



AFRL-SA-WP-SR-2014-0007

Endotracheal Tube Cuff Management at Altitude



**SSgt Tyler J. Britton, RRT¹; Richard D. Branson, RRT²;
Thomas C. Blakeman, RRT²; Dario Rodriguez Jr.,
RRT¹; Capt Heather Ortiz, RN, FNP-C³;
Maj John Eggert, RN¹**

¹U.S. Air Force School of Aerospace Medicine, Air Force
Expeditionary Medical Skills Institute, C-STARS Cincinnati;
²University of Cincinnati, Department of Surgery; ³U.S. Air Force
School of Aerospace Medicine, Aeromedical Research Department



February 2014

**Distribution A: Approved for public
release; distribution is unlimited.
Case Number: 88ABW-2014-2163,
9 May 2014**

**Air Force Research Laboratory
711th Human Performance Wing
School of Aerospace Medicine
Air Force Expeditionary Med Skills Inst
C-STARS Cincinnati
2510 Fifth St.
Wright-Patterson AFB, OH 45433-7913**

NOTICE AND SIGNATURE PAGE

Using Government drawings, specifications, or other data included in this document for any purpose other than Government procurement does not in any way obligate the U.S. Government. The fact that the Government formulated or supplied the drawings, specifications, or other data does not license the holder or any other person or corporation or convey any rights or permission to manufacture, use, or sell any patented invention that may relate to them.

Qualified requestors may obtain copies of this report from the Defense Technical Information Center (DTIC) (<http://www.dtic.mil>).

AFRL-SA-WP-SR-2014-0007 HAS BEEN REVIEWED AND IS APPROVED FOR PUBLICATION IN ACCORDANCE WITH ASSIGNED DISTRIBUTION STATEMENT.

//SIGNATURE//

LT COL MICHAEL PETRO
Chief, C-STARS Cincinnati

//SIGNATURE//

COL BENJAMIN A. HARRIS
Chair, Air Force Expeditionary Med Skills Inst

This report is published in the interest of scientific and technical information exchange, and its publication does not constitute the Government's approval or disapproval of its ideas or findings.

REPORT DOCUMENTATION PAGE				<i>Form Approved</i> OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.					
1. REPORT DATE (DD-MM-YYYY) 5 Feb 2014		2. REPORT TYPE Special Report		3. DATES COVERED (From – To) June 2012 – December 2013	
4. TITLE AND SUBTITLE Endotracheal Tube Cuff Management at Altitude				5a. CONTRACT NUMBER FA8650-12-2-6B12	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) SSgt Tyler J. Britton, Richard D. Branson, Thomas C. Blakeman, Dario Rodriquez Jr., Capt Heather Ortiz, Maj John Eggert				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) University of Cincinnati Sponsored Research Services 51 Goodman Drive, Suite 530 Cincinnati, OH 45221-0222				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) USAF School of Aerospace Medicine Air Force Expeditionary Medical Skills Institute/C-STARS Cincinnati 2510 Fifth St. Wright-Patterson AFB, OH 45433-7913				10. SPONSORING/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S) AFRL-SA-WP-SR-2014-0007	
12. DISTRIBUTION / AVAILABILITY STATEMENT Distribution A: Approved for public release; distribution is unlimited. Case Number: 88ABW-2014-2163, 9 May 2014					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT Care of the mechanically ventilated patient during aeromedical transport presents a number of challenges owing to the impact of alterations in barometric pressure on gas volumes and gas density. Hypobarism reduces the partial pressure of oxygen in the atmosphere, which can lead to hypoxia and causes expansion of gas trapped in closed spaces. In the latter case, gas trapped in the body (pneumothorax, bowel gas) or in devices (endotracheal tube (ETT) cuffs, pneumatic tourniquets) expands during ascent and contracts on descent. We designed a model study of endotracheal intubation including mechanical ventilation and four methods of cuff pressure management during ascent and descent aboard a Critical Care Air Transport Team training flight. The results of this study confirm previous work demonstrating a significant rise in ETT cuff pressure during ascent to 8,000 feet. Our data also demonstrate that while filling the ETT cuff with saline reduces the impact of altitude-related changes in cuff pressure, the initial cuff pressure exceeds the pressure associated with interruption of mucosal blood flow. The passive-acting PressureEasy® device reduced the altitude-related change in pressure but did not eliminate the pressure changes, nor could it prevent the low pressures seen on descent.					
15. SUBJECT TERMS Endotracheal tube cuff, mechanical ventilation, aeromedical transport					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT SAR	18. NUMBER OF PAGES 15	19a. NAME OF RESPONSIBLE PERSON SSgt Tyler J. Britton
a. REPORT U	b. ABSTRACT U	c. THIS PAGE U			19b. TELEPHONE NUMBER (include area code)

