Appropriate Needle Length for Emergent Pediatric Needle Thoracostomy Utilizing Computed Tomography

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APPROPRIATE NEEDLE LENGTH FOR EMERGENT PEDIATRIC NEEDLE THORACOSTOMY UTILIZING COMPUTED TOMOGRAPHY

Maria J. Mandt, MD, Kari Hayes, MD, Fred Severyn, MD, Kathleen Adelgais, MD, MPH

ABSTRACT

Objective: Needle thoracostomy is a life-saving procedure. Advanced Trauma Life Support guidelines recommend insertion of a 5 cm, 14-gauge needle for pneumothorax decompression. High-risk complications can arise if utilizing an inappropriate needle size. No study exist evaluating appropriate needle length in pediatric patients. Utilizing computed tomography (CT), we determined the needle length required to access the pleural cavity in children matched to Broselow™ Pediatric Emergency Tape color. Methods: Three investigators reviewed chest CTs of children <13 years of age obtained between 2010 and 2015. Patient exclusions included those with a chest wall mass, muscle disease, pectus deformity, anasarca, prior open thoracotomy, inadequate imaging, or missing height documentation.

Results: A total of 273 chest CTs were reviewed, of which 23 were excluded, for a resultant study population of 250 scans and 498 total measurements. Median patient age was 4 years, 52.8% were male. Children measuring Broselow Gray/Pink (<68 cm), had a median chest wall thickness at the 2nd ICS-MCL of 1.57 cm (95% CI 1.42 cm, 1.72 cm), 4th ICS-AAL 1.67 cm (95% CI 1.48 cm, 1.86 cm). Broselow Red/Purple (68.1–90 cm): 2nd ICS-MCL of 1.96 cm (95% CI 1.84 cm, 2.08 cm), 4th ICS-AAL 1.73 cm (95% CI 1.62 cm, 1.84 cm). Broselow Yellow/White (90.1–115 cm): 2nd ICS-MCL of 2.12 cm (95% CI 2.03 cm, 2.22 cm), 4th ICS-AAL 1.91 cm (95% CI 1.8 cm, 2.01 cm). Broselow Blue/Orange/Green (>115.1 cm): 2nd ICS-MCL of 2.45 cm (95% CI 2.3 cm, 2.6 cm), 4th ICS-AAL 2.19 cm (95% CI 2.02 cm, 2.36 cm).

Conclusion: Median chest wall thickness varies little by height or location in children <13 years of age. The standard 5-cm needle is twice the chest wall thickness of most children. Commercially available 14 g or 16 g standard-length 3.8 cm needle needles are of adequate length to access the pleural cavity, regardless of height as measured by Broselow LBT. Key words: needle thoracostomy; pediatric; emergent; needle size; Broselow

INTRODUCTION

Tension pneumothorax is a rare traumatic event that, if left untreated, can lead to rapid cardiovascular collapse and death. While the true pediatric incidence is unknown and adult literature is scant, one study of severe chest injury in adults revealed a tension pneumothorax incidence of 5% in major trauma (1). Emergent needle thoracostomy, used to relieve a tension pneumothorax, is a basic life-saving skill taught to both prehospital and in-hospital medical providers. Current advanced trauma life support (ATLS) guidelines recommend insertion of a 2-inch (5 cm), 14-gauge needle catheter in the 5th intercostal space slightly anterior to the midaxillary line (ICS-AAL) for needle decompression in the adult
population. This recent change, primarily supported by cadaveric studies reporting improved success in reaching the thoracic cavity when the 4th or 5th ICS-AAL is used, does not extend to the pediatric population due to a paucity of literature (2, 3). Recommendations for children remain broad and vague in this domain, with ATLS guidelines simply cautioning the healthcare provider to “take care” when placing a 14–18 gauge needle above the 2nd or 3rd intercostal space at the midclavicular line (ICS-MCL), as longer needles may result in further complications (3).

