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Comparative Analysis of Needle Thoracostomy Success Rates: A Cadaveric Study on Intercostal Space Selection

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ABSTRACT

Background: Needle thoracostomy is a critical intervention for tension pneumothorax, yet failure rates remain significant with traditional second intercostal space placement. Cadaveric studies suggest anatomical variations in chest wall thickness may impact success, but comparative data are limited in diverse populations.

Objective: To compare the success rates of needle thoracostomy placement in the traditional second intercostal space (midclavicular line) versus the fifth intercostal space (midaxillary line) in a cadaveric model.

Methodology: Thirty-two adult cadavers were studied with standardized needle thoracostomy placements in both the second and fifth intercostal spaces by using a 5-cm angiocatheters. Each site was assessed bilaterally (total 64 placements per site). Following needle insertion, thoracotomies were verified pleural cavity penetration. The thickness of chest wall was measured at both insertion points, with outcomes analyzed by gender and laterality.

Results: Results showed that 5th intercostal space approach demonstrated significantly higher success rates (96.9% vs. 59.4%) and thinner chest wall thickness (3.4 ± 0.8 cm vs. 4.7 ± 1.0 cm) compared to the second intercostal space with significant effect. Gender disparities were notable, with female cadavers showing lower success rates (90% vs. 30%) and greater chest wall thickness at both sites. A 4.2 cm chest wall thickness cutoff predicted 2nd ICS failure (AUC = 0.89).

Conclusion: The present study concluded that the fifth intercostal space (midaxillary line) provides significantly higher success rates for needle thoracostomy compared to the traditional second intercostal approach, particularly in female patients. The findings support updating current clinical guidelines to favor the lateral approach for more reliable emergent decompression of tension pneumothorax.

Keywords: Intercostal Space; Midclavicular Line; Midaxillary Line; Needle Thoracostomy

Introduction

Needle thoracostomy (NT) is an emergent procedure used in healthcare centers to decompress tension pneumothorax, which are collections of air in the pleural space under pressure, resulting in cardiopulmonary collapse if left untreated.[1] Current Advanced Trauma Life Support (ATLS) guidelines advocate a 5-cm catheter at the 2nd intercostal space (ICS) at the Midclavicular Line (MCL).[2] This technique has reportedly been used successfully with success rates of up to 90%. However, an increasing number of clinical reports have described failures of this technique, mainly because needles were too short in comparison to the thickness of the chest wall.[3-5] This has led to a reconsideration of alternative needle thoracostomy sites, one of which is the 5th intercostal space in the midaxillary line (MAL), where tube thoracostomy is commonly attempted. Different researchers have reported the failure rates of NT in the second ICS range from 30% to 65%, which depend on various factors related to the patient, such as their demographics and measurement methodologies.[6,7] Few studies based on Computed tomography (CT) have reported that chest wall thickness at the second intercostal space frequently exceeds the standard 5-cm needle length, especially in females and obese individuals.[2,8] Cadaveric investigations, such as the study by Inaba et al. (2011), further validated these findings, showing a 100% success rate in the fifth intercostal space compared to only 58% in the second intercostal space.[9] Despite this evidence, clinical adoption of the fifth ICS remains inconsistent, partly due to a lack of large-scale comparative studies and persistent adherence to traditional ATLS recommendations.

A few studies have also reported that the fifth intercostal space is more effective than the second one in the midaxillary line.[10,11] The significant advantage of this site is that it is almost free from muscle mass such as pectoralis major, which causes the chest wall to become thinner. Moreover, the more lateral approach might be of great benefit, as it can shift the hazard away from the thoracic vessels and heart skin, thus preventing injuries, particularly if an operation involves an anterior path. The fifth ICS can be chosen as the best place for instrumental tube insertion, implying that doctors can identify the position of the laceration in this region. On the other hand, there is a perception that the mobility restriction might slow down the treatment process.

Additionally, it has been suggested that the lateral incision point maximizes the risk of damage to the internal thoracic artery (ITA), a vital blood supply line, thereby causing ischemia of the heart. The well-known clinical method of tube thoracostomy can, therefore, not only serve as a landmark for ICS but also help mitigate the risk of mediastinal penetrating injuries. Moreover, the ICS5 position is the first choice for simple, fast, and safe methods of defining the spot from which to cut the tube thoracostomy.

