Thoracic needle decompression for tension pneumothorax: clinical correlation with catheter length

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Background: Tension pneumothorax requires emergent decompression. Unfortunately, some needle thoracostomies (NTs) are unsuccessful because of insufficient catheter length. All previous studies have used thickness of the chest wall (based on cadaver studies, ultrasonography or computed tomography [CT]) to extrapolate probable catheter effectiveness. The objective of this clinical study was to identify the frequency of NT failure with various catheter lengths.

Methods: We evaluated the records of all patients with severe blunt injury who had a prehospital NT before arrival at a level-1 trauma centre over a 48-month period. Patients were divided into 2 groups: helicopter (4.5-cm catheter sheath) and ground ambulance (3.2 cm) transport. Success of the NT was confirmed by the absence of a large pneumothorax on subsequent thoracic ultrasonography and CT.

Results: Needle thoracostomy decompression was attempted in 1.5% (142/9689) of patients. Among patients with blunt injuries, the incidence was 1.4% (101/7073). Patients transported by helicopter (74%) received a 4.5-cm sheath. The remainder (26% ground transport) received a 3.2-cm catheter. A minority in each group (helicopter 15%, ground 28%) underwent immediate chest tube insertion (before thoracic ultrasound) because of ongoing hemodynamic instability. Failure to decompress the pleural space by NT was observed via ultrasound and/or CT in 65% (17/26) of attempts with a 3.2-cm catheter, compared with only 4% (3/75) of attempts with a 4.5-cm catheter ($p < 0.001$).

Conclusion: Tension pneumothorax decompression using a 3.2-cm catheter was unsuccessful in up to 65% of cases. When a larger 4.5-cm catheter was used, fewer procedures (4%) failed. Thoracic ultrasonography can be used to confirm NT placement.

Contexte : Le pneumothorax compressif requiert une décompression urgente. Malheureusement, certaines thoracotomies à l'aiguille échouent parce que les cathéters ne sont suffisamment longs. Toutes les études antérieures se sont basées sur l'épaisseur de la paroi thoracique (obtenue par examen de cadavres, échographie ou tomographie assistée par ordinateur) pour extrapoler l'efficacité probable des cathéters. L'objectif de la présente étude clinique était de mesurer la fréquence de l'échec des thoracotomies à l'aiguille selon la longueur des cathéters utilisés.

Méthodes : Nous avons examiné les dossiers de tous les patients victimes d'un grave traumatisme fermé et soumis à une thoracotomie à l'aiguille avant leur arrivée dans un centre de traumatologie de premier niveau sur une période de 48 mois. Les patients ont été répartis en deux groupes selon que leur transport s'était fait par hélicoptère (gaine du cathéter 4,5 cm) ou par ambulance (3,2 cm). La réussite de la thoracotomie a été confirmée par l'absence de pneumothorax volumineux à l'échographie ou à la tomographie thoracique effectuée par la suite.

Résultats : La décompression par thoracotomie à l'aiguille a été tentée chez 1,5 % des patients (142/9689). Parmi les patients victimes d'un traumatisme fermé, l'incidence s'élevait à 1,4 % (101/7073). Les patients transportés par hélicoptère (74 %) ont reçu un cathéter de 4,5 cm. Les autres (26 % transportés par voie terrestre) ont reçu un cathéter de 3,2 cm. Chez une minorité dans chaque groupe (hélicoptère 15 %, transport terrestre 28 %) on a installé immédiatement un drain thoracique (avant l'échographie thoracique) en raison de l'instabilité hémodynamique. L'échographie et(ou) la tomographie ont révélé l'échec de la décompression de l'espace pleural par thoracotomie effectuée à l'aiguille dans 65 % des tentatives (17/26) au moyen d'un cathéter de 3,2 cm, contre 4 % seulement (3/75) au moyen d'un cathéter de 4,5 cm ($p < 0,001$).

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Conclusion : La décompression d'un pneumothorax compressif à l'aide d'un cathéter de 3,2 cm a échoué dans une proportion allant jusqu'à 65 %. Lors de l'utilisation d'un cathéter plus long (4,5 cm), un moins grand nombre d'interventions ont échoué (4 %). On peut utiliser l'échographie thoracique pour confirmer le positionnement du cathéter de thoracotomie à l'aiguille.

Tension pneumothorax (TPTX) is defined as a pneumothorax (PTX) that results in the lateral shift of a patient's mediastinum concurrent to respiratory distress (or difficulty ventilating) and/or hypotension.[1] It is caused by an injury to the lung, bronchi or trachea that allows continuous leakage of air into the pleural space and collapses the lung because the air cannot escape.[1] This life-threatening condition is treated by emergent chest decompression. In most settings, including prehospital care, needle thoracostomy (NT) is the most rapid method of achieving life-saving access to the pleural space.[2,3] If successful, it is met with an audible release of air, as well as stabilization of the patient's vital signs (hypoxia and/or hypotension).

