"A-OK": CHEST RADIOGRAPH DURING PRIMARY SURVEY FACILITATES
FASTER, MORE ACCURATE ENDOTRACHEAL TUBE POSITION IN INJURED
CHILDREN

BY

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TABLE OF CONTENTS

List of Illustrations and Tables

Figure I. Bedside posters placed in trauma bays at initiation of A-OK. Project.

Figure IIA. Flowchart of patient inclusion criteria and endotracheal tube (ETT) outcomes with respect to use of Broselow recommendations to confirm ETT placement**.**

Figure IIB. Flowchart of patient inclusion criteria and ETT outcomes with respect to assessment of breath sounds to confirm ETT placement.

Table I. Baseline Characteristics between A-OK cases and Pre-A-OK Controls

Table II. Outcome Comparison between Pre-A-OK Controls & Post-A-OK Cases

List of Abbreviations

ACS, American College of Surgeons
ACSCOT, American College of Surgeons, Committee on Trauma
AIS, Abbreviated Injury Scale
ATC, Adult Trauma Center
ATC-AQ, Adult Trauma Center with pediatric qualifications
ATLS, Advanced Trauma Life Support
BCH, Brenner Children's Hospital
CXR, Chest radiograph
ED, Emergency Department
Etc, Etcetera
ETCO2, End Tidal Carbon Dioxide
ETI, Endotracheal intubation
ETT, Endotracheal Tube
ISS, Injury Severity Score
Kg, Kilogram
LI, Level One
LII, Level Two
LIII, Level Three
LIV, Level Four
LV, Level Five
NSCOT, National Study on the Costs and Outcomes of Trauma
PTC, Pediatric Trauma Center
RSI, Rapid Sequence Intubation
TC, Trauma Center

Abstract

Purpose: The Advanced Trauma Life Support (ATLS) algorithm typically postpones radiographic confirmation of endotracheal tube (ETT) placement until the end of the secondary survey. Correct ETT depth is critical in pediatric trauma. We hypothesized that bedside confirmatory techniques are inaccurate and that early chest x-ray (CXR) would overcome such inaccuracies, allowing for faster intervention of malpositioned ETTs.

Methods: An "A-OK" algorithm of immediate CXR following intubation in injured children <16 years was implemented. Eligible patients the years prior to and after implementation were identified. The accuracy of bedside confirmatory techniques (auscultation of bilateral breath sounds and use of length-based depths) were assessed. Post-A-OK patients were compared to pre-A-OK controls for baseline characteristics, ETT depth accuracy, time to CXR, and time to intervention for malpositioned ETTs.

Results: Twenty-eight A-OK cases and 23 pre-A-OK controls were identified. The groups did not differ in age, weight, race, gender or mechanism of trauma. Bedside confirmatory techniques were accurate in only 61% (length-based depth) and 58% (auscultation of breath sounds) of patients. Time to first CXR and to ETT repositioning (required in 50% of A-OK cases and 44% of controls) were significantly shorter in post-A-OK cases than pre-A-OK controls (15.0 +/- 10.1 min vs. 25.7 +/- 14.9 min, p<0.01 and 21.1+/-11.8 min vs 35.2+/-15.9 min, p=0.03 respectively). Post-A-OK patients did not have delays in other life-saving interventions related to earlier CXR.

Conclusions: Bedside confirmatory techniques to determine ETT positioning are inaccurate in children. Inclusion of CXR in the primary survey is safe and allows for more rapid repositioning of malpositioned ETTs.

Chapter 1: Introduction

Literature Review

Injury is the leading cause of death and disability among children in the United States. The most recent Center for Disease Control Childhood Injury Report attributed 62% of deaths among those 1-19 years to intentional and unintentional injuries [1]. In 2010, injury accounted for 13,819 deaths among those 0-19 years of age. In 2012, unintentional injury remained the leading cause of death among those 1-19 years of age and the 5th leading cause of death among those <1 year of age. Meanwhile, homicide was ranked the 4th leading cause of death among those 1-14 years of age and the 3rd leading cause of death among those 15-19 years of age [2].

Non-fatal injuries also impart a large health burden upon United States. 8,768,800 such injuries were reported among those 0-19 years of age in the United States in 2013 [3]. Children with survivable injuries may suffer physical and cognitive disabilities [4,5]. Such children often require inpatient rehabilitation, though many never achieve their baseline functional status. The true burden and medical costs of such injuries in the US are unknown as the ability to fully quantify disability is limited.

Death and disability as a result of traumatic injury can be reduced by prompt and appropriate management. Traumatic deaths are classically described as occurring within one of three time peaks. The first peak, accounting for almost half of all traumatic deaths occurs within seconds to minutes of the injury. The second peak, accounting for approximately 30% of deaths occurs within a few hours of the injury. The final peak,

which accounts for the remaining 20% of deaths takes place within several weeks of the injury [6,7].

Traumatic deaths occurring within the first time peak are typically due to severe brain or high spinal cord injuries that preclude one's ability to breathe independently or due to rupture of the heart, aorta or other large blood vessels. These devastating injuries induce death almost instantaneously and are thus unlikely to be influenced by programs that increase the speed and quality with which trauma care is delivered. Thus, most trauma care improvement programs are directed at decreasing the number of deaths occurring during the second and third time peaks. Theoretically, such programs will also reduce subsequent disability associated with injuries, as prompt and appropriate treatment can reduce the incidence of secondary insults caused by hypovolemia, hypoxia and hypothermia [8–10].

Management of the trauma patient is complex, as they may present with multiple injuries and physiologic derangements. To assist with the initial management of the complex trauma patient, the Advanced Trauma Life Support (ATLS) algorithm was conceived in the late 1970s. This algorithm revolutionized trauma care and has become the international standard for the initial evaluation and management of the trauma patient. The ATLS algorithm manages life-threatening conditions in a systematic way. It prioritizes physical evaluation and management of a patient's airway, breathing and circulation as part of the primary survey. The secondary survey involves a head to toe physical examination, followed by attainment of radiographic films. The ATLS algorithm also guides front line clinicians with respect to the need for and timing of inter-facility patient transfer.[7]. To understand the need for and process of inter-facility transfer, one must understand the United States trauma system as a whole.

Since there early 1990s, there has been an effort towards organizing the United States into a series of regionalized trauma systems [11]. A trauma system is an organized group of facilities, services and persons that together ensure all injured persons in a given geographic area receive appropriate treatment [11,12]. Within a trauma system are numerous definitive care centers, or Trauma Centers (TCs) as well as numerous facilities without advanced trauma capabilities but with established processes to transfer severely injured patients to TCs in a timely manner.

TCs are accredited by the American College of Surgeons (ACS) or by state-level verification bodies. TCs may have differing capabilities to treat severely-injured patients and as such are designated as level I (LI), level II (LII), level III (LIII), level IV (LIV) or level V (LV) TCs [13,14]. State requirements for verification vary from state to state but are similar to ACS verification requirements. To become an ACS verified LI TC, a facility must employ acute care surgeons and designate that at least one such surgeon remain in-house 24 hours per day. Such facilities must also employ trauma-accredited nursing staff as well as subspecialists (including neurosurgeons and orthopedic surgeons) that are immediately available 24 hours per day. In addition, these facilities must house designated trauma operating rooms, CT scanners, surgical critical care units, blood bank operations and tertiary care equipment/staff with capabilities for such things as cardiac surgery, hemodialysis and microvascular surgery. Finally, such facilities must serve leadership roles in their communities with respect to trauma education and the provision of resources [11,14,15]. LII TCs have many of the same requirements as LI TCs but may lack the ability to provide certain tertiary care services. Furthermore, LII TCs are also not responsible for providing leadership and trauma education and resources to the

surrounding communities [11,14,15].   LIII, LIV and LV TCs are not considered major

trauma centers. Such facilities have differing requirements but all are required to have

basic emergency department facilities to initiate ATLS protocols as well as transfer

agreements with local LI or LII TCs [11,14,15].

It has been clearly demonstrated that for seriously injured patients, treatment at

designated LI and LII TCs leads to improved outcomes. The National Study on the Costs

and Outcomes of Trauma (NSCOT) was a landmark study that identified a 25% reduction

in mortality for severely injured patients who received care at Level I or II TCs rather

than non-TCs [16]. Another study of motor vehicle crash occupants in Massachusetts

identified a 62% decreased fatality rate among seriously injured occupants who received

immediate care at a TC [17]. This has been supported by multiple additional studies [18–

20].

Pediatric TCs (PTCs) evolved due to important physiologic and anatomic

differences between children and adults. PTCs can be verified as level I (LI PTC) or

level II PTCs (LII PTC) by the ACS. Some states also make special verifications for LI

ATCs with additional qualifications to treat children (LI ATCs-AQ). Though

discrepancies in the data exist, a growing body of evidence points to the fact that

seriously injured children may have better outcomes at PTCs and LI ATCs-AQ vs non-

pediatric TCs [21–25]. However, because the number of injured children in the United

States exceeds the capacity of PTCs to care for such children, many children are treated

at non-pediatric TCs [21,26].

One responsibility of a LI TC includes trauma education[15]. That is, such TCs

should provide education and resources for lower tier TCs and non-trauma facilities,

particularly with respect to ATLS processes, skills and guidelines. Thus, when traumatic injuries occur in areas far from TCs, first responders and local facilities can use ATLS algorithms to perform life-saving interventions and stabilization of a severely injured trauma patient while simultaneously arranging for transportation to an appropriate TC for definitive management[11,27]. Thus, patients should get the same initial quality of care and treatment no matter where their injury occurs.

As such, the ATLS algorithm and skills are taught in hands-on courses throughout the world to physicians responsible for the care of trauma patients, mostly through the efforts of LI TCs. LI TCs are supported in this effort by the ACS Committee on Trauma (ACSCOT) [28].

Use of the systematic ATLS approach has been shown to significantly improve outcomes among seriously-injured trauma patients [28,29]. For example in 1992, Messick and co-authors evaluated 12,417 trauma related deaths in North Carolina. Authors evaluated the relationship between per capita mortality rate and a number of factors hypothesized to contribute to such this rate. Of these, the most significant and only modifiable predictor of trauma-related mortality was the use of ATLS protocol within a region [30].

