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Visually Guided Tube Thoracostomy Insertion Comparison to Standard of Care in a Large Animal Model

Matthew C. Hernandez, MD¹, David Vogelsang⁴, Jeff R. Anderson, Ph.D.³, Cornelius A. Thiels, DO, Gregory Beilman, MD⁵, Martin D. Zielinski, MD¹, and Johnathon M. Aho, MD^{1,2}

¹Department of Surgery, Division of Trauma, Critical Care, and General Surgery, Mayo Clinic, Rochester, MN

²Department of Physiology and Biomedical Engineering, Mayo Clinic, Rochester, MN

³Office of Translation to Practice, Mayo Clinic, Rochester, MN

⁴Mayo Medical School, Mayo Clinic, Rochester, MN

⁵Department of Surgery, University of Minnesota, Minneapolis, MN

Abstract

Introduction—Tube thoracostomy (TT) is a lifesaving procedure for a variety of thoracic pathologies. The most commonly utilized method for placement involves open dissection and blind insertion. Image guided placement is commonly utilized but is limited by an inability to see distal placement location. Unfortunately, TT is not without complications. We aim to demonstrate the feasibility of a disposable device to allow for visually directed TT placement compared to the standard of care in a large animal model.

Methods—Three swine were sequentially orotracheally intubated and anesthetized. TT was conducted utilizing a novel visualization device, tube thoracostomy visual trocar (TTVT) and standard of care (open technique). Position of the TT in the chest cavity were recorded using direct thoroscopic inspection and radiographic imaging with the operator blinded to results. Complications were evaluated using a validated complication grading system. Standard descriptive statistical analyses were performed.

Results—Thirty TT were placed, 15 using TTVT technique, 15 using standard of care open technique. All of the TT placed using TTVT were without complication and in optimal position. Conversely, 27% of TT placed using standard of care open technique resulted in complications. Necropsy revealed no injury to intrathoracic organs.

Address correspondence and reprint requests to: Johnathon M. Aho MD, Mayo Clinic, 200 First Street SW, Rochester, MN 55905, Phone: 507-255-3812, aho.johnathon@mayo.edu.

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Conflicts of Interest: Mayo Foundation has a financial interest in technologies developed by some authors. Multiple authors report patent disclosures for multiple technologies for which they do not receive royalties.

Conclusion—Visual directed TT placement using TTVT is feasible and non-inferior to the standard of care in a large animal model. This improvement in instrumentation has the potential to greatly improve the safety of TT. Further study in humans is required.

Keywords

Tube thoracostomy; visual guidance; chest tube; trauma

Introduction

Tube thoracostomy (TT) is a potentially life-saving procedure performed by providers in multiple disciplines. Despite TT placement being considered a relatively minor procedure, the placement technique remains largely unchanged over time and is associated with high complication rates (20–40%) in contemporary series (1–6). A suboptimal placed TT prevents proper drainage of the pleural cavity and often requires replacement. Moreover, TT insertion outside the thoracic cavity or into organ tissues can be a devastating complication.

Several key maneuvers must be completed during standard of care insertion of a bedside TT. First, the correct location for placement, most commonly the “triangle of safety” as described by the British Thoracic Society, must be identified (7). Second is sharp and blunt dissection of the thoracic wall. Third, a digit or instrument is inserted and the pleural space assessed for access to the cavity. Fourth, blind TT insertion is performed into the pleural space. Complications can occur during all four steps (8–11), but are most common during the insertion maneuver (6) as the TT is significantly longer than the operator’s digit. Our efforts have thus been focused on determination of visualization of TT placement location.

Currently, providers are unable to directly visualize the chest wall, lung parenchyma, and other key structures while inserting TT. The inability to see these critical structures creates a potential for development of a TT related complication or placement in an incorrect location. This potential may be increased in the emergent or urgent setting as well as by the habitus of the patient (12,13).

Our previous work has demonstrated the feasibility of a visually directed technique for the direct visualization of TT insertion in a cadaver (14). In this present study, further refinement of both technique and device are presented to suggest that new technology may facilitate the safe placement of TT in a large animal model. The Tube Thoracostomy Visual Trocar (TTVT, Figure 1, and Supplemental Video) accommodates 22–40F chest tubes with a camera within the TT to provide direct visualization during placement. We aim to demonstrate the feasibility of direct visualization for TT insertion compared to the standard of care using a large animal model. We hypothesize that direct visual TT placement will have a reduced complication rate and improved positioning success as compared to the standard open technique.

