Endotracheal Tube and Laryngeal Mask Airway Cuff Pressures Can Exceed Critical Values During Ascent to Higher Altitude

Renee M. Miyashiro, MD and Loren Yamamoto, MD, MPH, MBA, FAAP, FACEP
Pediatrics, University of Hawaiʻi John A. Burns School of Medicine and Kapiʻolani Medical Center for Women & Children, Honolulu, HI

Background

Aeromedical transport is an important means of transporting critically ill and mechanically ventilated patients to tertiary care facilities. Some transport aircraft are unpressurized and some pressurize the cabin to sea level. Commercial passenger jets and many aeromedical transport aircraft maintain cabin pressures between 1700 and 2500 meters of equivalent altitude. Unpressurized helicopter transports fly at about 1700 meters. During ascent, ambient pressure decreases and any fixed volume of gas will expand, therefore increasing the relative pressure in a contained volume of gas. Air filled endotracheal tube (ETT) and laryngeal mask airway (LMA) cuffs are subject to pressure changes during altitude ascent and descent. It has been shown that tracheal mucosal perfusion is compromised at an ETT cuff pressure of 30 centimeters of water (cmH20), and blood flow is completely obstructed at a pressure of 50 cmH20. Complications of overinflation of the cuff include hoarseness, dysphasia, sore throat, inflammation, ulceration, granulation, and stenosis and ischemia of tissue at the site of the ETT cuff. In addition, underinflation with a cuff pressure less than 27 cmH20 can result in aspiration, ventilator associated pneumonia, and improper ventilation of the patient4. LMAs are frequently used for emergent respiratory assistance, when an airway cannot be secured with an ETT. The manufacturer recommendation of the LMA Classic warns against using intracuff pressures over 60 cmH20. Overinflation of the LMA cuff can lead to ischemia of the tongue and oropharynx, and both overinflation and underinflation results in displacement of the cuff and hypoventilation of the patient.

The pressure measured within the ETT and LMA cuff is equivalent to that exerted on the adjacent mucosa. A previous study confirmed that ETT cuff size diameters increase with increasing altitude. Methods to estimate ETT cuff pressures include: a) the minimal occlusive volume technique (a volume of air is injected into the cuff until there is no or minimal audible air leak detected when giving positive pressure ventilation), b) the predetermined volume technique (a preselected volume of air is used to inflate the ETT regardless of situation), c) the palpation technique (the ETT is inflated with air and the cuff pilot balloon is palpated as a gross indication of intracuff pressure). These techniques have been shown to be unreliable at accurately determining ETT cuff pressure, and therefore result in overinflation or underinflation of the cuff. Direct measurement of pressure within the cuff with a manometer is the most accurate measurement method to prevent overinflation and underinflation6.

The purpose of this study is to measure the change in pressure within ETT and LMA cuffs at varying altitudes to determine when adjustments in ETT and LMA cuff pressure might be necessary during aeromedical transport.

Methods

We measured the change in pressure of the inflated cuffs of 6.0 and 7.5 ETTs and a size 4 laryngeal mask airway (LMA) from sea level to 2400m. The ETTs and LMA cuff measurements were done with the devices uncontained, but an additional 6.0 ETT was placed in a 10 ml syringe barrel to mimic placement in a trachea. This latter model restricted cuff expansion simulating what would occur when it is placed within the trachea.cuff pressure might be necessary during aeromedical transport.