Van Olden and co-authors used a prospective cohort study to evaluate patient outcomes before and after implementation of an ATLS course at two teaching community hospitals. Before implementation of ATLS, 1-hour mortality among severely injured trauma patients was 24.2% while after implementation of ATLS, 1 hour mortality among similarly-injured trauma patients was reduced to 0.0% (p=0.02). Though the difference in overall mortality did not reach statistical significance, mortality rate among pre-ATLS

group was 48.4% vs 30.0% in post-ATLS group. The lack of statistical significance could represent type II error, given a relatively small sample size (31 pre-ATLS patients and 32 post-ATLS patients) [28].

The success of the ATLS algorithm can be attributed to its systematic prioritization of the assessment and management of the greatest threats to life above all else. Thus, the primary survey, which encompasses the very first portion of the algorithm, addresses the three key elements critical to maintain life: a patent airway, adequate breathing and ventilation, and adequate circulation (cardiac function, blood volume, etc.). This primary survey prioritizes establishment of a patent airway above all else. Patients with airway compromise will typically require definitive airway management, which is advantageous for several reasons. Definitive airway management allow for airway protection, improved oxygenation and ventilation, a provisional route for drug administration access for removal of foreign bodies, tracheal suctioning to remove blood and other debris from the airway and the ability to sense changes in lung compliance [31]. The current standard for pre-hospital and emergency definitive airway management is endotracheal intubation (ETI) with use of an endotracheal tube (ETT).

To assist with ETI, paralytics are often used. The use of paralytics in combination with sedatives to allow for intubation is termed Rapid Sequence Intubation (RSI). Use of RSI eliminates several barriers to intubation, including patient combativeness and masseter muscle spasm [31]. RSI can also decrease the risk of aspiration and improve patient comfort [32]. However, paralytics remove the ability of a person to breathe independently, thus increasing the risk to the patient if the ETT is misplaced [31,32]. ETTs can be misplaced into the esophagus, into the hypopharynx or into one of the main-

stem bronchi instead of the trachea. All forms of misplacements can lead to multiple complications.

Placement of an ETT into the esophagus instead of the trachea is extremely dangerous as this precludes appropriate oxygenation and ventilation of the lungs. Without oxygenation and ventilation, a patient with an unrecognized esophageal intubation will quickly deteriorate, especially if paralytics have been used to prevent the patient's spontaneous respiratory drive. Silvestri and colleagues report that of 13 unrecognized esophageal intubations in their study, 9 (69%) patients died and 2 (15%) were discharged with severe neurologic impairment [33]. However, even when recognized, the complications of an esophageal intubation can be catastrophic. Timmermann et al. demonstrated a 70% mortality rate among 10 patients with recognized and remedied esophageal intubations.   This compared to a 10% mortality rate among patients with initial successful tracheal intubations in the same study [34]. Conversely, Sakles and colleagues reported that only 8 of 33 (24.4%) patients with recognized esophageal intubations suffered complications. These complications included desaturations, vomiting and hypotension. Only one such patient's misplaced tube was associated with cardiac arrest (3%) [35]. The disparity in reported rates of the morbidity and mortality associated with esophageal intubations may be related the length of time before which inadvertent esophageal intubations were recognized in these studies, though neither study divulges this information. Nonetheless, these studies indicate that esophageal intubations, both recognized and unrecognized can lead to otherwise avoidable morbidity and mortality among already complex patients.

As previously mentioned, ETTs can also be misplaced with respect to their depth of insertion. Placement of an ETT into the hypopharynx occurs as a result of shallow ETT placement, or failure to advance the tube to the appropriate depth. Such incorrect placement increases the risk of aspiration and of accidental dislodgement and subsequent extubation [36,37]. Inadvertent extubation, especially during transport or during the acute resuscitation phase can be disastrous.

Placement of an ETT into one of the main-stem bronchi indicates ETT placement that is too deep. Main-stem intubation often results in hyperinflation of the ventilated lung and atelectasis (airway collapse) in the non-ventilated lung [34,38]. Single-lung hyperinflation can lead to pulmonary edema or pneumothorax on this side [34,39]. Meanwhile, the opposite lung is failing to oxygenate or ventilate. Such conditions lead to inadequate oxygenation and ventilation and may result in significant morbidity [34,38,39].

Non-tracheal intubations (including esophageal, hypopharyngeal and bronchial) occur at relatively high rates. Sakles et al reports that of 610 intubations in an urban university hospital's emergency department, the esophagus was inadvertently intubated 33 times (5.4% of intubations) and a main-stem bronchus was intubated 18 times (3.0% of intubations) [35]. Silvestri reports inadvertent esophageal intubations in 8.5% (13 of 153) of intubated patients. [33]. Timmerman demonstrates esophageal intubation rates of 6.7% and a bronchial intubation rate of 10.7% in a population of 149 patients undergoing intubation by emergency department physicians [34]. Katz reports an inadvertent esophageal intubation rate of 16.7% and an inadvertent hypopharyngeal intubation rate of 8.3% [40]. Though these percentages vary from study to study, the

take-away point is clear: non-tracheal intubations are not uncommon. Given the potential

for subsequent morbidity and mortality of such misplaced tubes, techniques to confirm

appropriate tube placement are essential.

ATLS protocol suggests laryngoscopy, end tidal carbon dioxide ($ETCO_2$)

detection, capnography and physical examination, including auscultation of bilateral

breath sounds, to confirm initial placement of an ETT into the airway as opposed to the

esophagus [27]. $ETCO_2$ detection requires placing a device at the end of the ETT that

changes color when carbon dioxide is detected. Capnography also detects the carbon

dioxide produced in a person's lungs and documents the levels of carbon dioxide exhaled

during ventilation.

Use of $ETCO_2$ detection devices and capnography are considered the most

reliable bedside techniques for confirming a tube's position in the airway. Silvestri

reported that use of $ETCO_2$ detection devices in the field by paramedics significantly

reduced the odds of an unrecognized esophageal intubations from 23% to 0% [33].

Takeda and colleagues evaluated 150 attempts at tracheal intubation at an urban

university hospital over a 1 year period. Within this period, 13 esophageal intubations

occurred. They evaluated use of $ETCO_2$ detection and auscultation of bilateral breath

sounds to detect esophageal intubations. Auscultation of breath sounds missed 1 of the

13 esophageal intubations and thus had a specificity of only 92.3% while the $ETCO_2$

detection device correctly identified all 13 esophageal intubations, with a specificity of

100% [41]. However, this study like many other single-institution studies regarding

$ETCO_2$ detection devices for use in the confirmation of airway intubation is limited by its

small sample size. For this reason, these $ETCO_2$ detection techniques were evaluated

further in a large meta-analysis. Search criteria included studies of $ETCO_2$ detection

devices and capnography in the emergency setting that reported the numbers of tracheal

and esophageal intubations, both recognized and unrecognized. Ten studies met these

criteria, producing 2,192 patients. False-negative failure rate of $ETCO_2$ detection devices

and capnography in this population (where the tube was in the trachea but capnography

reported an esophageal intubation) was 7%. The false-positive rate of $ETCO_2$ detection

devices and capnography (where the tube was in the esophagus but capnography reported

a tracheal intubation) was 3%. Thus, capnography cannot be used as the sole method to

determine correct placement of an ETT into the airway as opposed to the esophagus [42].

However, even the use of multiple confirmatory techniques can fail to recognize a

non-tracheal intubation. Bair and colleagues report on 1643 patients intubated in a

prehospital setting in which 35 (2%) of such patients underwent inadvertent esophageal

intubations that went unrecognized until the patient was received by the Emergency

Department. Of these 35 patients with unrecognized esophageal intubations, 60% of the

patients had undergone endotracheal placement confirmation with multiple techniques,

including laryngoscopy, auscultation of breath sounds and use of $ETCO_2$ devices [43].

To confirm correct depth of ETT placement (tracheal vs pharyngeal or bronchial),

ATLS protocol again suggests auscultation of bilateral breath sounds, as well as insertion

of the tube to a pre-specified depth [27]. ATLS protocol also posits that a CXR can be

obtained as an adjunct to these techniques during the primary survey but this is rarely

performed. However, just as bedside techniques suggested by ATLS to confirm the

placement of an ETT into the airway as opposed to the esophagus are not completely

accurate, the bedside techniques to ensure tracheal as opposed to pharyngeal or bronchial

intubations lack accuracy as well. Variations in patient anatomy may make standard depth recommendations inaccurate and auscultation of equal breath sounds is a very subjective physical exam finding, subject to error [27,34]. Likewise, unilateral aspiration or pneumothorax can lead to unilaterally diminished lung sounds, suggesting a bronchial intubation when the ETT is actually in the tracheal [34].

Despite the difficulty of endotracheal intubation and confirmation in adults, such techniques are even more challenging in children. The soft tissues in the oropharynx of a child (tongue and tonsils) are relatively large compared to the soft tissues in the oral cavity and are also highly compliant, making them susceptible to edema [44]. Additionally, a child's larynx is more cephalad and anterior in the neck and the vocal cords have a greater anteriocaudal angle [27,44]. These factors often make visualization of the trachea more difficult in a child compared with an adult.

A second factor that complicates intubation in a child is that a child's trachea has a shorter length and a smaller diameter than an adult's trachea. Additionally, the length and diameter of a child's trachea can vary immensely depending on the child's developmental stage. Thus, children require not only varying depths of ETT insertion but also require varying endotracheal tube sizes. ETTs come in a variety of lengths and widths and are also available as cuffed or un-cuffed tubes. Thus, multiple choices regarding tube length, width, cuff-presence and depth of placement must be made. During the acute treatment of an injured child, a speedy method to estimate the size and depth of ETT insertion is needed. Short tracheal length increases the likelihood of main-stem intubation or accidental tube dislodgement and thus these estimates are crucial [7].

Broselow tape is the most commonly used tool to assist with estimation of ETT

sizing and depth [45]. Most estimates in pediatrics are based upon a child's weight.

However, it is often impractical to weigh a child in the emergency setting. Broselow tape

is a color-coded measuring tool that can be placed beside a child on the resuscitation

table. The tape divides children into categories based on length. Each length category

corresponds to an estimated weight range and also to a color. Each color corresponds to

the appropriate sized equipment to use for that child (including ETT size and depth) as

well as to appropriate doses of key resuscitation drugs [45–49].