This page intentionally left blank.

TABLE OF CONTENTS

Section	Page
LIST OF FIGURES	ii
LIST OF TABLES	ii
1.0 SUMMARY	1
2.0 INTRODUCTION	1
3.0 METHODS	1
4.0 RESULTS	3
5.0 DISCUSSION	5
6.0 LIMITATIONS	7
7.0 CONCLUSION	7
8.0 REFERENCES	7
LIST OF ABBREVIATIONS AND ACRONYMS	9

LIST OF FIGURES

Figure	Page
1 Model system including model trachea, ETT, test lungs, and ventilators	3
2 Continuous pressure monitoring of all four cuff management techniques using the 7.5 ETT.....	4
3 Continuous pressure monitoring of all four cuff management techniques using the 8.0 ETT.....	5

LIST OF TABLES

Table	Page
1 Changes in ETT Cuff Pressure during the Study.....	4
2 Comparison of Studies Evaluating the Impact of Changes on Cuff Pressures of Artificial Airways.....	6

1.0 SUMMARY

Care of the mechanically ventilated patient during aeromedical transport presents a number of challenges owing to the impact of alterations in barometric pressure on gas volumes and gas density. Hypobarism reduces the partial pressure of oxygen in the atmosphere, which can lead to hypoxia and causes expansion of gas trapped in closed spaces. In the latter case, gas trapped in the body (pneumothorax, bowel gas) or in devices (endotracheal tube (ETT) cuffs, pneumatic tourniquets) expands during ascent and contracts on descent. We designed a model study of endotracheal intubation including mechanical ventilation and four methods of cuff pressure management during ascent and descent aboard a Critical Care Air Transport Team training flight. The results of this study confirm previous work demonstrating a significant rise in ETT cuff pressure during ascent to 8,000 feet. Our data also demonstrate that while filling the ETT cuff with saline reduces the impact of altitude-related changes in cuff pressure, the initial cuff pressure exceeds the pressure associated with interruption of mucosal blood flow. The passive-acting PressureEasy® device reduced the altitude-related change in pressure but did not eliminate the pressure changes, nor could it prevent the low pressures seen on descent.

2.0 INTRODUCTION

Early aeromedical evacuation of critically injured patients has been a hallmark of the recent conflicts in the Middle East and is credited with improvements in outcomes (Ingalls N, Zonies D, Bailey JA, et al. A decade of care in the air: review of the first 10 years of critical care aeromedical transport during Operation Iraqi Freedom and Operation Enduring Freedom. Submitted for publication to JAMA Surg) [1,2]. Care of the mechanically ventilated patient during aeromedical transport presents a number of challenges owing to the impact of alterations in barometric pressure on gas volumes and gas density [3-5]. Hypobarism reduces the partial pressure of oxygen in the atmosphere, which can lead to hypoxia and causes expansion of gas trapped in closed spaces [6]. In the latter case, gas trapped in the body (pneumothorax, bowel gas) or in devices (endotracheal tube (ETT) cuffs, pneumatic tourniquets) expands during ascent and contracts on descent.

In previous investigations, the emphasis on ETT cuff management at altitude has been focused on prevention of high pressures following ascent [7-15]. A number of investigations have evaluated the change in cuff pressure and volume during actual or simulated flight at a variety of altitudes [8,9,11-16]. These investigations typically measure changes at two static points at sea level and the resulting altitude. Results of these studies focus on the avoidance of high pressures at altitude associated with reductions in mucosal blood flow [17]. However, descent is associated with cuff deflation and the passage of oropharyngeal secretions into the lower airway, a key component in the etiology of ventilator-associated pneumonia [18].

