Prehospital Needle Decompression Improves Clinical Outcomes in Helicopter Evacuation Patients With Multisystem Trauma

A Multicenter Study

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ABSTRACT

Background: The utility of prehospital thoracic needle decompression (ND) for tension physiology in the civilian setting continues to be debated. We attempted to provide objective evidence for clinical improvement when ND is performed and determine whether technical success is associated with provider factors. We also attempted to determine whether certain clinical scenarios are more predictive than others of successful improvement in symptoms when ND is performed. **Methods:** Prehospital ND data acquired from one air ambulance service serving 79 trauma centers consisted of 143 patients (n = 143; ND attempts = 172). Demographic and clinical outcome data were retrospectively reviewed. Patients were stratified by prehospital characteristics and indications. Objective outcomes were measured as improvement in vital signs, subjective patient assessment, and physical examination findings. Univariate analysis was performed using chi-square for variable proportions and unpaired Student's *t*-test for variable means; $p < .05$ was considered statistically significant. **Results:** The success rate of ND performed for hypoxia (70.5%) was notably higher than ND performed for hemodynamic instability (20.3%; $p < .01$) or cardiac arrest (0%; $p < .01$). Compared to vital sign parameters, clinical examination findings as part of the indication for ND did not reliably predict technical success ($p > .52$ for all indications). No difference was observed comparing registered nurse versus paramedic ($p = .23$), diameter of catheter ($p > .13$ for all), or length of catheter ($p = .12$). **Conclusion:** Prehospital ND should be considered in the appropriate clinical setting. Outcomes are less reliable in cases of cardiopulmonary arrest or hypotension with respiratory symptoms; however, this should not deter prehospital providers from attempting ND when clinically indicated. Additionally, the success rate of prehospital ND does not appear to be related to catheter type or the role of the performing provider.

Keywords: *needle decompression; prehospital emergency care; tension physiology; cardiopulmonary arrest*

Introduction

Prehospital thoracic ND is an emergent and potentially life-saving procedure designed to allow release of tension pneumothorax. In the military setting, up to 33% of all preventable deaths on the battlefield are estimated to result from tension physiology.[1–4] Tension pneumothorax has also been cited as the second leading cause of preventable death in combat casualties and the third leading cause of combat mortality overall.[5] Data from the Vietnam conflict demonstrated that up to 3.4% of patients with penetrating torso trauma who died in the field potentially succumbed to tension pneumothorax.[6] Increasing use of prehospital ND has led to a substantial decrease in combat casualties from tension pneumothorax. Data from armed conflicts in Iraq and Afghanistan demonstrate a mortality rate of only 0.2%, a reduction of nearly 90% from the Vietnam conflict.[7] Accordingly, current military prehospital guidelines support the broad use of ND in patients with impending tension physiology or traumatic cardiac arrest, and this is the official recommendation of the US Department of Defense Joint Trauma System, as stated in the Tactical Combat Casualty Care (TCCC) guidelines.[8] The recommendations allow for expedient management of patients with high-risk mechanisms and respiratory symptoms, and the skill is increasingly being taught to all military prehospital practitioners as well as nonmedically trained combatants, given its procedural ease and perceived high clinical benefit.[9]

In the civilian sector, ND is a standard aspect of the Advanced Trauma Life Support (ATLS) approach to the injured patient, yet very little data supporting its use exist.[10,11] Similarly, prehospital providers are offered courses that provide in-depth training regarding prehospital ND placement, such as International Trauma Life Support and Pre-Hospital Trauma Life Support, although these courses are not a requirement for most emergency medical services (EMS) agencies, and their efficacy regarding prehospital ND has not been rigorously examined.[12,13] As such, the clinical indications, optimal technique, and expected outcomes remain unclear. Although the technique is taught to medical students and residents as an in-hospital resuscitative technique for tension physiology, a notable proportion of these NDs are performed in the prehospital setting by EMS providers, possibly because of accessibility to and/or provider preference for tube thoracostomy in the inpatient setting.[14] However, some evidence suggests that outcomes may be similar between the two techniques.[15]