Broselow Tape was originally validated for use in pediatric resuscitation in the

late 1980s [45]. Since that time, Broselow Tape has been called into question regarding

its accuracy, particularly with drug dosing. The idea that length corresponds to weight is

intuitive but given the growing obesity trend in the United States, many have questioned

whether the length-to-weight conversions created decades ago need to be restructured. A

subsequent evaluation of the accuracy of Broselow Tape in predicting actual weights

among 7,500 children from suburban elementary schools and an urban pediatric clinic

demonstrated that this tape was inaccurate in approximately one third of children [48].

The tendency of the Broselow Tape to underestimate a child's actual weight has been

confirmed in several other studies [47,49]. Despite such demonstrated inadequacies in

Broselow Tape, it remains the most widely used tool in the United States to estimate

equipment sizing and drug dosing in the acute setting.

Given the increased difficulty of intubation in a child and the various options for

tube depth and size, it is not surprising that ETT placement is often inaccurate in

children. Gausche and colleagues evaluated 186 pediatric patients in whom ETI was

12

believed to be successful by paramedics. Upon ETT assessment in the emergency department, 3 (2%) such children were ultimately found to have an esophageal intubation and 33 (18%) were found to have a main-stem intubation [50]. Furthermore, in this same study, 12 (6%) children suffered unrecognized tube dislodgement en route to the ED, 15 (8%) experienced recognized tube dislodgement and 44 (24%) were intubated with a tube of the wrong size [50]. Other studies of pediatric patients report inadvertent esophageal intubation rates ranging from 1.8% to 2.9% and bronchial intubation rates ranging from 9.5% to 12.6% [51,52].

Chest radiograph (CXR) remains the gold standard to confirm proper depth of endotracheal tubes in adults and children [36,53]. However, in the field CXR is not readily available. Once the patient arrives in the ED, even if a patient is already intubated, ATLS protocol starts from the beginning. The primary survey is repeated and is followed by a secondary survey, which includes a head-to-toe examination. Though radiographic confirmation of ETT position can be obtained during the primary survey, it is considered an adjunct and is postponed until after the secondary survey [27]. The length of the time of the primary and secondary survey depends on the condition of the patient and the available resources at the hospital. Thus, definitive confirmation of appropriate ETT depth with a CXR can be delayed for an extended period of time.

Quality Improvement Project

At our Level I Pediatric Trauma Center, we often receive pediatric trauma patients who have undergone definitive airway management prior to arrival at our institution through the placement of an ETT. The impetus for this project stemmed from a critical patient at our institution. This pediatric trauma patient arrived in our

Emergency Department (ED) with an ETT in place. This particular ETT had been inadvertently placed into the right main-stem bronchus. However, the patient also had a pneumothorax on the right side. Thus, breath sounds upon auscultation were equal. The ATLS protocol continued and it was not until later that the dangerous situation was identified and remedied.

We hypothesized that the bedside confirmation techniques of appropriate ETT depth were inaccurate, particularly auscultation of bilateral breath sounds and Broselow recommendations for ETT depth. We then hypothesized that performing an early CXR, as part of the airway assessment in the primary survey, would overcome the inaccuracies of bedside confirmation and allow faster intervention for ETTs inserted to inappropriate depths.

Specific Aims

Aim One: Determine the accuracy of bedside techniques for determining appropriate ETT depth

- **Sub-Aim 1**: Evaluate correspondence of Broselow recommendations with appropriate ETT depth on CXR

- **Sub-Aim 2**: Evaluate correspondence of auscultation of bilateral breath sounds with appropriate ETT depth on CXR

Aim Two: Evaluate the safety and effectiveness of confirming ETT positioning with CXR during the primary survey

- **Sub-Aim 1**: Evaluate for delays in the management of other key elements of the primary survey due to attainment of CXR as part of "airway"

confirmation (including – establishment of IV access, treatment of life-threatening circulatory conditions)

- **Sub-Aim 2**: Identify any unforeseen consequences or barriers to CXR during the primary survey

- **Sub-Aim 3**: Evaluate for reductions in time to first CXR after implementation of early CXR and for reductions in time to remedy of malpositioned ETTs after implementation of early CXR.

Chapter 2: Manuscript

Background

Injury is the leading cause of death and disability among children in the United States[1,2]. The death and disability resulting from traumatic injury can be reduced by prompt and appropriate treatment of life-threatening injuries. Given the complexities of the trauma patient, who often presents with multiple injuries and physiologic derangements, the Advanced Trauma Life Support (ATLS) algorithm was conceived in the 1970s to direct the initial care of trauma patients in a systematic way [27]. Use of the systematic ATLS approach has been shown to significantly improve outcomes among seriously injured trauma patients [28–30]. The success of this algorithm can be attributed to its systematic prioritization of the assessment and management of the greatest threats to life above all else. It prioritizes physical evaluation and management of a patient's airway, breathing and circulation as part of the primary survey. This is followed by a secondary survey, which involves a head to toe physical examination. Radiographic films may be obtained as adjuncts to the primary survey but are typically postponed until after completion of the primary and secondary surveys[27].

The ATLS algorithm prioritizes establishment of a patent airway above all else. The current standard for definitive airway management in the emergency setting is endotracheal intubation (ETI) with use of an endotracheal tube (ETT). Appropriate ETT placement is essential to ensure proper control of one's airway. ETTs can be misplaced into the esophagus, into the hypopharynx or into one of the main-stem bronchi instead of the trachea, all of which can have negative consequences on a patient's condition and outcome[33–35,38,39]. Bedside confirmatory techniques have been described to

16

evaluate for appropriate ETT placement but chest x-ray (CXR) remains the gold standard to ensure proper ETT positioning [36,53]. While ATLS protocol does state that CXR may be obtained as an adjunct to the primary survey, this is usually not done and attainment of CXR is typically delayed until after completion of the primary and secondary surveys. The time required to complete the primary and secondary surveys depends on the condition of the patient and the available resources at the hospital. Thus, definitive confirmation of appropriate ETT placement with a CXR can be delayed for an extended period of time.

Previous work has demonstrated that many of the bedside techniques suggested by the ATLS algorithm for assessing ETT placement during the primary survey are inaccurate in the adult population [33,34,42,43]. Of particular challenge in children is placing the ETT to the correct depth, for which ATLS protocol suggests use of standard length-based recommendations (Broselow tape) and auscultation of bilateral breath sounds. Broselow tape is the most commonly used tool to assist with pediatric resuscitation medication dosing and with the sizing medical devices, including ETT size and depth [45]. However, recent studies have revealed that many of the dosing recommendations suggested by Broselow tape are inaccurate [47–49]. To the authors' knowledge, no prior studies have evaluated the accuracy of Broselow's recommendations with respect to appropriate ETT depth. Given the inaccuracies of other bedside confirmatory techniques for assessing ETT depth in adults and given the dubious accuracy of Broselow dosing recommendations, we hypothesized that use of Broselow recommendations and other bedside confirmatory techniques are inaccurate to ensure appropriate ETT depth in children. We further hypothesized that the utilization of CXR
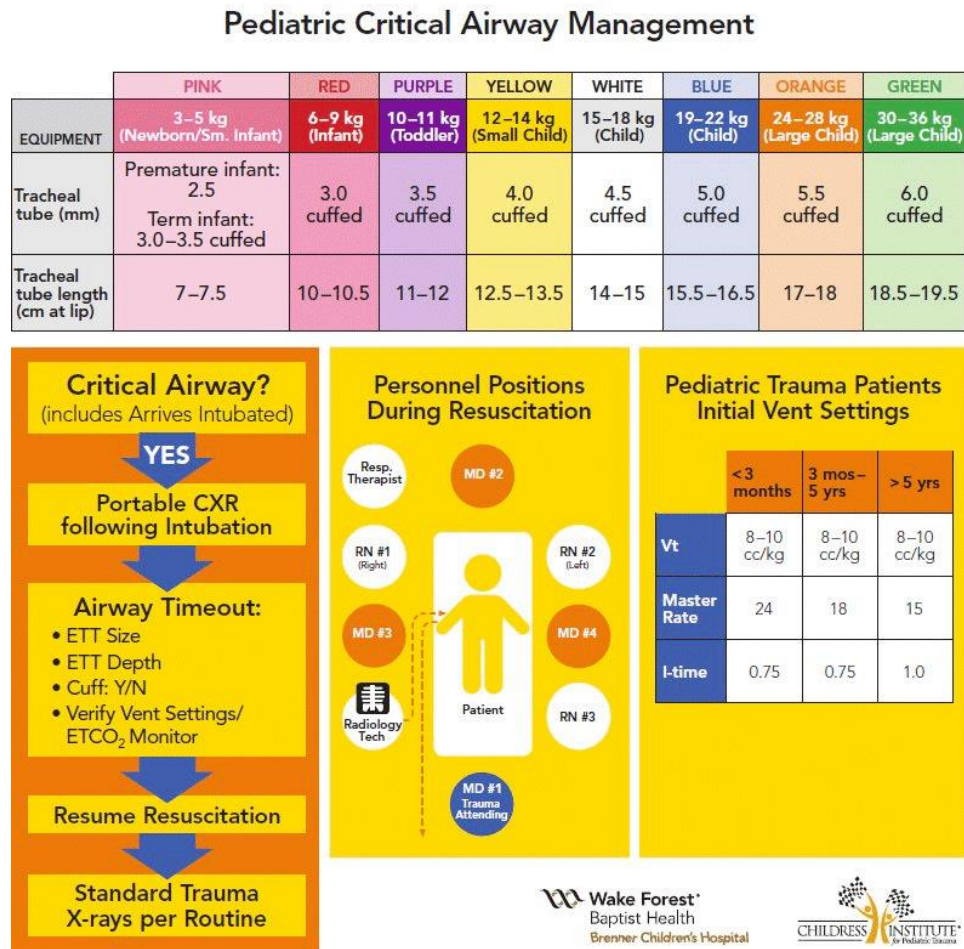
during the primary survey would overcome these inaccuracies and allow for faster intervention for improperly positioned ETTs, with respect to ETT depth. As such, the aims of this study were to evaluate the accuracy with which Broselow recommendations correlate with correct ETT depth, and to assess the safety and effectiveness of including CXR as part of the primary survey. Though discussion of esophageal intubations is included in this paper for completeness correction of esophageal intubations was not the primary goal of the study.