We designed a model study of endotracheal intubation including mechanical ventilation and four methods of cuff pressure management during ascent and descent aboard a Critical Care Air Transport Team (CCATT) training flight.

3.0 METHODS

The study was conducted at Lunken Airfield in Cincinnati, OH, while utilizing a C-130H airframe (U.S. Air Force, Kentucky Air National Guard) during routine CCATT

training flights. We evaluated cuff management techniques at sea level, 8,000 feet, and return to sea level. An altitude of 8,000 feet (representing a barometric pressure of 562 mmHg) was chosen to represent normal cabin altitude during CCATT flights. Lunken Airfield is at 483 feet above sea level, where barometric pressure was routinely 768 mmHg.

We tested two standard ETTs in the CCATT allowance standard commonly used for men (8.0-mm inner diameter (ID); Mallinckrodt Lo-Pro Oral/Nasal Tracheal Tube, Covidien, Mansfield, MA) and women (7.5-mm ID; Portex Clear PVC, Oral/Nasal, Soft Seal® Cuff Tracheal Tubes, Smiths Medical, Dublin, OH). Each flight used new ETTs for each experimental condition.

A model was built and outfitted with four flexible tracheal models (Laerdal Medical, Wappingers Falls, NY) with an ID of 22 mm. The tracheal models were then intubated using the 8.0-mm- and 7.5-mm-ID ETT. To simulate an in vivo tracheal model, the tubes were lubricated with Surgilube (Fougera Pharmaceuticals Inc., Melville, NY). The tracheal models were then connected to test lungs (Adult 190 1 Liter, Maquet, Rastatt, Germany) with standard corrugated tubing. A saliva substitute with specific gravity matching human saliva (Oralube Saliva Substitute 125 mL, Orion Laboratories, Balcatta, Australia) was placed above the cuffs. A 15-mL volume was used to simulate oropharyngeal secretions. A graduated cylinder was used to collect and measure the volume of saliva, if any, leaking around ETT cuffs.

To simulate the clinical environment, four transport ventilators (Model 731, Impact Instrumentation, West Caldwell, NJ) were used to ventilate each tracheal model using a manufacturer-supplied ventilator circuit. Ventilator settings were respiratory rate of 12, tidal volume of 450 mL, positive end expiratory pressure of 5 cm H₂O, inspiratory time of 1 second, and an FiO₂ of 21%. The tracheal models were attached to a board that was hung in a litter stanchion of the C-130H. The tracheal models were elevated to 30° to follow ventilator-associated pneumonia prevention protocol (Figure 1). ETT pilot balloons were then attached to a three-way stopcock. Pressure transducers (Edwards TruWave Disposable Pressure Transducer, Edwards Lifesciences, Irvine, CA) were attached to the opposite end of the three-way stopcock. Pressure transducers interfaced with a data logger (Sparx Engineering LLC, Manvel, TX), which recorded cuff pressures every second. The data logger had previously been approved for flight aboard the airframe.

ETT cuffs were managed using four methods:

1. Control – The ETT cuff was inflated with air to a pressure of 20-22 mmHg using a cuff pressure manometer (Rusch Endotest, Teleflex Inc., Limerick, PA) and not manipulated again.
2. Manual – The ETT cuff was inflated with air to a pressure of 20-22 mmHg using a cuff pressure manometer (Rusch Endotest, Teleflex Inc., Limerick, PA). At a cruising altitude of 8,000 feet, a respiratory therapist measured pressure and readjusted pressure to 20-22 mmHg. Upon descent, the cuffs were again adjusted to the standard pressure.
3. PressureEasy® Cuff Pressure Controller (Smiths Medical, Dublin, OH) – The PressureEasy® system was connected to the ETT pilot balloon and inflated through the device to a pressure of 20-22 mmHg and not manipulated again.

4. Saline – According to standard CCATT procedure, air was removed from the cuff and 10 mL saline inserted. The pressure was measured and the cuff was not manipulated again.



Figure 1. Model system including model trachea, ETT, test lungs, and ventilators.

