Optimal Positioning for Emergent Needle Thoracostomy: A Cadaver-Based Study

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Background: Needle thoracostomy is an emergent procedure designed to relieve tension pneumothorax. High failure rates because of the needle not penetrating into the thoracic cavity have been reported. Advanced Trauma Life Support guidelines recommend placement in the second intercostal space, midclavicular line using a 5-cm needle. The purpose of this study was to evaluate placement in the fifth intercostal space, midaxillary line, where tube thoracostomy is routinely performed. We hypothesized that this would result in a higher successful placement rate.

Methods: Twenty randomly selected unpreserved adult cadavers were evaluated. A standard 14-gauge 5-cm needle was placed in both the fifth intercostal space at the midaxillary line and the traditional second intercostal space at the midclavicular line in both the right and left chest walls. The needles were secured and thoracotomy was then performed to assess penetration into the pleural cavity. The right and left sides were analyzed separately acting as their own controls for a total of 80 needles inserted into 20 cadavers. The thickness of the chest wall at the site of penetration was then measured for each entry position.

Results: A total of 14 male and 6 female cadavers were studied. Overall, 100% (40 of 40) of needles placed in the fifth intercostal space and 57.5% (23 of 40) of the needles placed in the second intercostal space entered the chest cavity ($p < 0.001$); right chest: 100% versus 60.0% ($p = 0.003$) and left chest: 100% versus 55.0% ($p = 0.001$). Overall, the thickness of the chest wall was 3.5 cm ± 0.9 cm at the fifth intercostal space and 4.5 cm ± 1.1 cm at the second intercostal space ($p < 0.001$). Both right and left chest wall thicknesses were similar (right, 3.6 cm ± 1.0 cm vs. 4.5 cm ± 1.1 cm, $p = 0.007$; left, 3.5 ± 0.9 cm vs. 4.4 cm ± 1.1 cm, $p = 0.008$).

Conclusions: In a cadaveric model, needle thoracostomy was successfully placed in 100% of attempts at the fifth intercostal space but in only 58% at the traditional second intercostal position. On average, the chest wall was 1 cm thinner at this position and may improve successful needle placement. Live patient validation of these results is warranted.

Key Words: Tension pneumothorax, Needle thoracostomy, Optimal positioning, Cadaver model.

(*J Trauma.* 2011;71: 1099–1103)

Needle thoracostomy (NT) is a procedure designed to urgently decompress a tension pneumothorax.[1,2] As there are no well validated guidelines for when this procedure is indicated, the reported incidence varies widely from 0.2%[3] to 1.7%.[4] With the lack of consensus on the indications for this procedure and the inability to confirm a definitive diagnosis of tension pneumothorax before needle insertion, the true success rate of needle decompression is also unknown. In a recently published retrospective analysis of trauma patients undergoing prehospital NT over a 48-month period, an attempt at NT decompression was made in 1.5% of all blunt patients.[5] Using the absence of a large pneumothorax on initial admission ultrasound or computed tomography (CT) as a surrogate marker of success, depending on the size of the catheter used, failure of the needle to decompress was documented in 4% to 65% of cases. As a major assumption of this analysis was that all patients without a pneumothorax at the time of hospital arrival had a tension pneumothorax decompressed successfully, it is likely that the true failure rate of this procedure is even higher.

For NT, the 8th edition of the American College of Surgeons Committee on Trauma Advanced Trauma Life Support (ATLS) program recommends a 5-cm catheter, placed in the second intercostal space in the midclavicular line.[1,2] Using this placement technique, several CT-based studies have examined the ability of the recommended needle to enter the pleural space.[6] In one retrospective analysis of consecutive adult trauma patients undergoing chest CT, the NT decompression would have been unsuccessful in approximately half of the patients.[7] Gender and age may also be an important consideration with females having a significantly thicker chest wall, increasing the chance of failure.[8] These CT-based studies assume a perfectly perpendicular straight line needle placement into the chest, thus their conclusions may in fact underestimate the magnitude of this problem.

Although ATLS recommends the second intercostal space for NT decompression, tube thoracostomy placement is routinely performed in the fifth intercostal space, anterior to the midaxillary line.[1,2] In addition to being the location of

Submitted for publication April 15, 2011.
Accepted for publication July 13, 2011.