Methods

After obtaining approval from the institutional animal research review board, three domestic cross bred pigs (approximately 45+–5 kg) were used for experimentation. Multiple straight

thoracostomy tubes were utilized (36, 32, 28 French). Decreasing TT sizes were used to demonstrate the generalizability of the tube thoracostomy visual trocar (TTVT) for insertion. Ten chest tubes were placed (5 using standard of care, 5 with visual device) in each animal using the different sized tubes. Laterality for standard of care vs visual placement was assigned randomly and the procedure was repeated a total of five times on each side. For both the experimental and standard of care group a thoracoscope without insufflation was used to assess (1) intrathoracic TT placement, (2) location of TT position, (3) development complications based on a defined list of complication types (15). The TT operator was blinded to the thoracoscopic view during placement and was only allowed to utilize the TTVT for visually placed TT or open technique for standard of care.

The TTVT device is based upon the design of a disposable bronchoscope. Modifications included adjustments to the camera length, handle and clamping mechanisms to permit the user to rapidly assemble the device and provide visual guidance during TT insertion. Tube thoracostomy visual trocar placement TTVT was performed as follows. (1) The chest tube is fitted over the TTVT: (2) A thumb operated, clamping mechanism is actuated to position the tip of the camera at or near the distal end of the tube thoracostomy according to operator preference: (3) The tube thoracostomy is inserted through using an open technique and directed via visual guidance using the TTVT camera, to the apex of the lung (Figure 2A, 2B): (4) The clamping mechanism is released by trigger actuation and the TTVT withdrawn from the TT. The procedure is completed by securing the TT according to the standard of care.

For this experiment, all of the procedures were performed by a second year general surgery resident with endoscopic and tube thoracostomy insertion experience. The operator's relationship to the device was as a novice user, and prior *in vivo* visual trocar training was nil. Analysis comparing complications of standard of care compared to TTVT placement was performed using GraphPad Prism 7 (GraphPad Software, Inc. La Jolla CA).

Results

Thirty TT were placed, 15 using TTVT, 15 using standard of care open technique. All of the TT placed using TTVT were without complication and in optimal position. Conversely, 27% of TT placed using standard of care open technique resulted in TT malposition (p value = 0.0996 by Mann Whitney Exact Test). Of the complicated TT insertions (n=4), 100% were classified as insertional subtype (Table 2). In order to demonstrate important differences in anatomy using the TTVT, Figure 2 C and D outlines differences the TTVT can visualize between the thoracic and peritoneal cavities.

Detailed results by individual animal experiment are shown below and summarized in table 1.

Animal 1

Five, 36 Fr chest tube placements were performed in the left chest wall using standard of care method. Five, 36 Fr chest tube placements were performed in the right chest wall using TTVT. There were no complications using TTVT method. There were two complications

using the standard of care method. Complications included tube placement into the fissure of the lung, one caudally directed tube, and a kinked tube visualized on chest radiography (Figure 3, Table 2). Necropsy revealed no intrathoracic or parenchymal injuries.

Animal 2

Five, 32 Fr chest tube placements were performed in the right chest wall using standard of care method. Five, 32 Fr chest tube placements were performed in the left chest wall using TTVT. There were no complications using TTVT method. There were two complications using the standard of care method. Both complications were in the placement of the TT into the fissure (Table 2). Necropsy revealed no intrathoracic or parenchymal injuries.

Animal 3

Five, 28 Fr chest tube placements were performed in the right chest wall using standard of care method. Five, 28 Fr chest tube placements were performed in the left chest wall using TTVT. There were no complications using either method (Table 2). Necropsy revealed no intrathoracic or parenchymal injuries.