During each flight, attendants were required to remain seated during ascent and descent; thus, manual cuff pressure management was restricted to cruising altitude and while on the tarmac. Measurements were obtained during three flights with each size ETT.

All pressures were continuously measured. The mean pressure over a period of 5 minutes was recorded prior to ascent, at cruising altitude, and after landing. Data are expressed as mean $\pm$ standard deviation and compared using a t-test (Microsoft Excel, Redmond, WA).

4.0 RESULTS

The mean pressure at baseline using the three techniques was 21 ± 1.3 mmHg. Saline inflation of the 8.0-mm-ID ETT resulted in a pressure of 48 ± 6 mmHg and 40 ± 2 mmHg in the 7.5 ETT. During flight, the highest cuff pressures were obtained with the control and manual management methods (Table 1). The smallest change in cuff pressure was seen during saline inflation (mean increase of 7.0 ± 0.8 mmHg in the 7.5 ETT and 7.6 ± 0.5 mmHg in the 8.0 ETT). The PressureEasy® device maintained a lower pressure than either the control or manual methods, with a mean increase of 19.3 ± 7.7 mmHg with the size 7.5 ETT and 11.3 ± 2.5 mmHg with the size 8.0 ETT.

After descent, cuff pressure using all three air-inflation techniques was lower than the first baseline measurement and below the pressure recommended to prevent aspiration of secretions around the cuff (Table 1). Pressure in the saline-filled tubes after descent was within 2 mmHg of the baseline pressure. Leakage of artificial saliva around the ETT cuff was not seen with any of the four techniques. The change in pressure per 1,000 feet of altitude with the air-filled cuffs was 8.1 ± 0.7 mmHg. The change in pressure per 1,000 feet of altitude with the

PressureEasy® device was 2.3 ± 0.9 mmHg. Using saline inflation, the mean change in pressure per 1,000 feet of altitude was 0.87 ± 0.02 mmHg. Figures 2 and 3 demonstrate continuous measurements of cuff pressures using all four methods with a 7.5-mm-ID and 8.0-mm-ID ETT.

Table 1. Changes in ETT Cuff Pressure during the Study

Method	Sea Level (Baseline) ^a		8,000 ft ^a		Sea Level (Post-Flight) ^a	
	7.5 mm	8.0 mm	7.5 mm	8.0 mm	7.5 mm	8.0 mm
Control (mmHg)	21±0.8	20±1.1	85±0.8 ^b	85±0.6 ^b	9±0.3 ^b	8±0.6 ^b
Manual (mmHg)	21±0.7	20±1.5	82±1.1 ^b	84±0.4 ^b	5±0.8 ^b	4±0.4 ^b
PressureEasy® (mmHg)	21±0.8	21±1.4	39±8.9 ^b	36±1.6 ^b	14±2.4 ^b	14±3.2 ^b
Saline (mmHg)	40±2.1	63±6.0	47±1.1 ^c	68±2.9 ^c	37.5±1.4	60±3.3

^aData are mean ± standard deviation.

^bp<0.001 compared to baseline.

^cp<0.01 compared to baseline.