Methods

Protocol Implementation

An institutional protocol entitled "A-OK" was initiated on 01/01/2013 at Brenner Children's Hospital (BCH). BCH is a 160-bed pediatric hospital within the Wake Forest Baptist Health system. It has been accredited by the American College of Surgeons as a Level I Pediatric Trauma Center (PTC) since 2010. The A-OK protocol mandated that trauma patients less than 16 years requiring ETT placement prior to or upon arrival at the BCH Emergency Department (ED) undergo immediate CXR during the airway assessment portion of the primary survey before proceeding with the remainder of the ATLS protocol. The A-OK protocol also included an airway "time-out" to ensure that the appropriate sized ETT tube was placed to the appropriate depth according to the most recent Broselow Tape recommendations. All nurses, physicians and ancillary staff involved in the care of trauma patients were educated regarding this protocol prior to its implementation. Posters outlining the protocol and containing the most up-to-date ETT tube size and depth information were posted in the pediatric trauma resuscitation bays (**Figure I**).

Figure I. Bedside posters placed in trauma bays at initiation of A-OK. Project.

Pediatric Critical Airway Management

EQUIPMENT	PINK 3–5 kg (Newborn/Sm. Infant)	RED 6–9 kg (Infant)	PURPLE 10–11 kg (Toddler)	YELLOW 12–14 kg (Small Child)	WHITE 15–18 kg (Child)	BLUE 19–22 kg (Child)	ORANGE 24–28 kg (Large Child)	GREEN 30–36 kg (Large Child)
Tracheal tube (mm)	Premature infant: 2.5 Term infant: 3.0–3.5 cuffed	3.0 cuffed	3.5 cuffed	4.0 cuffed	4.5 cuffed	5.0 cuffed	5.5 cuffed	6.0 cuffed
Tracheal tube length (cm at lip)	7–7.5	10–10.5	11–12	12.5–13.5	14–15	15.5–16.5	17–18	18.5–19.5

Critical Airway? (includes Arrives Intubated)

YES

Portable CXR following Intubation

Airway Timeout:
- ETT Size
- ETT Depth
- Cuff: Y/N
- Verify Vent Settings/ ETCO$_2$ Monitor

Resume Resuscitation

Standard Trauma X-rays per Routine

Personnel Positions During Resuscitation

Resp. Therapist · MD #2 · RN #1 (Right) · RN #2 (Left) · MD #3 · MD #4 · Radiology Tech · Patient · RN #3 · MD #1 Trauma Attending

Pediatric Trauma Patients Initial Vent Settings

	<3 months	3 mos– 5 yrs	>5 yrs
Vt	8–10 cc/kg	8–10 cc/kg	8–10 cc/kg
Master Rate	24	18	15
I-time	0.75	0.75	1.0

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Patient Selection and Variable Abstraction

As an accredited PTC, an institutional trauma registry is maintained by a certified Trauma Registrar and support staff. Using this trauma registry, all intubated trauma patients <16 years of age the year prior to A-OK implementation (01/01/2012-12/31/2012) and the year following A-OK implementation (01/01/2013-12/31/2013) were identified. The group of patients identified prior to A-OK implementation was used as a pre-intervention historical control group. The group of patients identified after A-OK implementation was used as a post-intervention exposure group. To be included in the

study, patients had to be admitted through the BCH ED, rather than undergoing direct admission to an inpatient unit and also had to be alive at the time of arrival.

Variables abstracted from the registry included patient age, race, ethnicity, date of presentation, weight, gender, and Injury Severity Score (ISS). The ISS is calculated using Abbreviated Injury Scale (AIS). The AIS is an injury coding lexicon established by the Association for the Advancement of Automotive Medicine[54]. The AIS code consists of two numerical components – a "pre-dot" anatomic classification and a "post-dot" injury severity component, graded on a scale of 1 (minimal) to 6 (maximal)[54]. To calculate a patient's ISS, the highest AIS severity scores in each of the three most severely injured body regions are squared and summed together[55]. This results in an ISS score that may take on various integers from 0 to 75, with higher numbers indicating a more seriously injured patient[56].

Variables abstracted through chart review included the circumstances surrounding intubation, such as the number of attempts required prior to correct intubation and the location of intubation, particularly whether the patient was intubated in the field, at a referring institution or in the BCH ED. For analytic purposes, patients were thereafter categorized as having been intubated prior to or after arrival at the BCH ED, as the task of intubation in the ED could itself affect the time interval between a patient's arrival and their first CXR or further airway interventions.

ETTs come in a variety of lengths and widths and can be inserted to various depths. As such, ETT size and initial depth of placement were abstracted from charts. Depth is measured in centimeters using markings on the ETT. It is typically recorded using the centimeter marking noted on the ETT at the level of the patient's lip. The size

and depth of ETT insertion (measured in centimeters based upon the markings on the

ETT at the level of the lips) were compared to the size and depth recommended

according to Broselow Tape standards. Broselow Tape includes only patients weighing

less than 40 kilograms (kg) and thus those patients greater than or equal to 40 kg were not

included in this portion of the analysis. Among tubes requiring repositioning, it was

noted whether the tube required advancement or retraction. The depth of the tube after

repositioning (again measured in centimeters based upon the marking on the ETT at the

level of the lips) was recorded for each patient and this final depth was again compared to

the depth recommended by Broselow standards.

      Manual chart review was also utilized to determine the length of time from the

patient's arrival in the ED to the time of their first CXR as well as the length of time from

the patient's arrival in the ED to repositioning of an improperly positioned ETT.

Additional outcome variables abstracted from chart review included length of time to

attainment of intravenous access, length of time to completion of life-saving interventions

involving breathing or circulation, the number of CXRs required in the ED and patient

morbidity and mortality.

Aim One: Determination of Accuracy of Bedside Techniques

      To determine the accuracy of bedside confirmation techniques (Broselow

recommendations and auscultation of breath sounds) in assessing appropriate tube

placement, the percentage of patients in whom confirmatory techniques indicated the tube

was in correct position but CXR demonstrated that it was malpositioned was assessed.

This was compared to the number of patients in whom bedside confirmatory techniques

were not performed or followed but in whom CXR indicated correct tube position. Then,

after tube repositioning and final confirmation of correct ETT placement on CXR, patients were assessed to determine whether the final correct tube positioning matched Broselow recommendations or aligned with documented breath sounds.

Aim Two: Assess Safety and Effectiveness of Including CXR in Primary Survey

Key demographic variables and intubation circumstances were compared between A-OK cases and pre-A-OK controls to assess the comparability of the groups. Outcome measures, including the length of time after ED arrival to first CXR, the length of time after ED arrival to repositioning of malpositioned ETTs and the length of time after ED arrival to the management of other life-threatening issues, were also compared between A-OK cases and pre-A-OK controls.

Statistical Analysis

To assess aim one, the sensitivity of bedside techniques (auscultation of breath sounds and use of Broselow based depth) to accurately detect tracheal intubations and the specificity of these techniques to rule out bronchial or pharyngeal intubations were calculated. To assess aim two, percentages for categorical data and means or ranks for continuous variables were calculated. Chi square analyses and Fisher's exact tests were used as appropriate to compare the distributions of categorical variables between pre-A-OK controls and post-A-OK cases. This allowed for assessment of the differences in baseline characteristics between the comparison groups, such as mechanism of trauma and gender but also for the comparison of certain outcome measures such as mortality data between groups. Student's t-tests and Wilcoxon rank tests were used as appropriate to compare the means or ranks of continuous variables between A-OK cases and pre-A-OK controls. This included continuous baseline variables, such as age and weight, and

also included the main outcome variables of time to first CXR, time to first ETT intervention and time to attainment of IV access, which were treated as non-parametric continuous variables. All statistical analyses were performed utilizing SAS 9.3 (SAS Institute, Cary, NC) and JMP Pro 10.0.0 (SAS Institute, Cary, NC). Significance was defined as p-values of less than 0.05.

Results:

Fifty-three trauma patients <16 years of age requiring intubation were identified in the trauma registry between 01/01/2012 and 12/31/2013. However, one of these patients was dead upon arrival in the ED and another was admitted directly to the Pediatric Intensive Care Unit and therefore bypassed ED assessment. These two patients were excluded, resulting in a study population of 51 patients. Of these, 23 were pre-A-OK historical controls and 28 were post-A-OK cases. Of the 51 patients assessed, 4 (7.8%) underwent inadvertent esophageal intubation upon first attempt. Three such esophageal intubations occurred in the field and all three were recognized and corrected prior to arrival at BCH. These three instances of esophageal intubations were not included in our analysis of bedside confirmatory technique accuracy since they were corrected prior to BCH arrival and it was not known how such mal-positioning was detected. The three patients themselves, however, were included in the analysis, which proceeded based upon the position of their ETT upon arrival at BCH. One esophageal intubation did occur at BCH but was recognized immediately with bedside confirmation techniques prior to CXR. A total of 12 (23.5%) patients underwent initial bronchial intubations – 2 of which were noted by unequal breath sounds but the remainder of which

were not noted until CXR was performed. A total of five (9.8%) of patients had pharyngeal intubations upon CXR assessment.

Aim One: Determination of Accuracy of Bedside Techniques

Of these 51 patients, 33 were <40 kg and thus qualified for Broselow recommendations. Initial and corrected ETT depths were available for 31 of these 33 patients (**Figure IIA**). Among this cohort, 7 (22.5%) had initial ETT depths that matched Broselow recommendations. Among those 7 children, 5 were found to have ETTs in the appropriate position according to CXR but 2 were malpositioned, with CXRs demonstrating ETTs located in the right main-stem bronchus in both instances. After repositioning, both ETTs were in the correct position according to CXR, but the final depth of these ETTs matched Broselow recommendations for only one of these patients. Conversely, 24 (77.4%) children had initial ETT depths that did not match Broselow recommendations. Of these, 5 were in appropriate position according to CXR and 19 required repositioning. Of those 19 requiring repositioning, 3 were too shallow and were advanced and 16 were too deep and were retracted. Of the 16 that were retracted, 10 were in the right main-stem bronchus and 6 were at the level of the carina. After repositioning all were in appropriate position according to CXR but in only 13 of these 19 patients did the correct depth match the Broselow recommended depth (**Figure IIA**). Using the initial ETT placements, Broselow depth was 71% sensitive in detecting an appropriately placed ETT (5 out of 7 children with initially correct Broselow depths had correctly positioned ETTs) and 79% specific in identifying an inappropriately placed ETT (19 of 24 children with initially incorrect Broselow depths had incorrectly positioned ETTs). However, after ETT adjustments, the correct final depth of ETTs

according to CXR matched Broselow recommendations in only 19/31 (61.3%) patients (**Figure IIA**).