Emergent needle thoracostomy success rates at the 2nd ICS-MCL, commonly defined as either clinical improvement or resolution of concerning vital signs, range from 5% to 20% (4–6). Studies examining clinical outcomes, such as improvement in vital signs or post-procedure thoracic imaging, suggest that one reason for low success rate is the utilization of a needle too short to access the pleural cavity. To increase success at this location, some suggest increasing the needle length (2, 7, 8). An analysis of adult chest wall thicknesses via review of computed tomography (CT) scans revealed an expected failure rate of 42.5% with a standard needle placed at the 2nd ICS-MCL (9). Important in this consideration, however, is the inherent set of risks carried when decompressing a tension pneumothorax, including major vascular injury, pulmonary injury, cardiac tamponade, and creation of a pneumothorax when an assessment is incorrect (10, 11). The ability to maximize success rates while minimizing high-risk complications highlights the importance of choosing an appropriate needle length and location based upon a patient’s individual characteristics.

Without the aid of hospital-based tools such as ultrasound and radiography, prehospital field providers must rely on physical exam skills and system protocols to guide pediatric needle thoracostomy. Widely accepted prehospital field guides, such as the Broselow™ (Broselow) length-based tape (LBT), exist to aid in treatment and choice of equipment size for many pediatric emergencies. The Broselow LBT is a color-coded system based upon patient length to estimate weight. Each section details medication doses and equipment sizes based upon the estimated weight. Neither the Broselow LBT nor any other LBT system provides information to guide needle choice for emergent thoracostomy.

**IMPORANCE**

The paucity of literature examining needle length or optimal location for emergent needle thoracostomy in children results in the absence of any published recommendations for this population. Given the risks associated with needle lengths too short or too long, more data are needed to determine the appropriate needle length required to reliably access the pleural cavity based upon a child’s size.

The goal of this investigation was to determine the needle length required to safely access the pleural cavity at the 2nd ICS-MCL and the 4th ICS-AAL utilizing CT in children and to match optimum needle length to Broselow™ Pediatric Emergency Tape color.

**METHODS**

**Study Design and Setting**

This is a retrospective review of CT scans performed in pediatric patients aged 0–13 years between 2010 and 2015 at a free-standing children’s hospital network that serves as a Regional Pediatric Trauma Center and holds a Level 1 verification from the American College of Surgeons. All studies were obtained at one of the hospital’s 3 radiology-capable facilities and included the following machines: Definition Flash Siemens 256, Siemens Biograph 40 Pet CT, GE VCT 64, and Toshiba Acquillone prime 160. Scans were excluded from analysis if the patient had a chest wall mass, known muscle disease, pectus deformity, anasarca, prior open thoracotomy, if the patient height was not documented within 24 hours of the study, or when there was no anterior-posterior (AP) scout view of the thorax. The local institutional review board approved this study.

Data extracted from the electronic medical record (EMR) included patient age, sex, weight, and height at the time of CT attainment. Patients were grouped into 4 primary categories based upon height-determined Broselow LBT color: Gray–Pink (<68 cm), Red–Purple (68.1–90 cm), Yellow–White (90.1–115 cm), and Blue–Green (>115.1 cm). All measurements from the CT scans were obtained by 3 investigators (KA, KH, and MM). Two investigators were trained by a board-certified pediatric radiologist (KH). Inter-rater reliability was determined by secondary review of a randomly-selected 15% of the cohort.

**Computed Tomography Review**

Chest wall thickness was determined at the right and left 2nd intercostal spaces in the midclavicular line and the right and left 4th intercostal spaces in the anterior axillary line, as detailed in the following section. The CT scout film was used to identify
landmarks for all measurements. To determine the 2nd intercostal space, the sternal notch was identified, and a reference line was drawn through the patient’s midline. The right clavicle length was subsequently measured and divided in half to determine the midclavicular point. A right-sided scout line was established based upon this point and then correlated with axial images. The procedure was repeated to establish the left-sided scout line. From these scout lines, appropriate chest wall measurements were taken at both 2nd intercostal spaces (Figure 1).