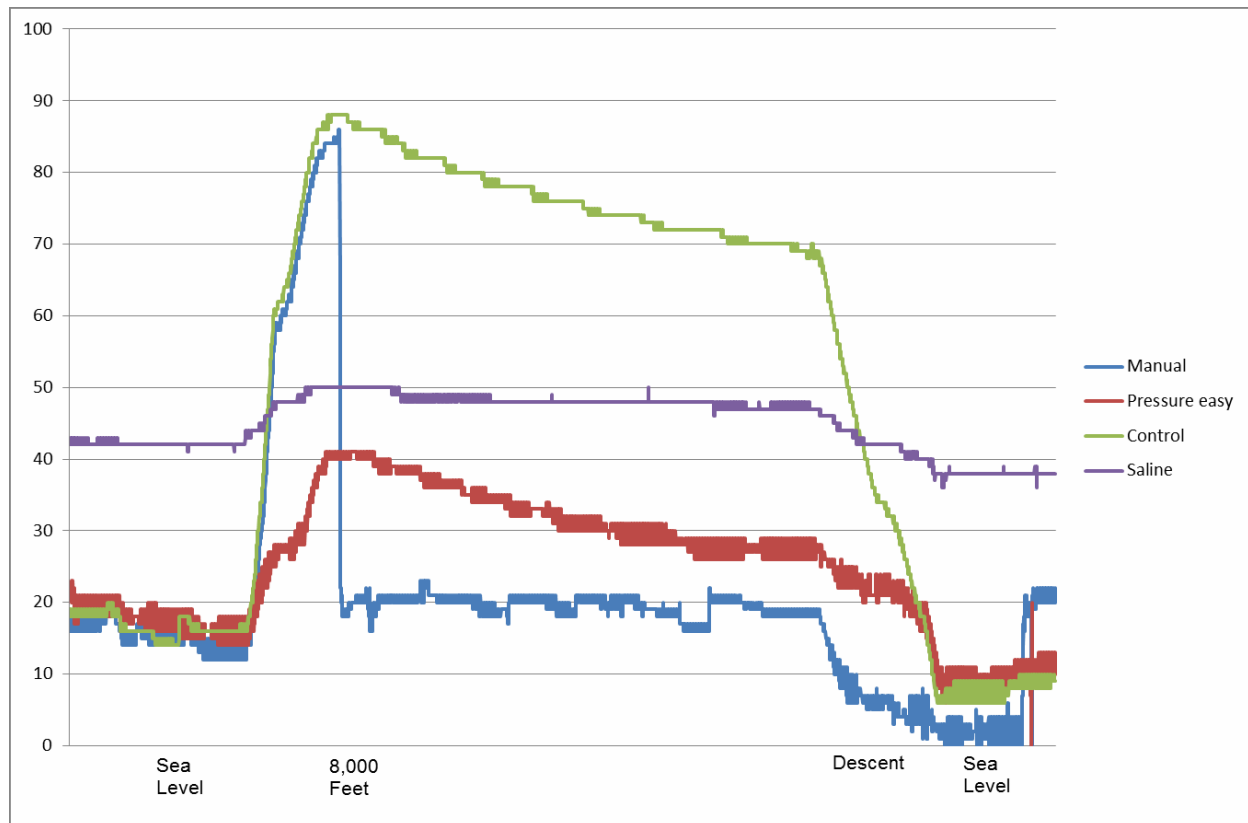


Figure 2. Continuous pressure monitoring of all four cuff management techniques using the 7.5 ETT.