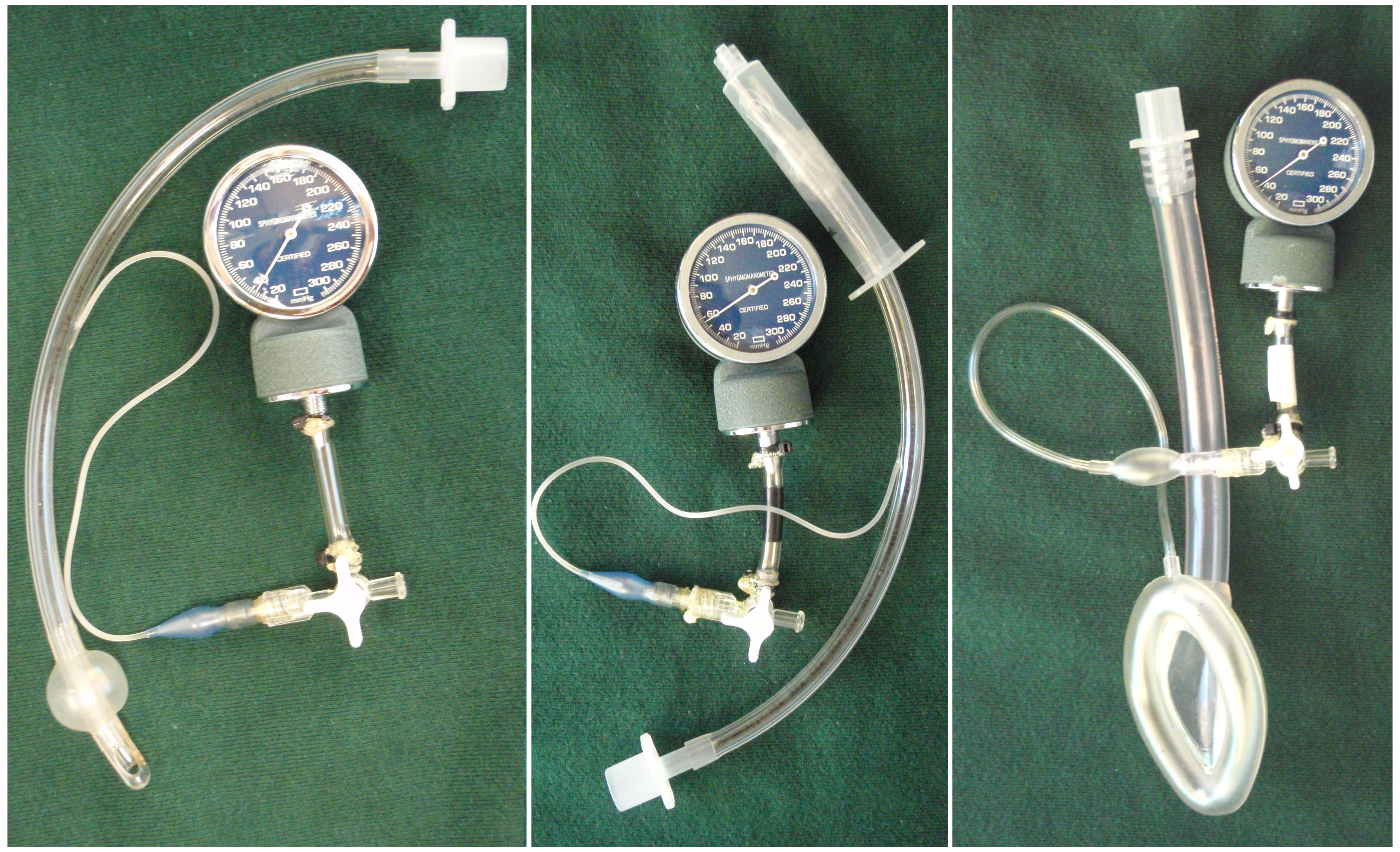
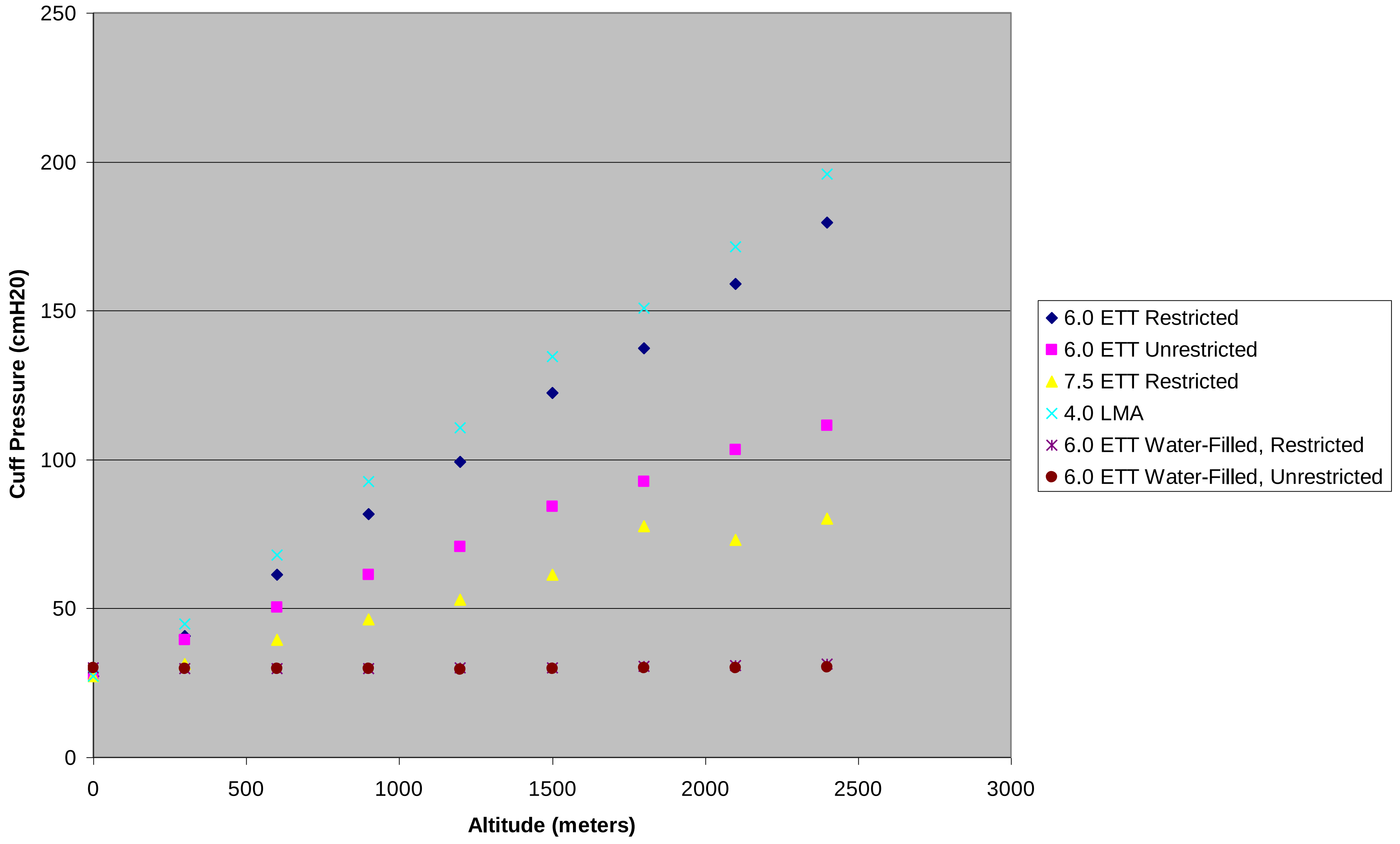


