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# Clinical Appraisal of Needle Thoracostomy in a Canadian Aeromedical System

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# Clinical Appraisal of Needle Thoracostomy in a Canadian Aeromedical System

by

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## Abstract

Background: Needle thoracostomy (NT) remains the standard for prehospital treatment of tension pneumothorax, but its effectiveness has been questioned in previous literature. The incidence of NT and clinical characteristics of patients receiving NT for tension pneumothorax in a Canadian helicopter emergency medical service (HEMS) setting have yet to be described. This lack of data leads to difficulty understanding who is at greatest risk for requiring NT, identifying factors that may be important to successful clinical outcomes, and implementing changes to practice.

Methods: A retrospective chart review was conducted of adult patients who received NT from a Canadian HEMS service and a case study was conducted to document the novel use of an endotracheal tube to perform an improvised tube thoracostomy in response to NT failure.

Results: Only a small proportion (1.3%) of patients attended by the HEMS service received NT during their care. The study sample was predominantly male (77.0%), with an average age of 46.4 years, and a presenting complaint of blunt trauma. Logistic regression analysis revealed initial NT treatment was associated with a low likelihood of clinical improvement in patients presenting with blunt trauma ($OR = 0.18$; $p = .021$), receiving CPR prior to NT ($OR = 0.14$; $p = .02$), or in those who received bilateral NT treatment ($OR = 0.13$; $p < .01$). A pre-treatment BP < 90 mmHg was the sole variable which was predictive of a positive clinical response to initial NT ($OR = 3.33$; $p = .04$).

The case study provided a descriptive account of the successful use of a simple thoracostomy in combination with endotracheal tube insertion into the thorax to relieve tension pneumothorax following the failure of standard NT treatment in the HEMS setting.

Conclusions: Of the patients studied, those most likely to receive NT were males who had suffered blunt trauma. NT may have questionable benefit for patients presenting with blunt trauma, cardiac arrest, or requiring bilateral NT. NT may be insufficient to adequately treat tension pneumothorax, and simple thoracostomy with thoracic endotracheal tube insertion has been successfully used to treat tension pneumothorax refractory to standard prehospital treatment.

*Keywords*: adult, air ambulance, Emergency Medical Services, pneumothorax, prehospital, retrospective studies, thoracostomy

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## Contribution of Authors

This thesis contains two manuscripts that have been published in peer-reviewed journals. The first author devised the project, led the conceptualization, performed the data collection and analysis of the results. The first author wrote the manuscripts in consultation with the supervisory committee. All authors contributed important intellectual content, provided critical feedback, reviewed and edited the final manuscripts. Following written permission from the co-authors (Appendix A) and publishers (Appendix B), the following manuscripts have been reproduced in their entirety as chapters contained in this thesis.

Newton, G., Laing, C., Reay, G., & King-Shier, K. (2021). Thoracic endotracheal tube insertion during prehospital thoracostomy: A case report. *Air Medical Journal*, *40*(3), 182-184. https://doi.org/10.1016/j.amj.2021.01.001

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## Table of Contents

# Chapter One: Introduction

Accidents or unintentional injuries are the third leading cause of death in Canada (Statistics Canada, 2019). For Canadians living in a rural setting, the logistics of receiving care following an accident are even more complex. Often this means delays in care, insufficient local resources, and transport from one's local community to a specialty hospital in an urban centre. Typically, rural Canadians have an increased mortality risk and inferior access to health care services when compared with those living in an urban area (Sibley & Weiner, 2011). To counter this disparity in healthcare, the use of helicopter emergency medical services (HEMS) provides timely access to critical care in the event of an accident or sudden illness.

The overarching aim of this thesis was to explore the prehospital treatment of tension pneumothorax in a Canadian HEMS context. When this research began in 2019, there was no published literature that focused on the patients who experienced tension pneumothorax, or the treatment effectiveness, for those served by HEMS in Canada. Although studies exist from other countries which describe this, it is unclear if the findings are generalizable to a Canadian population.

The research described in this thesis is intended to explore several key areas related to the prehospital treatment of tension pneumothorax. First, the current practice for the management of tension pneumothorax was examined by reviewing the existing literature. Second, the clinical characteristics and outcomes of patients undergoing needle thoracostomy (NT) in a Canadian HEMS system were explored using a retrospective chart review. Third, a novel treatment for tension pneumothorax was described using a case study to document a potentially emerging therapy and the need for future research. In the conclusion section of this thesis, the findings of

this study are discussed in the context of future research directions and the potential implications for current education and clinical practice.

**Background**

The rapid treatment of patients in Canada who suffer a traumatic injury can be logistically challenging due to a large geographical distribution of the population in relation to the available medical resources. One solution to the problem has been the integration of HEMS teams that bring tertiary-level expertise directly to the patient and also reduce the time of transfer to an appropriate medical facility. Due to a limited number of HEMS resources, these prehospital teams are typically dispatched to care for only the most urgent patients. Since 2012, the Shock Trauma Air Medical Service (STARS) has been serving communities over a vast geographical area in Canada from six bases located in Alberta, Saskatchewan, and Manitoba with a combined mission volume of over 2,000 patients transported per year (Shock Trauma Air Rescue Service, n.d.). Additionally, during the same time frame, an electronic patient care record has been used to document treatments and the clinical response in a standardized manner. The combination of this expansive prehospital HEMS system and over half a decade of standardized treatment and reporting could provide a robust data set to answer questions otherwise challenging to study using traditional randomized research methodology.

Due to the use of aeromedical resources for patients of the highest acuity, HEMS staff are frequently exposed to profoundly ill and injured patients, including individuals at increased risk for developing tension pneumothorax. For more than 10 years, the protocol for the treatment of tension pneumothorax at STARS has directed practitioners to insert a 14-gauge intravenous catheter at least 6.5 cm long into the chest to release the trapped air (Alberta Health Services,

n.d.). However, NT has exhibited variable clinical success rates and is inherently prone to mechanical failure, obstruction, and dislodgement (Waydhas & Sauerland, 2007).

**Knowledge Gaps and Significance**

Information is scarce regarding the prehospital treatment of tension pneumothorax in a Canadian population. This has undoubtedly led to the generalization of research from other populations. Performing research from a Canadian population will add to the global knowledge and provide a base for future research endeavours in Canada. To focus future efforts on improving prehospital care for patients with tension pneumothorax, it is first necessary to understand the patient population at greatest risk of treatment failure. Furthermore, there is a distinct lack of literature surrounding the use of an endotracheal tube employed as a temporary chest tube. This may be an opportunity for practice change in how HEMS teams treat tension pneumothorax, which has been essentially unchanged for over 30 years since first described by York et al. (1993).

**Research Objectives**

The research objectives for this study were: to identify the characteristics of patients treated with NT in a Canadian HEMS setting and examine factors that may influence their outcomes following NT use, and to document the novel use of a simple thoracostomy plus insertion of an endotracheal tube into the thorax as a rescue treatment in response to a failure of the NT procedure in a prehospital setting.

**Thesis Outline**

This manuscript-based thesis contains two published manuscripts (chapters 3 & 5) and four chapters that provide context. The introductory chapter provides an overview of the research purpose and background information to highlight the current gaps in knowledge. The second

chapter is a literature review that explores the science of tension pneumothorax, the various treatments used to treat the condition, and current trends in the research. The third chapter is a retrospective chart review of patients undergoing NT in a Canadian HEMS service. The findings from this review highlight the clinical characteristics of patients treated with NT in a Canadian HEMS program and provide essential information regarding pre-treatment attributes that were predictive of treatment success. This manuscript was submitted to the *Journal of Prehospital Emergency Care* for peer review and published online ahead of print (Newton, Reay, et al., 2021). The fifth chapter introduces a novel treatment for tension pneumothorax, which at the time of writing has not yet been described in the literature as successfully used in the prehospital setting. This was the genesis for the second manuscript, which, due to the concise nature of case reports and journal requirements, does not contain the research methodology. The fourth chapter fills this gap by providing an understanding of the case study methodology and the research techniques utilized in developing the second manuscript. The fifth chapter contains the qualitative results from the case study described in chapter four. This chapter was submitted to the *Air Medical Journal* and published (Newton, Laing, et al., 2021). The focus of the manuscript was to describe the novel use of an endotracheal tube as a temporary chest tube in a patient with tension pneumothorax refractory to traditional NT in the prehospital setting. The sixth and final chapter synthesizes the research findings, provides potential implications for current education and clinical practice as well as future research endeavours.

## Chapter Two: Literature Review

A review of the literature was conducted to examine the common therapeutic interventions used in the prehospital treatment of tension pneumothorax. Publications were identified from searches of MEDLINE, Excerpta Medica dataBASE (EMBASE), PsycINFO, and Cumulative Index to Nursing and Allied Health Literature (CINAHL) from database inception to September 2018. The search strategy consisted of the following combined keywords: *needle* or *needles, thoracostomy* or *thoracentesis* or *decompression*, *pneumothorax* or *tension pneumothorax*, and *prehospital* or *pre-hospital* or *emergency* or *emergency medical services*. All searches were limited to articles published in the English language with full-text availability. Grey literature, book reviews, letters, and magazines were excluded from consideration due to the lack of peer review or transparent methodology. Results from the search provided literature predominantly from the fields of medicine, science, and emergency medical services. The combined search of all four databases returned 279 articles, of which 220 remained after removing duplicates. To reduce the large number of studies retrieved, article abstracts were screened and excluded if the content was not applicable to the treatment of tension pneumothorax. Overall, 29 articles were retrieved, eight of which were found to be relevant to the scope of the literature review. During the review, three therapeutic interventions for tension pneumothorax were identified: tube thoracostomy, needle thoracostomy, and simple thoracostomy.

### Tube Thoracostomy

A thoracostomy is any procedure used to create an opening through the chest wall into the pleural space (American College of Surgeons Committee on Trauma, 2018). In resource-rich settings such as a hospital, the use of a tube thoracostomy is considered the definitive treatment

for tension pneumothorax and is typically performed by a physician if resources allow it to be done without any delay. Tube thoracostomy is performed by making a surgical incision in the chest and inserting a 36-Fr to 40-Fr chest tube in the fifth intercostal space at the anterior axillary line, and connecting it to an underwater seal drainage and suction system at 20 to 30 cm $H_2O$ vacuum (Walls et al., 2018). It is the use of a large-bore drainage tube explicitly designed to evacuate air or blood from the chest that separates the tube thoracostomy from other forms of thoracostomy and also gives rise to the common use of the term "chest tube" to describe the procedure (Walls et al., 2018). The educational support system required to learn the technique of tube thoracostomy and maintain ongoing clinical competency has been identified as a likely factor limiting the widespread use outside of the hospital environment. High et al. (2016) described the initial training for flight crew members to perform tube thoracostomy at their HEMS program to include orientation using mannequins, fresh tissue cadavers, as well as animal models. Access to these educational resources would prove limiting for most prehospital programs, especially programs based in rural areas because a cadaver laboratory or animal vivarium is typically only available in urban centers with ties to university research programs.