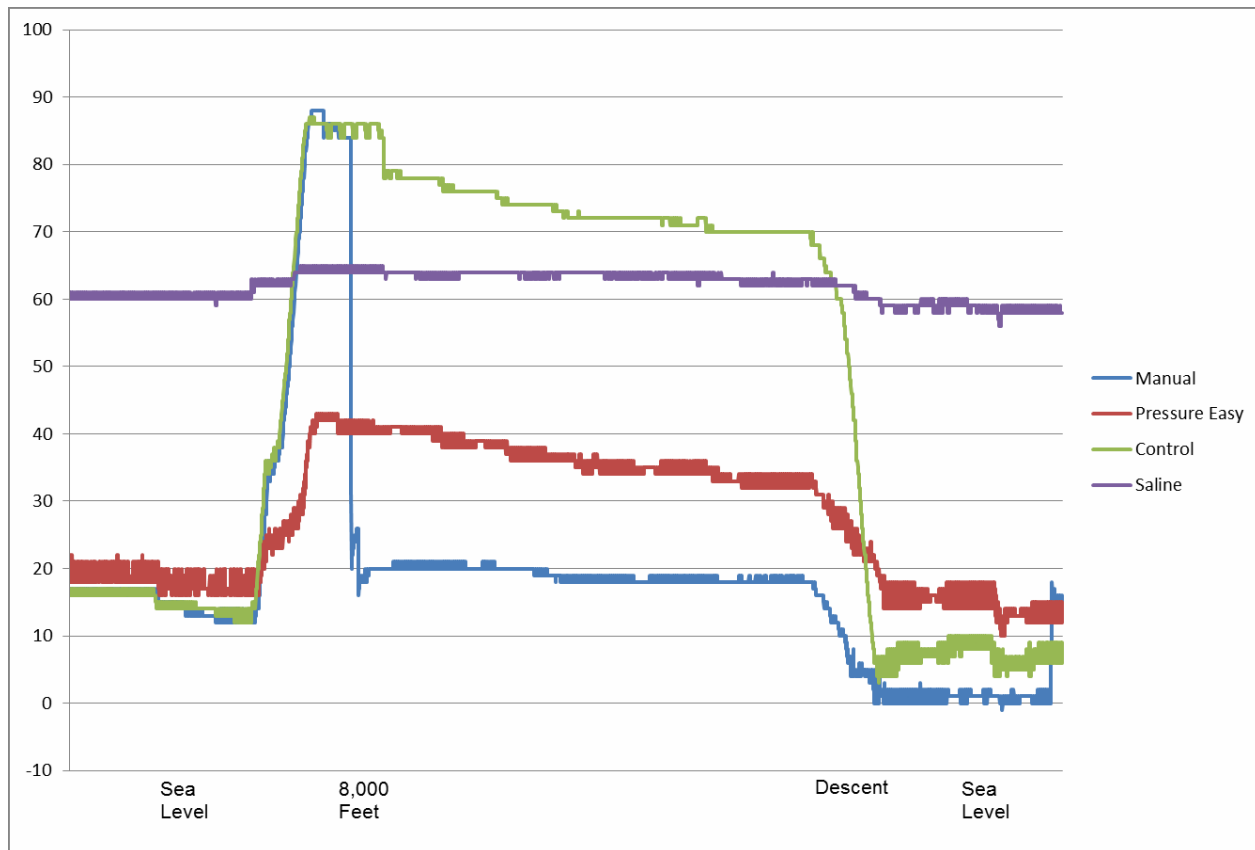


Figure 3. Continuous pressure monitoring of all four cuff management techniques using the 8.0 ETT.

5.0 DISCUSSION

The results of this study confirm previous work demonstrating a significant rise in ETT cuff pressure during ascent to 8,000 feet. Our data also demonstrate that while filling the ETT cuff with saline reduces the impact of altitude-related changes in cuff pressure, the initial cuff pressure far exceeds the pressure associated with interruption of mucosal blood flow. The passive-acting PressureEasy® device reduced the altitude-related change in pressure but did not eliminate the pressure changes, nor could it prevent the low pressures seen on descent.

An important finding of our study is the reduction in cuff pressures during and following descent. In fact, the pressures were lower than at baseline. Our observation of the cuffs suggests that the high pressures at altitude stretch the cuff, resulting in lower pressures after descent despite no change in the volume of air. In all three techniques using air-filled cuffs, the pressure upon landing falls below the threshold typically required to prevent aspiration of secretions around the cuff. These findings have important clinical implications, as cuff pressures < 25 cm H₂O are associated with the development of ventilator-associated pneumonia [19,20]. We did not experience any leakage of fluid around the cuffs using any cuff management method during the short period of reduced pressure after landing (approximately 10 minutes). However, our model included lubrication of the cuffs and the use of 5 cm H₂O positive end expiratory pressure, both of which have been shown to reduce or prevent leakage around the cuff in analog

models [21]. The increase in ETT cuff pressure at altitude is easily explained by Boyle's law. Boyle's law states that at a constant temperature, pressure is inversely proportional to volume. Commonly written as $PV \propto k$, P is pressure, V is volume, and k is a constant. With respect to the ETT cuff, the law can be written as $P_1V_1 = P_2V_2$. The decrease in barometric pressure at altitude results in a nearly linear change in volume, increasing the cuff pressure within the trachea. Table 2 compares studies evaluating the impact of altitude on cuff pressures and volume. Both patient and model studies demonstrate predictable increases in cuff pressure and volume. In studies where the tube and cuff are tested outside of a model or patient, the pressure changes are smaller. When the tubes are placed in the patient or in a model, the restriction of the cuff volume expansion results in higher measured pressures. This explains much of the disparity in the results of these trials.