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The true incidence of tension pneumothorax in the prehospital setting remains unclear; however, current literature indicates it is likely low. According to one series by Eckstein and Suyehara,[16] who examined civilian trauma patients who underwent prehospital ND, only 5% of patients demonstrated objective evidence of improvement in vital signs, and 7% had improvement in subjective symptoms. This brings into question how many of these patients had a tension pneumothorax as a result of their injuries. A separate study cites a wide range in the incidence of tension pneumothorax, from 0.2% of all advanced paramedic life support responses to 1.7% of major trauma patients with an Injury Severity Score (ISS) of at least 15.[17] Given this relatively low incidence and the concern for potential complications from prehospital ND, previous generations of surgeons have argued that field personnel should not perform the procedure because the potential benefit is minimal and risk of injury is high.[18–20]

The purpose of our study was to determine whether prehospital ND is beneficial in the civilian trauma setting and whether it should be routinely performed by EMS personnel, particularly in the critically ill who require extended transportation times by helicopter. Our specific aim was to identify objective evidence of ND success based on patient symptomatology and physiology, and to determine whether technical success of ND depends on the equipment (i.e., diameter and length of the catheter) or performing provider (i.e., registered nurse or paramedic).

Methods

After internal review board approval, a retrospective review of prehospital ND data (n = 143 patients, 172 NDs) were acquired from Air Evac Lifeteam, a single air ambulance service based out of the Midwest and Southeastern United States serving 79 trauma centers in 12 states (AR, AL, MO, WV, TX, IL, IN, OK, OH, MS, KY, TN). Records for all transport flights from January 2011 to November 2011 were reviewed. The prehospital record was used to abstract demographic data, resuscitation profiles, and clinical outcomes. Variables obtained included patient age, weight, gender, receiving facility, mechanism, intubation, vital signs before ND, vital signs after ND, laterality, need for bilateral and/or repeat decompression, physical examination and physiologic response to ND, ND catheter characteristics, patient mode of transportation, mechanism of ND failure if known, and provider training background (i.e., registered nurse vs. paramedic).

Patients were then stratified based on prehospital patient characteristics and the following indications for ND based on the strength of the indication and the likelihood of tension physiology. Tension physiology was defined using parameters similar to those used by various other groups[14,15]: (1) cardiopulmonary arrest; (2) hemodynamic compromise (spontaneous bacterial peritonitis <90mmHg and/or heart rate >120 or <50 beats per minute [bpm] and/or narrowed pulse pressure <20mmHg); (3) acute hypoxia (oxygen dissolved in blood plasma [PO_2] <60mmHg and/or oxygen saturation [SaO_2] <90%); (4) combined objective findings (cardiopulmonary arrest and/or hemodynamic compromise and/or hypoxia); (5) subjective findings only based on patient symptomatology and/or provider assessment; and (6) combined objective and subjective findings. This study defined objective findings as those with absolute values, such as blood pressure, SaO_2, and heart rate. Subjective clinical findings were those that can vary between providers. These were findings suspicious for tension physiology, such as clinician-perceived decreased/absent breath sounds, tachypnea/subjective shortness of breath or impending doom, rib fractures with chest wall crepitus, flail segment, subcutaneous emphysema, hyperresonance to percussion, and asymmetry of chest wall.

Specific outcomes included the following: (1) improvement in vital signs: diminished tachycardia (heart rate decreased to <100 or >10 bpm from baseline), improved bradycardia (defined as a heart rate >50 bpm), improved systolic blood pressure >90mmHg (if <90mmHg at baseline), or SaO_2 >90% (if <90% at baseline); (2) improvement in subjective patient assessment: decreased shortness of breath or improvement in tachypnea; and (3) improvement in physical examination findings: release of air or blood upon catheter placement, decreased asymmetry of the chest wall, improved lung compliance, decreased cyanosis, and/or improved breath sounds.