For the total sample size of 51 patients, breath sounds were documented in 48 cases (**Figure IIB**). In one case, breath sounds were not heard and the tube was noted to be in the esophagus and was replaced. After replacement, equal breath sounds were documented; though the tube was noted on CXR to be in the right main-stem bronchus. In two other cases, breath sounds were documented as unequal with subsequent retraction of the tube. In these 2 cases, subsequent CXR demonstrated that both ETTs were still too deep at the level of the carina and a second retraction was required. In the other 45 cases, equal breath sounds were documented. Among these 45 cases with documentation of equal breath sounds, the tube was appropriately positioned in only 25 (55.6%) such cases. In the remaining 20 cases, CXR determined that the ETT was too shallow among 4 patients and too deep among 16 patients. Of the 16 cases demonstrating an ETT in too deep a position, 9 were in the right-main-stem bronchus and 7 were at the level of the carina. Thus, including the corrected esophageal tube, 10/46 (21.7%) patients with main-stem intubations were documented as having equal breath sounds bilaterally (**Figure IIB**). Using initial breath sound and ETT placement data, the sensitivity of equal breath sounds in identifying a correctly positioned ETT was 55.6% (25 of 45 individuals with equal breath sounds had appropriately positioned ETTs) and the specificity of unequal breath sounds for detecting malpositioned ETTs was 100% (3 of 3 individuals with unequal or absent breath sounds had incorrectly positioned ETTs).

Figure IIA. Flowchart of patient inclusion criteria and endotracheal tube (ETT) outcomes with respect to use of Broselow recommendations to confirm ETT placement**.** **Figure IIB.** Flowchart of patient inclusion criteria and ETT outcomes with respect to assessment of breath sounds to confirm ETT placement.
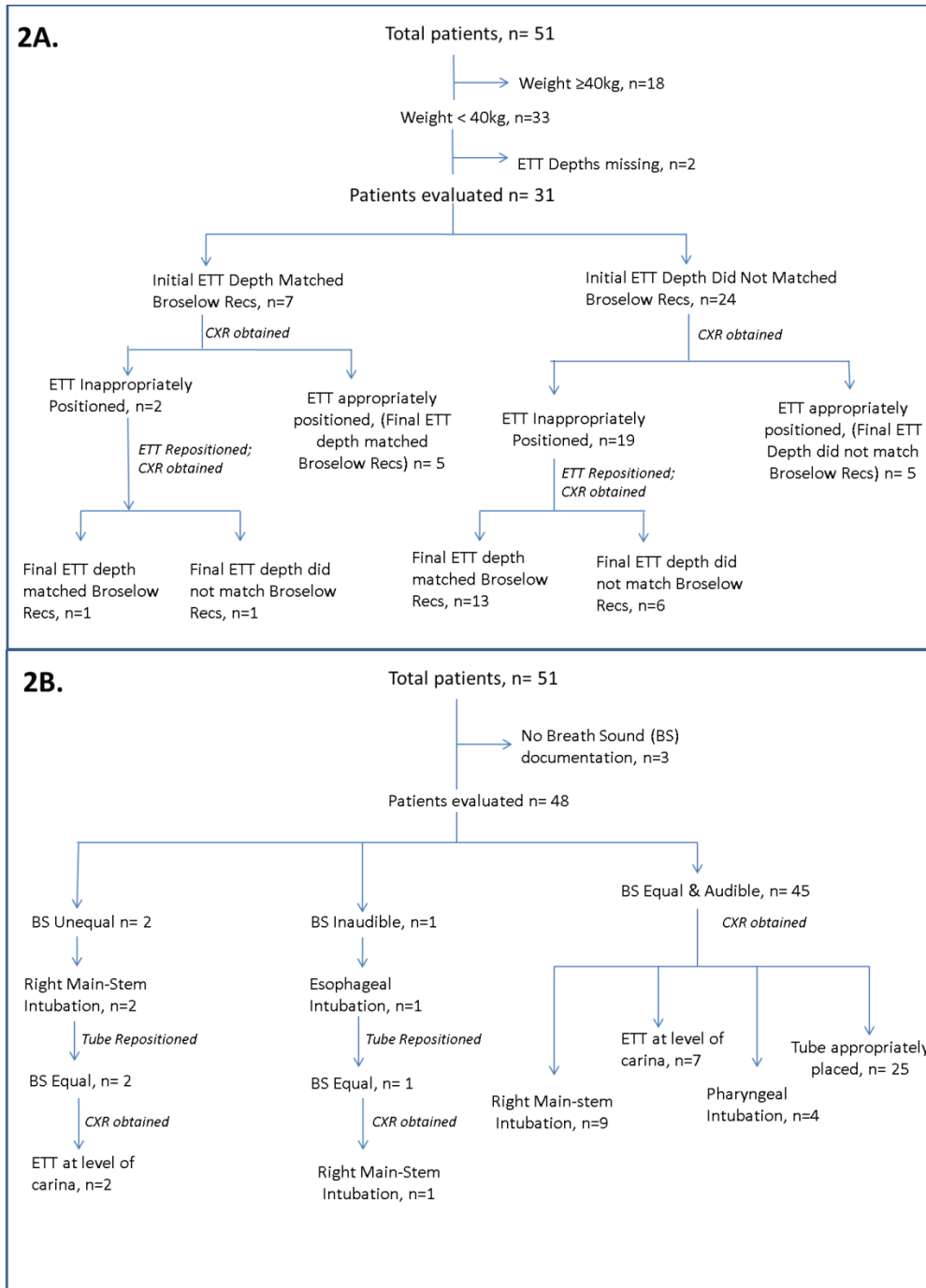
Aim Two: Assess Safety and Effectiveness of Including CXR in Primary Survey

Baseline characteristics of cases and controls are summarized in **Table I**. Pre-A-OK controls did not differ significantly from post-A-OK cases in terms of age, weight, gender or race. The majority of both pre-A OK controls and A-OK cases incurred injury by blunt force trauma (pre-A-OK: 83%, A-OK: 86%, p=1.00). The severity of injury sustained by pre-A-OK controls (median ISS and interquartile range (IQR): 11.5 and 5.0-33.0) did not differ significantly from that of A-OK cases (median ISS and IQR: 23.0 and 10.0-29.0, p=0.35).

Table I. Baseline Characteristics between A-OK cases and Pre-A-OK Controls

	Pre-A-OK Controls (n=23)	Post A-OK Cases (n=28)	p-value
Age (yr), mean +/- SD	6.8 +/- 5.3	7.9 +/- 5.2	0.43[†]
Weight (kg), mean +/- SD	31.6 +/- 27.7	36.6 +/- 26.1	0.51[†]
Male, n (%)	19 (83)	19 (68)	0.34[††]
Race/Ethnicity, n (%)			
White	16 (70)	20 (71)	1.00[††]
Black	5 (22)	6 (21)	
Hispanic	2 (9)	2 (7)	
Mechanism of Trauma, n (%)			
Blunt	19 (83)	24 (86)	1.00[††]
Penetrating	1 (4)	1 (4)	
Burn	3 (13)	3 (11)	
ISS, median (IQR)	12 (5 – 33)	23 (10 - 29)	0.35[†††]
No. Attempts to Intubate, median (IQR)	1 (1-2)	1 (1-1)	0.42[†††]
Location of Intubation, n (%)			
Prior to Arrival at BCH (n=38)	13 (57)	25 (89)	0.01[††]
After Arrival at BCH (n=13)	10 (43)	3 (11)	
Person performing intubation, n (%)			
Paramedic/EMT	5 (22)	8 (29)	0.06[††]
Referring Physician	8 (32)	17 (61)	
Resident at BCH	5 (22)	2 (7)	
Attending at BCH	5 (22)	1 (4)	

[†]Student's t-test
[††]Fisher's exact test
[†††]Wilcoxon rank sum test

With respect to the circumstances surrounding intubation, pre-A-OK controls did not differ significantly from A-OK cases in terms of the number of attempts required before successful intubation, both with a median of 1 attempt (p=0.42). However, 13 of 23 (57%) pre-A-OK controls were intubated prior to their arrival at BCH. This differed significantly from the distribution of the location of intubations among A-OK cases, in which 25 of 28 (89%) of patients underwent intubation prior to arrival at BCH (p=0.01).

As such, pre-A-OK controls and A-OK cases also differed in terms of the individual performing the intubation, with a greater percentage of A-OK cases undergoing intubation by a physician at a referring hospital, although this difference did not quite reach statistical significance (p=0.06).

Length of time to first CXR was significantly longer among pre-A-OK controls than among the post-A-OK cases (pre-A-OK: 25.7 +/- 14.9 min, A-OK: 15.0 +/- 10.1 min, p<0.01), as demonstrated in **Table II**. This held true upon sub-analysis of those intubated prior to arrival at BCH (n=38). Among this group, pre-A-OK controls required an average of 21.8 +/- 10.3 minutes before the first CXR was obtained, compared to an average of 13.9+/-10.0 minutes among A-OK cases (p=0.02). Among the much smaller group of patients intubated at BCH (n=13), the mean time to first CXR was longer among the pre-A-OK controls compared to the post-A-OK cases but the sample size was too small to draw statistical conclusions from this difference (30.9 +/- 18.8 min vs 23.7 +/- 8.0 min).

Ten of 23 pre-A-OK controls (43.5%) required ETT repositioning and this percentage did not differ significantly from the 14 of 28 A-OK cases (50.0%) that required ETT repositioning (p=0.64). Such repositioning was achieved in a significantly shorter amount of time among A-OK cases than among pre-A-OK controls (21.1+/-11.8 min vs 35.2+/-15.9 min, p=0.03) as demonstrated in **Table II**. Sub-analysis of those intubated prior to and after arrival at BCH was limited by small sample size.

Post-A-OK patients did not have an increased number of CXRs or an increased length of time to attainment of IV access or treatment of other circulatory issues due to earlier CXR attainment (**Table II**). No adverse events were reported specifically as a

result of earlier CXR. There were no significant differences in mortality, length of stay

or number of ventilator days between pre-A-OK controls and post-A-OK cases (**Table

II**).

