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Needle Thoracostomy: Clinical Effectiveness is Improved Using a Longer Angiocatheter

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Abstract

Background—Decompression of tension physiology may be lifesaving, but significant doubts remain regarding ideal needle thoracostomy (NT) catheter length in treatment of tension physiology. We aim to demonstrate increased clinical effectiveness of longer NT angiocatheter length (8cm) compared to current Advanced Trauma Life Support (ATLS) recommendations of 5cm NT length.

Methods—A retrospective review of all adult trauma patients from 2003–2013 (age >15 years old) transported to a level I trauma center. Patients underwent NT at the 2nd intercostal space, midclavicular line (2nd ICS-MCL), either at the scene of injury, during transport (prehospital) or during initial hospital trauma resuscitation. Before March 2011, both prehospital and hospital trauma team NT equipment routinely had a 5 cm angiocatheter available. After March 2011 prehospital providers were provided an 8 cm angiocatheter. Effectiveness was defined as documented clinical improvement in respiratory, cardiovascular, or general clinical condition.

Results—There were 91 NT performed on 70 patients (21 bilateral placements) either in the field (prehospital, n=41) or as part of resuscitation in the hospital (hospital, n=29). Effectiveness of NT was 48% until March 2011 (n=24). NT effectiveness was significantly higher in the prehospital setting than hospital (68.3% success rate versus 20.7%, $p<0.01$). Patients who underwent NT using 8 cm compared to 5 cm were significantly more effective (83% VS 41% respectively, $p=0.01$). No complications of NT were identified in either group.

Conclusion—8 cm angiocatheters are more effective at chest decompression compared to currently recommended 5 cm at the 2nd ICS-MCL

Level of Evidence—III Retrospective comparative study without negative criteria.

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Keywords

needle thoracostomy; needle decompression; tension pneumothorax; intercostal chest drain

Background

The rapid evaluation and treatment of life threatening injuries prioritizes airway and breathing. Tension physiology, as a major cause of immediate death, is caused by a space occupying lesion, most commonly a pneumothorax that interferes with cardiorespiratory function. As the thoracic intra-pleural pressure increases within the relatively non-distensible thoracic cavity, these pressures are transmitted to surrounding structures including the superior vena cava, inferior vena cava and right atrium. These structures are at the highest risk from compression as intra-luminal pressures within these structures are relatively low. This impairs cardiac output and ultimately results in patient demise. Immediate decompression may be lifesaving. The currently recommended treatment by Advanced Trauma Life Support (ATLS) is needle thoracostomy (NT) in the second intercostal space midclavicular line (2nd ICS-MCL) with a 5cm angiocatheter to urgently decompress the pleural space and rapidly increase venous return to the right atrium. (1)

NT has traditionally been thought to be simple and effective. Doubts, however, have risen in regards to its efficacy (2–9). A limitation of NT is the length of the angiocatheter, which must be adequate to traverse the chest wall to reach to the pleural cavity. It has been demonstrated that chest wall thickness (CWT) is highly variable and effective decompression may not be feasible in many patients (2–4,8–15). The growing obesity epidemic further increases the risk of ineffective NT as increased BMI has been correlated with increased CWT (13,16–18). The impact of increasing CWT is not known with regard to actual clinical efficacy as studies have only assessed theoretical effectiveness based on imaging or using shorter than the currently recommended 5-cm angiocatheter(2). Theoretical effectiveness using a longer catheter has been suggested to increase decompression rates(8,19,20). Therefore, there is a critical need to assess clinical effectiveness as compared to radiological effectiveness at the 2nd ICS-MCL comparing recommended 5-cm to longer 8-cm angiocatheters in NT. Furthermore several groups have suggested alternative sites which have controversial thickness compared to the 2nd ICS-MCL; therefore, we also compared radiological theoretical effectiveness at the 4th Intercostal Space Mid Axillary Line (ICS-MAL) to compare CWT in our patient population between proposed NT anatomical sites. We aim to describe the clinical impact of utilizing an 8cm angiocatheter compared to 5cm angiocatheter, CWT, and procedural setting on clinical NT effectiveness. We hypothesize that NT is a safe and overall effective technique for initial management of tension physiology and that increased needle length results in improved theoretical and actual effectiveness.

