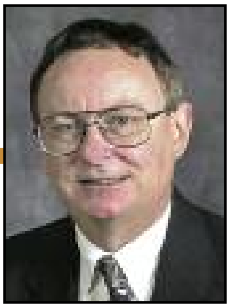

AEROSOLS WITH VENTILATORS – ALL THE NOOKS AND CRANNIES

Michael McPeck BS RRT FAARC

This is the second in a series of articles devoted to aerosol delivery during mechanical ventilation. In the previous installment, we set the stage for this series by stipulating that patients on ventilators may require aerosolized medications. Although this is sometimes debatable, we will assume it to be the case for the purpose of discussing techniques, limitations and peculiarities of administering drugs to the lungs during ventilator support. We also did a little reminiscing and recalled that the side-stream vs. mainstream controversy began in the late 1960s and doesn't really have a great deal of relevance today because it's not so much a clinical choice that we make, but a device type choice. We closed that installment by posing a list of other factors that influence the quality of aerosol delivery during mechanical ventilation along with a promise to explore them all in subsequent issues. So, in this issue, we will tackle one of the most fundamental of issues relating to aerosol delivery during mechanical ventilation, namely, what is the effect of the tracheotomy tube (trach) or endotracheal tube (ETT) on aerosol delivery and deposition? It may seem practically axiomatic that aerosol deposition in the lung is reduced due to aerosol deposition in the artificial tracheal airway. Recalling our physics and fundamental pulmonary physiology training, we are all familiar with the relationships between flow and driving pressure versus the resistive characteristics of the conduit through which we are attempting to maintain fluid flow. For the sake of this discussion, the conduit of which we speak is the artificial tracheal airway, either a trach or an ETT. The restricted diameter of either of these tubes is generally the first substantial downstream resistive element that the flow of gas or aerosol through a ventilator circuit encounters. Every time we operate a ventilator, we contend with the phenomenon that, when we attempt to direct a flow of gas through a smaller orifice or smaller pathway, such as the trach or ETT, the flowrate will diminish unless the driving pressure is increased. In certain modes of ventilation driving pressure is automatically increased as needed. Generally, increasing the driving pressure not only increases the flow but may change its characteristic from laminar to turbulent. We cannot see laminar flow or turbulent flow with the naked eye, but most of our textbooks have conditioned us with such compelling artist's renditions that we take it on faith that these phenomena are indeed at play. So, when it comes to imagining the fate of aerosol particles coursing through a ventilator circuit and an artificial tracheal airway, it is not difficult to assume that such a sufficient number of aerosol particles will impact the lateral wall of the airway that aerosol delivery to the lungs will be compromised. But is this really the case?

What is the effect of the tracheotomy tube (trach) or endotracheal tube (ETT) on aerosol delivery and deposition?

The extent to which artificial tracheal airways diminish aerosol delivery to the lung is not so clear, in part because there are also a large variety of other factors at work that influence aerosol delivery in and of themselves. In fact, the trach tube or ETT may or may not be a substantial barrier to aerosol passage depending on a large array of confounding factors. In other words, there are situations in which the artificial airway is a major barrier, and situations in which it is not. I am unable to be any more specific than that. It depends, of course, on the diameter, length, and even the shape of the airway; that is, whether it is gently curved (such as a trach tube) or has one or more acute bends (such as a kinked ETT). But the major factor is the inside diameter (ID). Another thing both these airways have in common is that they may be connected to the ventilator circuit by way of a right-angle elbow adapter. Even though the ID of the elbow adapter may be as large or large than the ID of the tracheal airway to which it is connected, it has been shown in many cases to be a greater barrier to aerosol than the trach or ETT itself. This is almost exclusively due to the right angle turn. And finally, median particle size appears to play a similar role with respect to impaction and deposition in the artificial tracheal airway, just as it does in the physiologic airway within the lung.

If you twisted my arm for some numbers, I could summon up only a small amount of data from the few of papers in the literature on this topic. One says that

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I was self-employed. But when things got slow, I let myself go."

for pediatric ETTs between 3 and 6 mm ID, the narrower the ID, the greater the deposition within the tube and, hence, the lower the mass of drug delivered to the lung. For adult mechanical ventilation with ETTs between 7 and 9 mm ID, another study found no difference in drug mass delivery, expressed as a percentage of the nebulizer charge. Although we are dogmatically taught that optimum particle size is between 3 and 5 microns, other studies have shown that devices that produce particles less than 2 microns are more efficient during mechanical ventilation.

Approximately 3 years ago I performed some bench testing of a proprietary proof-of-concept device that was designed with the aim of increasing the efficiency of pneumatic jet nebulizers placed in ventilator circuits. Although the primary data I was seeking was the "Inhaled Mass" in the "lung," (amount of drug deposited in an absolute filter at the end of an 8 mm ID ETT), I was able to directly measure the amount of aerosol deposited in the ETT (by using a radioactive tracer and placing the entire ETT in the measuring device). The ventilator was a Drager E4 with two different adult breathing patterns ventilating a Michigan TTL test lung; the nebulizer was a CIS-US Aerotech 2 with an MMAD of ~1.0 micron, operating from a continuous source of oxygen at 8 L/min and charged with 3 mL of 0.083% albuterol with a technetium radiolabel; the nebulizer was tee'd into the inspiratory circuit 12 inches proximal to the ventilator Y; and the humidifier was not used. Four bench runs were conducted at each of the two breathing patterns (n=8). ETT deposition ranged from 1.9 – 4.8% of the nebulizer charge (mean ± SD = 3.2% ± 0.8%) while "lung" deposition ranged from 11.2 – 16.3% of the nebulizer charge (mean ± SD = 13.7% ± 2.0%). Plotting the 8 pairs of data points against each other for linear regression shows absolutely no correlation, although there was a stronger correlation of "lung" deposition to breathing pattern (larger tidal volume). Admittedly, this is merely a tiny amount of coincidental data teased out of a study that examined something else. But it does tend to support one of the literature's scarce papers that suggested that ETTs between 7 and 9 mm ID make no difference with respect to aerosol delivery. The mean amount of albuterol that was delivered to the filter representing the lung (13.7% ± 2.0%) was not much different than the amount known to be delivered by typical nebulizers used noninvasively with a mouthpiece. It would therefore appear that ventilator delivery of aerosol medication through an adult ETT was not diminished due to the ETT. But I must warn that we should not draw the same conclusions for aerosol delivery during mechanical ventilation with pediatric ETTs and breathing patterns. Pediatric aerosol delivery is extremely correlated against breathing pattern (particularly tidal volume and minute volume) which confounds any assumptions we might make about the influence of the artificial airway. Aerosol assumptions are generally wrong. This is an area where further bench studies could be useful.

So, if we were asked to sum up the issue of aerosol deposition inside the trach or ETT, would we be able to quantify it? The answer is no, the best we can do is grossly generalize: aerosol deposition in the lung might be negatively affected by increased deposition inside the artificial airway which, in turn, might be negatively affected by increased flowrate, decreased ID of the tube or increased median size of the aerosol particles. And vice versa.

Mike McPeck, RRT, FAARC is a veteran therapist, lecturer and author considered by many to be a leading expert on the use of Aerosols in medicine. He can be reached at michael.mcpeck@gmail.com