In the prehospital setting, the use of tube thoracostomy by nurses and paramedics has been evaluated for complications such as infection or tube misplacement against a similar patient cohort treated by physicians in the emergency department during the same time frame (York et al., 1993). No statistically significant differences ($p < .05$) were found in the rates of procedural success or complications between groups, although inherent limitations of the retrospective review make it impossible to ensure there were no preexisting differences between groups. One important confounding variable is the time required for a prehospital team of only two members to set up the equipment needed for tube thoracostomy and perform the procedure in a manner

identical to the quality of care delivered in a hospital. Although treatment of tension pneumothorax must be done expeditiously, the delay in transporting a patient to definitive care has also previously been shown to have a positive linear correlation ($R = 0.962$, $p = .038$) with increasing mortality (Pham et al., 2017). York et al. (1993) noted that no aseptic technique was used in the prehospital group of their study, and this may account for the ability to maintain short scene times of less than 15 minutes. Ideally, the treatment of tension pneumothorax would be performed with an intervention allowing rapid technique, but without sacrificing efficacy or patient safety. One solution to the need for rapid treatment has been the widespread adoption of a needle thoracostomy technique, which is considered standard of care in most prehospital systems (Campbell & Alson, 2016).

**Needle Thoracostomy**

In an emergency, a needle thoracostomy can be rapidly performed by insertion of a large-bore intravenous catheter at a 90-degree angle over the superior border of the third rib into the second intercostal space at the mid-clavicular line and advancing the catheter into the chest to release the intrapleural pressure (Campbell & Alson, 2016). In contrast to the aforementioned tube thoracostomy, needle thoracostomy is considered only a temporizing measure and is typically still followed by tube thoracostomy as soon as is practical (American College of Surgeons Committee on Trauma, 2018). The Advanced Trauma Life Support (ATLS) training course for physicians still includes needle thoracostomy as a therapy for tension pneumothorax in the hospital setting, but only when the delay preparing the necessary resources to perform a tube thoracostomy would be detrimental to the patient (American College of Surgeons Committee on Trauma, 2018). An advantage of needle thoracostomy is that it only requires an intravenous catheter to perform the procedure, which can be readily found in most healthcare

settings or easily carried on the person such as in a combat environment. However, some authors have cast doubt on the efficacy of the needle thoracostomy despite its rapid technique and relative ease to learn (Axtman et al., 2019; Kaserer et al., 2017; Wernick et al., 2015).

### *Landmarking*

Results from a retrospective case series of 17 patients treated with prehospital needle thoracostomy indicated that only 18% ($n$ = 3) of the attempted procedures were successful as evidenced by clinical improvement in vital signs, dyspnea, or breath sounds (Kaserer et al., 2017). One of the potential downfalls of the needle thoracostomy procedure is that it relies on the practitioner to accurately identify the correct landmarks used in selecting the site for needle insertion. In a cohort of 25 emergency physicians who were asked to identify the second intercostal space at the midclavicular line on a human volunteer, only 60% ($n$ = 15) were able to correctly identify the second intercostal space, and all practitioners were found to identify a location medial to the midclavicular line (Ferrie et al., 2005). Due to the proximity of major organs and vasculature to the second intercostal space at the midclavicular line, it is unsurprising given the findings from Ferrie et al. (2005) that previously reported complications of needle thoracostomy include vascular injury, life-threatening hemorrhage, and even cardiac tamponade (Wernick et al., 2015). Furthermore, in patients wearing body armor such as police or soldiers, the ability to identify landmarks or access the anterior chest may be impossible thus necessitating an alternative needle insertion site (Beekley et al., 2007).

### *Needle Insertion Site*

One solution to the problem of accessing or landmarking the anterior chest has been performing the needle thoracostomy in lateral locations on the chest in either the fourth or fifth intercostal space at the midaxillary or anterior axillary line. Beekley et al. (2007) noted that the

lateral chest insertion site would permit a patient to remain wearing body armor in situations where care is provided in an active combat zone.

Perhaps the more compelling argument to investigate alternative needle insertion sites has been the hypothesis that needle thoracostomy may fail as a result of the increased anterior chest wall thickness preventing a standard 5 cm intravenous catheter from reaching the intrapleural space. The authors of a 2016 systematic review and meta-analysis compared 15 studies that investigated chest wall thickness at anterior and lateral chest locations and found no statistically significant ($p$ = .08) difference in chest wall thickness between the two sites; needle thoracostomy failure rates between sites still produced a statistically significant ($p$ = .01) difference with the fourth or fifth intercostal space at the anterior axillary line exhibiting the lowest overall rate of failure at 13% (Laan et al., 2016). One potential limitation of the studies used by Laan et al. (2016) is that the majority of measurements were conducted radiologically using computerized tomography (CT) scanning. Patients who undergo needle thoracostomy for tension pneumothorax typically present with their arms adducted laying supine on a stretcher, whereas typical chest CT protocol places the arms overhead and requires patients to hold their breath to reduce interference with imaging. The change in angle of the clavicle would subsequently change where the associated anatomical midclavicular line in the thorax would be located and thus where the chest wall thickness would be measured. Wax and Leibowitz (2007) indirectly addressed this by using a CT measurement half the width of the hemithorax to approximate the midclavicular line rather than using the mid-clavicle itself and found the anterior chest to have the lowest thickness, although the authors did not calculate whether the differences in distance were statistically different from anterior versus lateral locations. Because of the conflicting information about which anatomical site may be optimal for needle

thoracostomy, a pragmatic solution is to use a longer needle to ensure that it can reach the intrapleural space no matter which site is chosen.

***Needle Length***

One of the benefits of needle thoracostomy is that it can be performed using equipment that is found readily in most patient care settings. However, due to differences such as patient anatomy, position, and condition the standard 5 cm intravenous catheter may not successfully penetrate the pleural space. Trauma patients undergoing CT scan of the chest in Calgary, Canada had measurements taken at both the left and right anterior site for needle thoracostomy which found 35.4% ($n$ = 29) of women less than 40 years of age ($N$ = 82) had a left anterior chest wall thickness greater than the length of the standard 5 cm intravenous catheter (Zengerink et al., 2008). Measurements in the study varied by age and sex, with males less than 40 years ($N$ = 304) having the lowest risk of failure on the left side of the chest (9.9%, $n$ = 30). Notwithstanding the limitations generalizing the use of radiologic measurements to actual clinical success in decompressing a tension pneumothorax, the results indicated that at best nearly 10% of needle thoracostomies would fail due to needle length alone. This raises the important question of what optimal needle length is required to remove chest wall thickness as a barrier to procedural success. Cadaveric-based research ($N$ = 40) has been done by placing thoracostomy needles and then performing thoracotomy to visually identify successful entry into the pleural space, but it found only a 57.5% ($n$ = 23) success rate for a 5 cm needle at the second intercostal space in the midclavicular line (Inaba et al., 2011). Despite the limitations of extrapolating radiologic and cadaveric analogues to define the procedural failure rate for needle thoracostomy, results of a 2015 meta-analysis indicate a catheter of at least 6.44 cm would be required to produce a 95% success rate of reaching the pleural space in the sample ($N$ = 2,558) pooled from 18 studies

(Clemency et al., 2015). So far, clinical validation of the effectiveness of using a longer needle has been performed in a single before and after study which looked at 70 patients in the United States who were either treated with a 5 cm or an 8 cm needle by both prehospital and emergency department staff; the 8 cm needle was significantly ($p$ = .01) more effective, with 83% of patients experiencing improvement in clinical condition versus 41% of patients treated with a 5 cm needle (Aho et al., 2016). However, when the intervention groups for this study are scrutinized, it appears only 12 patients treated by prehospital practitioners received thoracostomy with an 8 cm needle, and the results were not significant ($p$ = .28) when compared against the group treated with a 5 cm needle by prehospital practitioners (Aho et al., 2016). Although the data to support the use of a longer needle when performing thoracostomy appears promising, there is still much uncertainty regarding where the benefits lay and what patient population is most at risk for treatment failure.

**Simple Thoracostomy**

The simple thoracostomy procedure for the treatment of tension pneumothorax combines the benefits of both needle and tube thoracostomy and appears to have first been reported by Deakin et al. (1995) in the prehospital setting. The simple thoracostomy is commonly referred to as the "finger thoracostomy," as it involves blunt dissection into the chest, followed by placing a finger through the thoracostomy opening to confirm placement and clear adhesions or blood (Deakin et al., 1995). The authors also found simple thoracostomy to save up to 10 minutes when compared to tube thoracostomy as it does not require chest tube insertion, suturing, and setup of a drainage system. This allows the procedure to be performed rapidly and with minimal equipment like the needle thoracostomy procedure, but also allows for definitive confirmation the pleural space has been entered via tactile feedback and a larger orifice for air to escape as in

the tube thoracostomy procedure. Furthermore, a simple thoracostomy site can later be converted to a formal tube thoracostomy by inserting a chest tube into the opening once time and resources permit. The simple thoracostomy procedure is typically limited to patients undergoing positive pressure ventilation to ensure that positive intrathoracic pressure can expel blood or air from the chest and prevent any entrainment of air from the atmosphere (Deakin et al., 1995). Perhaps fortunately, patients undergoing positive pressure ventilation are also some of the most high risk for developing tension physiology, with one study showing 68% of prehospital patients requiring thoracostomy were also ventilated (Coats et al., 1995).

Due to the small amount of published literature surrounding simple thoracostomy, it is difficult to accurately define the rates of procedural success, but one study of 55 trauma patients treated by an Italian HEMS service demonstrated no recurrent clinical or radiological signs of tension pneumothorax were found on admission to the emergency department following simple thoracostomy (Massarutti et al., 2006). However, complications may arise if the thoracostomy site does not remain patent, but a repeat finger sweep of the chest can be done rapidly to verify patency and confirm continued re-expansion of the lung (Leigh-Smith & Harris, 2005). In contrast, troubleshooting a tube or needle thoracostomy can consume valuable time and resources. Patients of larger body habitus in which subcutaneous tissue repeatedly occludes the simple thoracostomy site may benefit from the placement of a chest tube, rather than repeated finger sweeps. Anecdotally, one solution is to place an endotracheal tube into the thoracostomy as a rapid temporizing measure until arrival at hospital. This may confer the benefit from all three thoracostomy procedures as it is fast, employs readily available equipment, and can be promptly removed if re-examination of the thoracostomy site is necessary. In patients that experience a significant hemothorax, it may also control the risk of blood exposure to the

practitioner. No peer-reviewed studies addressing the use of an endotracheal tube as a temporary thoracostomy catheter were found at the time of this literature review. However, when expanding to include grey literature at the time of the original literature search, four editorial articles were retrieved which indicate this procedure has been previously employed in clinical practice. Beer et al. (2010) first described using the endotracheal tube as a temporary thoracostomy catheter in an animal model and found the endotracheal tube was faster to insert when compared to a standard chest tube. In response to this publication, a letter to the editor was published confirming the clinical use of the technique in resource-poor areas of the Philippines (Jardiolin, 2011). Finally, two further editorials described the prehospital use of the endotracheal tube as a temporary thoracostomy catheter by HEMS providers from Australia (Burns, 2015; Gluck et al., 2015). Although the novel use of the endotracheal tube as a temporary thoracostomy catheter appears promising, no studies validating this practice are available at the time of writing. Furthermore, none of the four editorials provide any reports of successfully employing this procedure, and in fact Gluck et al. (2015) provided a case report of a misplaced endotracheal tube into the subcutaneous tissue outside the thoracic cavity.