Methods

A retrospective review of all adult trauma patients (age >15 years old) transported by ground and air ambulance to a Level I Trauma center was conducted using local trauma registry, prehospital transportation records, and hospital records from 2003–2013 after IRB approval

in accordance with the Declaration of Helsinki. Patients who underwent NT either at the scene of trauma or during transport by professional providers (prehospital) or during initial hospital trauma resuscitation (hospital) were identified. We excluded patients who underwent NT at another hospital or who received during transport from another hospital. Our institutional guidelines recommend NT be done at the 2nd ICS-MCL at 90 degrees to the patients' surface anatomy. Patient demographic information, procedural data, and outcomes were collected. In March 2011 the equipment immediately available for prehospital providers to perform NT was changed, after multidisciplinary discussion by the Medical Transport Medical Direction team, from a 14G 5cm angiocatheter (actual length, 5.08cm) to a 14G 8cm angiocatheter (actual length, 8.26cm). The needle for the hospital trauma team (5cm angiocatheter), however, was not changed (Figure 1). Following trauma resuscitation, stable patients underwent subsequent CT imaging of the chest which was reviewed for CWT. CWT was defined as the distance from the skin at the 2nd ICS-MCL and at the 4th ICS-MAL to the pleural space on CT imaging using a standard weight based image acquisition protocol with volumetric reconstruction. Identification of the midclavicular or Mid Axillary Line was performed on coronal, or sagittal sections respectively, identified and marked in PACS and then axial slices were utilized to measure chest wall thickness. Measurements were taken perpendicular to surface anatomy based on recommended NT procedural practice at our institution. NT effectiveness was determined based on documentation of clinical improvement, defined as a documented respiratory improvement (increased PO₂, decreased respiratory rate, improved ventilator requirements), a cardiovascular improvement (normalization of the heart rate, blood pressure, return of pulses), or a documented general "general improvement" in the patient's condition per provider after NT was performed. Any complication that occurred as a direct result of NT, including those incidentally found on imaging or as a documented in the clinical note, was included. Mortality was defined as 30-day mortality. Descriptive statistics and univariate analysis including student's t test, chi-square, and Fisher's exact test, multivariable analysis was performed for age and injury severity score (ISS) based on power analysis. Statistical significance was defined as $p < 0.05$. Where appropriate, results were defined as mean $\pm$ standard deviation for normal distributions, or median, IQR if gross skewness was present.

Results

There were 91 NT performed on 70 patients (21 underwent bilateral placements) either in the field (prehospital, $n=41$) or by the trauma team as part of resuscitation in the hospital (hospital, $n=29$) (Figure 1). The majority of patients were male (77%, $n=54$) with an age (mean $\pm$ std dev) of 39.3 ± 18.1 years. Blunt trauma was the mechanism for 90%, ($n=63$) of patients. ISS was 28.7 ± 14.2 . NT was effective in 49% of patients as defined by clinical improvement (general improvement=8, cardiovascular=4 or respiratory=22) (Figure 2). NT effectiveness was significantly higher in the prehospital setting than hospital (68.3% success rate versus 20.7%, $p < 0.01$).

Prior to March 2011, NTs were performed on 50 patients (prehospital $n=29$, hospital $n=21$); effectiveness of NT was 48% ($n=24$). NTs performed prehospital were more effective than the ones performed in the hospital before 2011 catheter length change (75% versus 25%, $n = 18, 6$ respectively, $p=0.02$).