Similar to occult pneumothoraces (OPTXs), the incidence of TPTX reflects the inception cohorts involved. It varies from 0.2% of all advanced paramedic life-support responses[4] to 1.7% of major trauma patients with an injury severity score (ISS) greater than 15.[5] This high rate is not surprising given that thoracic injury accounts for 25% of all trauma mortality,[6,7] and PTXs are the single most common manifestation of intrathoracic blunt chest injury.[8–11]

Whereas advanced trauma life-support guidelines mandate midclavicular placement (second intercostal space) of a "large" caliber decompression needle,[12] recent literature questions the efficacy of many commonly used catheters in achieving pleural access.[13–24] These reports have used cadaver dissection,[13] as well as ultrasonography (US)[14] and computed tomography (CT)[15,16] to identify typical chest wall thickness. By extrapolation, they have inferred that many catheters are of insufficient length to quickly drain air from the pleural space. The inherent complication rates associated with NT[18,20,25] as well as with subsequent tube thoracostomy (TT)[26] also remain a concern. As a result, the primary goal of this study was to identify the frequency of needle decompression failure with catheters of different lengths (3.2-cm v. 4.5-cm sheaths) in a clinical series of severely injured trauma patients. Our secondary goals were to identify the overall incidence of TPTX and audit our institution's approach to these scenarios.

Methods

The initial study population consisted of all injured patients with prehospital NT insertion brought to an urban level 1 trauma centre between Jan. 1, 2004, and Dec. 31, 2007. This retrospective study group was divided into 2 cohorts based on the mode of prehospital transport (helicopter v. ground ambulance). The helicopter crews used a larger decompression needle (14-gauge 5-cm with a 4.5-cm sheath) than the ground-based paramedic services (14-gauge 3.5-cm catheter with a 3.2-cm sheath). This study was intended to be primarily descriptive in nature.

We excluded patients with penetrating mechanisms of injury, as well as those who arrived without signs of life (those with penetrating injuries were included in the calculation of the overall incidence of NT). We obtained patient demographics from the trauma registry. We used standard definitions for OPTXs (evident only on CT). Bedside thoracic US (extended focused assessment with sonography in trauma [EFAST])[27] performed immediately after arrival assisted in identifying the success and location of the decompression catheter. The EFAST was performed using 2 thoracic windows (parasternal and apical). Ultrasonic signs confirming the presence of a pneumothorax included the absence of lung sliding, as well as the loss of comet tail artifacts.[27]

We performed our analysis using Stata version 8.0 (Stata Corp.). Normally or near-normally distributed variables were reported as means and nonnormally distributed variables as medians. We compared means using the Student t test and medians using the Mann–Whitney U test. Differences in proportions among categorical data were assessed using the Fischer exact test. We considered p values less than 0.05 to be statistically significant.

Results

Records for 9689 injured patients were available for the 48-month study period. In total, 142 patients arrived with an NT in place. The overall incidence of NT among all live trauma patients was 1.5% (142/9689). In total, 101 patients with blunt injuries (71%) presented with a prehospital NT. The incidence of NT among live patients with blunt injuries was 1.4% (101/7073). Of the patients with blunt trauma, 75 (74%) arrived via helicopter, whereas the remainder were transported by ground.

Patient and injury demographics were statistically similar with regard to age, sex, ISS and length of hospital stay in the helicopter and ground-transport study groups (Table 1). The helicopter cohort was more acutely ill in terms of presentation with hemodynamic instability (28% v. 17%) and intubation (87% v. 61%) ($p = 0.035$). The helicopter cohort also had higher in-hospital mortality (58% v. 39%) ($p = 0.044$).

Among the 26 NT patients transported by ground, 4 (15%) underwent immediate TT because of concurrent clinical concerns (hemodynamic instability). The remaining 22 patients underwent an EFAST examination. Persistence of a PTX was identified in 17 (77%) patients, who then had a chest tube inserted. Two of the 5 patients with negative EFAST findings underwent CT (the remaining patients had a chest tube inserted). One patient who received a CT scan had an OPTX, whereas the other had normal thoracic CT windows.

Among the 75 patients in the helicopter prehospital NT group, 21 (28%) underwent immediate TT because of concurrent hemodynamic instability. The remaining 54 patients underwent an EFAST examination. Persistence of a PTX was identified in 3 (6%) patients, who then underwent TT. Twenty-eight of the 51 (55%) patients with negative EFAST findings underwent CT; the remaining patients had a chest tube inserted. One patient (4%) in the CT group had an OPTX, whereas the others (27) had normal thoracic CT windows.