Table II. Outcome Comparison between Pre-A-OK Controls & Post-A-OK Cases

	Pre-A-OK Controls (n=23)	Post-A-OK Cases (n=28)	p-value
Length of time to first CXR in min, mean +/- SD (n=52)	25.7+/-14.9 min	15.0 +/- 10.1	<0.01[†††]
ETT adjustment in ED, n (%)	10 (43)	14 (50)	0.64[†]
Length of time to ETT adjustment (min), mean +/- SD, (n=24)	35.2 +/- 15.9	21.1 +/- 11.8	0.03[†††]
Length of time to IV access (min), mean +/- SD	2.2 +/- 4.3	2.0 +/- 7.6	0.07[†††]
No. CXR in ED, median (IQR)	1 (1-1)	1 (1-2)	0.45
CT* placed because of CXR, n (%)	3 (13)	0 (0)	0.09[††]
Patient decompensation d/t mal-positioned ETT, n (%)	1 (4)	0 (0)	0.45[††]
No. Days on Ventilator, median (IQR)	2 (1-6)	1 (1-3)	0.40[†††]
Length of Stay, median (IQR)	5 (2-11)	9 (2-19)	0.40[†††]
Mortality, n (%)	6 (26)	7 (25)	0.86[†]

[†]Chi Square test
[††]Fisher's exact test
[†††]Wilcoxon rank sums test
*Chest Tube

Conclusions:

ATLS protocol prioritizes management of a patient's airway as a part of the

primary survey and but typically postpones radiographic confirmation of appropriate ETT

placement until after completion of the primary and secondary surveys[27]. Of key

importance is the depth of ETT placement, which is most commonly assessed using

length-based Broselow recommendations and auscultation of bilateral breath sounds.

However, these bedside estimations have not been extensively studied in their ability to

predict appropriate ETT depth in children. This study revealed that, when compared to

CXR, the gold standard for assessing ETT position, Broselow recommendations for ETT

depth aligned with final correct ETT depth in only 61% of cases. Furthermore,

approximately 22% of patients documented as having equal bilateral breath sounds were determined to have main-stem intubations. To avoid reliance on these techniques during the primary survey, the A-OK protocol included CXR during the primary survey. This protocol was safely implemented without causing delays in management of other life-threatening conditions and allowed for more rapid repositioning of malpositioned ETTs.

Airway management remains one of the most important yet challenging aspects in appropriate treatment of a pediatric trauma patient. Gausche and colleagues evaluated 186 pediatric patients in whom intubation was believed to be successful by paramedics. Upon ETT assessment in the emergency department, 3 (2%) such children were ultimately found to have an esophageal intubation and 33 (18%) were found to have a main-stem intubation [50]. Furthermore, in this same study, 12 (6%) children suffered unrecognized tube dislodgement en route to the ED, 15 (8%) experienced recognized tube dislodgement and 44 (24%) were intubated with a tube of the wrong size [50]. Other studies of pediatric patients report inadvertent esophageal intubation rates ranging from 1.8% to 2.9% and bronchial intubation rates ranging from 9.5% to 12.6% [51,52].

Rates of malpositioned ETTs were similarly high in our patient population. Three of 51 (5.8%) had initial esophageal intubations in the field but it is unknown how these were recognized, as they were corrected prior to arrival at BCH. One patient had an esophageal intubation at BCH which was recognized with bedside confirmatory techniques. Twelve of 51 (23.5%) patients were noted to have initial bronchial intubations (including the corrected esophageal intubation), of which only 2 were recognized with bedside techniques. Thus, even after the use of bedside confirmatory techniques and subsequent tube repositioning, CXR revealed that 24 (47%) of the 51

patients had malpositioned ETTs that required repositioning– 5 for intubations that were too shallow and 19 for intubations that were too deep (either in the bronchus or at the level of the carina).

Malpositioned ETTs may have negative consequences for patients. Placement of an ETT into the esophagus instead of the trachea precludes appropriate oxygenation and ventilation of the lungs. Silvestri and colleagues report that of 13 unrecognized esophageal intubations in their study, 9 (69%) patients died and 2 (15%) were discharged with severe neurologic impairment [33]. Likewise, pharyngeal intubations increase the risk of aspiration and of accidental ETT dislodgement with subsequent extubation [36,37]. Inadvertent extubation, especially during transport or during the acute resuscitation phase can be disastrous. Similarly, main-stem intubation may result in hyperinflation of the ventilated lung and atelectasis (airway collapse) in the non-ventilated lung [34,38]. Single-lung hyperinflation can lead to pulmonary edema or pneumothorax on this side [34,39]. Such conditions lead to inadequate oxygenation and ventilation and may result in significant morbidity [34,38,39]. Finally, intubations in which the ETT is <2cm from the carina risks main-stem intubation because the ETT can advance as much as 3cm with neck flexion [57]. Furthermore, constant irritation of the carina may contribute to continued bronchospasm [58].

Because malpositioned ETTs can have dire consequences upon a patient's condition, rapid identification and correction of malpositioned tubes is crucial. ATLS protocol suggests laryngoscopy, end tidal carbon dioxide ($ETCO_2$) detection, capnography and physical examination, including auscultation of bilateral breath sounds, to confirm initial placement of an ETT into the airway as opposed to the esophagus [27].

Though these bedside confirmatory techniques were accurate in our patient population (1/1 esophageal intubation was recognized by bedside technique prior to CXR), previous reports have suggested that this is not always the case. A large meta-analysis of ETCO2 devices and capnography revealed false-positive rates of 3% and false negative rates of 7%[42]. Another study reported that of 35 patients with unrecognized esophageal intubations, 60% had undergone endotracheal placement confirmation with multiple techniques[43].

Likewise, to confirm correct depth of ETT placement (tracheal vs pharyngeal or bronchial), ATLS protocol again suggests auscultation of bilateral breath sounds, as well as insertion of the tube to a pre-specified depth, [27] particularly with Broselow Tape [45]. Broselow Tape was originally validated for use in pediatric resuscitation in the late 1980s [45]. Since that time, Broselow Tape has been called into question regarding its accuracy, particularly with drug dosing. The idea that length corresponds to weight is intuitive but given the growing obesity trend in the United States, many have questioned whether the length-to-weight conversions created decades ago need to be restructured. A subsequent evaluation of the accuracy of Broselow Tape in predicting actual weights among 7,500 children from suburban elementary schools and an urban pediatric clinic demonstrated that this tape was inaccurate in approximately one third of children [48]. The tendency of the Broselow Tape to underestimate a child's actual weight has been confirmed in several other studies [47,49]. However, no recent studies have evaluated its accuracy in determining appropriate ETT depth in the pediatric population. In our study, Broselow Tape was found to correlate with correct ETT depth in only 61% of cases. Among those cases in which Broselow recommendations were initially followed, 2/7

(28.6%) were bronchially intubated. This makes a case for re-evaluation of the current

recommendations for initial ETT depths in children.

CXR remains the gold standard to confirm proper endotracheal tube placement

(with respect to depth) in adults and children [36,53]. However, in the field CXR is not

readily available. Once the patient arrives in the ED, even if a patient is already

intubated, ATLS protocol starts from the beginning. Though it posits that CXR may be

added as an adjunct to the primary survey, it routinely postpones radiographic

confirmation of the ETT position until after the secondary survey [27]. Given the

importance of airway control and the speed with which a CXR can be performed given

portable CXR machines, we hypothesized that the ATLS protocol unnecessarily delayed

the confirmation of ETT positioning in the intubated patient. The A-OK protocol, thus,

called for inclusion of CXR as a part of the airway assessment in any intubated trauma

patient less than 16 years. By doing so, this study revealed that the length of time from a

patient's arrival in the ED to the attainment of a CXR was significantly shortened.

Because the length of time to CXR may be affected by the location of intubation (prior to

BCH ED arrival or after BCH ED arrival), sub-analysis was performed. Among those

intubated prior to BCH ED arrival, time to first CXR remained significantly shorter in the

A-OK group compared to the pre-A-OK controls. However, the group intubated at BCH

consisted of only 13 patients and was thus underpowered to detect a significant difference

between groups.

Decreasing the length of time to first CXR will only impact care, however, if this

leads to more prompt action with respect to a malpositioned ETT. Analysis of all 24

patients requiring ETT repositioning again demonstrated that post-A-OK cases

underwent ETT repositioning in a significantly shorter time period than pre-A-OK

controls. This, however, can again be affected by the location of intubation.

Unfortunately, sub-analysis of those intubated prior to BCH ED arrival and requiring

ETT repositioning was limited to 19 patients and of those intubated after BCH arrival and

requiring ETT repositioning was limited to 5 patients. Thus, both analyses were

underpowered to produce significant differences between groups.

Perhaps more significantly, however, is that evaluation of the A-OK protocol

demonstrated that inclusion of CXR as part of the primary survey did not postpone

assessment and management of other life-threatening issues in the primary survey. Time

to achievement of intravenous access was not prolonged in the post-A-OK group. Nor

were instances of delayed chest tube insertion, blood transfusions, or other breathing or

circulatory interventions reported as a result of A-OK implementation.

Limitations of this study include its small sample size. Because of this, some of

the statistical analyses are underpowered. However, early analysis within a year of the

protocol's implementation was undertaken to assess the initial safety and feasibility of the

A-OK protocol and thus led to unavoidably small sample sizes, given the relatively small

number of pediatric trauma patients that require intubation overall. Thus, future analysis

will commence when the protocol has been in existence for a longer period of time to

allow for full assessment of its effects on airway interventions. Additional limitations of

this study include its retrospective design. Because of the nature of retrospective review,

data was not always complete. Furthermore, assessment of the length of time from ED

arrival to airway interventions was dependent upon accurate documentation, which was

not always present. Times were estimated based upon time-stamped notes in the

electronic medical record and nursing flow sheets and are thus inherently subject to errors. Finally, given that a historical control was utilized, this study is subject to maturation bias. That is, the implementation of other quality improvement or work-flow protocols and staff turnover or training could affect the time to CXR in a way that is unrelated to the A-OK protocol.

Despite the limitations of this study, it marks an important shift in pediatric trauma care. The ATLS protocol was first adopted in the 1970s and, despite advances in medical technology, few changes to the protocol have been made since that time. Given the portability of CXR, the speed with which it can be performed and the crucial information it provides, the ATLS algorithm's postponement of this diagnostic test until after the primary and secondary surveys seems unnecessary. Our study confirms that bedside techniques, particularly the use of Broselow recommendations and the auscultation of breath sounds, are inaccurate to determine proper positioning of an ETT and that CXR (the gold standard) can be obtained during the primary survey without inducing delays in the management of other key issues. This study also suggests that inclusion of CXR in the primary survey may lead to more rapid repositioning of malpositioned tubes, which may prove life-saving. Larger studies may demonstrate reductions in morbidity and mortality among pediatric trauma patients with use of the novel A-OK algorithm.