Gender and body habitus are very important in NT treatment outcomes. It has been observed that women and individuals with a higher body mass index (BMI) experience the highest failure rates during the second intercostal space.[12,13] This fact is a clear indicator of the necessity of a patient-specific, evidence-based approach to needle decompression. In light of the past research that has predominantly focused on Western communities, the differences in human anatomy among various ethnic groups remain insufficiently studied. The prevalence of trauma is indeed growing worldwide. Therefore, the need for region-specific data has become even more critical for the proper conduct of care in areas with limited resources where the use of alternative equipment or imaging is not always an option.

One of the primary objectives of the current study was to examine the persistent disparity between existing evidence and the actual needs of clinical care regarding the placement of NT. Research is conducted using both cadaveric and Computed tomography-based methods, which have verified that the fifth intercostal space is the preferred route. However, this finding has yet to be widely accepted in practice, particularly within diverse populations. This line of research aims to fill this innovation gap. It enables a direct and systematic comparison of the NT success rates across the second and fifth intercostal spaces in a cadaveric experimental model.

Regarding the latter, the thickness of the chest wall and demographic variables that might affect NT success, in particular, are taken into account. Through this work, the quest for the most suitable needle thoracostomy technique in various medical emergency settings, and consequently, the improvement of patient outcomes, will be further facilitated. This article aims to shed light on current chest tube insertion guidelines by highlighting the milestones in evidence-based medicine. To address the proposed questions, this research anticipates an increase in trends toward improved needle thoracostomy. It presents arguments on several points to reduce patient mortality in the event of a sudden emergency.

Objective

To compare the success rates of needle thoracostomy placement in the traditional second intercostal space (midclavicular line) versus the fifth intercostal space (midaxillary line) in a cadaveric model.

Methodology

This prospective cadaveric study was conducted at the Department of Anatomy, Narowal Medical College, Narowal, from January 2022 to March 2023 to evaluate

and compare the success rates of needle thoracostomy placement between the traditional second intercostal space (midclavicular line) and the alternative fifth intercostal space (midaxillary line). The present study included 32 fresh, unembalmed adult cadavers (22 male, 10 female) which were randomly selected from the laboratory. Inclusion and exclusion criteria were followed for the study, and all cadavers with evidence of thoracic trauma, previous chest surgery, or significant anatomical deformities were excluded from the study to ensure standardized anatomical conditions. All specimens were stored at 4°C until one hour before the procedure when they were allowed to reach room temperature (22-25°C) to approximate the characteristics of living tissue.

For the experimental procedure, the cadavers were placed in a supine position with arms abducted to 90 degrees, perfectly imitating an incident often encountered in the emergency department. To conduct all needle insertions, standard 14-gauge, 5-cm angiocatheters, which were the same as those recommended by ATLS guidelines, were used. Four entry sites were explored on the bilaterally positioned axial skeleton in each cadaver: the conventional second intercostal space at the midclavicular line (intended by palpation which was carried out below the clavicle) and the fifth intercostal space at the midaxillary line (found at the point of intersection with the horizontal plane of the xiphoid process). For the second and fifth intercostal space entries, perpendicular and 10-degree caudal angle approaches were used, respectively, which aimed to reduce the risk of entry into the abdominal organs.

The procedure included a bilateral thoracotomy after the needle was placed. This was done for direct visualization to confirm the surgical team's entry into the pleural cavity. The placement is called successful if the needle tip penetrates the pleura enough to be easily retracted. At every point of insertion, the thickness of the chest wall was accurately measured by the digital calipers (precision: 0.1 mm) from the external tissue to the pleura space.

For study purposes, a specially designed proforma was used to record the demographic details of the cadavers, successful pleural penetration rates, and thickness of the chest wall. The collected data were then transported and analyzed using SPSS version 23. Differences in success rates between insertion sites were assessed using the Fisher exact test. Continuous variables, such as chest wall thickness, were analyzed using independent t-tests. Sex differences were tested using the Mann-Whitney U test for non-parametric data. P-value < 0.05 was considered as statistically significant. The study protocol was designed after obtaining institutional review board approval, and all experiments were conducted by the ethical standards set by the Declaration of Helsinki for cadaveric research.

Results

The present study included 32 adult cadavers (22 male, 10 female) with a mean age of 48.5 ± 12.3 years (range 21-72 years). The mean thickness of the chest wall at the second intercostal space (midclavicular line) was 4.7 ± 1.0 cm, whereas at the fifth intercostal space (midaxillary line), it was 3.4 ± 0.8 cm with a significant association of p-value <0.001. Results showed that female cadavers demonstrated significantly greater chest wall thickness at both sites compared to males (Table 1).

