INTRODUCTION

Trauma is the leading cause of death in Australian children ¹. Thoracic trauma is common in the presentation of severely injured children, and is a leading risk factor for paediatric trauma death ¹. At our statewide paediatric major trauma centre (The Royal Children's Hospital Melbourne, RCH), 58 children died with chest injuries in the past 10 years, and the presence of a chest injury was associated with a tenfold increase in likelihood of trauma death (OR 9.5, CI 95% 5.6-16.2; unpublished registry data) ².

Until recent years, the standard of care for emergency pleural decompression in trauma has been needle thoracocentesis, e.g. in the management of tension pneumothorax, massive haemothorax, and traumatic cardiac arrest. However, in adult practice at least, concerns have been raised as to the efficacy and safety of needle thoracocentesis to both achieve and sustain pleural decompression, with associated high failure rates and morbidity due to cannula (or catheter) dislodgement, inappropriate length, occlusion and inability to penetrate the pleura ³⁻⁵. These important clinical misgivings are supported by clinical ⁶, cadaveric ⁷ and animal ^{8,9} studies, highlighting high rates of needle thoracocentesis failure. For these reasons, and after some debate, thoracostomy (often termed 'finger thoracostomy') has largely replaced needle thoracocentesis as the standard of care for emergency pleural decompression in many adult trauma care settings ^{3, 10-13}.

In paediatric trauma, the debate regarding needle thoracocentesis versus thoracostomy is less well advanced and needle thoracocentesis remains in wide use. Despite this, the experience gained in adult trauma care has prompted some to adopt thoracostomy as the preferred

This is the author manuscript accepted for publication and has undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record. Please cite this article as doi: [10.1111/1742-6723.13392](https://doi.org/10.1111/1742-6723.13392)

approach in paediatric trauma settings as well. For example, the *Paediatric Emergency Research network in UK and Ireland* (PERUKI) now recommends bilateral thoracostomies be performed instead of needle thoracocenteses in paediatric traumatic cardiac arrest ¹⁴.

Also, the *Australian and New Zealand Committee On Resuscitation* (ANZCOR) guidelines for adult and paediatric traumatic cardiac arrest recommend thoracostomy as the preferred method of emergency pleural decompression ¹¹. These examples notwithstanding, needle thoracocentesis is still taught on paediatric life support courses and practiced by those prehospital and hospital practitioners not trained in (or inclined to) thoracostomy.

Paediatric-specific evidence informing the debate regarding thoracostomy in severely injured children is lacking. Therefore, this study aimed to report the early experiences of thoracostomy in severely injured children within the Victorian State Trauma System (VSTS), a mature trauma system with specialist prehospital and paediatric trauma services.

METHODS

Victorian State Trauma System

The Australian state of Victoria established the VSTS in 1999 to more effectively triage and manage major trauma patients. Within this system a statewide ambulance service (Ambulance Victoria, AV) incorporates road, helicopter and fixed-wing services, as well as medical retrieval services. At present, the AV Helicopter Emergency Medical Service (HEMS) consists of five helicopters strategically distributed at 4 sites across Victoria. Each HEMS response is staffed by an intensive care paramedic, who is expertly trained in a range

of advanced trauma life support procedures, including rapid sequence intubation, administration of IV fluid and blood, chest drain insertion, and now thoracostomy.

RCH is a quaternary paediatric hospital, which alongside two state-designated adult major trauma services, is the sole paediatric major trauma service for the VSTS. RCH receives the vast majority of the state's severely injured children ¹⁵, who in accordance with the VSTS definition of 'paediatric' are aged <16 years. RCH has maintained a prospective registry of all severely injured children presenting to the hospital since 2001, the RCH Trauma Registry. Data are both electronically imported into, and manually augmented within, this registry by an experienced trauma epidemiologist (CSP).

Thoracostomy in children

Thoracostomy, as described here, involves opening and decompression of the pleural cavity through a lateral thoracic incision, sited within the anatomical landmarks of the "safe triangle" (Figure 1). Sustained effectiveness of decompression is promoted by judicious intra-pleural 'sweeping', which serves primarily to better secure a path for air and blood to exit the pleural cavity. In adults, the width of the intercostal space typically permits use of a finger as an ideal and safe tool to perform this sweep, hence term "finger thoracostomy" often used in adult trauma literature. Contrasting with this, a child's intercostal spaces are usually too narrow to permit a 'finger sweep' *per se*, and so a suitably blunt mosquito or artery forcep can be used instead. For this reason, we prefer the unqualified term of "thoracostomy" as the more appropriate and informative terminology in the context of paediatric trauma. These and other instructive 'tips' about thoracostomy in injured children are provided in Figure 2, and outlined in greater detail in a web-published RCH guideline¹⁶ and related publication ¹⁷.