Discussion

The incidence of NT among all severely injured trauma patients brought to a level 1 trauma centre was 1.5%. This fits within the published range[4,5,17] and most closely approximates a prospective report[5] of 1.7% among 6241 patients with major trauma. Among patients with blunt injuries in our cohort, the incidence of NT was 1.4%. This rate appears to be relatively consistent regardless of mechanism, as shown by Eckstein and Suyehara's population, which was composed patients with a higher percentage of penetrating trauma (93%) and a lower mean ISS (22).[5]

The rationale for excluding all patients with a penetrating mechanism from our analysis was 2-fold. First, thoracic US and subsequent CT were used to identify NT success (i.e., placement into the pleural space). Patients with a penetrating injury were therefore excluded because they typically avoided both imaging procedures. More importantly, nearly all patients with penetrating trauma can be imaged with a standard upright anteroposterior chest radiograph. This avoids the limitations of the supine chest radiograph, which is the least sensitive of all plain radiographic techniques for detecting PTX.[28–30] Most current literature also supports investigating a possible TPTX with imaging before performing definitive TT in a hemodynamically stable, nonhypoxic patient.[3,5,17,20,31–34] As a result, the treatment algorithm for patients with gunshot and stab wounds is more straightforward. If a patient with penetrating trauma is stable and not intubated, confirmatory imaging can be completed before TT.

This sequence addresses the concerns about inappropriately low thresholds for NT,[3,5,17,20,31–34] the frequent failure rate of NT insertion,[13–24] and the 22% rate of major complications associated with TT.[26] It also reflects the natural history of TPTXs, in that clinical decompensation typically requires a minimum of 30–60 minutes and often much longer.[3,35–37] Furthermore, Clark and colleagues[38] have also confirmed that virtually no patients with radiologic evidence of TPTX deteriorate while waiting for either imaging or subsequent TT.

It must be emphasized, however, that regardless of the mechanism, immediate NT and TT must be performed in any patient who presents with hemodynamic instability or hypoxia.[12,35] It should also be noted that the NT placement decision analysis by a physician in a controlled trauma bay differs significantly from paramedics with field challenges that include suboptimal sedation, environment, vital sign monitoring and the potential pulmonary effects of altitude. As a result, paramedics appropriately place NTs with greater frequency than their hospital-based colleagues to prevent potentially catastrophic consequences in difficult scenarios. This likely results in NT placement for some patients who do not actually have a PTX or TPTX and could also reduce the observed effect difference.

Our primary goal was to identify the frequency of NT failure. Although subcutaneous emphysema or chest wall hematomas may inhibit decompression, the most common scenario is a catheter that is too short to reach the pleural space.[3,13–24,31] This is the first clinical study to describe the effect of different catheter lengths on the ability to achieve adequate release of TPTX. All other publications have relied on the thickness of a patient's chest wall as defined in cadavers studies or by US or CT.[13–16,24] Although these indirect methods provide plausible explanations, they also have inherent limitations[24] and therefore remain an extrapolation to clinical patient care.

Upon decompression of a TPTX, an audible rush of air preceding the resolution of respiratory and circulatory failure is evident.[1–3] There should also be a return of apposition between the visceral and parietal pleural surfaces. This is confirmed by the reappearance of both lung sliding and comet tail artifacts on the EFAST examination.[27] Among patients in the helicopter prehospital cohort (4.5-cm sheaths), unsuccessful attempts at decompression (i.e., positive thoracic US for a PTX) occurred in up to 6% of hemodynamically stable patients. This is compared with 77% of ground-transport patients with a 3.2-cm catheter. To confirm this disparity, all patients with negative EFAST findings (i.e., no PTX) who underwent subsequent CT imaging of the chest and/or abdomen. Of the 28 patients (55%) in the air ambulance group with a CT, only 1 had evidence of an OPTX. This single patient (4%)

Table 1. Patient characteristics by type of prehospital transport

Characteristic	Helicopter	Ground
No. of patients	75	26
Mean age, yr	34	32
Sex, % male	90	88
Injury severity score, median	30	28
Mean length of stay, d	109	100

reflected either a false-negative EFAST result or continued leakage of air from a pulmonary injury in the interval between the US and CT. Whereas a direct comparison with the ground-transport group is difficult because of the small number of patients (5 patients with negative EFAST findings), 1 of 2 possible patients had an OPTX on a subsequent CT scan. Taken as a whole, it appears that up to 65% (17/26 total ground patients) of patients had a failed NT with a 3.2-cm sheath in comparison to 4% (3/75 total air patients) with a 4.5-cm cannula. This does not account for the 28% and 15% of helicopter and ground-transport patients, respectively, who presented with hemodynamic instability (NT in place) and underwent emergent TT before any imaging. On closer review, it appears that the vital signs of at least 2 patients in the ground-transport group normalized immediately after TT. We suspect that these were also decompression failures. Because it was unclear if the true cause of hemodynamic instability in patients undergoing immediate TT was failure to decompress a TPTX or hemorrhage, it is possible that the true overall rates of NT failure were actually higher than reported. More specifically, if all TT patients were also presumed to have a failed decompression, the rates would increase to 32% and 81% in the air- and ground-transport cohorts, respectively.