Following March 2011, 20 NTs were performed (prehospital n=12, hospital n=8). Prehospital teams' effectiveness in decompression improved with the increased angiocatheter length, although not statistically significantly (8 cm=83%, 5 cm=62% $p=0.28$). In comparison, hospital NT effectiveness did not improve over the same time period (prior to March 2011 28.6% vs 0.0%, $p=0.15$). Overall, comparing all patients who underwent NT with the 8 cm angiocatheter versus 5cm angiocatheter regardless of procedural setting showed that increased angiocatheter length was significantly more effective (83% vs 41% respectively, $p=0.01$)

Mortality was 33% overall and was significantly lower in those with documented clinical effectiveness than those with non-effective NT (20.6% vs 44.4%, $p=0.03$). Mortality was similar in those that received prehospital NT and hospital NT (26.8% vs 41.4%, $p=0.20$) and in those with increased angiocatheter length in the prehospital setting (16.7% vs 31.0%, respectively, $p=0.46$). Neither group, was statistically significant. There were no documented complications as a direct result of NT using either angiocatheter length.

Forty-nine patients underwent CT scan of the chest. CWT at the 2nd ICS-MCL and the 4th ICS-MAL were 41.0 ± 11.7 mm and 46.7 ± 21.0 mm respectively ($p=0.06$). Radiographic predictions suggest that a 5 cm angiocatheter would succeed in entering the thoracic cavity in 80% of patients at the 2nd ICS-MCL and 53 % of patients at the 4th ICS-MAL. Increasing needle length to 8cm would increase the rate of radiographically predicted decompression significantly at the 2nd ICS-MCL and 4th ICS-MAL (100% and 90%, respectively) (Figure 3). Actual NT effectiveness rates were significantly lower than predicted ($p<0.01$; Figure 3). 86% of patients had significant subcutaneous emphysema laterally on CT scan compared to 63% anteriorly. BMI data was available for 59 patients (Median BMI 27.7 IQR 9). Increasing BMI was correlated with increased CWT at 2nd ICS-MCL and 4th ICS-MAL, (R^2 0.55 and 0.65 respectively). BMI ≥ 30 was not associated with decreased NT effectiveness based on non-parametric testing ($p=0.55$). Similarly, age over 50, ISS, gender or type of trauma were not associated with decreased effectiveness (all $p>0.05$, Table 1).

On multivariable analysis we are underpowered to assess BMI or CWT and NT effectiveness. Controlling for age, use of the long (8 cm) needle had an increased odds of being effective compared to the short (5 cm) needle (OR 7.27, 95% CI 1.42–37.13, $p=0.02$). Similarly when controlling for ISS, 8 cm NT had an increased odds of being effective compared to 5 cm NT (OR 10.06, 95% CI 1.16–97.15, $p=0.04$).

Discussion

Needle thoracostomy may be a lifesaving procedure in the management of tension physiology. A growing body of evidence suggests the use of longer angiocatheters may result in more effective NT as compared to the currently recommended 5cm catheter by ATLS (2–5,8,9,14,18,19). No clinical data exists to our knowledge supporting increased clinical efficacy of NT with increasing angiocatheter length beyond the currently recommended 5cm in civilian populations, who tend to have higher BMI, and CWT. Herein, we report a decade of experience in performing NT in both the prehospital and trauma resuscitation settings, using both 5cm as currently recommended, and after change to 8cm

angiocatheter. This study suggests based on clinical documentation that half of our patients with tension physiology benefited from needle decompression with the use of recommended needle size by ATLS guidelines. Increasing catheter length from 5cm to 8cm further improved clinical effectiveness with a similar safety profile.

Ball and colleagues conducted a study in regards to the clinical effect of NT decompression. (2) They assessed clinical efficacy in the prehospital setting comparing 3.2cm and 4.5cm angiocatheter and found that failure to decompress with a 4.5 cm catheter occurred in only 4% of patients compared to 65% of patients with 3.2cm. The NT decompression in their study was confirmed by immediate ultrasound rather than clinical improvement, and nearly a third of patients underwent chest tube placement before radiological assessment could be performed. (2) While this study has significant utility, catheters of those lengths are not currently recommended. Furthermore, patients were excluded if suffering penetrating trauma or who arrived in pulseless arrest, of which tension physiology is a cause. Additionally, they did not report relevant patient characteristics such as BMI or CWT and this limits comparability of data. Contemporary studies which have shown correlation between increased patient CWT, and predicted failure rates of needle decompression which is difficult to reconcile between studies(9,16,19). To our knowledge Ball et al is the only study that has assessed actual clinical NT effectiveness; however the physiologic response, which is the clinical outcome, was not reported. Absence of detected pneumothorax is not equivalent to brief decompression of tension, the goal of NT, which is typically followed with tube thoracostomy.