To standardly identify the 4th intercostal space, the scout image was again used to identify the right fourth and fifth ribs and the margin between marked. The anterior-most location within this space at the intersection with the lateral edge of the pectoral muscle was identified in the corresponding axial window. That point was marked as the right 4th intercostal anterior axillary point of insertion. The procedure was repeated on the left chest wall measurements recorded at both points (Figure 2).

Data Analysis

The mean chest wall thickness was calculated in centimeters with standard deviation and 95% confidence intervals for 4 anatomic locations on the chest wall, stratified by 4 Broselow color ranges. For the purposes of this study, the difference between left and right anatomic locations for each intercostal space was assessed. Given no significant differences, the laterality of each anatomic location (2nd IC MCL and 4th IC AAL) was combined and the final number of measurements reported against the number of scans. The distribution of measurements was examined using density curves for each anatomic location across the 4 Broselow color categories. The body mass index (BMI) was calculated for each patient using the height and weight available at the time of the computed tomography scan and identified the

![Figure 1. Determination of the 2nd intercostal space (ICS). (A) Coronal non-contrast CT demonstrates a linear ruler at the 2nd ICS and triangulated with (B) Sagittal CT image at 2nd ICS. (C) Axial images bisecting the chest and measuring the left chest depth from skin to pleural space. (D) Scout CT image used to help identify the second ICS.](image-url)
prevalence of obesity in our population, as defined by BMI greater than or equal to 25, separately examining the range of chest wall thickness in this population. Pearson’s and Spearman’s correlation statistics were performed to identify if the patient’s body dimensions (BMI, height, and weight) or age closely aligned with the measured chest wall thickness at the 2 anatomic locations. Finally, a subpopulation of scans was examined in which the patients were >144 cm in height and would not reliably be measured on the Broselow Tape. These data are reported in supplemental tables.

For the inter-rater reliability analysis, 3 reviewers were compared using Pearson’s Correlation, Bland Altman Plots, Scatterplots, and Mean Inter-Rater Differences.

RESULTS

During the study a total of 273 chest CT scans were reviewed, of which 23 scans were excluded for distorted anatomy (39.1%), inadequacy of scout film (56.5%), and presence of penetrating injury (4.3%) (Figure 3). A total of 30 CT scans (14%) were reviewed by 3 reviewers for inter-rater reliability analyses. The Pearson correlation coefficient between reviewers ranged from 0.75 to 0.83. Across all 3 reviewers and both sites of chest wall thickness, the mean differences of measurements between raters ranged from 0.02 to 0.37 cm. Finally, Bland–Altman plots indicated that the majority of inter-rater differences were acceptable.

In the resultant study population, a total of 250 scans were reviewed with 498 total measurements taken. In this population, 29 scans (11.6%) were from patients > 144 cm in height. From the remaining 221 scans, the median patient age was 4 years (IQR: 2, 7) and 52.8% of patients were male (Table 1). Median BMI was 16.1. There was no difference in BMI between genders. Further demographics of our intended study population are shown in Table 1 stratified across the 4 Broselow color groupings.

Table 2 demonstrates the mean chest wall thickness at 2 locations (2nd ICS-MCL and 4th ICS-AAL),
Overall, the range of thickness was from 1.6 to 2.5 cm for the 2nd ICS-MCL and from 1.6 to 2.2 cm for the 4th ICS-AAL. Figure 4 demonstrates the density curves of the 2nd ICS-MCL and 4th ICS-AAL chest wall thicknesses for each of the Broselow color categories. As noted in this figure, there was no significant difference in mean chest wall thicknesses based upon location or patient size. The largest chest wall thicknesses found in this study are 3.8 cm at the 2nd ICS-MCL and 4.2 cm at the 4th ICS-AAL, representing the 95th percentiles in the Green/Orange/Blue category. Overall, the best correlation between the 3 body dimensions (weight, height, and BMI) and age with chest wall thickness was weight (Spearman’s correlation 0.532 (2nd ICS-MCL), 0.455 (4th ICS-AAL), \( p < 0.05 \)). These results are shown in Supplemental Table A.