Discussion

In this study, we utilized a swine model to test the feasibility of direct visual TT placement utilizing the tube thoracostomy visual trocar as compared to the standard of care. We have demonstrated that direct visual TT placement permits operators the ability to assess intrathoracic placement location of TT in order to avoid potential injury or suboptimal placement during insertion. Moreover, TTVT placement maximally optimizes tube location and orientation as compared to the standard of care which is directly related to TT function. This is critical so that operators may avoid common complications during insertion. Our data demonstrates that TTVT placement successfully positioned TTs at the thoracic apex without damaging the lung parenchyma or adjacent structure. Conversely, TT placement utilizing the standard of care had increased incidence of common insertional complications, specifically kinked tube and placement into the fissure leading to suboptimal function. The modern literature reports a complication rate of (20–40%) and the observed 27% complication rate in this study is in general agreement(1–6). These findings suggest that TTVT placement is feasible in our model and that TTVT placement is non-inferior compared to the standard of care with regard to insertional complications in swine.

Currently, we do not know which methodology for TT insertion is optimal for patient care. There are several methodologies for performing TT including trocar, blunt, bougie assisted and Seldinger technique with or without ultrasound guidance. Ultrasound has several benefits for improving visualization for accessing the thoracic cavity but is unable to image cavities containing gas due to acoustic impedance (such as the lung parenchyma or a thoracic cavity without pneumothorax), this leads to the inability to see the distal placement location. Camera visualization, however, is not limited by anatomic and acoustic properties which improves usability for operators.

Standardization of commonly performed procedures via additional adjuncts such as image guidance, as in central line insertion or endotracheal intubation, demonstrates reduction in

complication rates (16–18) and is currently in most practice locations standard of care. Moreover, utilization of visual assistance has improved first attempt rates during urgent and difficult intubation (19). The simple advantage of being able to see during TT placement has the potential to improve outcomes in TT insertion as well. Complications after blind TT insertion have variable severity (9,10). TTVT placement is a potential adjunct for the safe and reliable insertion of TT potentially by all providers (20,21). Image guidance may increase the operator's tactile sense during TT insertion and reduce complications often incurred during blind insertion (22). TTVT placement has the potential to be a major advancement for management of intrathoracic pathology compared to the standard of care in tube thoracostomy but this needs to be assessed through clinical study.

TTVT placement also has implications for changing post insertion management and confirmation of tube location, specifically routine post insertion chest radiography (CXR). With visual confirmation of intrathoracic location, the need for post insertion CXR may no longer be necessary. In the future, we anticipate that this technique would permit CXR omission for TT that is confirmed to be both adequately placed and completely functional under image guidance. This necessitates further study in humans. Additional studies assessing the device function in a large animal setting utilizing operators of varied skill levels and professions is an important next step. This device also may have potential for placements and application in non-traumatic disease, such as for bedside diagnosis or pleural effusion drainage.

Finally, our data demonstrates that smaller tube size was associated with fewer complications compared to the larger diameter tubes. Smaller 28F tubes did not demonstrate any complications compared to the 32F or 36F. Previous work demonstrates that smaller bore tubes can resolve pneumothorax(23). With the addition of TTVT, optimal and functional tube position may be better achieved using smaller diameter TT.

Limitations

Our animal model has several limitations. Chest wall thickness is markedly thinner in this animal model than in the majority of patients. Therefore, the complications rates in our study may be lower than expected in humans. However, swine rib interspaces are significantly smaller than in humans which may have increased the difficulty of TT placement. Furthermore, chest wall composition is different in swine than in humans. There is relatively increased musculature and reduced subcutaneous fat as compared to what may be encountered in the general human trauma population (13). This limitation significantly reduces the possibility of subcutaneously placed TT, a complication not uncommon during TT insertion (6). Moreover, this study was performed in a controlled environment without the stresses of a severely injured patient and may not reflect the difficulty of inserting TT in practice. Additionally, the experiment lacked time as a variable for comparison of TTVT and standard of care TT insertion. Further, though the operative field tended to become bloody with time and was able to visualize adequately this study did not assess TT placements into a hemothorax.