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Presented at the 41st Annual Meeting of the Western Trauma Association, February 27-March 5, 2011, Big Sky, Montana.
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DOI: 10.1097/TA.0b013e31822d9618

Figure 1. Photograph of a standard 14-gauge (5-cm long) angiocatheter used for needle thoracostomy as recommended by ATLS guidelines.

choice for open instrumentation of the chest wall, there is increasing experience being gained with the placement of percutaneous, wire-guided thoracostomy tubes using the Seldinger technique in this region. The first step in this procedure is the placement of a needle into the pleural cavity, much like placement of a NT for decompression.

The utility and optimal technique for NT for chest decompression is therefore unclear. The purpose of this study was to evaluate needle placement in the second intercostal space in the midclavicular line as compared with a puncture using the same needle, but in the fifth intercostal space, just anterior to the midaxillary line, where tube thoracostomy is routinely performed. Our hypothesis was that the traditional second intercostal space placement technique is less likely to be successful than insertion in the region where tube thoracostomy is routinely performed.

MATERIALS AND METHODS

From August 2009 to February 2010, a random selection of 20 adult fresh cadavers were included in this study. None of the cadavers had gross evidence of neoplastic, congenital, or developmental malformations.

Preparation and Procedures

The cadavers were kept in refrigerated storage at +4°C until 1 hour before the experiment. During this period, they were allowed to warm to room temperature. After placement in the supine position with arms at 90 degrees, the cadavers were subjected to NT using a 14-gauge (5 cm long) angiocatheter (Introcan; B. Braun, Melsungen, Germany) as specified by the ATLS guidelines for chest decompression[1,2] (Fig. 1). Two locations were compared: fifth intercostal space at the midaxillary line and second intercostal space at the midclavicular line. After placement of the needles in both hemithoraces, the needles were secured, and bilateral thoracotomies were then performed to assess penetration into the pleural cavity. Pleural puncture was used as evidence of penetration. The thickness of the chest wall at the site of penetration was then measured for each entry position using a standard metric ruler. The right and left sides were analyzed separately acting as their own controls for a total of 80 needles inserted into 20 cadavers.

Outcome Measures and Statistical Analysis

The following outcomes were compared between the two locations: (1) penetration into the chest cavity and (2) thickness of the chest wall (cm) at the site of penetration. Data collected included gender and outcomes. Data were entered into a computerized spreadsheet (Microsoft Excel 2003, Microsoft corporation, Redmond, WA) and analyzed using SPSS for Windows, version 12.0 (SPSS, Chicago, IL). Fisher's exact test was used to compare proportions, and Mann-Whitney U test was performed to compare means.

RESULTS

During the study period, a total of 14 male and 6 female cadavers were studied. Overall, all (40 of 40) needles placed in the fifth intercostal space and 57.5% (23 of 40) of the needles placed in the second intercostal space entered the chest cavity ($p < 0.001$). On the right hemithorax, the rate was 100% versus 60%, respectively ($p = 0.003$) and on the left hemithorax was 100% versus 55%, respectively ($p = 0.001$). Overall, the thickness of the chest wall was 3.5 cm ± 0.9 cm on the fifth intercostal space and 4.5 cm ± 1.1 cm on the second intercostal space ($p < 0.001$). On the right hemithorax, the thickness of the chest wall was significantly lower on the fifth intercostal space (3.6 cm ± 1.0 cm vs. 4.5 cm ± 1.1 cm, $p = 0.007$). The same was observed on the left hemithorax (3.5 cm ± 0.9 cm vs. 4.4 cm ± 1.1 cm, $p = 0.008$) (Table 1).

When outcomes were analyzed according to gender, in male cadavers, 75.0% of the needles placed in the second intercostal space penetrated the chest cavity, whereas in females the rate was 16.7% ($p < 0.001$). In males, the thickness of the chest wall was significantly lower in the fifth intercostal space (3.3 cm ± 0.8 cm vs. 4.1 cm ± 1.0 cm, $p = 0.001$). In females, the same was observed (4.1 cm ± 0.9 cm vs. 5.2 cm ± 1.0 cm, $p = 0.010$). The description of outcomes for each cadaver is presented in Table 2.

DISCUSSION

NT is a procedure designed to decompress a tension pneumothorax. Although there are documented cases where decompression has been closely associated at least temporally with unexpected survival,[3,4,9,10] the true indications for needle insertion, placement technique, and success rates all remain unclear.