Chapter 3: Ancillary Analysis and Future Work

Ancillary Analysis

Endotracheal Tube Size

The A-OK protocol consisted of two pieces. First, as discussed extensively in chapter 2, it called for inclusion of CXR during the primary survey. Second, it consisted of an airway time-out. This airway time-out called for those involved in intubation to confirm the patient's estimated length and weight (based upon Broselow tape) and to voice the ETT size and depth and medication doses corresponding to that length/weight. Though this would likely not affect those patients intubated prior to BCH ED arrival, it may have affected the patients undergoing intubation while in the BCH ED. One question that arises is whether or not the airway time-out led to closer adherence to Broselow recommendations with respect to ETT sizes and initial depths of placement among patients intubated in the BCH ED.

Thirty-three patients in our cohort qualified for Broselow recommendations (< 40 kg). ETT size information was available for all 33 patients but ETT depth information was available for only 31 patients. Thirteen of the 33 patients (39.4%) had ETTs in place that were of the recommended Broselow size and 20 (60.6%) did not. Among those with ETT sizes that did not match Broselow recommendations, 14 (70%) had ETTs in place that were smaller than recommended.

Only 8 of the patients who qualified for Broselow recommendations underwent intubation at BCH. Seven of these patients were pre-A-OK controls, of which 50% were intubated with ETTs of the correct size. Only one of these patients was a post-A-OK

case and this patient was not intubated using the correct Broselow size ETT. Similarly, of the patients undergoing intubation at BCH who qualified for Broselow recommendations, initial ETT depth was known for only 7 patients (6 pre-A-OK controls and 1 A-OK case). Thus, a lack of power exists to draw meaningful conclusions as to whether the "airway time out" affects whether or not Broselow recommendations are followed at BCH.

Use of Broselow Recommendations

Of those patients qualifying for Broselow recommendations, 8 were intubated by paramedics in the field, 17 were intubated by physicians at referring hospitals and 8 were intubated by physicians at BCH. Thus, 25 such patients were intubated prior to BCH ED arrival and 8 such patients were intubated after BCH ED arrival. It may be interesting to note whether or not BCH ED providers were more apt to follow Broselow recommendations compared to paramedics and referring physicians.

Of those intubated at BCH, 4/8 (50.0%) were intubated with ETT tubes whose sizes matched Broselow recommendations. In comparison, 9/25 (36.0%) of those intubated prior to BCH arrival were intubated with tubes whose sizes matched Broselow recommendations. These differences were not significantly different (p=0.68) but sample sizes were small and thus the comparison has limited power.

Initial ETT depth was known for 31 of the 33 patients meeting Broselow recommendations. Among these, three of the 7 (42.9%) intubated at BCH had initial ETT depths that matched Broselow recommendations. In comparison, four of the 24 (16.7%) intubated prior to BCH arrival had initial ETT depths that matched Broselow

38

recommendations. Again, this difference was not significantly different (p=0.16) but power was again quite limited.

With respect to whether or not an ETT ultimately required repositioning after CXR (irrespective of Broselow recommendations), 4 of the 13 patients (31%) intubated at BCH required ETT repositioning compared to 20 of the 40 patients (50%) intubated prior to BCH arrival. This, again, was not significantly different.

Future Work

Larger Study

Limitations of this study include its small sample size. Because of this, some of the statistical analyses are underpowered. However, early analysis within a year of the protocol's implementation was undertaken to assess the initial safety and feasibility of the A-OK protocol and thus led to unavoidably small sample sizes, given the relatively small number of pediatric trauma patients that require intubation overall. Thus, future analysis will commence when the protocol has been in existence for a longer period of time to allow for full assessment of its effects on airway interventions. Analysis of this larger dataset will allow for the creation of more thorough models to adjust for confounders that may affect CXR attainment and ETT adjustment.   It will also allow us a larger dataset with which to measure the ability of bedside confirmatory techniques to identify malpositioned ETTs.

A larger study would also allow for us to evaluate the way in which the protocol changed behaviors overtime. That is, as the emergency staff becomes more familiar with the protocol the longer it is implemented, the lengths of time to CXR attainment and ETT

adjustment might continue to decrease. Likewise, the consistency with which an airway "time-out" is performed and properly sized equipment is used may improve over time. This information would allow us to give other institutions that might want to implement our protocol an idea of the time period over which they may begin to see changes and improvements.

Broselow Restructuring

Given the inaccuracies of Broselow recommendations for ETT depth identified in this study, along with the inaccuracies of Broselow tape pointed out in previous studies, important questions are raised regarding whether or not this system needs restructuring. New recommendations for ETT depth and size would require large scale analysis of appropriate ETT depths when confirmed on CXR across a large spectrum of children. It would also require careful analysis of the current height to weight conversions as estimated by Broselow. Though weight may be more important for drug dosing, height may prove to be more important for ETT positioning, as it may be more reflective of tracheal length. Thus, careful consideration of the entire Broselow system would be required.

One possible avenue in which ideal ETT depths in children might be assessed is in the operating room. Nearly every child that presents for an operation undergoes general anesthesia with endotracheal intubation. CXR is not routinely obtained to ensure proper ETT placement intraoperatively as the ETT is typically removed at the conclusion of the case. However, intraoperative intubation may allow us a unique opportunity to evaluate appropriate endotracheal tube depths in a controlled setting. Both portable x-ray machines and portable fluoroscopy machines are available in the operating room and

could be used to assess appropriate ETT positioning in children. A prospective study might evaluate ETT depths during elective operation confirmed to be in appropriate position with portable x-ray or fluoroscopy machines. These correct depths could be correlated with pediatric age, height and weight intervals. This could allow for restructuring of current Broselow recommendations.

The Pre-hospital Setting

Earlier confirmation of correct ETT depth is paramount and the earlier that the depth can be confirmed, the better. Unfortunately, CXR is not an available modality in the pre-hospital setting, when many intubations initially occur. Thus, the utility of the A-OK protocol lies in its earlier detection of mal-positioned ETTs after arrival at the receiving hospital. The pre-hospital intubation accuracy will not be improved with this study.

Future studies restructuring the Broselow recommendations (as described above) could help to improve the accuracy of the initial intubation depths in the pre-hospital setting. Likewise, the use of other modalities to confirm ETT depth that may be available in the prehospital setting, such as portable ultrasound, may be explored in additional future studies.

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Curriculum Vitae

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EDUCATION:

07/2013-Present   Wake Forest University, Winston-Salem, NC
M.S., Clinical and Population Translational Sciences
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08/2006-06/2010   Wayne State University- School of Medicine;
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08/2002-05/2006   University of Notre Dame; South Bend, IN
B.S. Pre-professional Studies
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POSTDOCTORAL TRAINING:

07/2010-06/2011   Intern, Department of General Surgery
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PROFESSIONAL LICENSURE

07/2010 - Present   State of North Carolina, Resident Training License #165395

PROFESSIONAL MEMBERSHIPS

08/2006-06/2008   **AMSA's Humanistic Medicine**
Member & Co-coordinator ; *Organized seminars and evening classes devoted to learning about Humanism in Medicine and Integrative Medicine, Shadowed physicians that practice integrative medicine; Volunteered at various events, including Covenant House and Project H*

*HONORS AND AWARDS***:**

1. **Gold Medal Poster**, "Quantification of Injury Risk as Predicted by Age, Height and Weight in Pediatric Motor Vehicle Crash Occupants for Use in Advanced Automatic Crash Notification." Department of Surgical Sciences, Resident and Fellow Research Day, 11/2014.

2. **Second Place Winner**, "An Institutional Review of the American Society of Anesthesiologists Physical Status Classification," Clinical Outcomes Division of North Carolina Trauma/Acute Care Surgery Residents' Paper Competition. 07/2014.

3. **Childress Institute for Pediatric Trauma Scholar 07/2013-06/2015.** Awarded scholarship for attainment of M.S. over two year period and for pursuit of research activities in the treatment of children with traumatic injuries.

4. **Silver Medal Poster**, "Peritoneal Surface Disease with Synchronous Hepatic Involvement Treated with Cytoreductive Surgery and Hyperthermic Intraperitoneal Chemotherapy." Department of Surgical Sciences, Resident and Fellow Research Day, 11/2013

5. **Burn Resident of the Year 12/2011**, Wake Forest Baptist Medical Center.

6. **Board of Governor's Merit Scholarship**, Wayne State University School of Medicine; 08/2006-06/2010. Awarded scholarship for 100% of tuition for four years of medical school training.

7. **Athletic Scholarship Award**, University of Notre Dame, 08/2003-05/2006. Awarded scholarship for large percentage of tuition for undergraduate education for my collegiate athletic participation.

8. **Big East Conference Academic All-Star**: **2004, 2005, 2006**. Awarded to athletes in collegiate Big East Conference who maintain a minimum cumulative grade-point-average of 3.0 during the preceding academic year.

9. **Dean's List: Fall 2002 through Spring 2006**. University of Notre Dame.

NCAA ATHLETICS

> 2002-2006 **University of Notre Dame, Varsity Women's Rowing Team**
> Athlete 08/2002-06/2006;
> Captain of 2005-2006 team**;**
> *Competitive athlete during all four years of collegiate eligibility; Assisted team in winning its first three Big East Championships (2004, 2005 & 2006); Lead team to its first* **National Championship Competition** *in June of 2006.*

> 2004-2006 **University of Notre Dame's Academic Athletic Honor Program**
> Member & Service Committee Chair.
> Awarded Membership in 2004 for my dedication to NCAA athletics and academic achievements.

PUBLIC OUTREACH

1. **Volunteer**, "Code Blue;" Wayne State University School of Medicine Volunteer Program; 08/2006-05/2007: *Organized various "mini-courses" on health-related issues for children in Detroit public schools.*

2. **Service Committee Chair**, Academic Athletic Honors program; University of Notre Dame, 10/2004-04/2006: *Organized various charitable events in the local community, including cooking and distributing food at a local soup kitchen; and cleaning/organizing at a local homeless shelter.*

3. **Participant**, "Urban Plunge;" University of Notre Dame, 01/2005. One-credit winter break seminar through the Center for Social Concerns. My experience occurred in Detroit, MI, wherein we stayed in a local soup kitchen, had discussions with agencies/individuals affected by urban poverty and performed direct service.

