S408–S412.
25. Jones R, Hollingsworth J. Tension pneumothoraces not responding to needle thoracentesis. *Emerg Med J*. 2002;19:176–177.
26. Rawlins R, Brown KM, Carr CS, Cameron CR. Life threatening haemorrhage after anterior needle aspiration of pneumothoraces. A role for lateral needle aspiration in emergency decompression of spontaneous pneumothorax. *Emerg Med J*. 2003;20:383–384.
27. Lander OM, Sanchez LD, Pedrosa I. Anterior vs lateral needle decompression of tension pneumothorax: comparison by computed tomography chest wall measurement. *Acad Emerg Med*. 2005;12(5 Suppl 1):66.
28. Martin M, Satterly S, Inaba K, Blair K. Does needle thoracostomy provide adequate and effective decompression of tension pneumothorax? *J Trauma Acute Care Surg*. 2012;73:1412–1417.
29. Chen J, Nadler R, Schwartz D, Tien H, Cap AP, Glassberg E. Needle thoracostomy for tension pneumothorax: the Israeli Defense Forces experience. *Can J Surg*. 2015;58:S118–S124.
30. Eckstein M, Suyehara D. Needle thoracostomy in the prehospital setting. *Prehosp Emerg Care*. 1998;2:132–135.
31. Barton ED, Epperson M, Hoyt DB, Fortlage D, Rosen P. Prehospital needle aspiration and tube thoracostomy in trauma victims: a six-year experience with aeromedical crews. *J Emerg Med*. 1995;13:155–163.
32. Wernick B, Hon H, Muband R, Cipriano A, Hughes R, Rankin DD, et al. Complication of needle thoracostomy: a comprehensive clinical review. *Int J Crit Illn Inj Sci*. 2015;5:160–169.
33. Ferrie EP, Collum N, McGovern S. The right place in the right space? Awareness of site for needle thoracocentesis. *Emerg Med J*. 2005;22:788–789.
34. Massarutti D, Trillo G, Berlot G, Tomasini A, Bacer B, D'Orlando L, et al. Simple thoracostomy in prehospital trauma management is safe and effective: a 2-year experience by helicopter emergency medical crews. *Eur J Emerg Med*. 2006;13:276–280.
35. Fitzgerald M, Mackenzie CF, Marasco S. Pleural decompression and drainage during trauma reception and resuscitation. *Injury*. 2008;39:9–20.