Aim More Toward the Bed than the Head: A Proof-of-Concept Pilot Study on a Simple Technique for Keeping Trauma Thoracostomy Tubes Out of Lung Fissures

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ABSTRACT

Introduction: Tube thoracostomy (TT) is used to drain the pleural cavity in the setting of both traumatic and nontraumatic pathologies. Literature has shown that inappropriate tube positioning occurs in 30% of patients, including TTs placed within the fissure, which may result in further interventions in these patients. Our goal was to compare the rates of TT placed into a lung fissure in a controlled model using a simple approach to direct the tube more toward the bed than the patient's head at the time of placement to validate further investigations of the clinical applicability of this technique.

Methods: We performed 650 tube thoracostomies in 3 separate cadaver torsos with tracheal intubation and bag valve mask approximating a 50% pneumothorax. TTs were performed by experienced clinicians using a "more toward the head" direction and a "more toward the bed" direction while varying other factors, including side of the chest, tube size, and location on the chest wall, followed by lung re-expansion to better evaluate each approach in different common clinical scenarios. A power analysis was performed for our primary outcome of tube placement in a lung fissure by direction, not for any additional variables. Multivariate analysis was used to determine whether the "head" or "bed" direction was more likely to result in tube placement in a fissure when controlling for other changes.

Results: A total of 650 TTs were placed in 3 cadavers by 2 experienced performers. The overall rate of tube placement in a fissure was 41% using the "head" direction and 13% using the "bed" direction. On multivariate analysis, the "bed" direction also was shown to have significantly decreased tube placement in a lung fissure when controlling for side, tube size, and location ($P < 0.01$; odds ratio 0.22; 95% CI, 0.14 – 0.33).

Conclusions: Aiming more toward the bed than toward the head during TT placement is associated with a significantly decreased chance of placing the TT within a lung fissure in this highly controlled cadaveric proof-of-concept model. This technique requires no changes to standard TT placement set-up, time, cost, or equipment. We propose that it warrants further investigation as a potential intervention to decrease malpositioned tubes.

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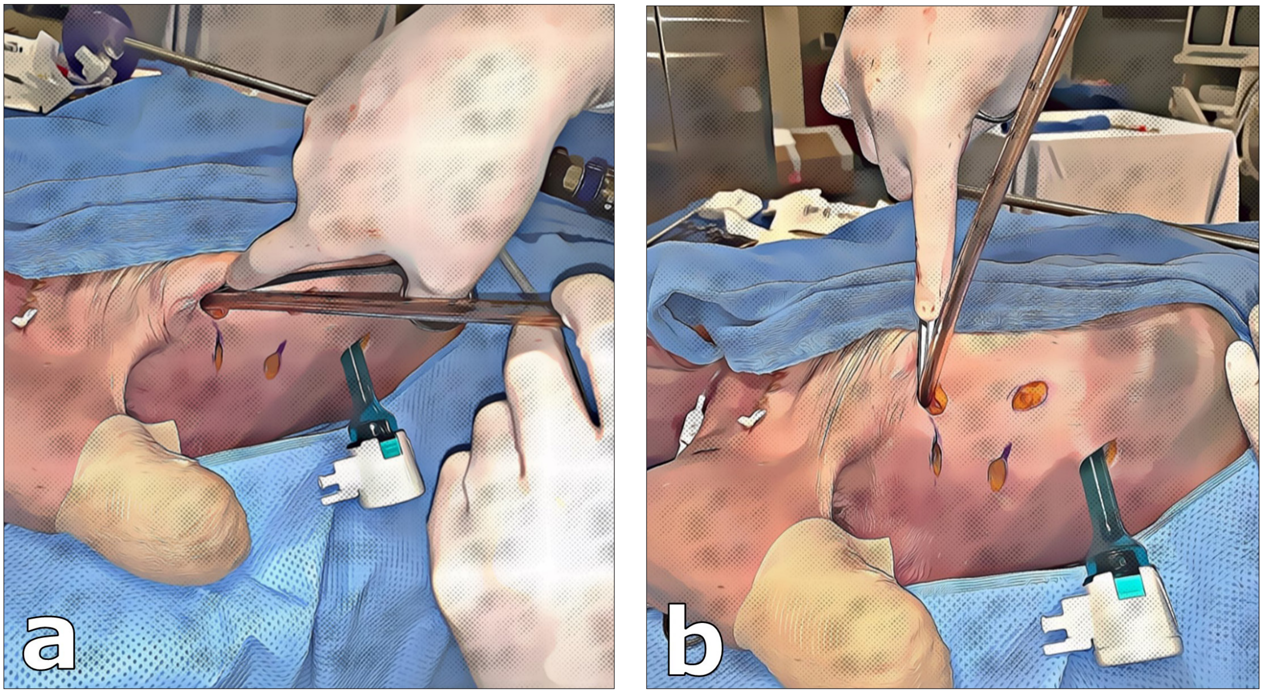
INTRODUCTION