Despite this, it remains a commonly performed procedure in the prehospital setting. In a study performed at Harborview for combined Advanced Life Support calls, 0.2% of patients had placement of a NT for decompression of a presumed tension pneumothorax.[3] This included both traumatic and nontraumatic indications. In comparison to this, a study by Eckstein at the LA County Medical Center documented a 1.7% incidence,[4] with the majority because of

TABLE 1. Summary of the Outcomes

	Fifth Intercostal Space		Second Intercostal Space	
	Entered the Chest (Y/N)	Wall (cm)	Entered the Chest (Y/N)	Wall (cm)
Right hemithorax	100.0% (20/20)*	3.6 ± 1.0; (3.5), (2.1, 4.9)*	60.0% (12/20)	4.5 ± 1.1; (4.7), (3.1, 6.2)
Left hemithorax	100.0% (20/20)*	3.5 ± 0.9; (3.3), (2.1, 4.8)*	55.0% (11/20)	4.4 ± 1.1; (4.4), (2.8, 6.1)
Overall	100.0% (40/40)*	3.5 ± 0.9; (3.4), (2.1, 4.9)*	57.5% (23/40)	4.5 ± 1.1; (4.5), (2.8, 6.2)

* *p*-values are significantly different ($p < 0.05$).

Continuous variables were reported as mean ± SD; (median), (range). Values were reported in centimeters. The *p*-values for categorical variables were derived from Fisher's exact test; *p*-values for continuous variables were derived from Mann-Whitney *U* test.

TABLE 2. Description of Outcomes on Each Cadaver

		Right Hemithorax				Left Hemithorax			
		Fifth Intercostal Space		Second Intercostal Space		Fifth Intercostal Space		Second Intercostal Space	
Number	Sex	Entered the Chest (Y/N)	Wall (cm)	Entered the Chest (Y/N)	Wall (cm)	Entered the Chest (Y/N)	Wall (cm)	Entered the Chest (Y/N)	Wall (cm)
1	M	Y	2.5	Y	3.6	Y	2.4	Y	3.5
2	M	Y	3.5	Y	4.7	Y	3.2	Y	4.3
3	F	Y	4.9	N	6.2	Y	4.7	N	6.1
4	F	Y	4.7	N	5.4	Y	4.8	N	5.7
5	F	Y	4.4	N	5.3	Y	4.2	N	5.1
6	M	Y	4.6	Y	4.9	Y	4.8	N	5.2
7	M	Y	2.9	Y	3.1	Y	2.5	Y	2.8
8	M	Y	2.8	Y	3.4	Y	2.6	Y	3.2
9	M	Y	3.0	Y	3.4	Y	3.0	Y	3.3
10	M	Y	3.4	Y	4.6	Y	3.3	Y	4.4
11	M	Y	4.8	N	6.2	Y	4.5	N	6.0
12	M	Y	2.9	Y	3.4	Y	2.7	Y	3.2
13	F	Y	4.7	N	5.8	Y	4.5	N	5.6
14	M	Y	4.1	N	5.2	Y	4.0	N	5.1
15	M	Y	2.5	Y	3.3	Y	2.9	Y	3.5
16	M	Y	4.6	N	5.2	Y	4.4	N	5.1
17	M	Y	2.1	Y	3.3	Y	2.1	Y	3.2
18	F	Y	4.1	N	5.6	Y	3.9	N	5.4
19	F	Y	2.4	Y	3.3	Y	2.1	Y	3.1
20	M	Y	3.1	Y	4.3	Y	3.0	Y	4.1

penetrating trauma (59% gunshot wounds and 30% stab wounds). In yet another study from Vanderbilt, the incidence was 0.68%,[11] underscoring the difficulty in tracking the utility of this procedure, in large part because of the lack of evidence-based guidelines for insertion.