**Summary**

The predominant research method used to investigate the prehospital treatment of tension pneumothorax is retrospective analysis obtained from chart audit. One possible reason retrospective data may be so prevalent in the literature is due to the numerous challenges of implementing experimental designs in a prehospital system. Furthermore, the nature of tension pneumothorax as a life-threatening condition precludes the ability to obtain informed consent. Therefore, the use of a random sequence of subject allocation or blinding procedure would be impossible to ethically implement during patient encounters in the field.

Of the three thoracostomy procedures, the needle thoracostomy appears to have the greatest number of published failures, although this may be a result of publication bias owing to the more common use of prehospital needle thoracostomy versus tube or simple thoracostomy. There are currently no studies that have comparatively assessed the efficacy of the three methods of treating tension pneumothorax. However, both the simple and tube thoracostomy procedure confer the benefit of allowing a practitioner to definitively identify that the pleural space has been entered by placing a gloved finger into the thorax. It stands to reason that the needle thoracostomy would have greater potential for failure due to the problems related to needle length, landmarking, and site selection. Based on the study from Aho et al. (2016), needle thoracostomy using an 8 cm intravenous catheter shows promise in improving the prehospital treatment success for tension pneumothorax, but the sample size of 12 was admittedly low. The standard equipment carried by STARS aeromedical crews for performing needle thoracostomy consists of a 14-gauge 8.3 cm needle, and to the author's knowledge, at the time of writing there is no literature currently available regarding the clinical characteristics of needle thoracostomy using this type of catheter in a Canadian population.

Finally, the feasibility of using an endotracheal tube as a temporary chest tube in addition to the simple thoracostomy procedure may offer a pragmatic balance between efficacy and simplicity. Although no formal studies exist to support this practice, based on the anecdotal mentions in the literature it may already be adopted in some prehospital systems. However, despite these early indications, no articles to date have reported the successful execution of this procedure. This manuscript will hopefully serve to stimulate much-needed academic discussion surrounding this novel procedure and establish a starting point from which more robust studies will be generated.

In summary, there are gaps in the literature which include an absence of publications documenting the clinical characteristics of patients undergoing needle thoracostomy in a Canadian population served by a HEMS team. Additionally, at the time of writing, there has been no publication that has detailed the successful use of an endotracheal tube in combination with the simple thoracostomy procedure as a rescue therapy for failed NT. Therefore, both the clinical characteristics of patients who undergo NT in a Canadian HEMS setting and a case in which an endotracheal tube in combination with the simple thoracostomy procedure was utilized will be examined.

## Chapter Three: Clinical Characteristics of Patients Undergoing Needle Thoracostomy in a Canadian Helicopter Emergency Medical Service


### Abstract

Objective: Needle thoracostomy (NT) can be a life-saving procedure when used to treat tension pneumothorax. However, there is some question regarding the efficacy of NT in the prehospital setting. Failure to treat tension pneumothorax in a helicopter emergency medical service (HEMS) setting may prove especially deleterious to the patient due to gas expansion with increasing altitude. This study's objective was to identify the characteristics of patients treated with NT in a Canadian HEMS setting and the factors that may influence outcomes following NT use.

Methods: This was a retrospective chart review of prehospital records from a Canadian HEMS service. Patients aged 18 years and older who underwent at least one NT attempt using a 14-gauge 8.3 cm needle from 2012 to 2018 were identified. Charts were reviewed to collect demographic data, NT procedural characteristics, vital signs, and clinical response metrics. Descriptive statistics were used to characterize the study sample and overall event characteristics. Binary logistic regression was performed to identify variables associated with a clinical response to the initial NT treatment.

Results: 163 patients (1.3%) of 12,407 patients attended received NT. A positive clinical response to NT was recorded in 37% ($n$ = 77) of the total events ($n$ = 208), the most common of which was an improvement in blood pressure (BP) (18.8%, $n$ = 39). Initial NT was associated with a low likelihood of clinical improvement in patients presenting with blunt trauma ($OR$ = 0.18; $p$ = .021; 95% CI [.04, .77]), CPR prior to NT ($OR$ = 0.14; $p$ = .02; 95% CI [.03, .73]), or in those who received bilateral NT treatment ($OR$ = 0.13; $p$ < .01; 95% CI [.05, .37]). A pre-

treatment BP < 90 mmHg was predictive of a positive clinical response to initial NT (*OR* = 3.33; *p* = .04; 95% CI [1.09, 10.20]).

Conclusions: Only a small portion of patients in the setting of a Canadian HEMS service were treated with NT. Patients most likely to receive NT were males who had suffered blunt trauma. NT may have questionable benefit for patients presenting with blunt trauma, in cardiac arrest, or requiring bilateral NT.

*Keywords*: pneumothorax, air ambulance, thoracostomy, prehospital, needle decompression

Pneumothorax has been reported in up to 50% of patients who suffer a significant traumatic injury to the chest (Walls et al., 2018). Tension pneumothorax is a life-threatening condition that can occur when enough air accumulates within the pleural space so that it collapses the affected lung, displaces the heart and trachea, thus decreasing venous return to the heart and ultimately reducing cardiac output (American College of Surgeons Committee on Trauma, 2018). Tension pneumothorax is of particular concern during helicopter emergency medical services (HEMS) transport due to the relationship between increasing altitude and volume expansion of the pneumothorax (Knotts et al., 2013). Needle thoracostomy (NT) is commonly used in the prehospital treatment of tension pneumothorax and has been described in literature specific to the air medical environment for over 25 years (York et al., 1993). Success rates using NT in a prehospital setting vary widely in the literature, from 5% to 96% (Ball et al., 2010; Martin et al., 2012; Stevens et al., 2009).

If sufficient air or blood cannot escape through the NT, the tension pneumothorax will not be successfully decompressed, thus requiring repeat NT or an alternative treatment such as tube thoracostomy. Ongoing assessment can prove challenging in the HEMS environment where diagnostic tools are limited and patient assessment is impeded by noise, vibration, and often poor lighting. Additionally, NT success can be affected by technical challenges such as kinking of the catheter or dislodgement simply during the process of transporting the patient (Kaserer et al., 2017). However, the majority of the literature surrounding the likelihood of NT success has focused on anatomical variation in chest wall thickness and the possibility that most standard intravenous (IV) catheters used to perform the procedure would be of insufficient length to reach the pleural space (Wax & Leibowitz, 2007; Waydhas & Sauerland, 2007; Weichenthal et al., 2018; Zengerink et al., 2008). In a meta-analysis of 13 studies in which the association between

chest wall thickness and NT failure was investigated, the authors concluded IV catheters at least 6.44 cm long would be necessary to reach the pleural space in 95% of patients in the pooled sample (Clemency et al., 2015).

At the time of writing, there is no literature currently available describing the characteristics of patients undergoing NT in a Canadian HEMS setting using an IV catheter greater than 6.44 cm long. A retrospective chart review was performed of adult patients who received NT using a 14-gauge, 8.3 cm long IV catheter in a Canadian HEMS system. The aims of this study were to report the characteristics of patients treated, examine the clinical response to NT treatment, and identify variables that may influence the rate of treatment success.

**Methods**

A retrospective review of electronic medical records was conducted for patients treated with NT by air medical crews in a Canadian HEMS service during a 6-year period. This HEMS service provides rotary-wing air ambulance coverage from six bases serving the provinces of Alberta, Manitoba, and Saskatchewan. The vast referral area spans over 1 million square kilometres, encompasses more than 200 referring hospitals, and contains 18 receiving hospitals. System wide, approximately 67% of the mission volume is related to interfacility transports and the remaining 33% is for requests directly to scene. The air medical crew consists of a registered nurse and paramedic team, with dedicated physician medical control available via radio or phone. On average, there are over 2,000 patients per year cared for by these HEMS teams.

Data were abstracted from the prehospital electronic medical record using an investigator-developed standardized form for all patients who received NT over a 6-year period from November 1, 2012 through November 1, 2018. The protocol utilized by air medical crews to treat suspected tension pneumothorax stipulates that a 14-gauge, over-the-needle IV catheter

of at least 6.5 cm is employed to perform NT for adult patients who demonstrate uncorrectable hypoxia or hemodynamic instability when tension pneumothorax is suspected (Alberta Health Services, n.d.). The protocol applies to both those suffering from a traumatic injury and also those suffering from a medical illness. The recommended NT insertion site is the second intercostal space, over the third rib, in the mid-clavicular line. Alternatively, crews may also elect to perform NT in the fifth intercostal space, above the sixth rib, in the mid-axillary line. A 14-gauge, 8.3 cm over-the-needle IV catheter was stocked by this HEMS team as part of standardized equipment for use when performing NT during the study period. All patients aged 18-years and older who underwent at least one NT attempt during the care of air medical crew members were selected for inclusion in the analysis. Patients were excluded if documentation indicated treatment deviation from the pneumothorax treatment protocol, such as the use of equipment other than the standard 14-gauge, 8.3 cm IV catheter. As the patient's condition may have changed throughout treatment and transport, an attempt at NT was considered discrete if five minutes had elapsed between attempts. Data were abstracted by a single researcher who was not blinded to the study purpose during the review.

General descriptive characteristics were collected for each patient, including age, sex, weight, mission profile (scene versus interfacility), time from dispatch to patient, illness or injury type, and prehospital index score (PHI). Data were also collected for each NT event, including anatomical location, positive pressure ventilation (PPV) status, cardiopulmonary resuscitation (CPR) status, number of NTs performed, return of spontaneous circulation (ROSC), and pre/post NT vital signs. Signs of clinical improvement following NT were determined based on previous literature in addition to the standardized pneumothorax protocol used by the HEMS service, then reviewed by a panel of nine prehospital physicians for content validity (Davis et al., 2005; High

et al., 2016; Weichenthal et al., 2018). NT effectiveness was categorized as having a positive clinical response if any of the identified clinical improvement criteria (Table 1) occurred within 5 minutes of treatment. Release of blood or air from the NT catheter following placement were identified from the health record; however, this subjective measure was not included as a criterion for a positive clinical response as previous literature has shown it does not accurately reflect correct NT placement (Waydhas & Sauerland, 2007).