Placement of a thoracostomy tube (TT), also referred to as a chest tube, is a technique used to drain the pleural cavity of blood or air following traumatic injuries, as well as fluid in other nontraumatic pathologies. While it is considered a fairly basic and common procedure with well-described and consistent steps, it also can be lifesaving for those with traumatic injuries. As such, it is a required procedural skill in the American College of Surgeon's Advanced Trauma Life Support (ATLS) training course.[1] This course is required of all physicians, nurse practitioners, and physician assistants who care for trauma patients in many states as it is expected that any clinician may be in a position to place a lifesaving TT in a trauma patient. The clinicians taking this course often are not experts in trauma care or TT placement. Therefore, ATLS focuses on safety during placement and outlines specific steps expected of all learners. By following these steps, ATLS teaches 1 way to perform a TT, which emphasizes directing the TT toward the patient's head.

Complications associated with TT placement, such as empyema, retained hemothorax, and intraparenchymal tube placement, continue to be reported in 20% to 40% of cases.[2,3] Multiple factors have been thought to increase the chance of complications, including but not limited to clinician experience, malposition of the tube, and placement location.[3,4] Incorrect pleural cavity positioning is believed to occur in approximately 30% of all TT pro-

Figure 1. (A) Tube Thoracostomy Aimed “More Toward the Head” and (B) Tube Thoracostomy Aimed “More Toward the Bed”



cedures, which can lead to an increased need for reintervention, a longer hospital stay, and increased cost.[5,6] One type of tube malposition is placement within a lung fissure. Although tubes that rest within a lung fissure can function similarly to tubes placed in the more ideal posterior, apically directed position within the pleural space, several studies have suggested that their poorer function increases the need for reintervention.[7,8]

The purpose of our proof-of-concept pilot study was to determine whether the direction of insertion of a TT aimed more toward the bed than toward the head would decrease the likelihood of a tube being placed in a fissure in a cadaver model compared with the standard apex-directed (head) insertion technique. This was based on the experience of one of the practicing trauma surgeons at our institution who regularly taught trainees using a bed-directed placement angle in order to best position the tube within the pleural space. The bed-directed insertion differed from most insertions by having the individual placing the tube bring their elbow over the patient’s chest to ensure the clamp holding the tube was directed in a more posterior than apical direction (Figure). Placement across the patient’s torso from the patient’s contralateral side also was discussed though considered less practical. We hypothesized that this simple change in insertion technique could impact the end position of the tube in the pleural cavity in a way that has the potential to have better function and could be included easily as part of future standard teaching to clinicians who place TTs in the setting of trauma.

METHODS

To determine the number of TT attempts utilizing the toward the head and bed approaches required to determine a difference in this study, the rates of TTs most commonly malpositioned into a lung fissure in the published literature were reviewed. In 5 selected publications, the reported malpositioned rates were 3%, 19%, 22%, 34% and 53%, yielding a median rate of 22% and a mean rate of approximately 26%, which was selected for our power calculation.[4,5,7,9,10] It was determined that a minimum of 320 TT placements would be needed (160 bed and 160 head placements) to detect a 50% decrease in the likelihood of fissure tubes at 80% power with $\alpha = 0.05$. To better simulate clinical TT placement variability, the authors elected to increase the sample size to 640 total insertions to provide sufficient power to control for the effects of additional relevant variables, including side of chest (right vs left), intercostal space (4th to 5th vs 6th to 8th), location (anterior vs mid-axillary), and tube size (28 French [Fr] vs 36 Fr). Chi-square tests were used to compare the rate of tube placement in a fissure by placement approach. A multivariate logistic regression model was constructed to control for the effects of other relevant clinical factors. All analyses were performed using version 9.4 of the SAS software suite (SAS Foundation, Cary, North Carolina).