Table 2. Comparison of Studies Evaluating the Impact of Changes on Cuff Pressures of Artificial Airways

Author	Device	Method	Cuff Measurement	Subject	Altitude Method/Height (ft)	Outcome
Smith [8]	ETTs	Air filled	Pressure	Tracheal model	Chamber/10,000	Cuff pressure > 100 cm H ₂ O at 8,000 ft
Henning [9]	ETTs	Air filled	Pressure	10 adults	Fixed wing/3,000	Cuff pressure 45 cm H ₂ O at 3,000 ft
Mann [11]	ETTs LMA	Air filled	Diameter	Bench top	Rotor wing/10,000	Cuff diameter increased by 4.5 mm at 10,000 ft
Wilson [12]	LMA	Air filled	Pressure	Adult & infant mannequin	Fixed wing/6,000 Rotor wing/2,200	Cuff pressure > 120 cm H ₂ O at 5,000 ft
Miyashiro [13]	ETTs LMA	Air filled	Pressure	Tracheal model	Ground ascent/ 7,874	Cuff pressure > 80 cm H ₂ O at 8,000 ft. In vitro pressures 30% greater than bench top
Law [14]	ETTs LMA LT Combitube	Air and water filled	Volume (volume displacement)	Bench top	Chamber/15,000	Cuff volume constant with saline-filled cuffs
Brendt [15]	ETTs	Air filled	Pressure	35 adults	Fixed wing/3,594 ^a	Cuff pressures exceed 40 cm H ₂ O at 3,000 ft
Bassi [16]	ETTs	Air filled	Pressure	114 patients	Rotor wing/2,260 ^a	Cuff pressure doubled at altitude, 72% were > 50 cm H ₂ O

Note: LMA = laryngeal mask airway; LT = laryngeal tube.

^aMean value.

We noted that it is difficult to completely empty the cuff of air and then fill it with saline. During initial model development, we noted that if a small amount of air remained in the cuff along with the saline, pressures as high as 80 mmHg could be measured at altitude. We believe the presence of 2-4 mL of air within the non-compressible saline creates these high pressures and uneven inflation of the cuff. Most ETT manufacturers warn against saline inflation, as the saline is difficult to remove and can lead to cuff wear and rupture. Additionally, a single 10-mL filling volume is associated with excessive pressures at sea level.

6.0 LIMITATIONS

Our study uses a mechanical model to simulate the trachea and may not accurately represent the human anatomy. The size and shape of the trachea vary widely and the size of the tracheal diameter relative to the internal diameter of the ETT and cuff can alter the volume required to create an effective seal [22]. Ventilator settings can also alter cuff pressures. Our model only used a single set of ventilator parameters and lung model characteristics.

7.0 CONCLUSION

Management of the ETT cuff at altitude remains a challenge for civilian and military operations. The use of a single inflation with 10 mL of saline avoids pressure changes at altitude, but pressure at sea level exceeds the pressure associated with tracheal mucosal blood flow occlusion. Additionally, most ETT manufacturers warn against saline inflation. Manual adjustment is limited by access to the patient. A passive device helps ameliorate the high pressures, but cannot prevent low pressures on descent, which may lead to aspiration of secretions above the cuff. Closed loop control of cuff pressure may represent an answer to management at altitude, but should be tested in a tactical environment [23].