Descriptive statistics and multivariable analysis were used to examine the data. Absolute numbers (n) and percent (%) were used to report categorical data, means and standard deviations (SD ±) were used to report numerical data. Binary logistic regression was used to examine the relationship between a positive clinical change after initial NT and 13 variables including age, sex, weight, mechanism of injury, CPR or PPV prior to NT, bilateral NT, anatomical NT insertion site, and vital signs prior to NT (systolic BP < 90 mmHg, SpO2 < 90%, HR < 60 bpm, HR > 120 bpm). Statistical significance was defined as $p < .05$. All statistical analyses were conducted using the statistical software package, IBM SPSS Statistics (version 26.0). This study was approved by the Conjoint Health Research Ethics Board (REB# 18-1507).

**Results**

Over the six-year period, the HEMS service attended to 12,407 patients. There were 163 patients (1.3%) who received 208 discrete NT treatments for suspected tension pneumothorax. Two patients did not meet inclusion criteria and were excluded from analysis due to the use of equipment which was not the standard 14-gauge, 8.3 cm IV catheter. The study sample (Table 2) was comprised primarily of males ($n$ = 124). Patient ages ranged between 18 years and 95 years old ($M$ = 46.4 years; $SD$ ± 18.9 years). The weight of individual patients ranged between 40 kg and 150 kg ($M$ = 85.4 kg; $SD$ ± 18.9 kg). Overall, blunt trauma was the most common preceding

event (95.9%), and the mean PHI score was 16.7 (*SD* ± 4.9) for trauma patients. The majority of mission profiles were scene responses (82.6%), and the mean time from dispatch to the patient was 32 min (*SD* ± 16 min). The mean initial vital signs included: HR 111 bpm (*SD* ± 59 bpm), systolic BP 96 mmHg (*SD* ± 53 mmHg), SpO2 87% (*SD* ± 44%), and a shock index of 1.3 (*SD* ± 0.7).

Within the 161 patients included in the study, 47 repeat NT insertions were required. The characteristics of the 208 discrete NT events are illustrated in Table 3. In summary, 88.5% of events (*n* = 184) were preceded by PPV, CPR preceded 51.9% of events (*n* = 108), and half of the events (*n* = 104; 50%) were recorded as bilateral treatment with both hemithoraces treated concurrently. Of the unilateral NT events, 25.5% were performed on the right hemithorax (*n* = 53) and 24.5% were performed on the left hemithorax (*n* = 51). The insertion site for the majority of NT attempts was at the second intercostal space in the mid-clavicular line (*n* = 182; 87.5%). Of the 208 discrete NT events, a positive clinical response to NT was noted in 37% (*n* = 77). The most common positive response to NT was an improvement in BP (*n* = 39; 18.8%). There were 108 NT events performed during CPR, of which 9.3% (*n* = 10) resulted in ROSC. Among the 184 events performed during PPV, there were 29 (15.8%) where a decrease in PIP was documented.

Patients undergoing CPR before initial NT were less likely (*OR* = 0.14; *p* = .02; 95% CI [.03, .73]) to exhibit an improvement in condition compared to patients who did not receive CPR before NT (Table 4). Similarly, where bilateral NT was performed, there was a significant decrease in the likelihood of an improvement in clinical condition compared to unilateral treatment (*OR* = 0.13; *p* < .01; 95% CI [.05, .37]). When the preceding incident was blunt trauma, there was over an eight-fold decrease in the likelihood of clinical improvement (*OR* =

0.18; $p$ = .02; 95% CI [.04, .77]). Patients who presented with a systolic BP less than 90 mmHg were 3.3 times more likely to respond to NT treatment compared to patients who had a systolic BP over 90 mmHg ($OR$ = 3.33; $p$ = .04; 95% CI [1.09, 10.20]). Age, sex, weight, PPV prior to NT, anterior vs. lateral NT location, SpO2 < 90% prior to NT, and HR <60 or >120 bpm prior to NT were not statistically significant predictors of outcome in the model.

**Discussion**

This study is the largest retrospective chart review to date of NT used to treat tension pneumothorax in the setting of a Canadian HEMS service. Given the discussion in previous literature surrounding insufficient needle length as a likely cause of NT failure, this study helps to establish the clinical characteristics surrounding NT in a Canadian population where an 8.3 cm IV catheter was used. Further, in light of the potential for HEMS transport at altitude to exacerbate a tension pneumothorax, analysis was performed to determine which clinical characteristics of the study cohort were associated with successful NT treatment.

The incidence of NT, demographic characteristics of patients who received NT, and circumstances under which NT was performed in this study were consistent with what has been found in the literature. The overall use of NT was rare; only 1.3% of patients attended received NT. This is consistent with previous literature regarding NT in the prehospital and air medical environment (High et al., 2016; Kaserer et al., 2017; Weichenthal et al., 2016). The demographic characteristics of patients in this study also resemble what has been reported in previous literature, with the cohort of those receiving NT being overwhelmingly male patients in their forties who had sustained blunt trauma. The majority of NTs (82.6%) were performed during scene response missions, which is unsurprising assuming that most patients from a referral

hospital would already have some degree of differentiation of their illness and treatment implemented prior to the arrival of the HEMS team.

A 14-gauge, 8.3 cm over-the-needle IV catheter was used to treat suspected tension pneumothorax in this study sample. Longer catheters, such as this, have been reported to be more effective when treating tension pneumothorax compared to typically available IV catheters (Aho et al., 2016; Chang et al., 2014). The 8.3 cm over-the-needle IV catheter is significantly longer than those commonly available in the prehospital setting for IV access. It is also longer than the recommended 6.44 cm catheter required to successfully traverse the chest wall in 95% of the pooled sample in a previous metanalysis (Clemency et al., 2015). Of note, despite using the longer IV catheters to perform NT, there were 47 repeat NT events recorded in the study sample. One possible explanation could be that these repeated events represent a limitation of the NT procedure for ongoing chest decompression.

Even if a patient has been successfully treated with a longer IV catheter, ongoing pleural decompression is not guaranteed. Irrespective of reaching the pleural space, there are additional modes of failure to which all IV catheters are susceptible when utilized for NT. Previous research using an animal model has shown that even under ideal laboratory conditions 26% of initially successful NTs fail to adequately relieve tension pneumothorax within five minutes of placement due to mechanical failure (Martin et al., 2012). Obstruction, kinking, or dislodgement occurred despite NT being performed correctly and initially being functional. In a HEMS setting, the failure of NT could complicate patient management as increasing altitude may exacerbate tension physiology. Furthermore, noise and vibration make reassessment difficult, and the limited physical space inside a helicopter can restrict further treatment options.

Blunt trauma, cardiac arrest prior to NT, or receipt of bilateral NT were all associated with significantly decreased odds of a clinical response to NT. Patients treated with bilateral NT may have had more significant injuries requiring treatment bilaterally or may have been in cardiac arrest resulting in empiric treatment. Similarly, the low odds of clinical response for those in cardiac arrest may reflect the poor outcomes and mortality bias for patients who present in cardiac arrest, rather than an association with NT efficacy. Lastly, the association of decreased likelihood for a positive clinical response to NT in patients presenting with blunt trauma is supported by a previous systematic review in which the authors concluded that NT is often insufficient in decompressing tension pneumothorax following blunt trauma (Waydhas & Sauerland, 2007).

There are many well-described cases of survival from traumatic cardiac arrest due to the prehospital treatment of tension pneumothorax (Mistry et al., 2009; Warner et al., 2008). Given that the sensitivity and specificity of clinical exam for tension pneumothorax is problematic during CPR, air medical teams may elect to simultaneously decompress both hemithoraces in the setting of traumatic cardiac arrest. This may explain why the study results include nearly an equal number of bilateral NT events ($n$ = 104) and events in which CPR was performed prior to NT ($n$ = 108). However, of the patients undergoing CPR at the time of NT, 10 events resulted in ROSC. Unfortunately, survival to discharge information was unavailable for these events, so it remains unclear what role NT played in overall mortality rates.

A significant diagnostic dilemma for prehospital practitioners is the lack of reliable assessment tools to determine when the patient has a pneumothorax. The use of point-of-care ultrasound to detect pneumothorax in the air medical environment has been suggested as having promise, but widespread adoption and validation of this testing modality have yet to occur

(Quick et al., 2016). One of the clinical characteristics commonly used in the literature as confirmation of tension pneumothorax has been the release of air or blood when NT is performed (Davis et al., 2005; High et al., 2016; Peters et al., 2017). However, false-positive results have been described from accidentally entering the lung or an area of subcutaneous emphysema, while false-negative results can occur from failure to enter the pleural space or mechanical obstruction of the catheter (Fitzgerald et al., 2008). Additionally, the noise in a HEMS environment makes listening for a release of air difficult at best. This study utilized quantifiable clinical characteristics to denote NT success, which may align more closely with patient-oriented outcomes. It was found that despite a 48.6% reported incidence of air or blood released during NT, there was only a 37% rate of positive clinical response.

Patients in this study who had a systolic BP less than 90 mmHg before NT were the most likely to demonstrate a positive response. This association may suggest not only that those patients in which there was hemodynamic compromise were more likely to benefit from NT, but also indirectly reveal mortality bias as only those with a measurable BP would have been included in this portion of the analysis.

**Limitations**

There are certain limitations to undertaking a retrospective health record audit. The findings must be interpreted with some caution to ensure that the association between clinical characteristics is not mistaken for causation. Furthermore, as this was a prehospital study, we did not have confirmation that all patients undergoing NT initially had tension pneumothorax. Previous studies have cited that 18% to 26% of prehospital patients treated with NT who survived to hospital admission were eventually found to have no evidence of pneumothorax during their initial imaging (Blaivas, 2010; Kaserer et al., 2017). Unfortunately, until diagnostic

tools such as ultrasound are more commonplace in prehospital care, this will be a reality for most prehospital care practitioners.

Due to the complexities of resuscitation, it would be impossible to know if a positive response resulted from NT or an additional intervention within the 5 minutes following NT. While the positive response criteria for this study were based on prior literature and expert opinion, there is currently no universally agreed-upon clinical criteria to denote a positive response to NT. Finally, while the authors strived to ensure that the positive response criteria were based on quantitative data rather than subjective provider judgement, an element of error may have been introduced by practitioners as they input data into the electronic health record.

