Endotracheal Tube and Laryngeal Mask Airway Cuff Pressures Can Exceed Critical Values During Ascent to Higher Altitude
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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 (cmH2O), and blood flow is completely obstructed at a pressure of 50 cmH2O. 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 cmH2O can result in aspiration, ventilator associated pneumonia, and improper ventilation of the patient. 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 cmH2O.

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 cuff and 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.

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 (trachea, barrel restricted) 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 altitude. 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 air. 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 ETT. This is consistent with our observation that filling an ETT cuff with water and removing most of the air was time consuming.

LMA cuffs were 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.

Figure 2 Changes in cuff pressure with changes in altitude

Conclusion
This model indicates that ETT 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. Therefore we suggest ETT cuff pressures should be monitored and adjusted continuously during ascent and decent.