To our knowledge, no other study reports actual complication rates in civilian patients with tension pneumothorax who underwent needle decompression with comparing contemporary catheter lengths of 5cm and to 8cm as recommended by Tactical Combat Casualty Care guidelines for military NT decompression (21). The nearest report comparable to our study is recent data from the Israeli military by Chen et al.(23) who compared a 10 Fr 8cm length catheter to 8 cm 14 gauge catheter for NT decompression as recommended by TCCC guidelines. In their study clinician reported improvement was demonstrated in respiratory status 83% of the time, and while the majority of these patients expired, this data is in agreement with our clinically reported decompression rates. While the cause of the patients' ultimate demise in that study and ours is unclear, both our experience and the Israeli study have similarly severe ISS of approximately 30.

In studies assessing radiological decompression rates Chang et al found a theoretical risk of injuring an underlying structure to be 0% and 6–9% with a 5cm and 8cm needle, respectively(19). Like our study, Chang et al found, based on radiographic measurements, 8-cm catheters have a higher chance of pleural decompression when compared with 5-cm catheters, but a higher simulated rate of injury at lateral decompression sites and at the 2nd ICS-MCL. In clinical use, our complication profile was favorable compared to predictions based on Chang's model.

Theoretical rates of successful decompression based on CWT have been shown to be nearly 100% in patients using a 7cm catheter at the second intercostal space.(17,19) Our radiological data would support this conclusion, but temper it with clinical failures. While

our study found no definite complications with an 8 cm catheter at the second intercostal space, we were unable to evaluate needle decompression done at more lateral locations like the 4th or 5th intercostal space along the anterior- or mid-axillary line as this is not the practice at our institution. Alternatively, we analyzed CT measurements at the 4th ICS-MAL. We demonstrated that the 4th ICS-MAL had an even greater CWT which more positively correlated with BMI. In addition, there appears to be greater rates of catheter kinking when placed at the midaxillary line(22). Provider awareness of CWT and available equipment is essential.

Inaba and colleagues reported that needle decompression would fail in 42.5% at the second intercostal space at the midclavicular line using the currently recommended 5cm needle (16). Although we report clinical improvement as the primary outcome for determining NT effectiveness rather than radiographic measures, our data showed a similar failure rate (48%). In our cohort, CWT correlated with BMI, which also has been previously shown(16–18).

Our data suggest that performing NT in the prehospital setting before arriving at the trauma center increases decompression and subsequent clinical improvement and may improve mortality. Performing NT earlier in the management of the trauma patients appears justified, both in terms of safety and effectiveness. (2,24,25). This may be due to increased provider comfort level with performance of the procedure or providers encountering the pathology earlier in the course of the patients' resuscitation. Success, however, was even better with the use of longer needles. Cantwell et al showed that educating paramedics to perform NT decreased the number of unrecognized and untreated tension pneumothoraxes without any reported complications. Interestingly, they also reported that shorter needles may fail to reach the pleural cavity more often(24). Our data strongly supports treatment of tension physiology by Emergency Medical Service (EMS) providers and we suggest advanced life support and critical care trained prehospital providers be equipped and trained to recognize and treat suspected cases of tension physiology.