**Conclusion**

This study revealed that only a small portion of patients in the setting of a Canadian HEMS service were treated with NT. Furthermore, of the NT events recorded, only 37% may have resulted in a benefit for the patient. Although regression modelling provided variables associated with clinical response to NT in the study cohort, it is unclear if these may be representative of the broader population and how prehospital practitioners could integrate this knowledge into practice.

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Table 1

*Clinical Improvement Criteria*

- BP increase ≥ 90 mmHg or an increase by ≥ 20 mmHg if BP < 90 mmHg
- HR increase by ≥ 10 bpm if initially ≤ 60 bpm
- HR decrease by ≥ 10 bpm if initially ≥ 120 bpm
- $SpO_2$ increase by ≥ 10 %
- ROSC
- Decreased peak inspiratory pressure

*Note*. BP = systolic blood pressure; HR = heart rate; bpm = beats per minute; $SpO_2$ = peripheral capillary oxygen saturation; ROSC = return of spontaneous circulation.

Table 2

*Individual Characteristics of Patients Undergoing NT*

| Variable | | *N* = 161 |
|---|---|---|
| Age, yrs | 46.4 | *SD* ± 18.9 |
| Sex, male | 124 | 77.0% |
| Weight, kg | 85.4 | *SD* ± 18.9 |
| PHI[a] | 16.7 | *SD* ± 4.8 |
| Time to patient, min | 32 | *SD* ± 16 |
| Mission profile | | |
| Interfacility | 28 | 17.4% |
| Scene | 133 | 82.6% |
| Mechanism of injury/illness | | |
| Blunt trauma | 139 | 86.3% |
| Penetrating trauma | 6 | 3.7% |
| Medical | 16 | 9.9% |
| Initial vital signs[b] | | |
| HR, bpm | 111 | *SD* ± 59 |
| BP, mmHg | 96 | *SD* ± 53 |
| SpO2, % | 87 | *SD* ± 44 |
| Shock index | 1.3 | *SD* ± 0.7 |

*Note*. PHI = prehospital index score; *SD* = standard deviation; NT = needle thoracostomy; BP = systolic blood pressure; $SpO_2$ = peripheral capillary oxygen saturation; HR = heart rate; bpm = beats per minute. Data reported as frequency with percentage, or mean with *SD*.
[a]PHI score calculated for trauma patients only (*n* = 145). [b]Patients not presenting with cardiac arrest (*n* = 83).

Table 3

*Overall NT Event Characteristics*

| Variable | | *N* = 208 |
|---|---|---|
| NT events | | |
| Repeated x1 | 34 | 16.4% |
| Repeated x2 | 9 | 4.3% |
| Repeated x3 | 2 | 1.0% |
| Repeated x4 | 1 | 0.5% |
| Repeated x5 | 1 | 0.5% |
| PPV prior to NT | | |
| Yes | 184 | 88.5% |
| No | 24 | 11.5% |
| CPR prior to NT | | |
| Yes | 108 | 51.9% |
| No | 100 | 48.1% |
| Hemithorax treated | | |
| Right | 53 | 25.5% |
| Left | 51 | 24.5% |
| Bilateral | 104 | 50% |
| NT location | | |
| Anterior | 182 | 87.5% |
| Lateral | 26 | 12.5% |
| NT response | | |
| Yes | 77 | 37.0% |
| No | 131 | 63.0% |
| Response type[a] | | |
| HR improved | 28 | 13.5% |
| $SpO_2$ improved | 19 | 9.1% |
| BP improved | 39 | 18.8% |
| ROSC[b] | 10 | 9.3% |
| PIP decreased[c] | 29 | 15.8% |
| Air or blood released | 101 | 48.6% |

*Note*. NT = needle thoracostomy; PPV = positive pressure ventilation; CPR = cardiopulmonary resuscitation; HR = heart rate; $SpO_2$ = peripheral capillary oxygen saturation; BP = systolic blood pressure; ROSC = return of spontaneous circulation; PIP = peak inspiratory pressure. Data reported as frequency with percentage.

[a]More than one positive response type may have occurred per NT event. [b]For events undergoing CPR at time of NT (*n* = 108). [c]For events undergoing PPV at time of NT (*n* = 184).

Table 4

*Predictors of Clinical Improvement Following Initial NT*

| Variable | *p* | *OR* | 95% CI |
|---|---|---|---|
| Age (yrs) | .94 | 1.00 | [.98, 1.02] |
| Sex (female) | .54 | 1.39 | [.48, 4.01] |
| Weight (kg) | .97 | 1.00 | [.98, 1.02] |
| Blunt trauma | .02 | .18 | [.04, .77] |
| Penetrating trauma | .13 | .12 | [.01, 1.88] |
| CPR prior to NT | .02 | .14 | [.03, .73] |
| PPV prior to NT | .68 | 1.31 | [.36, 4.81] |
| Bilateral NT | < .01 | .13 | [.05, .37] |
| NT Location (lateral) | .40 | 2.05 | [.39, 10.90] |
| Pre BP < 90 mmHg | .04 | 3.33 | [1.09, 10.20] |
| Pre SpO2 < 90 % | .90 | 1.08 | [.33, 3.52] |
| Pre HR < 60 bpm | .94 | .94 | [.16, 5.51] |
| Pre HR > 120 bpm | .45 | 1.59 | [.48, 5.28] |

*Note*. OR = odds ratio; CI = confidence interval; CPR = cardiopulmonary resuscitation; NT = needle thoracostomy; PPV = positive pressure ventilation; BP = systolic blood pressure; $SpO_2$ = peripheral capillary oxygen saturation; HR = heart rate; bpm = beats per minute.
The logistic regression model constructed to analyze initial NT events was statistically significant, $\chi^2(13, N = 161) = 72.082$, $p < .001$. The model explained 49.1% (Nagelkerke $R^2$) of the variance in NT response and correctly classified 80.1% of cases.

## Chapter Four: Transition Chapter

The case study in chapter five was conducted to document a novel treatment used by a HEMS team to overcome the failure of traditional NT in a prehospital setting. The purpose of including both the retrospective chart review and case study in this thesis was to identify the population treated with NT by a Canadian HEMS service, clarify the treatment success rate, and describe a novel example of how treatment failure may be overcome. In the publication process of the case study, some of the academic details were excluded in exchange for brevity in the journal article. Those elements have been included in this chapter.

### Methods

#### *Design*

Stake (2005) was one of the first authors to characterize case study into three main types: intrinsic, instrumental, and collective. The term instrumental case study describes when a particular case is used as a backdrop to illuminate a greater issue. An instrumental case study was performed based on a single patient encounter to document the successful use of a simple thoracostomy in combination with an endotracheal tube as a temporizing measure in response to NT failure in a HEMS setting. The intent was to provide a detailed account of the novel treatment used and to illuminate the issue of how HEMS providers may need to adapt practice to overcome failure of the NT procedure in a resource-limited setting. To the author's knowledge at the time of publication, no literature existed to describe the successful execution of this procedure in the prehospital setting.

#### *Participants and Recruitment*

A request for an interview with the practitioner who was responsible for performing the procedure was made via e-mail. The interview was conducted at a time and place mutually

agreed upon by the interviewer and participant. The investigator informed the participant of the intended purpose for the study, offered the use of a pseudonym, and ensured the participant was aware that responses would be later be validated using member checking. The participant was reminded that participation was voluntary with no remuneration.

### *Ethics*

Participation in the study, by responding to the invite for interview, was voluntary and the details of the case were anonymized. The study was reviewed and approved by the Conjoint Health Research Ethics Board at the University of Calgary (REB18-1507). The study was also reviewed and approved by the medical director of STARS research division. The research was conducted, and informed consent to participate was documented (Appendix D), in accordance with the Tri-Council Policy Statement (TCPS2) guidelines for the ethical conduct of research involving humans (Canadian Institutes of Health Research et al., 2018).

### *Data Collection*

Data were collected via a semi-structured interview with the practitioner responsible for performing the novel treatment described in the case study. The interview was audio-recorded and transcribed verbatim for analysis. The interview was guided by the questions included in Appendix E. In addition, the de-identified electronic patient care record for the patient who underwent the procedure was reviewed to triangulate data obtained from the interview and obtain an accurate timeline for the events during the case study.

### *Data Analysis*

Data analysis was conducted following principles described by Merriam (2009), namely that data analysis is conducted in conjunction with data collection and the coding of data into categories. The interview was transcribed and coding was performed to identify important

comments throughout the interview which provided context for the case and contributed to the subsequent outcome for the patient. These data were further analyzed into clusters and were then tentatively named as themes. To conclude the analysis, the themes were checked against criteria set forth by Merriam (2009) which stipulates themes must be sensitive, exhaustive, mutually exclusive, and conceptually congruent. Following completion of the thematic analysis of the interview, the validity of the results was reinforced through the use of triangulation, member checking, and providing rich descriptions (Merriam, 2009). To ensure consistency, triangulation was performed between the interview data and documentation in the electronic patient care record. Member checking was performed by providing the interviewee with a copy of the transcribed and coded interview to confirm the investigator's interpretations were congruent with the original intent of the participant. Finally, constructing a rich and concise description of the case allows future readers of the published case study to determine the extent to which their situations may match the research context, and therefore if findings are transferrable.

## Results

The overall results of the case study have been published and are included in the following chapter. However, thematic analysis of the interview data resulted in four themes that contributed to the outcome of the case and helped focus the published case study. The four themes noted were: responding/adapting, anticipating, environment, and uniqueness. These four themes were integrated into the written account of the case, but not directly described, in keeping with the word count requirements of the journal and to ensure a concise case study.

### *Responding/Adapting*

The theme of responding or adapting was noted to be important to how the practitioners were required to prioritize and solve problems differently during the case in the context of

HEMS operations. Early on in the interview, the comment "*you're super stressed but super excited at the same time*" was noted to give insight into how prehospital practitioners personally experience physiological adaptions and responses, perhaps even prior to reaching the patient. Further, when during the case it was identified that an airway intervention was required despite multiple competing treatment concerns, the team responded with temporizing measures which allowed them to keep focused on high value and time-dependent interventions: "*We tried to stabilize the exsanguinating open fracture on the left arm by just kind of internally rotating and put it by her side and strap that kind of around herself.*"

Finally, the case was noted to be bounded by adapting to the resources available, as the practitioners were required to change their practice in a prehospital setting as opposed to a traditional setting where equipment and staff are plentiful:

> *So then the nurse said "we don't have anything, all we have is endotracheal tubes." Well, that's the next best thing that we can think of. It's an open tube, holes on both sides, that should at least splint the chest wall open enough so that we can keep providing positive pressure [ventilation].*

The team clearly understood that they would need to adapt a piece of equipment that was readily available if they wanted to approximate a chest tube and chose to use an endotracheal tube of similar size.