8.0 REFERENCES

1. Fang R, Dorlac GR, Allan PF, Dorlac WC. Intercontinental aeromedical evacuation of patients with traumatic brain injuries during Operations Iraqi Freedom and Enduring Freedom. *Neurosurg Focus* 2010; 28(5):E11.
2. Dorlac GR, Fang R, Pruitt VM, Marco PA, Stewart HM, Barnes SL, et al. Air transport of patients with severe lung injury: development and utilization of the Acute Lung Rescue Team. *J Trauma* 2009; 66(4 Suppl):S164-71.
3. Rodriguez D Jr, Branson RD, Dorlac W, Dorlac G, Barnes SA, Johannigman JA. Effects of simulated altitude on ventilator performance. *J Trauma* 2009; 66(4 Suppl):S172-7.
4. Barnes SL, Branson R, Gallo LA, Beck G, Johannigman JA. En-route care in the air: a snapshot of mechanical ventilation at 37,000 feet. *J Trauma* 2008; 64(2 Suppl):S129-34.
5. Lawless N, Tobias S, Mayorga MA. FiO₂ and positive end-expiratory pressure as compensation for altitude-induced hypoxemia in an acute respiratory distress syndrome model: implications for air transportation of critically ill patients. *Crit Care Med* 2001; 29(11):2149-55.
6. Muhm JM, Signal TL, Rock PB, Jones SP, O'Keeffe KM, Weaver MR, et al. Sleep at simulated 2438 m: effects on oxygenation, sleep quality, and postsleep performance. *Aviat Space Environ Med* 2009; 80(8):691-7.
7. Ruth MJ. Pressure changes in tracheal tube cuffs at altitude. *Anaesthesia* 2002; 57(8):825-6.
8. Smith RP, McArdle BH. Pressure in the cuffs of tracheal tubes at altitude. *Anaesthesia* 2002; 57(4):374-8.
9. Henning J, Sharley P, Young R. Pressures within air-filled tracheal cuffs at altitude--an in vivo study. *Anaesthesia* 2004; 59(3):252-4.
10. Lowes T. Pressures within air-filled tracheal cuffs at altitude. *Anaesthesia* 2004; 59(9):919-20.

11. Mann C, Parkinson N, Bleetman A. Endotracheal tube and laryngeal mask airway cuff volume changes with altitude: a rule of thumb for aeromedical transport. *Emerg Med J* 2007; 24(3):165-7.
12. Wilson GD, Sittig SE, Schears GJ. The laryngeal mask airway at altitude. *J Emerg Med* 2008; 34(2):171-4.
13. Miyashiro RM, Yamamoto LG. Endotracheal tube and laryngeal mask airway cuff pressures can exceed critical values during ascent to higher altitude. *Pediatr Emerg Care* 2011; 27(5):367-70.
14. Law J, Bair A, Capra J, Holder A, Allen R. Characterization of airway device cuff volumes at simulated altitude. *Aviat Space Environ Med* 2011; 82(5):555-8.
15. Brendt P, Schnekenburger M, Paxton K, Brown A, Mendis K. Endotracheal tube cuff pressure before, during, and after fixed-wing air medical retrieval. *Prehosp Emerg Care* 2013; 17(2):177-80.
16. Bassi M, Zuercher M, Erne JJ, Ummerhofer W. Endotracheal tube intracuff pressure during helicopter transport. *Ann Emerg Med* 2010; 56(2):89-93.
17. Seegobin RD, van Hasselt GL. Endotracheal cuff pressure and tracheal mucosal blood flow: endoscopic study of effects of four large volume cuffs. *Br Med J (Clin Res Ed)* 1984; 288(6422):965-8.
18. Kollef MH. Ventilator-associated complications, including infection-related complications: the way forward. *Crit Care Clin* 2013; 29(1):33-50.
19. Sierra R, Benítez E, León C, Rello J. Prevention and diagnosis of ventilator-associated pneumonia: a survey on current practices in Southern Spanish ICUs. *Chest* 2005; 128(3):1667-73.
20. Blot S, Rello J, Vogelaers D. What is new in the prevention of ventilator-associated pneumonia? *Curr Opin Pulm Med* 2011; 17(3):155-9.
21. Zanella A, Scaravilli V, Isgrò S, Milan M, Cressoni M, Patroniti N, et al. Fluid leakage across tracheal tube cuff, effect of different cuff material, shape, and positive expiratory pressure: a bench-top study. *Intensive Care Med* 2011; 37(2):343-7.
22. Mackenzie CF, McAslan TC, Shin B, Schellinger D, Helrich M. The shape of the human adult trachea. *Anesthesiology* 1978; 49(1):48-50.
23. Valencia M, Ferrer M, Farre R, Navajas D, Badia JR, Nicolas JM, et al. Automatic control of tracheal tube cuff pressure in ventilated patients in semirecumbent position: a randomized trial. *Crit Care Med* 2007; 35(6):1543-9.

LIST OF ABBREVIATIONS AND ACRONYMS

CCATT	Critical Care Air Transport Team
ETT	endotracheal tube
ID	inner diameter