Our study has significant limitations. Due to the nature of tension physiology, patients present acutely and in extremis making tension physiology in trauma patients very difficult to study, both prospectively and retrospectively, particularly with respect to quantitation and measurement of NT success. Our method of assessment of NT effectiveness based on prior documentation of provider assessment, though we believe has merit, as providers are basing moment to moment treatment decisions on their assessment, has severe limitations. Measuring outcomes based on provider judgment, is inherently not confirmed by a second, more objective method which would allow corroboration of actual success. Unfortunately this outcome assessment method though likely fraught with error, should theoretically be equal in both the 5 cm and 8 cm groups, but we are unable to confirm this. We acknowledge that the use of clinical documentation and the subjective assessments used to assess effectiveness have significant limitations such as observer and recall bias as well as the subjective nature of general clinical improvement with concomitant trauma resuscitation and other therapeutic maneuvers Furthermore, while our EMS and trauma providers are required to document all procedures performed, there may be incomplete documentation both from EMS providers and in hospital providers of NT. Patients may have had NT without having

the procedure documented and therefore not have been included in our analysis. The retrospective nature of a review of this type also makes it possible that complications of NT may be attributed to the trauma itself rather than NT intervention; we have attempted to minimize this by assigning all possible complications to the NT. In this study patients had NT documented before any evidence of positive pressure airway interventions were performed. However, there may have been discrepancy in invasive ventilation strategies and NT performance times. Furthermore we are limited by patients actually having tension, there is no current method to reliably, and expeditiously, diagnose tension pneumothorax during trauma resuscitation as tension is an inherently clinical and physiological, rather than radiological diagnosis, in the absence of invasive monitoring, rarely present at time of trauma resuscitation. Another limitation of our study is lack of power in certain subgroup analyses, such as CWT and BMI on effect of NT effectiveness. Despite these limitations, we believe this study represents significant addition to the civilian literature regarding increasing NT length on the clinical effectiveness of NT.

Conclusion

The goal of NT is expeditious and effective treatment of tension physiology. Although patients are critically ill with inherently poor outcomes, our data suggests that NT remains beneficial and may be improved with an 8 cm angiocatheter in the 2nd ICS MCL. Our institution has subsequently made the 8cm catheter available in our resuscitation bays and utilizes this length routinely for all NT. Furthermore, given the success of NT in the prehospital period, prehospital providers should be trained and enabled to perform NT.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1. Study flowchart of needle thoracostomy patients, detailing inclusion criteria, timing of equipment change, and needle thoracostomy placement setting.

Figure 2.

Documented needle thoracostomy by effectiveness by category in 70 patients. Effectiveness was defined as documented clinical improvement in respiratory, cardiovascular, or general clinical condition.

Figure 3.

(A.) Radiographically predicted effectiveness of 5cm and 8cm catheters in the 2nd ICS-MCL and (B.) 4th ICS-MAL. (C.) Actual effectiveness of 5cm and 8cm catheters at the 2nd ICS-MCL. BMI and CWT for each group graphed as R^2 .

Table 1

Descriptive comparison of NT groups (asterisks indicated missing data).

	5cm (n=58)	8cm (n=12)	Prehospital (n=41)	Hospital (n=29)	Effective (n=34)	Not Effective (n=36)
Male Sex n (%)	45 (78)	9 (75)	31 (76)	23 (79)	25 (74)	29 (80)
Age (Mean±SD)	39.0±18.3	25.0±6.5	41.0±15.7	36.8±20.4	43.3±18.1	35.5±16.9
ISS* (Mean±SD)	29.9±14.1	21.3±11.0	25.2±11.7	33.3±15.5	24.2±11.9	32.8±14.6
BMI* (Median± IQR)	28.7 (25, 33)	26.9 (21, 30)	28.8 (24, 33)	29.4 (25, 35)	27.0 (24, 33)	29.0 (24, 32)
2nd ICS-CWT* (Mean±SD)	41.2±11.2	40.5±12.9	42.6±12.0	37.8±9.9	41.1±11.7	41.0±11.2
Presence of subcutaneous air/emphysema 2nd ICS-MCL*						
n (%)	23 (59)	8 (80)	23 (69)	8 (50)	20 (71)	11 (52)
Bilateral placement n (%)	19 (33)	3 (25)	9 (22)	12 (41)	7 (20)	14 (40)
30-day Mortality n (%)	21 (36)	2 (16.7)	11 (27)	12 (41)	7 (20)	16 (44)