Among patients with a height > 144 cm in length, the mean chest wall thickness was 3.3 cm for the 2nd ICS-MCL and 3.4 cm for the 4th ICS-AAL, (SD 1.2 and 1.4, respectively). Only 24% of these patients had a BMI >25. Among this group, the mean chest wall thickness for the 2nd ICS-MCL and 4th ICS-AAL were 5.1 cm and 4.8 cm, respectively (Supplemental Tables B and C).

**Discussion**

Emergent needle thoracostomy is a life-saving procedure with variable published rates of success and considerable risk for adverse events. Successful penetration into the pleural cavity of adults is dependent, in part, upon chest wall thickness and length of needle. The standard length of commercially available needle angiocatheters used in United States hospitals and on ambulances is 4.4 cm. In the adult population, 2018 ATLS guidelines recommend inserting a 5 cm, 14-gauge needle catheter into the 5th ICS-AAL. No published data supports a change in location or length of needle in emergent needle thoracostomy for children; thus, pediatric recommendations remain unchanged, with placement of a 14–18 gauge catheter at the 2nd ICS-MCL (3). To our knowledge, ours is the first study to examine the needle length required to reliably and safely

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**Table 1.** Patient demographics by Broselow category

<table>
<thead>
<tr>
<th>Broselow color</th>
<th>Overall (n=221)</th>
<th>Gray/Pink (n=19)</th>
<th>Red/Purple (n=51)</th>
<th>Yellow/White (n=83)</th>
<th>Blue/Orange/Green (n=68)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median Age, years (IQR)</td>
<td>4 (2, 7)</td>
<td>0 (0, 0)</td>
<td>1 (1, 2)</td>
<td>4 (3, 5)</td>
<td>8 (7, 9)</td>
</tr>
<tr>
<td>Male, %</td>
<td>52.8</td>
<td>52.6</td>
<td>54.9</td>
<td>56.6</td>
<td>48.4</td>
</tr>
<tr>
<td>Mean Height, cm (SD)</td>
<td>103 (22.7)</td>
<td>62.3 (5.4)</td>
<td>80.1 (7.2)</td>
<td>104.6 (6.9)</td>
<td>128.7 (7.5)</td>
</tr>
<tr>
<td>Mean Weight, kg (SD)</td>
<td>17.9 (8.9)</td>
<td>6.2 (1.6)</td>
<td>10.8 (3.7)</td>
<td>17.4 (3.9)</td>
<td>26.9 (8.4)</td>
</tr>
<tr>
<td>Mean BMI, kg/m² (SD)</td>
<td>16.1 (4.5)</td>
<td>15.7 (5.4)</td>
<td>17.1 (6.7)</td>
<td>15.6 (2.8)</td>
<td>16.1 (4.4)</td>
</tr>
</tbody>
</table>

\( cm = \) centimeters; \( kg = \) kilograms; \( IQR = \) interquartile range.
access the pleural cavity for emergent needle thoracostomy in children.

Published rates of success in emergent needle thoracostomy range widely. Factors including differing amounts of subcutaneous tissue due to gender, ethnicity, trauma or BMI, location of the tension pneumothorax, needle angle, and arm position can all affect the functional thickness of the chest wall and thereby impact success of needle thoracostomy placement (6, 9, 12–15). Our study illustrates that, for the pediatric population, the variation in chest wall thickness is not as great as that seen in adults and is not significantly dependent upon needle thoracostomy location. Thus, location choice for needle thoracostomy in children should not impact the likelihood of access to the pleural space.