***Anticipating***

The theme of anticipating was noted to contribute to the overall outcome of the case and highlighted the importance of publishing the case study so that others may use it to anticipate the needs of patients cared for under similar circumstances. Comments such as "*I don't know what to expect, I don't know who's there, what we have,*" and *"we didn't know anything,*" highlighted

how important it was to the success of the case for the team to prepare for a worst-case scenario before reaching the patient and to be prepared to be self-sufficient in terms of equipment. The space and weight limitations of HEMS operations necessitate that not all equipment available in a hospital setting can be brought to the patient. Multipurposing equipment, such as an endotracheal tube as a temporary chest tube, allows HEMS teams to reduce duplication of equipment and weight.

***Environment***

One of the primary determinants of the case study was the environment in which it occurred. The environment was noted to provide context for the events leading to tension pneumothorax in a high velocity blunt traumatic injury:

> *…there was a 55-year-old female motorcyclist who lost control kind of going around the corner. She laid her bike down and went in pretty fast, going right into the guardrails where it hit her arm, her chest, and sliced her face open*.

The environment also bounded the physical location of the case as a factor contributing to why the novel treatment could be transferable to other prehospital settings and may even be preferred under austere conditions:

> *I had more of an appreciation for what the prehospital setting has to go through because of the austere conditions that they actually work in and not having all the equipment that they need, or I think that they can provide in the perfect place and time.*

What made the novel treatment possible in this environment appeared to be a combination of limited equipment and the conditions that tempered the expectation of standard practice when placing a chest tube.

### *Uniqueness*

One of the last factors bounding the case was that the practitioner recognized that there was limited precedent for using an endotracheal tube as a temporary chest tube and the novel procedure was "*going to be used off label for a different indication,*" and "*nothing really exists to say that this is an acceptable procedure.*" Addressing these limitations in the case study provided a richer description of the case and allowed readers to use caution when considering the implications of the results for their practice setting. However, the case study also added to the body of literature that suggests a failure of the NT procedure itself is not unique and requires consideration in the undifferentiated hypotensive trauma patient. The practitioner stated that they "*realized that there was decreased air entry bilaterally and it just didn't seem like that [NT] worked at all*" and "*we know that there's a miss rate on that [NT] as far as below 50%.*". The standard of care in the prehospital setting continues to be the use of NT, even when practitioners recognize that failure is commonplace.

## Conclusion

The case study in the following chapter is the culmination of the qualitative investigation just described. Limitations due to the concise nature of case report publications, and the target journal requirements, necessitated the inclusion of the research methodology in a separate chapter in order to offer a comprehensive understanding of the case study.

## Chapter Five: Thoracic Endotracheal Tube Insertion During Prehospital Thoracostomy: A Case Report


### Abstract

This case highlights the novel use of endotracheal tubes to maintain patency of simple thoracostomies (ST) performed to relieve tension pneumothorax after failed needle thoracostomy (NT). Treatment of tension pneumothorax in the prehospital setting is typically performed using NT due to the minimal equipment required and rapid application. However, the variable efficacy of NT has led to a rise in the use of ST as an alternative procedure to treat tension pneumothorax. A potential complication of ST is the occlusion of the thoracostomy site, which left unresolved, may lead to the reoccurrence of tension physiology. In a resource-rich setting, such as in a hospital, the ST would be followed by tube thoracostomy (TT) to ensure patency. Unfortunately, this may not be feasible in prehospital environments where constraints exist due to time, equipment, and personnel. A review of the literature surrounding prehospital ST reveals previous reports of endotracheal tubes being used to maintain patency temporarily. However, no cases documenting the successful use of this novel procedure in an air medical setting were found at the time of writing. This case documents the successful utilization of this novel procedure during the treatment of a poly-traumatized adult female resulting from a motorcycle crash.



*Keywords*: pneumothorax, air ambulance, HEMS, thoracostomy, prehospital

The successful treatment of tension pneumothorax using needle thoracostomy (NT) ranges widely from 5% to 96% (Ball et al., 2010; Martin et al., 2012; Stevens et al., 2009). This variability can be especially deleterious during air medical transport where ongoing patient assessment or treatment may be limited and increasing altitude can lead to further expansion of an unresolved pneumothorax. Ideally, the treatment of tension pneumothorax should be effective and definitive, such as when performing a tube thoracostomy (TT). However, this may be impractical and time-consuming in a prehospital setting. Alternatively, a simple thoracostomy (ST) is performed by making a small incision at the 5th intercostal space in the mid-axillary line, followed by blunt dissection and digital decompression through the pleura. This procedure was first described by Deakin, Davies and Wilson, who suggested it as a pragmatic alternative to TT in the prehospital setting (Deakin et al., 1995). Due to the open communication via the chest wall, the procedure necessitates that patients are receiving positive pressure ventilation to ensure air is not entrained back into the chest through the thoracostomy. A previous series of 55 trauma patients treated with ST by helicopter emergency medical (HEMS) crews demonstrated no cases of recurrent tension pneumothorax, despite deferring placement of a chest tube until arrival at the emergency department (Massarutti et al., 2006). Nonetheless, Waydhas and Sauerland (2007) recommended monitoring patients for spontaneous closure of the ST in their subsequent systematic review of prehospital pleural decompression techniques. The following case report highlights the potential for spontaneous closure of the ST and features the novel use of an endotracheal tube as an improvised thoracostomy tube to remedy this problem.

**Case Report**

We report the case of a 55-year-old female who sustained multiple injuries as a result of a motorcycle crash. She reportedly lost control of her motorcycle while navigating a bend in the

road and was ejected off the motorcycle and into the guard rail. A companion with whom she was travelling witnessed the crash and immediately called 911. Due to the remote location, the companion needed to leave the scene to obtain cellular coverage. Emergency Medical Services (EMS) was notified approximately 18 minutes after the crash and immediately requested HEMS support to the scene. A HEMS team consisting of two pilots, a registered nurse, a paramedic, and a physician were immediately dispatched to the scene. In the meantime, EMS arrived and began to treat the injured rider while two off-duty physicians who were passing the scene stopped and lent assistance. Due to the remote location, HEMS rendezvoused with EMS 44 minutes after the initial call for help.

Before HEMS arrival, the EMS crew had already implemented spinal motion restrictions, obtained both intraosseous (IO) and intravenous vascular (IV) access, and administered a 0.5 mg/kg dose of ketamine IV along with 1 L of normal saline. The off-duty physicians had attempted NT twice on each side of the chest and were attempting to assist ventilation. The HEMS team rapidly examined the patient, noting that she was unconscious with a Glasgow Coma Scale (GCS) of 4 and her pupils were unequal in size. She had sustained significant head and facial trauma including a comminuted fracture of her mandible, a large laceration extending from the corner of the mouth to nearly the tragus of the ear, and her teeth were displaced into the mouth. A leak caused by the large facial laceration complicated Bag Valve Mask (BVM) ventilation. Examination of the chest revealed decreased breath sounds bilaterally along with a large laceration at the axilla through which intercostal muscles were visible. Her abdomen was unremarkable and the pelvis was stable. There were open long bone fractures of the right humerus and left tibia/fibula. Her initial vital signs were a pulse of 136 beats per minute, blood pressure 96/66 mmHg, shock index 1.4, BVM assisted respiratory rate of 16 breaths per minute,

oxygen saturation (SpO2) 84%, blood glucose 7 mmol/L, and a temperature of 36 degrees Celsius.

The HEMS team rapidly intubated the patient following standard procedure. During intubation, blood was suctioned from the oropharynx and multiple teeth retrieved from the upper airway. Following intubation, her SpO2 improved marginally to 88% on 100% oxygen, and the decision was made to perform bilateral ST. Despite the four prior NT attempts, an immediate return of air was observed along with initial drainage of approximately 500 mL of blood when the left chest was decompressed. The SpO2 transiently increased to 93%, however soon after it decreased to 89%. The HEMS team realized that despite positive pressure ventilation, patency of the thoracostomies was being compromised due to a combination of swelling and the patient's body habitus. They inserted size 6.5 and 7.0 endotracheal tubes into the thoracostomies to maintain patency. Following this, the SpO2 increased to 97%, where it remained for the duration of care. The patient was transferred to the helicopter for transport to tertiary care 29 minutes after HEMS had arrived at the scene. In flight, the remainder of the patient's prehospital treatment included administration of 1 gram of tranexamic acid, two units of packed red blood cells, 225 mL of 3% hypertonic saline, and two push doses of epinephrine, 25 mcg and 20 mcg, respectively.

**Discussion**

Tension pneumothorax is a life-threatening condition that has been estimated to occur in 1% to 3% of prehospital, major trauma and ICU patients (Roberts et al., 2015). Despite treatment failure rates that have been reported to exceed 80%, NT remains the standard of care for treatment of tension pneumothorax in many prehospital services (Kaserer et al., 2017). This case report emphasizes not only the importance of anticipating treatment failure of NT but also the

infrequently discussed potential for ST to occlude. The most recent Advanced Trauma Life Support course from the American College of Surgeons provides guidance for ST as an alternative treatment in the setting of failed NT (American College of Surgeons Committee on Trauma, 2018). Even when performed correctly, the NT has multiple failure modes such as insufficient catheter length to traverse the thickness of the chest wall, kinking of the catheter, occlusion by blood or tissue, and dislodgement during patient movement. In this case, the patient failed to have a tension pneumothorax effectively decompressed after multiple NT attempts. The HEMS team anticipated NT treatment failure and promptly moved to perform ST in response. However, in contrast to NT, the failure modes for ST have not been well documented in the literature. As evidenced by this case report, there is a potential for failure of ST which may have resulted in patient harm if not recognized and addressed promptly.

In contrast to the NT procedure, performing ST permits the ability to check for continued lung re-expansion and patency of the thoracostomy site by re-inserting a finger through the thoracostomy (Leigh-Smith & Harris, 2005). Nevertheless, in this case, the HEMS team discovered that the overriding tissue would occlude the thoracostomy site without ongoing intervention. In anticipation of the reduced access to the patient once in the helicopter and to free the team to address further management priorities, the decision was made to place endotracheal tubes through both thoracostomy sites to ensure ongoing patency. The endotracheal tubes were left in place for the remainder of the prehospital phase of care and were then changed to standard chest tubes once the patient had been stabilized in the receiving emergency department.

The novel use of endotracheal tubes as a temporary replacement for chest tubes has been previously studied using a sheep model. The experimental procedure included the standard approach to performing ST with the notable omission of placing a finger into the chest cavity and

instead adding the use of a 14 Fr intubating bougie as a guide to insert the endotracheal tube into the thorax (Beer et al., 2010). In this instance, the authors found that the use of an endotracheal tube proved to be as effective as a standard chest tube when draining both air and blood, and resulted in quicker insertion times.