Previous studies describing chest wall thickness at the midclavicular line (second intercostal space) via CT (3.1 cm in 100 heterogeneous adults;[16] 3.41 cm in men,[24] 3.92 cm in women,[24] 4.24 cm in 111 resuscitated patients[15] and 5.36 cm in military personnel[13]) or US[14] (57% thicker than 3 cm) support the observed 65% failure rate using a 3.2-cm sheath. These publications also describe patients with chest walls thicker than 4.5 cm that may not allow decompression with the larger catheters used by our air crews. This subgroup ranges from 4% among US-imaged patients,[14] to 10% of men under 40 years of age, to 33% of women under 40 years.[24] Given that our patients were mostly male (90%) with a mean age of 33 years, the NT failure rate of 6% in helicopter-transported patients with a 4.5-cm sheath is plausible.

Although some authors[13,16] have called for 7- to 8-cm needles to ensure that all OPTXs are decompressed, it appears that even catheters as short as 4.5 cm can puncture the heart at standard insertion locations in 2.5% of trauma patients.[24] Other complications include chest wall hematoma, hemothorax, empyema and dislodgement in up to 8% of patients.[18,25] In an attempt to avoid these issues, as well as access the pleural space more reliably, support for axillary NT is increasing.[3,18,22,25,39] This lateral location takes advantage of a thinner chest wall (mean 2.6 cm)[16] and is the military's first choice if under fire because it allows medics to keep a soldier's body armor in place while achieving decompression.[40] Although we observed no direct complications in our study, we support the use of a catheter at of least 4.5 cm in length.

Limitations

This study has several limitations. First, it relied on both thoracic US and CT to identify NT failure. Whereas CT represents the gold standard for identifying PTX, the EFAST examination has a sensitivity of 92%–100% in acute settings.[41–44] Although this is far superior to the supine chest radiograph, we cannot rule out the possibility that some patients who had a thoracic US that did not show a PTX (and who did not receive a subsequent CT scan) could have had an untreated PTX. This would have introduced conservative bias, however. It should also be noted that sonographic confirmation of TPTX resolution by the return of lung sliding is obvious and reliable.[45]

Second, the delay between an immediate thoracic US and the subsequent CT may also have introduced a conservative bias because 2 patients had an OPTX that was missed by the preceding EFAST examination. This represents either a false-negative EFAST finding or an interval accumulation of intrapleural air while waiting for a CT scan.

Third, no confirmatory imaging was available for the patients who presented with cardiorespiratory instability because TT was performed immediately. As a result, these patients may also have had NT failures.

Fourth, we could not definitively confirm the presence of a PTX. It can be argued that this actually strengthens our conclusions, however, because fewer patients with TPTX/PTX in the initial cohort would increase the proportion of NT failures.

Fifth, the patient groups (air v. ground transport) were not evenly matched for hemodynamic status, need for urgent intubation or mortality. Because the aim of this study was to define failure rates associated with different catheter lengths, not injury status, we believe that our conclusions remain intact. Finally, the skill level of individual paramedic crews was also not available to interpret the effect of experience on NT success.

Conclusion

The purpose of this study was to identify the frequency of NT failures using different catheter lengths in the clinical care of acutely injured patients. When employing a 3.2-cm sheath, failure will occur in a significant number of blunt trauma patients. Using a 4.5-cm cannula will decrease this rate substantially. Thoracic US can be used to asses NT in hemodynamically stable, nonhypoxic patients before committing them to the risks of chest tube insertion. Finally, consideration of a lateral axillary approach is a viable option given the increasing rate of obesity among patients.

Competing interests: None declared.

Contributors: Drs. Ball, Wyrzykowski, Dente, Nicholas, Rozycki, Kortbeek and Feliciano designed the study. Drs. Ball and Salomone

acquired the data, which they analyzed together with Drs. Kirkpatrick and Rozycki. Drs. Ball and Salomone wrote the article, which Drs. Ball, Wyrzykowski, Kirkpatrick, Dente, Nicholas, Kortbeek, Rozycki and Feliciano reviewed. All authors approved its publication.

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