Conclusion

TTVT is feasible and non-inferior to the standard of care for correct placement in a large animal model. The addition of visual confirmation of correct location during placement would have utility in improving clinical practice and potentially ameliorate complications. Further study in humans is required.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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References

1. Bailey RC. Complications of tube thoracostomy in trauma. J Accid Emerg Med [Internet]. 2000; 17(2):111–4. 2000/03/16. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/10718232>.
2. Lim KE, Tai SC, Chan CY, Hsu YY, Hsu WC, Lin BC, et al. Diagnosis of malpositioned chest tubes after emergency tube thoracostomy: is computed tomography more accurate than chest radiograph? Clin Imaging [Internet]. 2005; 29(6):401–5. 2005/11/09. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/16274893>.
3. Elsayed H, Roberts R, Emadi M, Whittle I, Shackcloth M. Chest drain insertion is not a harmless procedure—are we doing it safely? Interact Cardiovasc Thorac Surg. 2010; 11(6):745–8. [PubMed: 20864452]
4. Sethuraman KN, Duong D, Mehta S, Director T, Crawford D, St George J, et al. Complications of tube thoracostomy placement in the emergency department. J Emerg Med [Internet]. 2011; 40(1): 14–20. 2008/12/23. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/19097724>.
5. Menger R, Telford G, Kim P, Bergey MR, Foreman J, Sarani B, et al. Complications following thoracic trauma managed with tube thoracostomy. Injury [Internet]. 2012; 43(1):46–50. 2011/08/16. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/21839442>.
6. Hernandez MC, Laan DV, Zimmerman SL, Naik ND, Schiller HJ, Aho JM. Tube thoracostomy. J Trauma Acute Care Surg [Internet]. 2016 Aug; 81(2):366–70. [cited 2016 Jul 25]. Available from: <http://content.wkhealth.com/linkback/openurl?sid=WKPTLP:landingpage&an=01586154-201608000-00023>.
7. Surgeons AC of. Advanced Trauma Life Support: Student Course Manual. 9th. Chicago, IL: American College of Surgeons; 2009.
8. Matsumoto S, Sekine K, Funabiki T, Yamazaki M, Orita T, Shimizu M, et al. Chest tube insertion direction: is it always necessary to insert a chest tube posteriorly in primary trauma care? Am J Emerg Med [Internet]. 2015; 33(1):88–91. Available from: <http://ovidsp.ovid.com/ovidweb.cgi?T=JS&CSC=Y&NEWS=N&PAGE=fulltext&D=medl&AN=25468216>.