In contrast, previous studies in adult populations examining chest wall thickness in different common locations for needle thoracostomy find vast differences in the between individuals. When accounting for both gender and needle location, chest wall thickness at the 2nd ICS-MCL can vary from 33 mm to

<table>
<thead>
<tr>
<th>Broselow</th>
<th>2nd ICS-MCL chest wall thickness</th>
<th>4th ICS-AAL chest wall thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gray/Pink</td>
<td>1.57 (0.44) 1.42, 1.72</td>
<td>1.67 (0.56) 1.48, 1.86</td>
</tr>
<tr>
<td>Red/Purple</td>
<td>1.96 (0.61) 1.84, 2.08</td>
<td>1.73 (0.56) 1.62, 1.84</td>
</tr>
<tr>
<td>Yellow/White</td>
<td>2.12 (0.58) 2.03, 2.22</td>
<td>1.91 (0.68) 1.80, 2.01</td>
</tr>
<tr>
<td>Blue/Orange/Green</td>
<td>2.45 (0.84) 2.3, 2.6</td>
<td>2.19 (1.02) 2.02, 2.36</td>
</tr>
</tbody>
</table>

*cm* = centimeters; *SD* = standard deviation; *CI* = confidence intervals; *ICS* = Intercostal space; *MCL* = Mid-clavicular line; *AAL* = Anterior axillary line.
59.6 mm. Chest wall thickness at the 4th or 5th ICS-AAL also varies greatly in these studies, ranging from 20.1 mm to 51.6 mm (2, 5, 7, 9, 16–20). A 2016 meta-analysis by Laan et al. evaluated all cadaveric and CT-based evaluations of chest wall thickness. The mean thickness at the 2nd ICS-MCL was 42.79 mm and at the 4th or 5th ICS-AAL was 34.33 mm (21). Not all studies accounted for BMI, which could skew the mean measurement. While some studies evaluated trauma patients only, others retrospectively evaluated all CTs obtained or utilized ultrasound, all of which could alter the chest wall thickness. Lastly, many of the pooled results contained a largely-male population, which would result in a lower mean chest wall thickness compared to those including an equal number of women. In our study of pediatric patients, there was no significant difference based on location. Our study did include 2 female adolescents over age 11; the mean chest wall thickness was between 1.9 cm and 2.1 cm with a maximum of 2.9 cm. When examining patients >50 kg, the median chest wall thickness was between 4.5 cm and 5 cm, the majority of these patients being taller than 144 cm and therefore not fitting on a pediatric LBT.

Previous studies indicate a probable correlation with chest wall thickness and BMI (22–24). A study of trauma patients grouped by BMI undergoing CT found that the average BMI was 29 (categorized as obese) and the corresponding average chest wall thickness was 6.2 cm on the right and 6.3 cm on the left, rendering a high likelihood of needle thoracostomy failure with current recommended ATLS guidelines (23). While this single-center study is limited in its generality given obesity variances by region, other studies of similar methodology have shown similar results (5, 9, 25). In our pediatric study, only 3 (1.3%) patients had a BMI >25 with median chest wall thicknesses ranging between 2.25 cm (Broselow color category Red/Purple) and 4.9 cm (Broselow color category Blue/Orange/Green). Similar to adult studies (19), we noted a larger distribution of weight as age increased. Weight was also the only body dimension significantly correlated with chest wall thickness. Only a very small number of children measuring in the Yellow/White Broselow category or above would require longer needle lengths, with the largest child measuring 6 cm at the 2th midclavicular intercostal space. This child was a 10-year old female with a height of 143.5 cm and a BMI of 24.4. Of note, however, the vast majority of Broselow-measured children in this study, regardless of weight, had a chest wall thickness through which the pleural cavity would be accessed by a standard angiocatheter.