Statistical Analysis

Chi-square analysis and Fisher's exact test were used to compare proportions among variables, and an unpaired Student's *t*-test or single variable analysis of variance was used to compare continuous data. Results were reported as mean ± standard deviation or median ± interquartile range. We considered *p* values <.05 to be statistically significant. Analysis was performed using SAS Studio Software for Windows, version 3.6 and R version 3.5.1.

Results

Study Population

The demographic profile of the study cohort is depicted in Table 1. There were 143 patients in total. The patient population was predominantly male (107; 74.8%), middle aged (age = 44 ± 19.2 years), with most having experienced blunt injuries (127; 88.8%). In these patients, 172 attempts at ND were performed. A notable proportion of prehospital NDs were performed at the scene (103/172 attempts; 59.9%). Twenty-nine repeat NDs were performed, 11 for misplaced right-sided catheters, 11 for misplaced left-sided catheters, and 7 for misplaced catheters during bilateral placement. A total of 129 providers performed NDs, stratified equally based on background (79 registered nurses vs. 97 paramedics). The success rate of ND, as determined by prespecified, clinically relevant cutoffs and definitions of clinical success on examination, was 80.2% overall.

The distribution of indications for prehospital ND is depicted in Table 2, which shows the distribution of reasons why prehospital personnel performed ND. The data indicate that most patients underwent ND because of the classic features of pneumothorax (e.g., diminished breath sounds), which may or may not have manifested with tension physiology. Of note, clinical examination findings linked to respiratory pathophysiology were the No. 1 and No. 2 reasons most reported by prehospital personnel, closely followed by hemodynamic compromise.

The clinical observations by prehospital providers post-ND are depicted in Table 3. After ND, patients were noted to have significant improvement in pulmonary pathophysiology more than any other findings. A rush of air or blood coincided with improvements in oxygen saturation, improvement of breath sounds, and improvements in respirations.

TABLE 1 *Demographics*

Participating centers	79	
Number of patients	143	
Age, mean (±SD)	44 (±19.2)	
Male (%)	107 (74.8%)	
Type of arrest		
Medical (%)	4 (30.0%)	
Traumatic (%)	139 (97.2%)	
Penetrating (%)	16 (11.2%)	
Blunt (%)	127 (88.8%)	
Number of providers	129	
Registered nurse (%)	79 (61.2%)	
Paramedic (%)	97 (75.2%)	
	ND Attempts (172)	**Number Successful (%)**
Total successful (N/n)	—	138 (80.2%)
Done in field	103	84 (81.5%)
Decompression prior to Intubation	36	34 (94.4%)
Right decompressions	57	49 (86.0%)
Left decompressions	65	59 (90.8%)
Bilateral decompressions	24	13 (54.2%)
Repeat decompressions	29	22 (84.6%)

TABLE 2 *Reasons Prehospital Providers Performed Needle Decompression*

Indication	Patients	%*
Absent or diminished breath sounds	120	83.9
Low oxygen saturation (Spo_2)	88	61.5
Hemodynamic instability	64	44.8
Rib fractures or flail segment	46	32.3
Crepitus	45	31.5
Apnea/dyspnea/tachypnea	44	30.8
Paradoxical chest rise or asymmetry	37	25.9
Cardiopulmonary arrest	30	21.0
Decreased compliance	26	18.2
Signs of poor perfusion	20	14.0
Cyanosis	16	11.2
Tracheal deviation	13	9.1
Documented pneumothorax	11	7.7
Subcutaneous emphysema	9	6.3
Diaphoresis/sense of impending doom	7	4.9
Mechanical failure of initial catheter	6	4.2
Pleuritic chest pain	3	2.1
Penetrating torso wound	3	2.1
JVD	3	2.1
Chest wall contusion/seatbelt sign	2	1.4

*Percentages shown are the frequency of indication reported. Patients may have combined findings; thus, the sum of percentages exceeds 100%.

Prehospital ND Success Based on Physiologic Parameters and Clinical Examination

The percentages of successful outcomes based on indications for which ND was performed are shown in Table 4. The success rate when performed for hypoxia with positive clinical examination (70.5%) was notably higher than when performed for abnormal examination without hemodynamic impairment or hypoxia (52.4%; $p < .01$), hemodynamic compromise with positive clinical examination (20.3%; $p < .01$), or cardiopulmonary arrest (0%; $p < .01$).