In our case, the HEMS team performed a standard ST with a finger sweep to clear any adhesions and confirm the correct placement of the thoracostomy site before inserting the endotracheal tube. However, placing an endotracheal tube guided by a bougie into the intercostal space could minimize the risk of injury to the practitioner from fractured rib edges. A secondary benefit would be the elimination of redundancy by using equipment readily available in most prehospital medical kits, rather than a specialty item that comes in lengthy packaging such as a traditional chest tube. Our case report highlights how the HEMS team adapted the procedure using the equipment available to perform the ST and inserted endotracheal tubes which are otherwise readily available for the purpose of airway management.

While the patient in this case report was successfully treated and transported to definitive care, the risks of substituting endotracheal tubes for traditional chest tubes are largely unknown. For patients undergoing prehospital chest tube insertion, findings from a systematic review showed complication rates ranging from 5.4 to 21% (Waydhas & Sauerland, 2007). This may include iatrogenic injury, tube malposition, insufficient drainage, or infection. Additionally, during review of the literature a case review was noted which described the unsuccessful execution of ST with endotracheal tube insertion. Gluck, Ellis and Pearce described a case in which the prehospital use of an endotracheal tube as a temporary chest tube led to migration or misplacement of the tube and subsequently caused a delay in management (Gluck et al., 2015). Despite the potential benefits of the novel use of endotracheal tubes as temporary chest tubes, it

should be noted that complication rates are still unknown and may not correlate with previous literature on the traditional use of prehospital chest tubes. Until more research is available to guide practice, close monitoring is necessary if practitioners elect to insert intercostal endotracheal tubes to maintain patency after ST in the prehospital setting. Practitioners should resort to using endotracheal tubes only if traditional tube thoracostomy is impractical and ST alone is insufficient to relieve tension pneumothorax.

**Summary**

This unusual case emphasizes the potential for NT to unsuccessfully relieve tension pneumothorax and features the temporary use of bilateral endotracheal tubes to maintain patency of the ST subsequently performed. At the time of writing, the authors were unable to locate any reports in the literature of endotracheal tubes being successfully used in combination with ST in the prehospital setting. The procedure has, however, been previously described in both animals and unsuccessfully in humans. Our case report may demonstrate the first documented successful case of this novel response to NT failure.

Prehospital practitioners must be mindful of the potential for NT to either inadequately or only temporarily treat tension pneumothorax. Significant morbidity and mortality could have occurred in this case without the recognition of NT failure and the implementation of a successful alternate technique to relieve the tension pneumothorax. Practitioners performing NT should maintain a high suspicion for tension pneumothorax in the context of the undifferentiated trauma patient, despite appropriately performed NT. Practitioners performing ST should be cognizant of the potential for the thoracostomy to spontaneously occlude, even in the setting of positive pressure ventilation. Insertion of an endotracheal tube to prevent the overriding

subcutaneous tissue from occluding the thoracostomy was used successfully in this case, but further research is necessary before any recommendations about practice are made.

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## Chapter Six: Conclusions and Future Directions

The principal intention of this thesis was to explore and document the prehospital treatment of tension pneumothorax in a Canadian HEMS context. Three methodologies were utilized to accomplish this:

1. A review of the current literature;
2. A retrospective chart review of NT utilization in a Canadian HEMS service;
3. A case study of a novel therapy employed during HEMS retrieval of a patient with tension pneumothorax refractory to standard treatment.

This final chapter provides a summary of findings, strengths and limitations, implications for clinical practice and education, and suggestions for future research.

### Summary of Findings

The findings from the literature review emphasized several areas key to the prehospital treatment of tension pneumothorax. Three thoracostomy procedures were described in the literature for the prehospital treatment of tension pneumothorax: NT, simple thoracostomy, and tube thoracostomy. Of the three procedures, NT had the greatest body of literature describing its widespread use, but also had the greatest number of failures which ranged from 5% to 96% (Aho et al., 2016; Ball et al., 2010; Eckstein & Suyehara, 1998). The prehospital use of simple and tube thoracostomy appeared in a minority of publications and was primarily described in advanced prehospital systems such as HEMS and prehospital critical care teams (Chesters et al., 2015; Deakin et al., 1995; High et al., 2016; Massarutti et al., 2006; Waydhas & Sauerland, 2007). Various hypotheses were suggested to explain the wide variation in failure rates of the NT procedure such as kinking of the catheter, insufficient catheter length, and blockage of the catheter with blood or tissue. At the time of writing this thesis, there was no literature available

to describe the characteristics of patients undergoing NT in the Canadian HEMS setting. Nevertheless, it is clear from the literature review that prehospital practitioners have been searching for alternative treatments to NT for nearly 30 years (York et al., 1993).

The utilization of NT in the HEMS system studied occurred in 1.3% of all patient encounters. This aligned with previous efforts to define the overall incidence of tension pneumothorax at between 1% to 3% (Roberts et al., 2015). Historically, one of the primary causes for NT failure implicated in the literature has been the use of standard intravenous catheters which have insufficient length to penetrate the pleural space (Clemency et al., 2015). In the HEMS system studied, the limitation of catheter length in relation to chest wall thickness was addressed by utilizing a long 14-gauge, 8.3 cm catheter. Despite this, a positive clinical response to NT treatment in the retrospective chart review was observed in just 37% of all NT events. Intuitively, longer catheters would offer a greater chance of reaching the pleural space, but when examining needle length as it relates to patient-oriented outcomes the authors of recent literature found that there was no statistically significant decrease in mortality between standard and long intravenous catheters (Aho et al., 2016; Weichenthal et al., 2018). Unfortunately, patient survival data were not available for the retrospective chart review conducted. Nevertheless, the results from the retrospective chart review demonstrated a low likelihood of clinical improvement associated with initial NT treatment in patients who received bilateral decompression, presented with blunt trauma, or in whom CPR was performed prior to NT. The only variable predictive of a positive clinical response to NT in the retrospective chart review was a pretreatment blood pressure of < 90 mmHg.

Although the wide-ranging efficacy of NT has been well documented, it remains controversial what the optimal solution for tension pneumothorax treatment should be in a

prehospital setting. The simple thoracostomy procedure has become the predominant alternative to NT described in the literature but it is not without complications. In the case study, the treating practitioner identified that large body habitus and chest wall injuries of the patient played a role in the failure of both NT and simple thoracostomy. In this case, the novel use of an endotracheal tube as a temporary replacement for a chest tube contributed to the successful resuscitation of the patient and safe transfer to definitive care. Though it appears that the case study is the first reported successful use of this procedure, the mere fact that a now equal number of unsuccessful reports exist would indicate both that this practice is being actively explored in some regions but also that further research is still necessary (Gluck et al., 2015).

**Strengths and Limitations**

While every attempt has been made to ensure the rigour and validity of the research performed for this thesis, there are specific strengths and limitations worth noting. While a comprehensive literature review was conducted, the possibility exists that not all the relevant literature was retrieved for analysis. Moreover, publication bias is a well-known phenomenon where studies with nonsignificant results never end up reaching publication (Woo, 2019). This may introduce bias when examining the current state of the literature which exists surrounding the various procedures for treating tension pneumothorax and their associated success rates.

The strengths and limitations of using a retrospective chart review to examine the characteristics of patients undergoing NT also need to be understood. Compared to a prospective study design, the retrospective chart review allowed leveraging of existing data to explore a treatment that occurs with an overall low frequency in the population served by the HEMS service. While every effort was made to regulate the methodology surrounding data collection, such as employing a standardized data abstraction tool (Appendix C), additional improvements

in standardizing the reporting of results could have been made through the use of a reporting framework such as the RECORD guidelines (Benchimol et al., 2015).

Unfortunately, the very nature of tension pneumothorax requires swift intervention, thus making it both ethically and logistically challenging to study prospectively. A convenience sample and lack of a control group for confounding variables limits the ability to separate factors that may be causative versus factors simply associated with NT success or failure. Additionally, due to tension pneumothorax primarily being diagnosed clinically in the prehospital setting, it is unclear whether all the patients who underwent NT had pathology in the first place. However, the results of the chart review still provide an introductory look at the utilization of NT in a Canadian HEMS setting and identify the characteristics of the population in which it is being used.

While NT may be a lifesaving procedure when successful, the variable efficacy rates have already spurred some prehospital systems to adopt simple thoracostomy as the standard of care (High et al., 2016). Notwithstanding the ability of simple thoracostomy to overcome many of the limitations of the NT procedure, the case report served to demonstrate that simple thoracostomy may also fail in some circumstances. In this case, the use of an endotracheal tube as a temporary chest tube provides anecdotal evidence that this novel procedure can be used successfully. Even so, the transferability of this procedure to other practice settings or patients remains largely unknown.

**Implications for Clinical Practice and Education**

Critically reflecting on the literature review and findings from the studies performed in this thesis leads to the following implications in the context of the current state of prehospital treatment for tension pneumothorax.

Current literature, including systematic review and meta-analysis, suggests that an intravenous catheter longer than 5 cm should be the standard when performing NT (Clemency et al., 2015; Laan et al., 2016). However, the mediocre results of the retrospective chart review demonstrate that there are likely still unidentified variables that play a role in the overall clinical response for patients undergoing NT. The dogmatic approach of applying research conducted in a hospital environment to clinical practice in the prehospital setting has been previously identified as a major challenge to improving prehospital care (Bigham & Welsford, 2015). A number of the studies in which the authors promote the use of longer intravenous catheters as the solution to low NT efficacy rates have been performed from retrospective review of radiologic data to identify chest wall thickness in the population (Akoglu et al., 2013; Clemency et al., 2015; Inaba et al., 2012; Laan et al., 2016; Schroeder et al., 2013; Wax & Leibowitz, 2007). It stands to reason that if an intravenous catheter of insufficient length to reach the pleural space is used for NT the chance of success is essentially zero. However, simply using a longer catheter does not address the myriad of alternate ways in which the NT procedure may fail, or the sheer physics of trying to move a sufficient volume of air through a relatively small tube quickly enough to be clinically relevant during resuscitation.

Despite NT continuing to be taught as the standard of care in the prehospital context, the variable effectiveness makes it an unreliable method to decompress a tension pneumothorax. In practice, this means that the clinical results of performing NT should be interpreted with caution. The treatment could fail to produce clinical improvement because it was ineffective, because the patient is unsalvageable, or because the source of the patients' instability may not in fact be tension physiology. The result may be a patient with an untreated tension pneumothorax or a practitioner distracted by a suboptimal treatment. One potential solution is the more widespread

use of prehospital diagnostic tools, such as ultrasound, which could be used to increase the certainty that a pneumothorax exists in otherwise undifferentiated patients (Quick et al., 2016; Richards et al., 2017). Until then, education efforts should focus on ensuring the NT procedure is given appropriate consideration with respect to its efficacy, that practitioners clearly understand the clinical indications for its use in both spontaneously breathing and ventilated patients, and that practitioners are also aware multiple NT attempts may be necessary for the patient in which a high suspicion of tension pneumothorax exists.