Studies demonstrate that the current ATLS recommendations may be insufficient for accessing the pleural space in adult trauma patients. In fact, several studies recommend the utilization of a longer needle, up to 8 cm in length, to account for differences found in chest wall thickness in adult trauma patients (12, 13, 17, 23). Our study revealed that the 5-cm needle recommended by ATLS is more than twice the chest wall thickness of most children. This raises concern that children would be placed at increased risk for adverse events should ATLS guidelines, or the newer literature suggesting an 8 cm needle length, be extrapolated to the pediatric population.

Longer angiocatheters would be expected to carry a higher complication rate, should a rush of air be missed or lacking and the needle is pushed beyond the pleural space, as the risk for penetration into deep structures increases (4, 5). As discussed in current ATLS guidelines, this risk would be increased in those with a smaller body habitus (3). While there is a relative paucity of evidence regarding the morbidity associated with emergent needle thoracostomy, current literature reports cardiac tamponade (10, 26), significant hemorrhage or vessel transection resulting in life-threatening bleed (8, 10), iatrogenic pneumothorax or hemothorax (4), organ injury (27), nerve injury at insertion site (28), infection complications (28), as well as lack of clinical improvement or ineffective drainage can occur (4, 15, 29, 30). Traditional dictum is that the mortality risk of a clinically diagnosed tension pneumothorax overrides these morbidity risks. However, one study of emergent needle thoracostomy placement demonstrated that only 5% of patients had tension physiology, bringing into question the risk-benefit of such a procedure (15). Should further increases in needle size be formally recommended in the adult population, the appropriate recommendations in children become even more critical.

LIMITATIONS AND FUTURE DIRECTIONS

There are several limitations to this study. This is a retrospective study of randomly selected children <13 years of age and certain factors in may bias the reported outcomes. For example, because it is rare for children to receive chest CT imaging in trauma, some of the patients in the study received imaging due to oncologic diagnosis. Lymphadenopathy associated with this illness may increase the chest wall thickness measurements at the 4th IC-MAL. As instances of certain findings in trauma such as lung contusion, sternum fracture, subcutaneous emphysema, and multiple rib fractures are rare in the
pediatric population, we were not able to obtain the number of pediatric trauma patients required to make a similar assessment of how these can affect chest wall thickness in this single-center study (16). In addition, given that positioning the arm raised overhead (5), as is often done in the pediatric population for CT scanning, the pectoralis muscle is stretched and may result in a thinner chest wall than would be encountered in the field when performing emergent needle thoracostomy. In this study, for a child measuring the entire length of the Broselow tape, the mean maximum needle length required to access the chest was 3 cm. The recommendation for a standard 3.8 cm (or 1.5 inch) angiocatheter would be expected to account for any additional tissue thickness secondary to a lowered arm position.

Other factors not addressed in this study could affect the rate of success in accessing the pleural space with a standard angiocatheter. This study assumes perpendicular needle placement, while in a real-life, chaotic, prehospital scenario, an imperfect, angulated needle placement is expected to be more likely. This may increase the functional thickness of the chest wall and requires further study in the prehospital setting. This study also did not consider the risk of decompression failure, dislodgement during movement or deep breathing that could occur should a needle length be chosen that is too short.

Finally, a radiographic study cannot determine a decreased or increased adverse event rate that may be found when these recommendations are utilized. Further studies in a live patient population or in anthropomorphic models are needed to determine whether the use of standard angiocatheters in children alters adverse event rates.

CONCLUSIONS

In this chest CT-based analysis of chest wall thickness in the pediatric population stratified by Broselow tape length, the median chest wall thickness varies little by height or location in children <13 years of age. The 5-cm needle recommended by ATLS guidelines is twice the chest wall thickness of most children. A commercially available 14 g or 16 g standard-length 3.8 cm (1½ inch) angiocatheter should be used to access the pleural cavity in children, regardless of height as measured by Broselow LBT. A longer needle should be considered only in children who are visibly morbidly obese.

References