Two experienced performers – 1 faculty trauma surgeon and 1 postgraduate year 4 (PGY4) general surgery resident – performed the TTs in 3 separate cadaver models following the same steps for each TT placement. Tracheal intubation was performed on each cadaver model. A sternotomy was completed so that the placement/location of each TT could be identified with direct visualization/palpation. The sternum was reapproximated after each performance to ensure a more normal chest wall structure before the next attempt. A bag valve was connected to the endotracheal tube, and for each individual placement attempt, the lung was inflated to approximate a 50% pneumothorax based on visual estimates of the observed lung filling the pleural cavity with the bag valve inflation. A 50% pneumothorax equivalent was selected to reflect a traumatic pneumothorax in a clinical setting that would warrant intervention as opposed to potential observation.

Two approaches to placement were employed: placement using the traditional approach, in which the tube was inserted from the ipsilateral side of the body (the more towards the head approach), and using the alternative approach, in which the tube was inserted with care taken to direct it more laterally than apically (the more towards the bed approach) (Figure). These placement techniques were utilized in series via the same skin incision and chest wall tract at each of our varied locations to imitate different potential clinical situations (ie, an incision placed lower or more anteriorly than ideal). After the tube was placed, the lung was reinflated with the bag valve mask from 50% to 100% expanded to simulate re-expansion of the lung for final determination of how the tube would rest with an expanded lung. The final tube position was then assessed via the sternotomy, with direct visualization/palpation of each tube as a binary outcome; the tube was either within a fissure or not and resting between lung parenchyma and chest wall. An anterior or posterior position was not differentiated for the purposes of this end point. The performers were not blinded to the tube placement results.

RESULTS

A total of 650 tube thoracostomies were completed in 3 separate cadavers by 2 experienced physicians individually. These were completed on each side of the cadaver, varying the placement direction (head vs bed), side, tube size, and location. The number of attempts made were 160, 170, and 320 in cadavers 1, 2, and 3, respectively. The overall rate of tubes placed in the fissure was 27%. Using the "bed" direction, 13% of TTs were placed in a fissure, and while using the "head" direction, 41% of tubes were placed in a fissure ($P < 0.01$). All "bed" attempts yielded tubes directed either within the fissure or between the posterior chest wall and the lung. During 1 "head" attempt, a tube was placed intraparenchymal.

A multivariate analysis was completed to better identify the effect of placement direction in the context of separate clinical scenarios. Variables in the model included direction of placement (head vs bed), cadaver, side of chest (right vs left), intercostal space (4th to 5th vs 6th to 8th), location (anterior vs mid-axillary), and tube size (28 Fr vs 36 Fr). In the multivariate regression, placement direction was found to significantly affect the rate of a TT being placed in a fissure (Table 1) ($P < 0.01$; OR 0.22; 95% CI, 0.13 – 0.30). The cadaver itself also seemed to affect the initial regression model, with cadaver 1 being associated with a decreased chance of placement within a fissure ($P < 0.01$; OR 0.2; 95% CI, 0.11 – 0.39). Cadaver 1 had an incomplete fissure on 1 side, which likely resulted in a significantly decreased chance of placement within a fissure. When excluding cadaver 1 data, only placement direction still significantly affected the rate of placement in a fissure (Table 2) ($P < 0.01$; OR 0.22; 95% CI, 0.14 – 0.33). The side of the chest, tube size, intercostal space, and location on the chest did not affect the ultimate positioning of a TT.

Table 1. Multivariate Regression Results

Variable	Comparison	OR (95% CI)	*P* value
Direction of placement	Head vs bed	0.20 (0.13 – 0.30)	< 0.0001
Cadaver	1 vs 3	0.20 (0.11 – 0.39)	< 0.0001
Cadaver	2 vs 3	0.99 (0.62 – 1.60)	0.97
Side	Left vs right	0.70 (0.43 – 1.11)	0.13
Tube size, Fr	28 vs 36	0.75 (0.51 – 1.10)	0.14
Intercostal space	4-5 vs 6-8	1.28 (0.87 – 1.89)	0.21
Location	Anterior axillary vs mid axillary	0.98 (0.67 – 1.45)	0.94

Abbreviations: OR, odds ratio.

Table 2. Multivariate Regression Results Excluding Cadaver 1

Variable	Comparison	OR (95% CI)	*P* value
Direction of placement	Head vs bed	0.22 (0.14 – 0.33)	< 0.0001
Cadaver	2 vs 3	1.05 (0.65 – 1.71)	0.83
Side	left vs right	0.82 (0.50 – 1.33)	0.40
Tube size, Fr	28 vs 36	0.84 (0.56 – 1.27)	0.40
Intercostal space	4-5 vs 6-8	1.18 (0.78 – 1.79)	0.42
Location	Anterior axillary vs mid-axillary	0.92 (0.61 – 1.39)	0.69

Abbreviations: OR, odds ratio.