Paediatric thoracostomy within the Victorian State Trauma System

Thoracostomy in injured children was introduced into the VSTS in 2016, initially as a prehospital intervention by AV, and subsequently by medical staff at RCH in 2017. In both instances, implementation was preceded and supported by specific guidelines and education programmes to promote appropriate case selection and proceduralist competency^{16, 18}.

Within this system, thoracostomy is performed on children by specifically-trained intensive care paramedics in the prehospital setting, or in-hospital by consultants or senior trainees of the Paediatric Surgery, Emergency Medicine or Intensive Care teams. Consistent with the practice of VSTS adult major trauma services, time-efficient (but effective) skin decontamination precedes thoracostomy using povidone iodine or chlorhexidine¹⁹. This, together with routine antibiotic prophylaxis aims to reduce incidence of empyema²⁰, which is well-reported in adult trauma thoracostomy patients^{19, 21}. In distinction to adult trauma, steps to reduce infective complications in our paediatric practice do not extend to routinely making separate incisions for thoracostomy versus chest drain insertion¹⁶.

Data acquisition

The RCH Trauma Registry was reviewed over the period from August 2016 to February 2019, to identify all patients who underwent thoracostomy prehospital or as a part of emergency trauma reception at RCH. The study period start date corresponds with AV introduction of thoracostomy in Victoria. The RCH Trauma Registry, ambulance and hospital patient records were used to extract data including patient demographics, injury event details, as well as prehospital and in-hospital management. Specific information was sought to ascertain the indications for thoracostomy, procedures performed, and any complications

attributable to thoracostomy or chest drain insertion. Patients were followed up until discharge from surgical outpatient care. Because of the admittedly small number of patients identified, analyses were descriptive.

Additional definitions

In this study, as in our paediatric trauma practice, 'hypoxia' was defined as SpO₂ <92%. Further, 'hypotension' was defined as a systolic blood pressure below age-based ranges used in the VSTS guidelines for the identification and triage of major trauma patients ²².

Ethical considerations.

Institutional research ethics approval was provided by the RCH Human Research Ethics Committee (HREC 38179A).

RESULTS

During the 31-month study period, 14 children underwent 23 (9 bilateral, 5 unilateral) thoracostomies, with ages ranging 1.2-15 years; Table 1. Eight children underwent paramedic-performed thoracostomy at the scene of injury, four (50%) of whom underwent bilateral prehospital procedures. Six patients underwent thoracostomy within the ED, including two patients who had previously undergone contralateral prehospital thoracostomy.

Mechanism of injury

With the exception of two children injured by falls from a height, patients in this series sustained transport-related injuries: six as car occupants in a motor vehicle crash (MVC); two pedestrians hit by a vehicle; one cyclist hit by a vehicle; one motorcyclist hit by a vehicle;

one child on a quadbike; and one child run over by a tractor. All children sustained blunt thoracic trauma, with no penetrating injuries in this reported cohort.

Clinical indication and chest injury diagnoses

The most common indications for thoracostomy were hypoxia and/or hypotension; Table 1. Two children with hypoxia were also in traumatic cardiac arrest. An additional five children had hypoxia without hypotension, principally in the setting of tension pneumothoraces and immediate resolution of hypoxia following thoracostomy. Three patients had hypotension without hypoxia. All 14 children provided evidence for a clinically significant haemothorax and/or pneumothorax at pleural decompression by thoracostomy. Importantly, in all cases the indication(s) resolved or showed sustained and notable improvement post-thoracostomy. A single patient underwent precautionary contralateral thoracostomy, having already had a clear therapeutic response to thoracostomy on the other side.

Needle thoracocentesis

Needle thoracocentesis was performed prior to thoracostomy in 10 (71%) children; Table 1. Reasons for needle thoracocentesis included primary response by a practitioner not trained or accredited for thoracostomy, a protocolised prehospital bridging procedure where a delay in pleural decompression by thoracostomy was anticipated¹⁸. All attempts at needle decompression were performed prehospital using either a widebore intravenous cannula or proprietary device, e.g. ARS® (Air Release System) decompression needle or Pneumocath® by an anterior approach (midclavicular line, 2nd intercostal space).