Decompression of air under pressure, and even blood, is possible through a 14-gauge catheter as demonstrated in a controlled preclinical evaluation by Holcomb et al.[12] In their model of spontaneously ventilated swine, with 10% of their calculated blood volume injected into their chest cavity with induced needle insufflation to create a tension hemopneumothorax, the positive intrapleural pressure was successfully relieved by a catheter. While the catheter itself may not limit the decompression of tension physiology, the traditional placement site may. As described by ATLS, needle placement should target the second intercostal space, in the midclavicular line. Several studies have examined chest wall thickness at this site,[6–8,13] using CT and found that it exceeds the recommended catheter length in a significant proportion of injured patients. In a retrospective analysis of 110 consecutive adult trauma patients undergoing chest CT,[7] the mean chest wall thickness was 4.5 cm ± 1.5 cm on the right and 4.1 cm ± 1.4 cm on the left. They concluded that in half of the patients, a standard angiocatheter would have been unsuccessful in penetrating the chest cavity. As with all of these CT-based measurement studies, this implies that the catheter is placed perfectly perpendicular to the body surface to minimize the distance to the pleural space. In a study by Harcke et al.[6] using virtual autopsy data from deployed male military personnel, the mean chest wall thickness was 5.36 cm. The group in Calgary[8] reviewed ISS more than 12 trauma admissions undergoing chest CT and stratified their results by gender and age <40 years or ≥40 years. Again, assuming that the needle is placed perfectly, more than 9.9% to 35.4% of patients would not have had chest wall penetration depending on their age and gender. The mean chest wall thickness was seen to be significantly higher for females. In addition, these studies were all performed in a static environment, using either autopsy or CT scan measurements. This would not account for variations in the thickness of the chest wall with active respiratory efforts, which could impact the depth of NT placement or potentially dislodge a properly placed catheter.

In this study, a cadaveric model was used to assess the efficacy of placement in the traditional second intercostal space in the midclavicular line when compared with the placement site for a thoracostomy tube in the fifth intercostal space, midaxillary line. Alternative placement sites as suggested in a case series by Rawlins et al.[14] were examined in a CT-based study by Wax and Leibowitz.[15] These authors examined the chest CT of 100 random patients who had undergone a video-assisted thoracoscopic procedure. They evaluated a variation on the traditional sites, measuring chest wall thickness at the sternal angle, along a line they defined as the midhemithorax line, medial to the midclavicular line. The investigators felt that using palpable landmarks such as the sternal angle would facilitate consistent needle placement. This decision was driven by a study by Ferrie et al.,[16] in which 25 emergency medicine physicians of varying experience demonstrated that although most (88%) could name the site where the needle should be placed, many could not correctly mark this spot on a human volunteer. In addition to this, Wax and Leibowitz measured the chest wall thickness at the level of the xiphoid process in the midaxillary and the anterior axillary lines. The median distance and range for the mid hemithorax line were 3.1 cm (1.4–6.9 cm), midaxillary 3.5 cm (1.7–9.3 cm), and anterior axillary the thinnest at 2.6 cm (1.0–7.7 cm). The authors did not provide a cut-off analysis for catheter length, thus the overall success rates of the patients undergoing NT decompression at each of these sites could not be compared.

In this study, only 57.5% of the catheters placed into the traditional second intercostal space entered the chest cavity. This was in comparison to 100% of the needles placed in the fifth intercostal space where a tube thoracostomy is routinely performed. The chest wall thickness in this region, primarily because of the absence of the pectoralis muscle, was approximately 1 cm thinner. As demonstrated in previous CT-based studies, women had a thicker chest wall when compared with men by approximately 1 cm. As a result, the success rate for placement in the second intercostal space in women was only 16.7%. The success rate of needle placement in the traditional second intercostal position, confirmed visually in this human model, was therefore highly variable. This study, the first of its kind to our knowledge using a human cadaveric model, confirms earlier work using CT measurements of the chest wall. Either use of a longer needle where available or an alternative location will be required to increase the probability of chest wall penetration. If a specialized needle is not available, the fifth intercostal space should be considered due to the thinner chest wall in this region.