TABLE 3 *Provider Observations After Prehospital Needle Decompression*

Observation	Patients	%
Rush of air or blood on placement	115	80.4
Oxygen saturation improved to >90%	102	71.3
Improved breath sounds	60	42.0
Improved respirations	47	32.9
Less shortness of breath	37	25.9
Improved hemodynamics	25	17.5
Improved compliance/easier to bag-mask	23	16.1
Decreased asymmetry/equal chest wall rise	17	11.9
Recovery from arrest	7	4.9
Cyanosis or skin color improvement	7	4.9

To determine whether clinical examination findings as part of the indication enhanced the likelihood of success, the data were stratified as shown in Table 5. The results did not reach statistical significance for any indication, including combined indications (arrest and hypoxia or hemodynamic instability and hypoxia; $p = .078$).

In analyzing whether intubation and mechanical ventilation affected ND outcomes, there was no significant difference of any recorded parameter between pre- and post-intubation states ($p = .16$). Most notably, intubation status had no effect on the reversal of hypoxia ($p = .35$).

ND Success Based on Equipment and/or Provider

There was no significant difference in success rates based on catheter bore size (Figure 1). Additionally, 10-gauge catheters were not found to be statistically different from 16-gauge catheters, although the success rate was lower (67.1% vs. 85.3%; $p = .17$). Similarly, catheter length was not associated with a significant difference in success rate (mean length in procedural success cases = 7.62cm vs. mean length in procedural failure cases = 7.15cm; $p = .12$), suggesting that other contributory factors to ND ineffectiveness should be considered. (Figure 2). Looking specifically at cases in which the procedure was performed with catheter lengths <4.5cm, only 4 patients had outcomes recorded, with 3 of 4 experiencing technical success. The background training of the performing provider made no significant difference in success rate; paramedics had an 86.2% success rate compared with 77.4% for registered nurses ($p = .23$).

Discussion

This study is one of the few multicenter series to analyze the success rate of thoracic ND in the prehospital setting for civilian trauma patients. To our knowledge, this is also the first study to exclusively analyze helicopter evacuation patients, who represent a growing subset of prehospital patients. The results suggest that ND is more often successful at reversing respiratory indications (i.e., hypoxia) than it is hemodynamic indications. Furthermore, the success rate does not differ notably based on the equipment used or the role of the performing provider.

Many studies have documented the success of thoracic ND as a life-saving intervention (LSI), especially in the military setting. In a large prospective multicenter study of 1,003

TABLE 4 *Success of Prehospital Needle Decompression Based on Indication*

Indication	Attempts	Success	%	Outcome	*p* Value (vs hypoxia with positive clinical exam)
Cardiopulmonary arrest alone	12	0	0.0	Achieved ROSC	<.01
Cardiopulmonary arrest with positive clinical exam	22	2	10.0	Achieved ROSC	.06
Hemodynamic compromise	7	3	42.9	Improved hemodynamics	.18
Hemodynamic compromise with positive clinical exam	64	13	20.3	Improved hemodynamics	<.01
Hypoxia alone	6	4	66.7	Improved hypoxia	.63
Hypoxia with positive clinical exam	88	62	70.5	Improved hypoxia	—
Combined indications alone	5	3	60.0	Improved vital signs and/or examination	.21
Combined indications with positive clinical exam	5	2	40.0	Improved vital signs and/or examination	.12
Abnormal exam but no hemodynamic impairment or hypoxia	124	65	52.4	Improved clinical examination	<.01

ROSC = return of spontaneous circulation.