Needle thoracocentesis was documented to have released air only in three patients, blood only in two patients, air and blood in two patients, whilst 3 patients were recorded as having no output from their thoracocentesis device(s). Of these 10 patients, six failed to demonstrate clinical improvement in response to needle thoracocentesis. The remaining four patients showed an initial clinical improvement, but all subsequently deteriorated with recurrence of their tension physiology, prompting thoracostomy. One of these four patients was intubated and ventilated *prior* to effective needle thoracocentesis, but underwent thoracostomy due to deterioration within five minutes. Two other patients were intubated *after* needle thoracocentesis, with re-accumulation of tension prompting thoracostomy 12 and 19 minutes following introduction of positive pressure ventilation, respectively. Finally, re-accumulation of tension in another patient occurred during a prolonged prehospital transport. Emergency thoracostomy was performed on this patient immediately after arrival to the ED, 90 minutes after initially effective needle thoracocentesis. Importantly, all 10 children managed first with needle thoracocentesis demonstrated profound and sustained improvement in clinical status after thoracostomy; Table 1.

An example of a patient who underwent ineffective needle thoracocentesis prior to thoracostomy is illustrated in Figure 3.

Chest drain insertion

All 14 children had chest drains inserted post thoracostomy; Table 1. In one case, chest drain insertion was deferred until after CT imaging, on the basis of competing clinical priorities with a suspected catastrophic head injury.

Injury Severity

All children undergoing thoracostomy were severely injured, and the vast majority (86%) had associated non-thoracic injuries with AIS severity ≥ 3 ; Table 1. Injury Severity Score (ISS) ranged from 17 to 75, with a notably high median ISS of 35.5. Further indicative of severe injury, conscious state was reduced in all children: first recorded age-appropriate Glasgow Coma Scale (GCS) ranged between 3/15 and 14/15, and six (43%) children scored the lowest possible GCS of 3/15.

Surgical Management, Length of Stay and Discharge

Eight patients required emergency surgery, including laparotomy, thoracotomy and neurosurgery. At the time of analysis, one child remained an ICU in-patient 55 days post injury. Three (21%) children died in-hospital, two within 12 hours and one within 48 hours of presentation. Six children (43%) were discharged home and four (29%) were discharged to an in-patient rehabilitation service; Table 1. In those surviving to discharge, the median length of ICU stay was 5 days (3-16 days) and median hospital stay (excluding rehabilitation) was 14 days (3-36 days).

Complications

In our small paediatric trauma cohort, there were no reported instances of iatrogenic injury on thoracostomy or drain insertion, drain dislodgement or need for drain re-positioning. All of our patients received antibiotics during their initial resuscitation, and we saw no instances of empyema, tracheostomy wound cellulitis or generalised sepsis. The 10 patients surviving to discharge had surgical follow-up for a median of 9.5 (6-59) weeks post injury. During this

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follow-up period, there were no reported unplanned readmissions or new complications attributable to either thoracostomy or chest drain, including longer term complications, e.g. chronic airway fistula.

DISCUSSION

The discussion and debate regarding needle thoracocentesis versus thoracostomy is not a moot point. The severely injured child with life-threats such as traumatic cardiac arrest, tension pneumothorax and/or large haemothorax needs effective pleural decompression as a time-critical intervention. Therefore, it is essential that any intervention considered to address such life-threats is reliably effective and safe, both immediately and throughout any ongoing transport and/or resuscitation. This is the first trauma case series to specifically examine thoracostomy in children, and affirms the reliable, definitive and safe nature of the technique across a broad paediatric age range. We hope the outcomes presented here will encourage broader adoption and research of the technique in paediatric trauma care, the absolute need for supporting governance, training and quality review notwithstanding. Importantly, our series included several children under 2 years of age, and we consider this technique to have wide application for injured children beyond the neonatal age-range.

There is growing consensus that needle thoracocentesis is not reliable for effective pleural decompression in adults^{3, 5, 6, 9-11, 23}. Multiple reasons for such 'failure' in adults have been proposed in adults, focussing on technical challenges to enter the pleural cavity. These include introduction of the catheter into subcutaneous bullae (which may cause false positive impression of a 'hiss'), cannula obstruction, insufficient cannula length, and increased chest

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wall thickness either due to patient habitus and/or subcutaneous emphysema^{4, 24}. The safety of needle thoracocentesis is debated, and devastating injuries including those to the underlying cardiopulmonary vasculature have been reported^{25, 26}.