Table 1. Baseline Characteristics of Study Cadavers

Characteristic	Overall (n=32)	Male (n=22)	Female (n=10)	p-value
Age (years)	48.5 ± 12.3	46.2 ± 11.8	53.4 ± 12.6	0.12
2nd ICS thickness (cm)	4.7 ± 1.0	4.1 ± 0.8	5.4 ± 1.1	<0.001
5th ICS thickness (cm)	3.4 ± 0.8	3.0 ± 0.6	4.1 ± 0.9	<0.001

Results showed that needle thoracostomy at the fifth intercostal space gives significantly higher success rates compared to the traditional second intercostal space approach (96.9% vs 59.4%) with p-value <0.001 declared as significant. This difference was consistent across both genders, though female cadavers showed lower success rates at both sites (Table 2).

In the present study, analysis of chest wall thickness revealed that 41% of second intercostal space placements would require longer needles than the standard 5 cm to reach the pleural cavity. In contrast to this, only 6% of fifth intercostal space placements exceeded this threshold. This association was significant with a p-value <0.001. The optimal thickness cutoff for predicting second intercostal space failure was 4.2cm (AUC 0.89, 95% CI 0.82-0.96) (Table 3).

The second intercostal space placement was affected by two complications (both cases of female cadavers), where the inner mammary artery was contacted. No severe difficulties occurred during the surgery at the fifth

Table 2. Success Rates by Insertion Site in study sample

Site	Overall Success	Male Success	Female Success	p-value
5th ICS (n=64)	62 (96.9%)	44 (100%)	18 (90%)	0.03
2nd ICS (n=64)	38 (59.4%)	32 (72.7%)	6 (30%)	<0.001

intercostal space. The process duration was approximately identical for both locations (42 ± 12 seconds for the 2nd ICS vs 38 ± 10 seconds for the 5th ICS, P-value = 0.15) (Table 4).

Results showed that female cadavers demonstrated significantly lower success rates at both insertion sites. The success rate disparity was particularly pronounced at the second intercostal space, where female cadavers had a 70% relative reduction in success compared to males (30% vs. 72.7%), and this association was significant (p<0.001). This difference correlated with greater chest wall thickness in females at both anatomical sites (p-value <0.001).

Discussion

Based on our autopsy study, the findings show that the 5th intercostal space (5th ICS) in the middle of the person's axillary line is the safest site for the emergent needle thoracocentesis. The most influential results showed a 96.9% success rate at the 5th ICS, compared to a success rate of only 59.4% at the 2nd ICS using the MCL approach (p < 0.001). These findings are consistent with the study carried out by Inaba et al. (2011), which reported 100% success at the 5th ICS and 58% success at the 2nd ICS using the dead body model.[8] The uniformity among the reports, despite the sample sizes (32 vs 20 cadavers) and the population's characteristics, makes these results more reliable. Our study has complicated these findings by providing precise and stratified data, including chest wall thickness measurements, which were not previously reported in isolation.

It is the direct relationship between the 5th ICS approach and anatomical considerations that is the cause of the superior performance. Our measurements disclosed that the chest wall at the 5th ICS was constantly thinner (mean 3.4cm) than at the 2nd ICS (mean 4.7cm, p<0.001). The present result is consistent with those of Wax and Leibowitz (2007), who revealed an average thickness of 3.5 cm at the anterior axillary line and 4.5 cm at the midclavicular line in living patients in CT-based studies.[14] The clinical importance of the 1.3 cm gap remains obvious when one considers that 41% of 2nd ICS placements, in our research, would have required needles longer than the standard 5cm to reach the pleural space, while only 6% at the 5th ICS. In the study by Zengerink et al. (2008), the authors argue that needle length, rather than gauge, is a decisive factor in successful decompression.[15]

The identification of gender disparities was the most important outcome of our research. The female cadavers'

Table 3. Needle Length Requirements by Insertion Site

Thickness Category	2nd ICS (n=64)	5th ICS (n=64)
≤5cm	38 (59.4%)	60 (93.8%)
>5cm	26 (40.6%)	4 (6.2%)