TABLE 5 *Clinical Examination Ability to Augment Prehospital ND Success*

	Without Examination			With Examination			
Indication	Success	Attempts	%	Success	Attempts	%	*p* Value
Cardiopulmonary arrest	0	12	0	2	22	9.1	.52
Hemodynamic compromise	3	7	42.9	13	64	20.3	.63
Hypoxia	4	6	66.7	62	88	70.5	.98
Combined Indications	3	5	60.0	2	5	40.0	.99

FIGURE 1 *Needle decompression success rate based on bore size.*

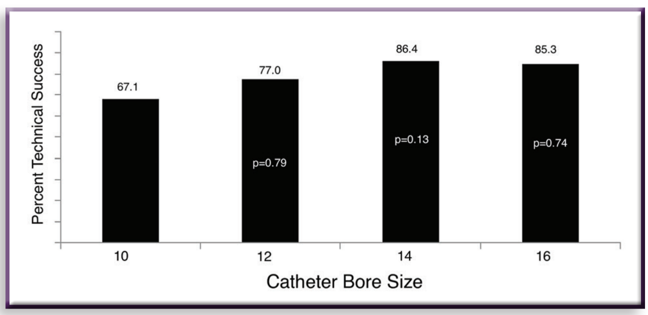
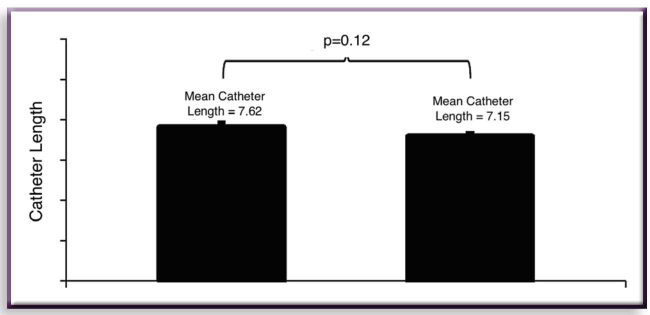


FIGURE 2 *Needle decompression success based on catheter length.*



combat-wounded soldiers between 2009 and 2011, casualties were assessed in the prehospital setting for mechanism of injury and airway management, as well as chest, hemorrhage, and resuscitation interventions.[21] The number of LSIs resulting in a successful outcome were compared with the number of missed LSIs, defined as procedures that were not performed in the prehospital setting but should have been performed according to the evaluation of the treating physician. Although a low frequency of penetrating trauma was noted in this series (24%), thoracic ND was the intervention that comprised the highest percentage (48%) of overall missed LSIs (252 patients). This suggests that prehospital ND is a potentially life-saving procedure with a high success rate. The TCCC guidelines for prehospital trauma care, including ND for tension pneumothorax, have been studied, and the technique was shown to be underutilized, particularly in critical patients with high injury burden. This had led to the sanctioned use of ND by a range of Servicemembers.[8]

Whereas data supporting prehospital ND in the military setting is convincing, data to support its use in the civilian trauma setting remains unclear. In a prior study of helicopter-evacuated trauma patients, the use of ND was infrequent (18/254), and the authors identified only one case in which failure to perform ND resulted in a true tension pneumothorax.[22] Even with substantial injury burden, the incidence of tension pneumothorax has been shown to be as low as 0.5% to 1.7% in patients with an ISS of at least 15.[17] This differs from rates reported for inpatients; a recent study found that 16.2% of patients admitted with a spontaneous pneumothorax progressed to tension physiology.[23] ND itself is also not without risk. This study did not focus on adverse events; however, complications resulting from catheter insertion, malposition, or infection requiring additional procedures are all well described.[24–26] These issues, along with low procedural success rates seen in other civilian studies, give rise to debate on whether prehospital ND should be performed.[16,27,28]

The findings of this study support the use of prehospital ND for the indication of hypoxia because of a relatively high success rate. Other studies also suggested a more selective approach based on specific symptoms, physical examination findings, and physiologic parameters.[6] The low success rate of ND performed for cardiopulmonary arrest or hemodynamic compromise brings into question the effectiveness of the procedure in patients with the late sequelae of tension physiology. Martin et al.[29] demonstrated similar findings with swine models in cardiac arrest resulting from tension pneumothorax. In their study, ND failed to restore perfusion in 64% of cases.