In pre-adolescent children, chest wall thickness is typically less than the recommended 5cm cannula length²⁷, making successful needle entry into the pleural cavity more reliable unless confounded by morbid obesity. Consistent with this, several of our patients showed initial improvement following needle thoracocentesis, indicating relief (or palliation) of the tension physiology. Importantly however, this therapeutic benefit was not sustained in any of our included children, whose recurrent or refractory cardiorespiratory compromise demanded a more definitive response: thoracostomy. Thoracostomy followed intubation in all but one of our needle thoracocentesis cases, and we suggest positive pressure ventilation and prehospital transport time are likely contributors to recurrent tension in these children. Therefore, ‘failure’ of needle thoracocentesis in children may have less in common with the adult challenges to enter the pleural cavity, and more to do with failure to provide definitive, both immediate and sustained, pleural decompression. In light of these considerations, we and others^{11, 14, 16} advocate in favour of thoracostomy over needle thoracocentesis when emergency and definitive pleural decompression is required in severely injured children.

It would be amiss, in this principally positive reflection on thoracostomy in children, to overlook the potential negatives of this procedure in the paediatric population. Although thoracostomy – *entry into the pleural cavity* – is a simple enough endeavour, it can present technical challenges, especially in smaller children or for those unfamiliar with the procedure.

To assist overcoming these challenges, Figure 2 offers ‘practical tips’ of particular relevance to the *paediatric* setting. These tips complement more detailed descriptions in published guidelines for prehospital¹⁸ and in-hospital^{16, 17, 19} application of thoracostomy in children.

It is recommended that the thoracostomy incision^{16, 18, 19, 28}, as with chest drain insertion²⁹, be made within the ‘triangle of safety’, the boundaries of which are the lateral edge of pectoralis major (anterior), anterior border of latissimus dorsi (lateral), base of the axilla (apex) and a horizontal line at the level of the nipple (inferior); Figure 1. In more general terms, this corresponds to the 4th or 5th intercostal space, between the anterior and mid axillary lines¹³. The problem arises however, that these anatomical landmarks are poorly recalled³⁰. Further, even when recalled, the landmarks are poorly identified^{31, 32}, even more so perhaps under the cognitive demands of trauma resuscitation³³. Failure to correctly site the incision for either thoracostomy or chest drain is recognised as a contributor to morbidity, including iatrogenic injuries due to the incision being too low (endangering diaphragm, liver or spleen) or too high (endangering axillary vessels)³⁴⁻³⁶. Challenges in determining anatomical landmarks are also a limitation of safe and effective needle thoracocentesis³⁷. Failure to correctly identify the midclavicular line is associated with an increased risk of cardiac and vascular injury if the needle entry point is too medial²⁶.

In adults, the mid-arm point (i.e. halfway between the tip of the acromion and tip of the olecranon) is a guide to accurately and rapidly determine the site for pleural decompression^{18, 28}. It remains to be confirmed if the mid-arm point has similar utility in children, but the linear anthropometric relationship between humeral length and height during childhood³⁸

would suggest this is likely. In children, we have also recently promoted an aide memoire, *The Rule of 4's*, to assist in siting and performing pleural decompression in children ¹⁷.

In our series, thoracostomy performed in-hospital was typically immediately followed by chest drain insertion. Chest drain insertion is of secondary importance and can be suitably deferred when thoracostomy is performed prehospital ³⁹, or drain insertion is at odds with the patient's immediate clinical concerns, e.g. unresolved traumatic cardiac arrest ³. It is our experience, that chest drain insertion in this setting adds less than 10 minutes to the overall procedural time and minimises the risk of re-accumulation of pleural contents under tension. However if the child's clinical priorities demand that chest drain insertion be deferred, a suitable dressing will reduce additional risk to staff due to blood and other thoracostomy output, e.g. an open-ended ileostomy bag, which acts in the fashion of Heimlich valve. Also, a clear plan must be communicated as to when, where and by whom a chest drain will be inserted when the child's status permits.

In children, we consider that it is appropriate to use the same thoracostomy tract for chest drain insertion, especially if the thoracostomy is performed in-hospital. This avoids the morbidity of a second incision, and appears in our small series to be without increased risk of empyema. In adoption of a state trauma system-wide approach, we have routinely used antibiotic prophylaxis in paediatric patients undergoing thoracostomy to reduce the risk of infection complications. Whether or not antibiotic prophylaxis reduces the risk of post-traumatic empyema is a matter of ongoing debate, and current evidence is insufficient to either support or refute the practice ⁴⁰. Our results, with no empyema, wound cellulitis or

sepsis provide us with no reason to abandon our protocol for routine use of antibiotic prophylaxis in children undergoing thoracostomy.

Limitations

This study is subject to selection bias, given inclusion was limited to children undergoing thoracostomy, rather than adopting broader inclusion criteria to also sample children managed with needle thoracocentesis alone. In addition, this study has a small sample size, precluding opportunity for statistical analyses, and exposing the study to a bias akin a type 2 error, i.e. real points of distinction (e.g. complications) being overlooked because they did not arise in such a small sample. That being said, this first reported series of paediatric thoracostomy in trauma will hopefully provide impetus for additional reporting and collaborative paediatric trauma research to enhance the learning and ameliorate such biases towards a larger and stronger evidence base.