9. 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* [Internet]. 2014; 45(9):1435–9. Available from: <http://ovidsp.ovid.com/ovidweb.cgi?T=JS&CSC=Y&NEWS=N&PAGE=fulltext&D=medl&AN=24974160>.
10. 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* [Internet]. 2014; 96(8):609–13. Available from: <http://ovidsp.ovid.com/ovidweb.cgi?T=JS&CSC=Y&NEWS=N&PAGE=fulltext&D=medl&AN=25350185>.
11. Iribhogbe PE, Uwuigbe O. Complications of Tube Thoracostomy using Advanced Trauma Life Support Technique in Chest Trauma. *West Afr J Med* [Internet]. 2011; 30(5):369–72. 2012/07/04. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/22752826>.
12. Schroeder E, Valdez C, Krauthamer A, Khati N, Rasmus J, Amdur R, et al. Average chest wall thickness at two anatomic locations in trauma patients. *Injury Elsevier Ltd*. 2013; 44(9):1183–5.
13. Laan DV, Vu TDN, 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* [Internet]. 2016 Apr; 47(4):797–804. [cited 2016 Nov 4]. Available from: <http://linkinghub.elsevier.com/retrieve/pii/S0020138315007688>.
14. Aho JM, Ruparel RK, Schiller HJ. A technique for visual confirmation of intrathoracic placement of tube thoracostomy using a fiberoptic laryngoscope in a cadaver. *Eur J Trauma Emerg Surg* [Internet]. 2014 Apr 26; 41(2):199–202. [cited 2015 Feb 20]. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/26038265>.
15. Aho JM, Ruparel RK, Rowse PG, Brahmabhatt RD, Jenkins D, Rivera M. Tube Thoracostomy: A Structured Review of Case Reports and a Standardized Format for Reporting Complications. *World J Surg* [Internet]. 2015 Jul 10; 39(11):2691–706. [cited 2015 Jul 13]. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/26159120>.
16. Miller AH, Roth BA, Mills TJ, Woody JR, Longmoor CE, Foster B. Ultrasound guidance versus the landmark technique for the placement of central venous catheters in the emergency department. *Acad Emerg Med*. 2002; 9(8):800–5. [PubMed: 12153885]
17. Froehlich CD, Rigby MR, Rosenberg ES, Li R, Roerig PJ, Easley KA, et al. Ultrasound-guided central venous catheter placement decreases complications and decreases placement attempts compared with the landmark technique in patients in a pediatric intensive care unit. *Crit Care Med*. 2009; 37(3):1090–6. [PubMed: 19237922]
18. Shiloh AL, Savel RH, Paulin LM, Eisen LA. Ultrasound-guided catheterization of the radial artery: A systematic review and meta-analysis of randomized controlled trials. *Chest The American College of Chest Physicians*. 2011; 139(3):524–9.
19. Silverberg, MJ., Li, N., Acquah, SO., Kory, PD. Comparison of Video Laryngoscopy Versus Direct Laryngoscopy During Urgent Endotracheal Intubation: A Randomized Controlled Trial. *Crit Care Med* [Internet]. 2014 Dec 4. [cited 2015 Feb 20]; Available from: <http://www.ncbi.nlm.nih.gov/pubmed/25479112>
20. Pastis NJ, Tanner NT, Taylor KK, Silvestri GA. Interventional Pulmonary Medicine Tube Thoracostomy Evaluation of a Steerable Tube Thoracostomy System Compatible with a Flexible Bronchoscope. 2016:14–8.
21. Yokoyama T, Toda R, Tomioka R, Aizawa H. Medical thoracoscopy performed using a flexible bronchoscope inserted through a chest tube under local Anesthesia. *Diagn Ther Endosc*. 2009; 2009(c):1–5.
22. Chen CH, Chang H, Lee SY, Liu HC, Hung TT, Chen CH, et al. Video-guided tube thoracostomy with use of an electrical nonfiberoptic endoscope. *Ann Thorac Surg Elsevier Inc*. 2013; 96(4):1450–4.
23. Horsley A, Jones L, White J, Henry M. Efficacy and complications of small-bore, wire-guided chest drains. *Chest* [Internet]. 2006; 130(6):1857–63. 2006/12/15. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/17167009>.

Figure 1.

User Sequence of Visually Guided TT Device: **(A)** Insertion of optical portion of scope into the thoracostomy tube which goes over the camera. **(B)** At the desired position, the thumb actuator clamps the scope and tube together. **(C)** Manipulation of the scope and tube can be performed using a single hand or two hands as desired by the operator. **(D)** Once the tube is visually confirmed in the optimal position, the forefinger trigger actuator releases the clamped scope from the tube and the device may be withdrawn.

Figure 2.

Direct visualization method using Tube Thoracostomy Visual Trocar (TTVT). **(A)** Insertion of the scope into the thoracostomy tube. **(B)** Manipulation of the scope/tube can be performed in unison. **(C)** Visual confirmation of intrathoracic structures permitting navigation to optimal TT placement. **(D)** Purposeful intraperitoneal insertion, showing splenic tissue, demonstrating an imperfect insertion and alerting the operator early to complication.

Figure 3. Chest radiograph comparing the standard of care (SOC) (animal left) and TTVT placement (animal right). Note the caudally directed, kinked tube 32 Fr TT (left hemithorax) resulting in a poorly functional TT compared to the optimally placed direct visual placement.

Table 1

Results of TT placement using TTVT and standard of care.

Animal	TT Size (French)	Successful Standard of Care Placements	Successful TTVT Placements
1	36	3/5	5/5
2	32	3/5	5/5
3	28	5/5	5/5

Table 2

Complication data comparing standard of care and direct visual TT placement

Number of Complications for Chest Tube Placement							
	<i>Animal 1</i>		<i>Animal 2</i>		<i>Animal 3</i>		
Tube Size	36 Fr		32 Fr		28 Fr		
Chest Side	Left		Left		Left		
Placement	Standard of Care	Right	Standard of Care	Right	Standard of Care	Right	Direct Visual
		(n=5)		(n=5)			(n=5)
Number of Complications	2 *	0	0	2 **	0	0	0

* 1 - Fissural, 1 - Caudally directed kinked tube (Fig. 3)

** 2 - Fissural