Figure 1: Aneroid manometers were permanently affixed to the ETT and LMA cuffs after initial inflation to 20 mmHg. Left-6.0 ETT unrestricted cuff. Center-6.0 ETT and cuff contained within a syringe barrel. Right-LMA.

Results

By linear regression, the pressure within the ETT cuffs increased with elevation by 3.0 cmH2O (6.5 ETT), 2.1 cmH2O (7.5 ETT), 7.4 cmH2O (LMA), and 6.4 cmH2O (6.5 ETT contained within trachea) per 100m of increasing elevation. Note that pressure increases faster when the ETT cuff is contained within the rigid syringe barrel because cuff size expansion is restricted. The trachea is not as rigid as the syringe barrel, thus, the ETT cuff pressure within the trachea should increase at a rate of somewhere between 3.0 and 6.4 cmH2O per 100m. Starting at an ETT cuff pressure of 20 cmH2O would result in a pressure of 50 cmH2O (the critical value) between 468 and 1000m elevation. At a typical flight altitude of 2000 meters, the ETT cuff pressure would increase to a pressure between 80 and 148 cmH2O. LMA cuff pressures increase more rapidly despite being unrestricted because of the greater thickness (lower compliance) of the plastic comprising the cuff.

Figure 2 Changes in cuff pressure with changes in altitude



Discussion

This model indicates that ETT and LMA cuffs inflated prior to air transport are likely to exceed critical pressure levels rapidly during flight, and cuff pressures will decline during descent resulting in a compromised cuff seal, unless the cuff pressures are adjusted during ascent or descent, to maintain an appropriate cuff pressure. Starting at an ideal cuff pressure of 27 cmH2O at sea level, this model predicts the 6.0 ETT critical cuff pressure of 50 cmH2O (that potentially compromises mucosal perfusion) is reached at an altitude between 400 meters (syringe barrel restricted ETT cuff) and 600 meters (unrestricted ETT cuff). Another study using unrestricted 8.0 and 9.0 ETT cuffs demonstrated cuff pressures of 50 cmH2O were reached between 550 and 865 meters altitude8. These were larger ETTs and the cuffs were unrestricted, which accounts for the higher altitudes for this study. Our study confirms the expectation that cuffs that are restricted by an external tube such as a syringe barrel or trachea would reach the critical pressure sooner during ascent (i.e., at a lower altitude) compared to an unrestricted ETT cuff. Our study also confirms the expectation that smaller cuffs would reach the critical pressure sooner during ascent (at a lower altitude) compared to larger cuffs.

The pressure data on the water filled ETT cuff demonstrates that the pressure does not change significantly with altitude which potentially justifies the recommendation to inflate cuffs with saline instead of air5. However, it has been shown in a previous study that saline was an impractical choice for clinical use in emergent situations as it was difficult to evacuate all air from the cuff and it took considerably longer to inflate and secure the ETT8. This is consistent with our observation that filling an ETT cuff with water and removing most of the air was time consuming.

The LMA cuff was unrestricted, yet its pressure slope was higher than that of the restricted ETT cuff. This occurred because the thickness of the LMA cuff bladder material was greater than the cuff material of the ETT.

Conclusion

This model indicates that ETT cuffs inflated prior to air transport are likely to exceed critical pressure levels rapidly during flight. Additionally, there will be loss of ETT cuff pressure, with loss of a good seal, during descent if a cuff is initially inflated at peak altitudes. Therefore we suggest ETT cuff pressures should be monitored and adjusted continuously during ascent and decent.