CONCLUSION

In severely injured children, as in adults, thoracostomy is an effective and reliable method to achieve pleural decompression, including in the young child. Whilst the technical challenges presented by children are real, these can be readily overcome by a commitment to procedural training, careful practice as well as use of pertinent guides and aide memoires^{17, 19, 28}. The attraction of thoracostomy includes a more definitive and sustained pleural decompression compared with needle thoracocentesis, balanced by an acceptable morbidity profile. Because of this, we and others^{11, 14, 16} recommend thoracostomy over needle thoracocentesis as the

first-line intervention in children with traumatic cardiac arrest, tension pneumothorax and massive haemothorax.

ACKNOWLEDGEMENTS

A/Prof Warwick Teague's position as Director of The Royal Children's Hospital Trauma Service and Academic Paediatric Surgeon and is proudly supported by the Royal Children's Hospital Foundation.

REFERENCES

1. Mitchell RJ, Curtis K, Foster K. A 10-year review of child injury hospitalisations, health outcomes and treatment costs in Australia. *Inj Prev*. 2018;24(5):344-50.
2. RCH Trauma Registry. Melbourne: Trauma Service, The Royal Children's Hospital (RCH); 2009-2018.
3. Fitzgerald M, Mackenzie CF, Marasco S, Hoyle R, Kossmann T. Pleural decompression and drainage during trauma reception and resuscitation. *Injury*. 2008;39(1):9-20.
4. Laan DV, Vu TD, Thiels CA, Pandian TK, Schiller HJ, Murad MH, et al. Chest wall thickness and decompression failure: A systematic review and meta-analysis comparing anatomic locations in needle thoracostomy. *Injury*. 2016;47(4):797-804.
5. Waydhas C, Sauerland S. Pre-hospital pleural decompression and chest tube placement after blunt trauma: A systematic review. *Resuscitation*. 2007;72(1):11-25.
6. Kaserer A, Stein P, Simmen HP, Spahn DR, Neuhaus V. Failure rate of prehospital chest decompression after severe thoracic trauma. *Am J Emerg Med*. 2017;35(3):469-74.
7. Inaba K, Karamanos E, Skiada D, Grabo D, Hammer P, Martin M, et al. Cadaveric comparison of the optimal site for needle decompression of tension pneumothorax by prehospital care providers. *J Trauma Acute Care Surg*. 2015;79(6):1044-8.
8. Kuckelman J, Derickson M, Phillips C, Barron M, Marko S, Eckert M, et al. Evaluation of a novel thoracic entry device versus needle decompression in a tension pneumothorax swine model. *Am J Surg*. 2018;215(5):832-5.
9. 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(6):1412-7.
10. Escott ME, Gleisberg GR, Kimmel K, Karrer A, Cosper J, Monroe BJ. Simple thoracostomy. Moving beyond needle decompression in traumatic cardiac arrest. *JEMS*. 2014;39(4):26-32.
11. Australian and New Zealand Committee on Resuscitation (ANZCOR). ANZCOR Guideline 11.10.1: Management of cardiac arrest due to trauma: Australian Resuscitation Council; 2016. Available from: <https://resus.org.au/wpfb-file/anzcor-guideline-11-10-1-als-traumatic-arrest-27apr16-pdf/>.
12. Major trauma: assessment and management of major trauma (NICE Guideline NG39: Methods, evidence and recommendations): National Institute for Health and Care Excellence;

2016. Available from: <https://www.nice.org.uk/guidance/ng39/evidence/full-guideline-2308122833>.

13. Advanced Trauma Life Support (ATLS®) Student Course Manual. 10th ed. Chicago: American College of Surgeons; 2018.

14. Vassallo J, Nutbeam T, Rickard AC, Lyttle MD, Scholefield B, Maconochie IK, et al. Paediatric traumatic cardiac arrest: the development of an algorithm to guide recognition, management and decisions to terminate resuscitation. *Emerg Med J*. 2018;35(11):669-74.

15. Deasy C, Gabbe B, Palmer C, Babl FE, Bevan C, Crameri J, et al. Paediatric and adolescent trauma care within an integrated trauma system. *Injury*. 2012;43(12):2006-11.

16. Quinn N, Amarakone K, Teague WJ. RCH Trauma Guideline: management of traumatic pneumothorax and haemothorax: The Royal Children's Hospital, Melbourne; 2018 updated 24 October 2018. Available from: <https://www.rch.org.au/uploadedFiles/Main/Content/trauma-service/RCH-trauma-management-of-traumatic-pneumothorax-and-haemothorax.pdf>.