Any discussion of an invasive intervention such as NT must weigh the potential risks versus benefits. The well-described risk of an untreated or inadequately treated tension pneumothorax is cardiorespiratory collapse and death. This has been documented in the civilian trauma population, and recent military combat data demonstrate that tension pneumothorax is the cause of death in up to 4% of fatalities and is one of the most common causes of "preventable" deaths on the battlefield.[17–19] Although multiple studies have demonstrated a low complication rate associated with NT placement by trained personnel,[9,20] the findings of our study highlight the fact that the most common complication of this procedure is likely to be failure of the catheter to penetrate the thoracic cavity with resultant persistence or worsening of a tension pneumothorax. Our data clearly demonstrate the superiority of a lateral approach for NT placement in a controlled environment, but applying this to civilian or military prehospital settings must also consider patient positioning and accessibility issues. From a civilian emergency medical service perspective, placement of the catheter laterally in the fifth intercostal space will require minimal additional exposure and would not impede transportation. However, in the combat setting this area may be particularly difficult to access because of body armor and equipment. Although the fifth intercostal space was examined specifically in this study due to the aggregate experience with tube thoracostomy at that location, an even higher placement of the needle at the fourth or third intercostal space may be considered based on accessibility. This may also mitigate the incidence of potential complications such as intraabdominal needle placement.

This study used randomly selected, unpreserved cadavers providing a high-fidelity reproduction of the native chest wall. The exact age, height, or weight of the cadavers was not available, but in general, age was higher than the average trauma cohort and their muscle mass may have been more atrophic. In addition, the needle placement was performed in a highly controlled situation. The majority of NT decompressions would be expected to occur under austere operating conditions, resulting in even less optimally perpendicular tangents into the chest wall. All of these limitations would be expected to increase the magnitude of our findings however, and the findings correlated well with the actual measurements performed of the chest wall thickness. Finally, this study was not designed to comment on the indications for NT decompression, but rather the technical aspects of the procedure itself. Further work will be required to clarify this aspect of the procedure.

CONCLUSION

In a cadaveric model, NT was successfully placed in 100% of attempts at the fifth intercostal space but in only 58% at the traditional second intercostal position. On average, the chest wall was 1 cm thinner at this position and may improve successful needle placement. Live patient validation of these results is warranted.

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EDITORIAL COMMENT

Dr. Inaba et al. have provided a valuable addition to our trauma literature. For my entire professional career, Advanced Trauma Life Support (ATLS) has taught, and even I as an instructor early in my career was forced to endorse (or at least mention), the policy of placing a needle for suspected tension pneumothorax in the midclavicular line at the second intercostal space. My experience as a resident on the front lines at a busy trauma center in San Antonio with excellent trauma protocols and teams was that this was not uniformly effective. In fact, at times, it seemed dangerous. As a young thoracic faculty, my experience was more morbidity from this procedure than utility. Dr. Inaba et al. are to be congratulated for this novel, simple, and succinct article, which conclusively demonstrates that it is simply easier and safer to get at the thoracic cavity routinely and through the least amount of tissue by going in the fourth or fifth intercostal space along the midaxillary line. The purpose of this editorial is to reinforce this kind of novel simple investigation. The continued questioning of practices that have become routine and endorsed by major bodies is one we should all adhere to. Like midclavicular second intercostal needle placement, some "established" practices probably do not represent the best way to perform a procedure or medical treatment. In this case anecdotally, I can provide numerous occasions where a needle (in teaching students I prefer the term "harpoon") was placed and the internal mammary artery was perforated, or intercostal arteries were perforated as one could not feel the ribs easily. Worse still, the chest cavity was never entered and the patient suffered under false pretense tension pneumothorax was no longer a possibility. This false assumption occasionally led to the death of an inadequately or untreated patient. Even today, ATLS policy is a second intercostal midclavicular line needle thoracostomy as initial treatment. Fortunately, it must be followed by immediate chest tube placement before the patient is transferred to high level care (if they get there). Although ATLS thought process must presume the average emergency room or family medicine doctor can do this easily, in my experience it is much easier to do as the authors suggested. This article and its clear findings warrant a recommendation to ATLS to change their teachings. Certainly, there are risks of the fifth intercostal space needle puncture. Like most of you, I have seen well intended and actually quite expert operators place a needle into the heart in cases where the patient had significant cardiomyopathy or cardiac malposition. Nonetheless, I think this article is sufficient to suggest change in standard trauma and resuscitation protocols where a tension pneumothorax is of concern. This article also could be a great place for an enterprising investigator to create a randomized trial of needle thoracosotmy in the second intercostal space midclavicular line versus one in the fifth intercostal space mid axillary line for suspected tension pneumothorax. This study could answer the question definitively. Regardless, the article challenged an accepted status quo and gave us all a chance to reevaluate the best initial approach to tension pneumothorax.

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