Another area of debate is centered around catheter type and the role of the performing provider. Various studies involving cadavers, along with ultrasound and CT findings, comment on catheter length as a factor in ND success.[30–32] Ball et al.[17] demonstrated a notably higher rate of failure when catheters <4.5cm in length were used. We were unable to detect a significant difference in catheter length between successful and unsuccessful ND attempts, although in both groups, the mean catheter length was >7cm. Similarly, catheter bore size did not significantly affect success rates. This is in contrast with other studies, which found that smaller-gauge catheters were unable to adequately decompress the chest.[33] Cadaver, ultrasound, and computed tomography studies have also brought into question whether ND success depends on catheter length.[30–32,34,35] The differences in findings are likely the result of variability in body habitus as well as location of placement (i.e., midaxillary vs. midclavicular lines). As of the most recent ATLS recommendations, catheters between 5 and 8cm in length should be considered for axillary placement at the fifth intercostal space.[36] Regarding the role of the performing provider, we found no significant difference in success rate; both paramedics and registered nurses were able to perform the procedure with similar efficacy. Both sets of providers receive basic training on ND as part of their certification process.[37,38]

Aside from training, one factor that may improve success rates among prehospital providers is increased availability of portable imaging equipment. While the detection of pneumothorax by Extended Focused Assessment with Sonography in Trauma (eFAST) has gained acceptance as an adjunct during trauma resuscitation in the emergency department, portable ultrasound has yet to become standard for prehospital personnel. If made universally available, it may help decrease the number of unnecessary prehospital decompressions and increase the number of successful field interventions.[39]

There are several limitations to this study, one of which is its retrospective design. Because there are no standardized indications for prehospital ND across all institutions, we were forced to rely on self-reported indications by the performing providers. Air Evac Lifeteam, the company responsible for operating the helicopter fleet, does not standardize clinical indications or the setting for ND. These decisions are made by the regional emergency medical service directors. We attempted to use predefined objective clinical criteria (e.g., vital signs, improvements in physical examination findings) to offset any potential variability in interpretation of what constituted a clinical success. We were also limited by a lack of reporting on the Abbreviated Injury Score, ISS, Glasgow Coma Scale, or survival. For this reason, we chose to capture clinical presentation, symptoms, and the change in physiologic parameters immediately pre- and post-ND instead of standard outcome measures, such as mortality, which depend on overall injury burden and therapeutic interventions performed throughout hospitalization.

Other prehospital variables were not accounted for, such as fluid resuscitation, timing of oxygen administration, duration between injury and ND, endotracheal intubation and mechanical ventilation, and tourniquet placement. Furthermore, although the procedure setting was a recorded variable, we were unable to determine whether assessment of success was performed on the ground or midflight. The change in atmospheric pressure at varying altitudes can have implications on the success of ND. Collectively, these variables likely contributed to post-procedure hemodynamic parameters; however, we were unable to perform a matched analysis to determine whether ND was independently associated with clinical improvement. In addition, without postmortem findings, we could not reliably identify patients who suffered cardiopulmonary arrest from blunt cardiac injury rather than tension pneumothorax. Finally, we make no mention of complication rates or location of needle placement on the chest because these data were not available.

Early identification and treatment of a tension pneumothorax by prehospital providers is critical for improving trauma patient outcomes. Success in military settings demonstrates the feasibility of ND, and the results of this study demonstrate that when performed on civilians in select circumstances, a high rate of success can be achieved. More specifically, when performed for hypoxia rather than for cardiopulmonary collapse, a larger proportion of patients will show improvement. Nonetheless, this should not deter providers from attempting ND in all clinically indicated scenarios. Lastly, the success rate of prehospital ND does not appear to be related to catheter size used or the role of the performing provider.

Previous Presentation
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Conflict of Interest
None of the authors has any conflict of interest to disclose.

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Author Contributions
The literature review was performed by RH, CG, AG, CPF, and AS. The study design was by RH, CG, AG, ME, CPF, DEB, KI, and AS. Data collection was by RH, CG, AG, ME, CPF, DEB, KI, and AS. Data analysis/interpretation was performed by RH, AG, KM, HT, and AS. All of the authors contributed to the writing and critical revision of the manuscript.

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