4. **Volunteer**, St. Mary's Medical Center, Livonia, MI, 06/2004-08/2004. Volunteered in Emergency Department and assisted with cleaning rooms, comforting patients and carrying out needed errands.

5. **Volunteer**, St. Joseph's Regional Medical Center, 11/2004-11/2005. Volunteered in Emergency Department and assisted with cleaning rooms, comforting patients and carrying out needed errands.

GRANTS

> Sponsor: Center for Child Injury Prevention Studies, National Science Foundation
> Dates: 05/2014-04/2015
> Budget: 50,000 /year direct cost
> Title: Investigating Injuries in Pediatric Occupants for use in Advanced Automatic Crash Notification System, Year 2
> Co-I: Andrea Doud, MD

Sponsor: Center for Child Injury Prevention Studies, National Science Foundation
Dates: 05/2013-04/2014
Budget: 50,000 /year direct cost
Title: Investigating Injuries in Pediatric Occupants for use in Advanced Automatic
Crash Notification System, Year 1
Co-I: Andrea Doud, MD

BIBLIOGRAPHY:

Peer-Reviewed Journal Articles:

1. **Doud A**, Weaver A, Talton W, Barnard T, Schoell S, Petty J, Stitzel J.
    Evaluation of Developmental Metrics for Utilization in a Pediatric Advanced
    Automatic Crash Notification Algorithm. Accepted, *Traffic Injury Prevention*.

2. **Doud A**, Weaver A, Talton W, Barnard T, Schoell S, Petty J, Stitzel J.   Mortality
    Risk in Pediatric Motor Vehicle Crash
    Occupants: Accounting for Developmental Stage and Challenging Abbreviated
    Injury Scale Metrics. Accepted, *Traffic Injury Prevention*.

3. **Doud A**, Lawrence K, Goodpasture M, Zeller, K. Prematurity and Neonatal
    Comorbidities as Risk Factors for Non-Accidental Trauma. *J. Pediatric Surg*.
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4. Schoell SL**, Doud AN**, Weaver AA, Barnard RT, Meredith JW, Stitzel JD, Martin
    RS. Development of a time sensitivity score for frequently occurring motor
    vehicle crash injuries. *J Am Coll Surg*. 2015 March; 220(3).

5. Schoell SL**, Doud AN**, Weaver AA, Barnard RT, Meredith JW, Stitzel JD, Martin
    RS. Predicting patients that require care at a trauma center: Analysis of injuries
    and other factors. *Injury*. 2014 Dec 9.

6. **Doud A**; Randle, R; Clark C; Levine E, Swett K, Shen P, Stewart J;
    Votanopoulos, K. Impact of Distal Pancreatectomy on Outcomes of Peritoneal
    Surface Disease Treated with Hyperthermic Intraperitoneal Chemotherapy.
    Annals of Surgical Oncology, August 2014.

7. Randle RW, **Doud AN**, Levine EA, Clark CJ, Swett KR, Shen P, Stewart JH,
    Votanopoulos KI. Peritoneal Surface Disease with Synchronous Hepatic
    Involvement Treated with Cytoreductive Surgery (CRS) and Hyperthermic
    Intraperitoneal Chemotherapy (HIPEC). *Annals of Surgical Oncology*, August
    2014.

8. **Doud A**, Weaver A, Talton J, Barnard R, Meredith J, Stitzel J Miller P, Miller A.
    Has the Incidence of Thoracolumbar Spine Injuries Increased in the United States

From 1998 to 2011?. *Clinical Orthopaedics and Related Research,* August 2014.

9. **Doud A**, Hines M, Pranikoff T. <u>Management of Venous Bullet Embolus in a Child</u>. *The American Surgeon*, September 2014; 80(9):832-3.

10. **Doud A**, Swanson J, Ladd M, Neff L, Carter J, Holmes J. <u>Referral patterns in pediatric burn patients.</u> *The American Surgeon*, September 2014; 80(9):836-40.

11. Zeeshan S, Rubinfeld I, Patton J, Ritz J, Jordan J, **Doud A**, Velanovich V. <u>Using Procedural Codes to supplement risk adjustment: a nonparametric learning approach</u>. *J Am Coll Surg*. 2011 June; 212(6):1086-1093.

<u>Abstracts/Scientific exhibits/Presentations at national meetings:</u>

1. Doud A, Monafo A, Neff, L, Zeller K. "Vague Standards for American Society of Anesthesiologists Classification Lead to Inappropriate Risk Adjustment." Accepted for **poster presentation** at 2015 ACS NSQIP National Conference, July 25-28, Chicago, IL.

2. **Doud A**, Weaver A, Talton W, Barnard T, Schoell S, Petty J, Stitzel J. "Mortality Risk in Pediatric Motor Vehicle Crash Occupants: Accounting for Developmental Stage and Challenging Abbreviated Injury Scale Metrics." Accepted for **oral presentation**. 59th Association for the Advancement of Automotive Medicine Conference. October 2015, Philadelphia, PA.

3. **Doud, AN**; Hostetter, O; Gardner, A; Petty, J. **"**"A-OK": Chest Radiograph during Primary Survey Facilitates Faster, More Accurate Endotracheal Tube Position in Injured Children." **Poster presentation**. 46th Annual Meeting of the American Pediatric Surgical Association, April 30, 2015.

4. **Doud, AN**; Fitzgerald, N; Levine, E; Shen, P; Stewart, J; Votanopoulos, K. "Stoma Creation and Reversal after Cytoreductive Surgery with Heated Intraperitoneal Chemotherapy." **Oral presentation**. 10th Annual Academic Surgical Congress, February 4, 2015.

5. **Doud, AN**; Fitzgerald, N; Levine, E; Shen, P; Stewart, J; Votanopoulos, K. "Stoma Creation and Reversal after Cytoreductive Surgery with Heated Intraperitoneal Chemotherapy." **Oral presentation**. 10th Regional Perfusion Conference, February 14, 2015.

6. **Doud A**, Stitzel J, Weaver A, Talton W, Barnard T, Schoell S, Petty J. "Use of Age, Height and Weight to Predict Injury in Pediatric Advanced Automatic Crash Notification." **Oral Presentation**. First Annual Pediatric Trauma Society, November 14, 2014. Chicago, IL.

7. **Doud A**, Stitzel J, Weaver A, Talton W, Barnard T, Schoell S, Petty J. "Defining Severity, Time-Sensitivity and Predictability of Common Pediatric Injuries." **Oral Presentation**. First Annual Pediatric Trauma Society, November 15, 2014. Chicago, IL.

8. **Doud A**, Massengill K, Goodpasture M, Zeller K. "Prematurity and Neonatal Co-Morbidities as Risk Factors for Non-Accidental Trauma." **Oral Poster Presentation**. American Academy of Pediatrics National Meeting, Section on Surgery. October 11, 2014. San Diego, CA.

9. **Doud A**, Massengill K, Goodpasture M, Zeller K. "It's No Accident: Breastfeeding as a Protective Factor against Non-Accidental Trauma." **Poster Presentation**. American Academy of Pediatrics National Meeting, Section on Breastfeeding. October 13, 2014.

10. **Doud A**, Stitzel J, Weaver A, Talton W, Barnard T, Schoell S, Petty J. "Quantification of Injury Risk As Predicted by Age, Height and Weight in Pediatric Motor Vehicle Crash Occupants." **Poster Presentation**. American Academy of Pediatrics National Meeting, Section on Surgery. October 11-12, 2014.

11. **Doud A**, Hunter C, Chang M, Miller P. "An Institutional Review of the American Society of the Anesthesiologists Physical Status Classification." **Oral Presentation** at the North Carolina/South Carolina American College of Surgeons – Committee on Trauma & Acute Care Surgery Resident Paper competition, July 18, 2014.

12. **Doud A**, Weaver A, Talton J, Barnard R, Meredith J, Stitzel J Miller P, Miller A. "Incidence of Thoracolumbar Spine Injuries is Increasing in the United States." **Poster Presentation**. 30th Annual Meeting of the Orthopaedic Trauma Association, October 16-18, 2014.

13. **Doud A**, Hines M, Pranikoff T. "Management of Venous Bullet Embolus in a Child." **Poster Presentation**. Southeastern Surgical Congress, February 2014.

14. **Doud A**, Swanson J, Ladd M, Neff L, Carter J, Holmes J. "Pediatric Burn Centers: Are Children Being Appropriately Referred in North Carolina?" **Poster Presentation**. Southeastern Surgical Congress, February 2014.

15. **Doud A**., Boyd S. "Location of AVT Target Neurons in the Amphibian Hindbrain," **Poster Presentation**. SICB Conference, 01/06/2006, Orlando, FL

16. **Doud A**., Rubinfeld R. "Reproducibility of American Society of Anesthesiologists (ASA) as an Acuity Measure." **Poster Presentation**. 2009 ACS NSQIP National Conference

1. **Doud, A**. "Investigating Motor Vehicle Crash Injuries among Pediatric Occupants." Presented to Industrial Advisory Board, Center for Child Injury Prevention Studies, Columbus, OH, November 2013.

2. **Doud, A**. "Investigating Injuries Amongst Pediatric Occupants for use in an Advanced Automotive Crash Notification System." Presented to Industrial Advisory Board, Center for Child Injury Prevention Studies, Philadelphia, PA., April 2014.

3. **Doud, A**. "Investigating Motor Vehicle Crash Injuries among Pediatric Occupants." Presented at the Advances in Childhood Injury Prevention Conference, Plymouth, MI, May 2014.

4. **Doud A**. "Investigation Motor Vehicle Crash Injuries among Pediatric Occupants: Year 2 Update." Presented to Industrial Advisory Board, Center for Child Injury Prevention Studies, Columbus, OH. Nov 2014.

COMMUNITY ACTIVITIES AND SERVICE

Mistletoe Half Marathon (12/2013), Detroit Flagstar Half Marathon (10/2008 11th place, females 20-24), Detroit Flagstar Half Marathon (10/2009 14th place, females 25-30), Get Your Rear in Gear (03/2014); Matthew Gfeller Donut Run (10/2013), Detroit Turkey Trot (11/2008), Detroit Flagstar Marathon, Relay Team (10/2006), Reindeer Run (12/2006)