Although the use of an endotracheal tube as a temporary chest tube was executed successfully in the case study, there is currently is no strong evidence to recommend this practice. The future may hold promise for this procedure, but more information is needed to better understand the risks and benefits when utilizing a piece of medical equipment in a way that it was not designed for. The literature review revealed that this procedure has been attempted in other areas of the world before, but it remains unclear what the patient outcomes were, and if the practice is acceptable or simply an option of last resort in resource deplete settings (Burns, 2015; Jardiolin, 2011). A notable counter-argument for this prehospital practice is that having a tube in situ prevents confirming that the lung has re-expanded by inserting a finger into the chest should the clinical condition of the patient change, thus leading to treatment delays (Gluck et al., 2015). The publication of the case study will hopefully encourage others with more experience using this procedure to add their findings to the body of literature surrounding this procedure.

**Suggestions for Future Research**

One of the ongoing challenges with prehospital research is that it is very difficult to standardize treatment groups, interventions, and apply appropriate blinding in this setting. These problems are compounded further when seeking to study phenomena with low rates of

occurrence, such as the treatment of tension pneumothorax. If retrospective chart review remains the most pragmatic way to study the treatment of tension pneumothorax, it may be useful to perform a subgroup analysis of those with a pre-treatment BP < 90 mmHg. This was the only positive predictor of NT success in the retrospective chart review conducted for this thesis and may provide further insight into which clinical variables could lead to improved patient-oriented outcomes.

While the clinical benefit of using an endotracheal tube as a temporary chest tube remains anecdotal, it does warrant further investigation. As the simple thoracostomy procedure gains recognition in the prehospital setting it would be prudent to research the complication rates resulting from occlusion to identify if there is a sufficient ongoing need for utilizing an endotracheal tube as a temporary chest tube. Ideally, this step could be avoided altogether, thus limiting transport time delays and potential complications related to tube placement.

**Conclusion**

The vast Canadian geography and dispersed population have given rise to a disparity in healthcare for those living outside large urban centers. This is a multifaceted problem that extends far beyond the purview of HEMS teams. These teams are one solution for improving timely access to critical care in underserved rural populations; however, the treatment of tension pneumothorax accounts for only a small proportion of their work. The retrospective chart review helps identify the patients most likely to benefit from treatment with NT in the HEMS service studied but also highlights the need to explore alternative treatments which may prove more effective. Furthermore, the case study provides initial confirmation that simple thoracostomy in combination with an endotracheal tube as a temporary chest tube is feasible in the HEMS setting and can successfully be used to overcome failure due to occlusion.

Prior to this thesis work, no literature existed describing the incidence and outcomes for patients treated with NT by a HEMS team in a Canadian population. Further research is required to better understand the barriers to treatment success when utilizing NT, but this initial research appears to correspond with existing prehospital literature worldwide which details an overall low frequency of prehospital treatment for tension pneumothorax and a wide-ranging NT success rate.

Evidence-based practice has become synonymous with quality in health care and should be the principal goal in prehospital systems. Unfortunately, studying interventions for tension pneumothorax in an emergent setting will continue to prove both ethically and logistically challenging, especially in the prehospital environment. The results from this thesis add to the body of literature worldwide that describes overall poor success rates for patients treated for tension pneumothorax using NT in the prehospital setting. However, the results may also be useful for Canadian HEMS programs to better understand the ramifications of using NT as the standard of care and the estimated incidence for tension pneumothorax when determining whether to make a practice change.

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# Appendix C: Data Abstraction Tool

| | | | | | | | Pre-procedure Vital Signs | | | Post-procedure Vital Signs | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Event # | Sex (female=1/male=0) | Age (years) | Estimated weight (kg) | Time from lift-off to reach patient (min) | Prehospital Index score (0-20, if trauma) | # of NT performed | HR (/min) | Systolic BP (mmHg) | SpO2 (%) | HR (/min) | Systolic BP (mmHg) | SpO2 (%) | Positive clinical response following NT (no=0/yes=1) | Mechanism of injury/illness (medical=0/trauma=1) | Trauma category (blunt=0/penetrating=1) | Positive pressure ventilated prior to NT (no=0/yes=1) | CPR prior to NT (no=0/yes=1) | Mission profile (interfacility=0/scene=1) | Bilateral NT during care (no=0/yes=1) | Repeat NT event during care (no=0/yes=1) |
| E16A001234 | 1 | 36 | 74 | 42 | 4 | 2 | 131 | 64 | 80 | 105 | 92 | 92 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 0 |
| | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | |

# Appendix D: Consent Form

**Informed Consent Form**

**TITLE:** Clinical Appraisal of Needle Thoracostomy in a Canadian Aeromedical System.
**STUDY SPONSOR:** University of Calgary, Faculty of Nursing
**PRINCIPAL INVESTIGATOR:** Catherine Laing
**STUDENT RESEARCHER:** Graham Newton
**SUPERVISORS:** Catherine Laing & Gudrun Reay

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This consent form is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, please ask. Take the time to read this carefully and to understand any accompanying information. You will receive a copy of this form for your records.

**BACKGROUND:**
Pneumothorax, an accumulation of air within the pleural space, has been reported in up to 50% of patients who suffer a significant traumatic injury to the chest. Left untreated, the condition can lead to tension pneumothorax, a life-threatening problem which occurs if enough air accumulates within the chest. Currently, the recommended immediate treatment for tension pneumothorax is to insert an intravenous catheter needle into the anterior chest allowing the release of accumulated air. A recent retrospective analysis performed on patients who underwent the needle thoracostomy procedure showed an unacceptably low treatment success rate of 18%. The simple thoracostomy procedure has been described in the prehospital environment as an alternative treatment for relief of tension pneumothorax which is not subject to the same limitations as a needle thoracostomy. However, despite the improved overall success rate of simple thoracostomy to treat tension pneumothorax there is on occasion a re-accumulation of air due to the occlusion of the thoracostomy site. The introduction of an endotracheal tube through the thoracostomy site has been suggested in the literature as one method to maintain patency, but to the authors knowledge at the time of writing the successful use of this technique has not yet been published.

**WHAT IS THE PURPOSE OF THE STUDY?**
The focus of the qualitative component of this project is to document the novel use of successful endotracheal tube placement into a thoracostomy site as a temporizing measure to relieve tension pneumothorax in the prehospital air medical environment. This research is being conducted as part of

the thesis requirements for the Master of Nursing program at the University of Calgary and will be submitted for publication.

**WHAT WOULD I HAVE TO DO?**

- The method of data collection for this study will be an individual interview. The interview will be a one-on-one semi-structured interaction between an investigator and a participant who knows something about the topic of interest. You will be asked some questions about your particular experience.
- Participation in the study will include an interview that will last around 60 minutes. Your participation is voluntary.
- You do not have to answer any questions you do not wish to answer, and you may terminate the interview at any time.
- The interview will be audiotaped to make an accurate record of what is said during the interview and tapes will be later transcribed.

**WHAT ARE THE RISKS?**

There are no physical risks and limited anticipated emotional risks if you chose to participate. However, you may find talking about your experiences to be upsetting. You will not have to answer any question that makes you feel uncomfortable or that you find upsetting.

**WILL I BENEFIT IF I TAKE PART?**

There is no compensation for participating in this study. However, your participation will be a valuable addition to the research and findings could help improve the treatment of tension pneumothorax in the field.

**DO I HAVE TO PARTICIPATE?**

Your decision to participate in the study is voluntary. You may refuse to participate or you may withdraw from the study at any time. The data collected in the interview will be deleted if you chose to withdraw from the study. However, data cannot be withdrawn if it has already been published or otherwise disseminated.

**WILL MY RECORDS BE KEPT PRIVATE?**

Your participation in the interview process will be treated confidentially. Your name will not be attached to any audio-recording of the interview, nor to any transcriptions of the interview. You will have the chance to choose a pseudonym for yourself, otherwise one will be chosen for you. It will be this pseudonym that will be referred to in any of the subsequent reports. Please note that all efforts will be made to provide anonymity, however anonymity cannot be guaranteed. Recordings of the interview will be kept for five years after the completion of the study, as stipulated by the University of Calgary Conjoint Health Research Ethics Board. Only the student researcher and the faculty supervisors will have access to the interview recording and the transcript made of the interview.

The pseudonym I suggest for myself is:

_____

**Signatures (written consent)**
Your signature on this form indicates that you have understood to your satisfaction the information regarding your participation in the research project and agree to participate as a participant. In no way does this waive your legal rights nor release the investigators or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time without jeopardizing your health care (or education or employment as relevant). If you have further questions concerning matters related to this research, please contact:

Dr. Catherine Laing (403) 210-6135

If you have any questions concerning your rights as a possible participant in this research, please contact the Chair, Conjoint Health Research Ethics Board, University of Calgary at 403-220-7990.

| | |
|---|---|
| Participant's Name | Signature and Date |
| Investigator/Delegate's Name | Signature and Date |
| Witness' Name | Signature and Date |

The University of Calgary Conjoint Health Research Ethics Board has approved this research study.

A signed copy of this consent form has been given to you to keep for your records and reference.

## Appendix E: Semi-Structured Interview Questions

The following questions will be used to guide the interview. The interviewer will use discretion as to how the questions are asked, and if the questions will be used. The questions and the wording chosen will depend upon the answers received. The interviewer will ask subsequent questions for elaboration on answers.

1. Please tell me about your professional background as a healthcare provider.
2. With regards to the case under discussion, can you describe the setting?
3. How is this setting different from your typical workplace?
4. What happened that day (timeline of events)?
5. Can you describe what the problem was (if applicable)?
6. How did you know what to do?
7. What is your opinion on NT as a treatment for tension pneumothorax (pro/con)?
8. Have you previously experienced any difficulty or complications with the NT procedure?
9. What is your response to failed NT in your typical practice setting?
10. Had you previously heard of the use of an endotracheal tube in conjunction with the simple thoracostomy?
11. Did you feel that the use of an endotracheal tube was of benefit in this situation? Why or why not?
12. Were there any complications as a result of the use of the endotracheal tube? Can you think of any potential complications?
13. What do you think are the limitations of this procedure?
14. What could be done moving forward to address the issue of NT failure in the HEMS setting?
15. Did this case affect your practice? If yes, how so?
16. What could be done to prevent the problem in the future?
17. What could be done to minimize the impact of the problem if it occurs in the future?