



AEROSOLS WITH VENTILATORS

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In the previous installment in this series about delivering aerosolized medication during mechanical ventilation I addressed the effect of humidification on aerosol delivery. I touched on the phenomenon of hygroscopic growth of aerosol drug particles in a hot humid circuit which may cause some particles to rain out in the circuit thereby diminishing delivery. I further explored the options that we have to deal with this phenomenon and indicated my preference was to leave the humidifier on and in the circuit and deal with the reduced drug delivery by other means, at least for bronchodilators. After that article was published, I received an e-mail from the industry side of our profession pointing out that a new humidification technology based upon the principle of capillary force humidification has recently been introduced. The device can apparently be used in a ventilator circuit or

in an open-ended mode such as with a nasal cannula at high flowrates. When used in a ventilator circuit, one of the advantages is that it can turn on or off instantaneously. When switched off, no heat or humidification is delivered. When switched on, it heats and humidifies instantly and reaches 37° C within about

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20 seconds. An auto-suspend mode turns the heat and humidity off, so an aerosolized medication treatment can be administered into a dry, cool ventilator circuit, and then automatically turns heat and humidity back on again after 2, 10, or 15 minutes. The advantages of nearly instant cooling, or instant heating, along with quickly achieving the appropriate level of heat and humidification, bodes well for use in mechanical ventilator circuits. The obvious scenario would be to place the device into auto-suspend mode as the aerosol treatment commences. This will drop the heat and humidity and presumably reduce the impediment to aerosol delivery caused by hygroscopic growth in a hot and humid circuit. At the end of the predetermined time, the device will switch back on and very quickly provide heat and humidity once again – automatically, without therapist intervention – thereby eliminating the possibility of deriving the patient of humidification. Some bench work has already been undertaken in this area and will undoubtedly be made available by the vendor. In addition, this device was reviewed in the *Sept/Oct 2008* issue of this Journal.

At this point in this series, I would like to review a few of the key papers that have improved our understanding of the topic of aerosol delivery during mechanical ventilation. The one that, in my mind, kicked off our inquisitiveness about aerosol delivery during mechanical ventilation was by Hughes & Saez in 1987. Prior to this paper many well-meaning RTs simply assumed that the closer you placed the nebulizer to the airway opening in a ventilator circuit, the better the aerosol delivery to the patient. However, this well-constructed bench study, at its time, showed that this was not necessarily the case. It seems that by placing the nebulizer in the inspiratory tubing at what was known as the “manifold position,” approximately 18 inches from the Y piece, aerosol delivery was greater than if the nebulizer had been placed immediately in front of the Y piece. One of the reasons cited for this is the “reservoir effect” that the inspiratory tubing imparted to aerosol drug delivery. However, I think this is a slight misnomer; a “reservoir” would imply that particles are held or stored, but this is surely not the case in a dynamic ventilator circuit. I believe it has been subsequently shown by other investigators that by emitting the nebulizer output into the inspiratory tubing at some distance away from the Y piece, instead of almost directly into the Y piece, the velocity of the particles slows and the particles assume the inspiratory flow velocity of the bulk gas flow. This, in turn, transports a greater density of particles into the patient without the untoward effects of turbulence and inertia causing the particles to prematurely impact within the circuit. Emitting the nebulizer output directly into the Y piece would no doubt cause a great deal of impaction within the Y piece. So, it is less a reservoir effect and more of an effect on particle velocity and impaction.

Another aspect of our dogma at the time was also challenged by the Hughes and Saez study. They also investigated aerosol delivery during continuous versus intermittently operated nebulization. Again, dogma would have predicted that the continually running nebulizer would achieve the greatest aerosol delivery, but it turned out not to be true. Dogma again assumed a reservoir effect in the inspiratory tubing proximal to the Y piece and also in the expiratory tubing distal to the Y piece. But it turned out that the continually running nebulizer simply tended to waste more of the medication that had been nebulized and brought to our attention the effect of the



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“breathing pattern” (rate, tidal volume and inspiratory time or I:E ratio) on efficiency of aerosol delivery. Thus, we learned that, at least for the so-called “second generation” ventilators at that time, intermittently operated nebulizers, powered by the ventilator, were more efficient than running the nebulizer continuously. And the breathing pattern mattered.

By 1993, “third generation” ventilators were in widespread use as exemplified by the Puritan-Bennett 7200, Bear 1000, Hamilton Veolar, and Infrasonics Adult Star. These machines, with internal microprocessors controlling ventilator parameters, also had nebulizer drivers that could be switched on for a period of time, during which the nebulizer would be intermittently powered during inspiration only. Our group at SUNY Stony Brook studied all of these devices on the test bench and found differences in the efficacy of nebulization with different ventilators. Driving pressure and flow to the nebulizer during inspiration varied from one ventilator brand to the other and was responsible for significantly altering nebulizer performance and treatment duration. It seems there were no industry standards for nebulizer flow and pressure capabilities in ventilators and each manufacturing developed their own separate approach. Unfortunately, this caused significant variation in aerosol delivery, ranging from 3.2% to 14.7% of the nebulizer loading dose being delivered in 30 – 90 minutes. Oddly, the ventilator in the study group that had the lowest nebulizer driving pressure and flow, and thus the lowest aerosol output, also had the shortest nebulization time (15 minutes) on the nebulizer on/off control. In 15 minutes, the ventilator could deliver no more than 1% of the nebulizer loading dose compared to nearly 10% in 15 minutes and 14.7% in 30 minutes for another ventilator in the test group.

So, these early studies, now 15 years old and older, paved the way for what we now know today about aerosol delivery during mechanical ventilation. However, aerosol delivery continues to be a moving target due to advances in ventilator technology and the introduction of new operating schemes and ventilatory modes. Currently we use so-called “5th generation” ventilators, with extensive computer control, sensing and feedback for decision making, flow-triggering and bias (continuous) gas flow. Whether we like it or not, the lessons we once learned from the pioneering papers, such as Hughes and Saez, need to be challenged again to see if they still hold true in the face of all the changes in ventilator technology that have been introduced in the last 15 years. In addition, we have seen, and will continue to see, more advances in humidification that will undoubtedly influence aerosol delivery along the lines that we have already discussed. And most especially we will see the old familiar plastic disposable jet nebulizer that we’ve come to know and love be replaced by a variety of contemporary electronic devices that no longer depend on the idiosyncrasies of a flow of pressured gas to operate. In the next installment of this series, we will take a closer look at contemporary ventilator technology as well as contemporary aerosol generation (notice I didn’t say nebulizer) technology and try to examine how well they work together. I believe there is plenty of opportunity for investigation because we still need to ask the same questions we started asking over 15 years ago: how does this work? What is the effect on the mass of drug delivered to the patient? How does it interact with the ventilator, and vice versa? Our work is far from done.

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