DISCUSSION

Using cadaver models, we found that the rate of TT placement in a fissure was lower using the more toward the bed direction when controlling for multiple factors, including tube size, location, and intercostal space. While these results are promising, the impact of implementing this technique in training and practice remains to be determined. While we also saw no significant complications with this technique and expect that training will not add any complexity to the procedure, a primary question remains: how much a tube placed in a lung fissure even matters. Batchelder and Morris established that TT placement within a fissure is considered non-ideal; however, data remain mixed about the true clinical impact.[11] In a retrospective radiographic evaluation following TT placement, Maurer and colleagues recognized that tubes placed in the minor or major fissure required replacement in certain cases with potential for inadequate drainage of the pleural space.[12] More recently, Kim et al also noted retrospectively that tubes placed within the fissure have a higher chance of need for reintervention.[8] However, one concern is a clinician hindsight bias that having identified the tube as within the fissure, a lower threshold for replacement or another secondary intervention was maintained due to the expectation it was less likely to work. Conversely, Kugler et al completed a retrospective review evaluating whether tube position or function affected the need for reintervention after TT. They found that if TTs were not kinked, there was no increased risk of reintervention.[9] In a prospective trial, Curtin and colleagues found that placement in a fissure had no significant effect on patient outcomes.[3]

While our study was not powered to specifically examine other variables, including tube size or location (intercostal space, mid vs anterior axillary line) and their impact on tubes placed into a fissure, we did feel it was necessary to evaluate these variables as they are common variations seen when tubes are placed clinically–especially in emergent trauma situations. The data also would suggest they do not have significant clinical impact. Maybauer et al performed an extensive retrospective review of 1065 patient records and evaluated TT placement based on location. The authors found no difference in complication rate based on position in the 4th to 5th intercostal space at the midaxillary line or in the 2nd to 3rd intercostal space at the midclavicular line.[10] Hernandez et al reviewed adult trauma patients requiring TT over 1 year and evaluated whether the angle of placement increased the rate of complications. They radiographically reviewed the angle of insertion and noted that an increased angle (>45°) was associated with increased complications.[7]

Although questions remain regarding the clinical impact of a TT resting in a fissure, the goal for placement remains an optimally positioned tube–one that is posterior and superiorly directed and not in a fissure. Therefore, there seems to be little reason not to adopt a technique more likely to achieve this goal if there is no associated increase in cost, time, equipment or complications. Etoch et al completed a retrospective review and found increased complications in TT completed by nonsurgeon physicians.[5] They postulated that further training in the TT placement would improve outcomes. Aiming more toward the bed than the head is a simple, free, easily replicated, and easily taught technique that can be utilized at the time of TT placement.

Using a highly controlled cadaver model to assess the issue of malpositioned tubes placed in a clinical setting does have limitations. We attempted to recreate reinflation with tracheal intubation and bag-valve-mask; however, this may not adequately model reinflation after TT placement and would only be for pneumothorax drainage versus drainage for a hemothorax or effusion. Presence of a pleural fluid density itself also could alter the path the tube travels in the chest cavity, which was not part of this model. We also looked at the binary outcome of in the fissure or not in the fissure. As previously discussed, "malpositioned" is inconsistently defined in the literature, making ultimate attribution of function to location a challenge. A tube along the diaphragm or in the fissure may very well function adequately for the patient's pathology but radiographically be defined as malpositioned. For this proof-of-concept pilot, we focused specifically on tubes within the fissure for our outcome based on our interpretation of the available literature of this position more likely affecting function and the suspected overall physiologic impact of the tube's drainage holes being opposed on all sides by lung parenchyma versus tubes not in the apex but in the space between lung and posterior, which would communicated with more contiguously with the pleural space. Debate on the validity of this assumption is very reasonable and can be assessed in future models that include more details on other positions (ie, along the diaphragm), and when the presence of fluid or coagulated blood is part of the pathology, the tube must evacuate to be considered successful.