17. Teague WJ, Amarakone KV, Quinn N. Rule of 4's: Safe and effective pleural decompression and chest drain insertion in severely injured children. *Emerg Med Australas*. 2019;<https://doi.org/10.1111/742-6723.13299>.

18. MFP Pleural Decompression with Finger Thoracostomy (Applicable to MICA Flight Paramedics AAV); CWI/OPS/170. Ambulance Victoria; 2016.

19. Anderson M, Fitzgerald M, Martin K, Santamaria M, Arendse S, O'Reilly G, et al. A procedural check list for pleural decompression and intercostal catheter insertion for adult major trauma. *Injury*. 2015;46(1):42-4.

20. Bosman A, de Jong MB, Debeij J, van den Broek PJ, Schipper IB. Systematic review and meta-analysis of antibiotic prophylaxis to prevent infections from chest drains in blunt and penetrating thoracic injuries. *Br J Surg*. 2012;99(4):506-13.

21. Burton PR, Lee M, Bailey M, Pick AW. What causes post-traumatic empyema? *Emerg Med Australas*. 2009;21(2):153-9.

22. Trauma Victoria. Pre-hospital triage: identification of potential major trauma: Victorian Department of Health; 2019. Available from: <https://trauma.reach.vic.gov.au/guidelines/pre-hospital-triage/identification-of-potential-major-trauma>.

23. Lesperance RN, Carroll CM, Aden JK, Young JB, Nunez TC. Failure Rate of Prehospital Needle Decompression for Tension Pneumothorax in Trauma Patients. *Am Surg*. 2018;84(11):1750-5.

24. Clemency BM, Tanski CT, Rosenberg M, May PR, Consiglio JD, Lindstrom HA. Sufficient catheter length for pneumothorax needle decompression: a meta-analysis. *Prehosp Disaster Med.* 2015;30(3):249-53.
25. Wernick B, Hon HH, Mubang RN, Cipriano A, Hughes R, Rankin DD, et al. Complications of needle thoracostomy: A comprehensive clinical review. *Int J Crit Illn Inj Sci.* 2015;5(3):160-9.
26. Butler KL, Best IM, Weaver WL, Bumpers HL. Pulmonary artery injury and cardiac tamponade after needle decompression of a suspected tension pneumothorax. *J Trauma.* 2003;54(3):610-1.
27. Mandt MJ, Hayes K, Severyn F, Adelgais K. Appropriate Needle Length for Emergent Pediatric Needle Thoracostomy Utilizing Computed Tomography. *Prehosp Emerg Care.* 2019:1-9.
28. Bing F, Fitzgerald M, Olaussen A, Finnegan P, O'Reilly G, Gocentas R, et al. Identifying a safe site for intercostal catheter insertion using the mid-arm point (MAP). *Journal of Emergency Medicine, Trauma & Acute Care.* 2017(3):<http://dx.doi.org/10.5339/jemtac.2017.3>.
29. Laws D, Neville E, Duffy J, Pleural Diseases Group SoCCBTS. BTS guidelines for the insertion of a chest drain. *Thorax.* 2003;58 Suppl 2:ii53-9.
30. Griffiths JR, Roberts N. Do junior doctors know where to insert chest drains safely? *Postgrad Med J.* 2005;81(957):456-8.
31. Bowness JS, Nicholls K, Kilgour PM, Ferris J, Whiten S, Parkin I, et al. Finding the fifth intercostal space for chest drain insertion: guidelines and ultrasound. *Emerg Med J.* 2015;32(12):951-4.
32. Carter P, Conroy S, Blakeney J, Sood B. Identifying the site for intercostal catheter insertion in the emergency department: is clinical examination reliable? *Emerg Med Australas.* 2014;26(5):450-4.
33. Bennis MV, Egger ME, Harbrecht BG, Franklin GA, Smith JW, Miller KR, et al. Does chest tube location matter? An analysis of chest tube position and the need for secondary interventions. *J Trauma Acute Care Surg.* 2015;78(2):386-90.
34. Remerand F, Luce V, Badachi Y, Lu Q, Bouhemad B, Rouby JJ. Incidence of chest tube malposition in the critically ill: a prospective computed tomography study. *Anesthesiology.* 2007;106(6):1112-9.
35. Kong VY, Oosthuizen GV, Sartorius B, Keene C, Clarke DL. An audit of the complications of intercostal chest drain insertion in a high volume trauma service in South Africa. *Ann R Coll Surg Engl.* 2014;96(8):609-13.