Table 4. Characteristics and Complications of procedures

Parameter	2nd ICS	5th ICS	p-value
Success Rate	59.4%	96.9%	<0.001
Complications	2 (3.1%)	0 (0%)	0.24
Procedure Time (s)	42 ± 12	38 ± 10	0.15

chests were significantly thicker at both measurement levels (5.4 cm at the 2nd ICS vs. 4.1 cm at the 5th ICS) with a lower success rate (30% vs. 90%). These data go beyond the work of Givens et al. (2004), who, by the way, not only established gender differences in chest wall thickness but also obtained such results from CT measurements for the first time.[16] Our cadaveric model is the direct physical verification of the typical radiographic method. The most abysmal performance at the 2nd ICS in females (30% success) has given serious alarm about the no more trustworthiness of this approach in almost a third of shock patients. The data may contribute to the 65% failure rate described in the clinical studies of the same group of authors who tried to use 5 cm standard needles.[17]

Our study has detected complications that require close examination. The injuries in the two internal mammary arteries at the place of the 2nd ICS are like the events of IMA injuries that have been recorded in case series by Rawlins et al. (2003).[18] While no abdominal injuries happened at the 5th ICS in our study, this complication might be found in the reports of the lateral approaches.[19] This could have been prevented by an insight of a 10-degree direction caudally of the 5th ICS insertion that supports the conclusion by Ferrie et al. (2005) from the landmark identification study for the skill recommendations.[20]

The analysis of the ROC has found that 4.2 cm is the best threshold of thickness that leads to failure in the 2nd ICS, demonstrating a good ability to be applicable in the clinical profession. This point of reference demonstrates a very satisfactory predictive capacity (AUC 0.89). It falls within the spectrum of a mean thickness of 4.5 cm presented by the CT study by Stevens et al. (2009).[21] In practice, this could direct healthcare providers to patients suitable for lateral approach positioning or the use of longer needles in the 2nd intercostal space (ICS).

Please note that our findings have to be reviewed in the context of the research. On the one hand, we cannot be certain that, as this was a study of dead bodies, no dynamic factors, such as respiratory motion or patient positioning, were involved in the real-world performance tests. The age range of our cadavers (the average being 48.5 years) might not cover all ages present in trauma patients. Furthermore, we used to refrigerate and unembalmed yet non-living tissue-like cadavers for our experiments; hence, our use of such, as complete as it was, was not entirely faithful to the real-life conditions of living tissue characteristics.

These findings have numerous significant clinical implications. First, especially for female patients, they strongly advocate for using the 5th ICS approach as the primary site for needle thoracostomy. Second, they emphasize that the 2nd ICS approach requires longer needles (≥7 cm), particularly for patients with thicker chest walls. Third, they propose that in marginal cases, site selection may be aided by the visual or ultrasonographic evaluation of chest wall thickness.

Prospective clinical trials comparing methods in live patients, assessing ultrasound-guided techniques, and creating standardized training protocols incorporating these findings should be the focus of future research. The gender differences we found, in particular, call for more research into the best practices for trauma patients who are female.

Our study concludes by offering solid anatomical proof that, in comparison to the conventional 2nd ICS midclavicular approach, the 5th ICS midaxillary approach offers noticeably higher success rates for needle thoracostomy. These results, which are in line with earlier cadaveric and radiographic research, imply that the ATLS guidelines should be updated to take this evidence into account. The significant gender disparities in success rates further underscore the need for individualized strategies tailored to patient anatomy.

Conclusion

This study concluded that robust anatomical evidence supporting the fifth intercostal space (5th ICS) in the midaxillary line as the optimal site for emergent needle thoracostomy. Our findings demonstrate significantly higher success rates and reduced chest wall thickness at the 5th ICS compared to the traditional second intercostal space (2nd ICS) approach. These results were consistent across genders, though female cadavers exhibited particularly pronounced differences, with a 70% relative reduction in success rates at the 2nd ICS.

Limitations

The clinical implications of these findings are substantial. The high failure rate of the 2nd ICS approach, especially in females and individuals with thicker chest walls, suggests that current ATLS guidelines recommending this site may need revision. Our data support adopting the 5th ICS as the primary site for needle decompression, as it not only improves success rates but also reduces the risk of significant vascular injury. Furthermore, our identification of 4.2 cm as a critical threshold for chest wall thickness in predicting 2nd ICS failure provides a practical decision-making tool for clinicians.

Recommendations

While this cadaveric study establishes important anatomical principles, we recommend prospective clinical trials to validate these findings in living patients. Future research should also explore the role of ultrasound guidance and optimal needle lengths for different patient populations. Until such data are available, our results strongly suggest that the 5th ICS approach should be considered the preferred technique for needle thoraco-

stomy in adult trauma patients.

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