Anatomic variants were also limited in this pilot. One cadaver had an incomplete fissure, which highlights the anatomic variability that may affect the ultimate tube position but is outside of the clinician's control. Other patient factors that could impact the direction a tube takes once in the pleural cavity, such as presence of adhesions from previous thoracic pathology, presence of traumatic injuries such as rib fractures or hemothorax with clot, and patient body mass index (BMI) (all of the cadavers' BMIs were <25) impacting the length of the subcutaneous tract, could not be assessed. In this model, we were limited to 1 skin and chest wall tract at each location due to the limited number of cadavers available. Tract likely has a significant impact in direction of a TT, particularly in larger BMI patients; therefore, we were not able to identify if tract-specific factors including length affected the rate of tubes within a lung fissure. Additionally, after placing over 100 TTs in each cadaver, it is possible that tracts along the lung parenchyma or directed toward the fissure led to recurrent placement in the same position, which would not occur in a clinical scenario where a single tube is placed in a single attempt. Muscle memory of the performers with immediate unblinded feedback on tube location also could have affected placement in or out of a fissure and could not be controlled for within the design of this study. This may have been further amplified by the fact we only had two performers available to participate in the TT placements for the study. More performers with various experience could have limited the possible muscle memory component but would have added additional variables in what was meant to be a highly controlled proof-of-concept trial.

CONCLUSIONS

Using a highly controlled cadaver model and experienced performers, we varied the approach to TT placement from the classic "more toward the head" direction to the "more toward the bed" direction and reduced our rates of TT placement within lung fissures. This functioned as a proof-of-concept pilot model to support next steps in investigation in both the training and patient outcomes for this simple technique. When controlling for multiple clinical scenarios, including tube size, location on the chest, side, and intercostal space, only the proposed placement technique significantly decreased the likelihood of a TT being placed within a fissure. Implementation of an "aim more toward the bed than toward the head" mantra during TT skills training could very easily be incorporated in standard TT placement steps without adding any significant complexity to the procedure for learners.

The next steps in the evaluation of this approach will include training of more novice performers and adding additional pathology, including fluid or coagulated blood models, to compare the "head" and "bed" directions. However, this further investigation appears warranted given this simple change adds no cost, time, or equipment to current TT placement standards and has the potential to reduce the need for reintervention due to tube malfunction.

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REFERENCES

1. American College of Surgeons Committee on Trauma. *Advanced Trauma Life Support: Student Course Manual*. 10th ed. American College of Surgeons; 2018.

2. Bailey RC. Complications of tube thoracostomy in trauma. *J Accid Emerg Med*. 2000;17(2):111-114. doi:10.1136/emj.17.2.111

3. Curtin JJ, Goodman LR, Quebbeman EJ, Haasler GB. Thoracostomy tubes after acute chest injury: relationship between location in a pleural fissure and function. *AJR Am J Roentgenol*. 1994;163(6):1339-1342. doi:10.2214/ajr.163.6.7992724

4. Hernandez M, El Khatib M, Prokop L, Zielinkski M, Aho J. Complications in tube thoracostomy: systematic review and meta-analysis. *J Trauma Acute Care Surg*. 2018;85(2):410-416. doi:10.1097/TA.0000000000001840

5. Etoch S, Bar-Natan M, Miller F, Richardson D. Tube thoracostomy: factors related to complications. *Arch Surg*. 1995;130(5):521-526. doi:10.1001/archsurg.1995.01430050071012

6. Sethuraman K, Mehta D, Mehta S, Director T, Crawford D, George J, Rathlev N. Complications of tube thoracostomy placement in the emergency department. *J Emerg Med*. 2011;40(11):14-20. doi:10.1016/j.jemermed.2008.06.033

7. Hernandez M, Laan D, Zimmerman S, Naik N, Schiller H, Aho J. Tube thoracostomy: increase in angle of insertion is associated with complications. *J Trauma Acute Care* Surgery, 2016;81(2):366-370. doi:10.1097/TA.0000000000001098

8. Kim YW, Byun CS, Cha YS, Kim OH, Lee KH, Park IH. Differential outcome of fissure-positioned tube in closed thoracostomy for primary spontaneous pneumothorax. *Am J Surg*. 2015;81(5), 463-466. doi:10.1177/000313481508100526

9. Kugler NW, Carver TW, Knechtges P, Milia D, Goodman L, Paul JS. Thoracostomy tube function not trajectory dictates reintervention. *J Surg Res.* 2016;206(2):380-385. doi:10.1016/j.jss.2016.08.021

10. Maybauer MO, Geisser W, Wolff H, Maybauer DM. Incidence and outcome of tube thoracostomy positioning in trauma patients. *Prehosp Emerg Care*. 2012;16(2):237-241. doi:10.3109/10903127.2011.615975

11. Batchelder T, Morris K. Critical factors in determining adequate pleural drainage in both the operated and nonoperated chest. *Am J Surg.* 1962;28:296-302.

12. Maurer JR, Friedman PJ, Wing VW. Thoracostomy tube in an interlobar fissure: radiologic recognition of a potential problem. *AJR Am J Roentgenol*. 1982;139(6):1155-1161. doi:10.2214/ajr.139.6.1155

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