36. Kong VY, Clarke DL. The spectrum of visceral injuries secondary to misplaced intercostal chest drains: experience from a high volume trauma service in South Africa. *Injury*. 2014;45(9):1435-9.
37. Ferrie EP, Collum N, McGovern S. The right place in the right space? Awareness of site for needle thoracocentesis. *Emerg Med J*. 2005;22(11):788-9.
38. Gerver WJM, De Bruin R. Paediatric morphometrics: a reference manual. 2nd ed. Maastricht: Universitaire Pers Maastricht; 2001.
39. 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(5):276-80.
40. Moore FO, Duane TM, Hu CK, Fox AD, McQuay N, Jr., Lieber ML, et al. Presumptive antibiotic use in tube thoracostomy for traumatic hemopneumothorax: an Eastern Association for the Surgery of Trauma practice management guideline. *J Trauma Acute Care Surg*. 2012;73(5 Suppl 4):S341-4.

FIGURE LEGENDS

Figure 1. Anatomical landmarks for the ‘triangle of safety’: lateral edge of pectoralis major, anterior border of latissimus dorsi, base of the axilla, and 5th intercostal space at the level of the nipple.

Figure 3. Chest X-ray of a young child who underwent first bilateral needle thoracocentesis, followed by thoracostomy for traumatic cardiac arrest. The therapeutically ineffective cannulae remain in situ. Following thoracostomy, there was immediate return of spontaneous circulation.

EMM_13392_Figure 1.tif

Figure 2.

8 TIPS FOR PERFORMING A THORACOSTOMY IN INJURED CHILDREN

Tip #1: What is the number one priority of a thoracostomy? To effectively decompress the pleural cavity. Inserting a chest drain is a lesser priority, even if still an important step; see also Tip #6.

Tip #2: Where should I make my thoracostomy incision? 4th or 5th intercostal space, between the anterior and mid-axillary lines. This correlates with the 'safe triangle' outlined in **Figure 1**.

Tip #3: How long should my thoracostomy incision be? 2-4cm, according to the size of the child.

Tip #4: What should I use to enter the pleural cavity? Blunt dissection is performed with a mosquito (infant), artery (child) or Roberts (adolescent) forcep. Once you have entered the pleural cavity, widen your thoracostomy by opening up the forcep jaws as much as possible, ideally parallel to the intercostal space for maximal effect. Never use chest drain trochars and avoid scissors as these can cause dangerous, iatrogenic injuries inside the chest.

Tip #5: What keeps the thoracostomy open prior to chest drain insertion? A judicious sweep with either the instrument you have used to enter the chest cavity, or (*if the intercostal space allows*) your finger. The purpose of this sweep is to clear a path for air and blood to exit the pleural cavity, and free any obstructing pleura, especially if impinged by a nearby fractured rib.

Tip #6: When should I put the chest drain in? A chest drain should be inserted as soon as the clinical priorities of the injured child allows. In most circumstances, this will be directly after effective decompression by thoracostomy, but in the setting of unresolved traumatic cardiac arrest or other more pressing clinical priorities, this step can be deferred. If no chest drain is inserted, a suitable dressing should permit ongoing decompression. An open-ended stoma bag is an excellent 'dressing', working in the fashion of a Heimlich valve.

Tip #7: When I put the chest drain in, what size should I use? The recommended chest drain size is 4x the size of uncuffed endotracheal tube: $4 \times (\text{Age}/4 + 4)$... rounded pragmatically to the nearest multiple of 4, as this matches chest drain calibre sizing.

Tip #8: When I put the chest drain in, how far should I advance it? A common mistake is to advance the chest drain in *too far*, even dangerously too far. A good rule of thumb is to advance the chest drain only as far as the 4cm marking on the drain. This mark is 4cm from the last side hole, not 4cm from the chest drain tip. If the chest drain size is matched the age (and size) as above, this rule of thumb reliably guides your chest drain to be in far enough, but not too far.

For more information about the practicalities of pleural decompression and chest drain insertion in injured children, see *The Rule of 4's*¹⁷.

EMM_13392_Figure 3.tif

PATIENT DETAILS			THORACOSTOMY DETAILS					OTHER TRAUMA MANAGEMENT				ASSOCIATED SERIOUS INJURIES				
Age (y)	First GCS	Chest Injuries	Setting performed	Prior needle thoracocentesis?	Thoracostomy side	Thoracostomy indication	Thoracostomy Result	ICD?	Intubation Setting & Timing	Urgent Theatre	Discharge	Head	Face	Neck/Spine	Abdo	Pelvis
1.2 y	12/15	L tension PTX	ED	None	Left	Hypoxia	Hypoxia resolved	Bilateral	ED, Pre thoracostomy	No	Home	Yes	No	No	No	No
1.3 y	7/15	R tension PTX Bilateral HTX	ED	None	Bilateral	Could not ventilate Hypotension	Improved post R thoracostomy	Bilateral	Prehospital, Pre thoracostomy	Neurosurgery, Laparotomy	Home	Yes	No	No	Yes	No
1.4 y	3/15	R tension H/PTX L HTX	Prehospital	Yes, Bilateral	Bilateral	Traumatic cardiac arrest, Hypoxia	From asystole to PEA	Bilateral	Prehospital, Pre thoracostomy	No	Death	Yes	No	Yes	No	No
4 y	3/15	Bilateral H/PTX	Prehospital, later in ED	Yes (18G), Bilateral	Left, Later Right	Hypotension	Hypotension resolved	Bilateral	Prehospital, Pre thoracostomy	No	Death	Yes	No	Yes	No	No
10 y	8/15	R tension PTX	Prehospital	Yes, Bilateral	Bilateral	Hypoxia	Hypoxia resolved	Bilateral	Prehospital, Pre thoracostomy	Neurosurgery, Laceration suture	Rehab	Yes	No	No	No	Yes
10 y	14/15	R Tension PTX	Prehospital	None	Right	Hypoxia, Poor AE	Hypoxia resolved	Right	Prehospital, Post thoracostomy	Laparotomy, Plastics	Home	No	No	No	No	No
11 y	3/15	Bilateral tension PTX	Prehospital	Yes, Bilateral	Bilateral	Hypoxia	Hypoxia resolved	Bilateral	Prehospital, Pre thoracostomy	Neurosurgery	Inpatient	Yes	No	Yes	No	No
11 y	8/15	Bilateral PTX R HTX	Prehospital	Yes, Right-sided	Bilateral	Hypoxia, Poor AE Hypotension	Hypotension resolved	Bilateral	Prehospital, btw thoracostomies	Neurosurgery	Rehab	Yes	No	No	No	No
13 y	3/15	R tension H/PTX L PTX	Prehospital, later in ED	Yes, Right-sided	Right, Later left	Hypoxia, No AE Hypotension	Hypoxia resolved	Bilateral	Prehospital, Post R thoracostomy	No	Home	No	No	No	No	No
13 y	15/15	L PTX	Referring hospital	None	Left	L PTX, Poor AE	Improved AE	Left	Not intubated, ICD placed without delay	Orthopaedic (Limb)	Home	No	No	No	No	Yes
13 y	3/15	R tension PTX	ED	Yes, Bilateral	Bilateral	Hypoxia, Poor AE	Hypoxia resolved	Bilateral	ED, between thoracostomies	Neurosurgery, Laceration suture	Rehab	Yes	Yes	No	No	No
13 y	14/15	L PTX	ED	Yes, Left-sided	Left	Reaccumulated L PTX, Poor AE	Improved AE & oxygenation	Left	Not intubated, ICD inserted without delay	No	Home	No	No	No	Yes	No
14 y	3/15	R H/PTX	ED	Yes, Bilateral	Bilateral	Hypotension	Hypotension resolved	Bilateral	Prehospital, Pre thoracostomy	No	Death	Yes	No	No	No	No
15 y	7/15	R tension H/PTX	Prehospital	Yes, Right-sided	Right	Absent lung slide, Hypotension	Hypotension resolved	Right	Prehospital, Pre thoracostomy	Neurosurgery	Rehab	Yes	No	Yes	No	No

Table 1. Summary of injured children undergoing thoracostomy. Ages <2 are stated to 1 decimal place, whilst ages ≥2 are stated as whole years. R, right; L, left; H/PTX, haemopneumothorax; PTX, pneumothorax; HTX, haemothorax; GCS, Glasgow Coma Scale; ED, emergency department; Unless specified otherwise, prehospital needle thoracocentesis performed in 2nd intercostal space and midclavicular line using 14G proprietary device, i.e. ARS® or Pneumocath®; ICD, intercostal chest drain; ‘Serious injury’ defined as 2008 Abbreviated Injury Scale severity ≥3; neck includes cervical spine.

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Title:

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Date:

2019-09-18

Citation:

Quinn, N., Palmer, C. S., Bernard, S., Noonan, M. & Teague, W. J. (2019). Thoracostomy in children with severe trauma: An overview of the paediatric experience in Victoria, Australia. EMERGENCY MEDICINE AUSTRALASIA, 32 (1), pp.117-126. <https://doi.org/10.1111/1742-6723.13392>.

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