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Nebulised drug therapy may be less effective in patients undergoing mechanical ventilation than in those spontaneously breathing for two main reasons – firstly, ventilated patients often have severe lung disease associated with airway plugging and collapsed segments which limit the spread of aerosols to affected areas, and secondly, aerosol deposition from nebulisers and metered dose inhalers is reduced during mechanical ventilation compared with spontaneous breathing. This is due to a number of factors including the site of the nebuliser in the ventilator circuit, the ventilator settings, the method of triggering of the nebuliser, and the size of the endotracheal tube. The indications for nebuliser therapy in mechanically ventilated patients are given in table 1.

In ventilated patients compliance is not a problem and it is not necessary for nebulised treatments to be completed rapidly. Indeed, continuous nebulisation may be appropriate for some conditions so nebulisers need not be selected on the basis of rapid output characteristics.

Nebulisers tend to leak around their joining parts, especially when used in conjunction with a ventilator. The back pressure necessary to cause leaks should be documented by the manufacturer and users should be encouraged to use systems which do not leak. There is also a need to determine the nebuliser outputs and the particle size produced when attached to humidification, the absence of small particle bacterial aerosols. Suitable filters should be placed between the ventilator circuit and the inspiratory and expiratory ports of the ventilator to protect the valves in the ventilator from the effects of deposited aerosol.

Methods of aerosol administration

Nebulisers and metered dose inhalers, rather than nebulisers. These are attached to an adapter in the ventilator circuit and actuated during lung inflation. The method is simple and treatments can be administered rapidly. The amount of drug reaching the lungs has been estimated as 1.5–2% in infants and 3.9–5.6% in adults. Administration using a metered dose inhaler is increased by using an aerosol holding chamber and this method may be more efficient than using an inspiratory phase actuated jet nebuliser. A Arnon et al. found that the use of a metered dose inhaler and an Aerochamber (MV15, Trudell Medical, Canada), attached to the inspiratory limb of the ventilator circuit, the ventilator settings, the size of the endotracheal tube. The indications for nebuliser therapy in mechanically ventilated patients are given in table 1.

Table 1 Indication for use of nebuliser in patients receiving mechanical ventilation

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<tr>
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<td>[C]</td>
</tr>
<tr>
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<td>Anticholinergic drugs (ipratropium bromide)</td>
</tr>
<tr>
<td>Adult and infant respiratory distress syndrome (C)</td>
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Particle drying tube, is clinically proven although deposition associated with this apparatus is unknown and delivery in vitro is poor.

Several factors may improve aerosol delivery to the mechanically ventilated subject from jet nebulisers. Placing the nebuliser in the inspiratory limb of the ventilator circuit rather than at the catheter mount connection or on the expiratory limb increases delivery.36,37 However, placing the nebuliser too far from the patient (>30 cm) may increase deposition on the circuit and reduce delivery.36 Delivery is also increased by inspiratory triggered nebulisation, increasing the fill in the nebuliser,26 interrupting humidification during nebulisation,26,31 and attaching the nebuliser to a spacer in the inspiratory limb.26,32 Alteration of the ventilator settings also affects deposition which is increased by decreasing the respiratory rate, increasing the inspiratory time, and by decreasing minute ventilation.26,32 In spontaneously breathing subjects the use of positive end-expiratory pressure (PEEP) can increase the improvements in lung function provided by inhaled salbutamol,28 but use during mechanical ventilation will increase peak airways pressure and may also worsen air trapping associated with severe bronchospasm.3 Small particles are associated with increased penetration of endotracheal tubes34 and nebulisers which produce these may be associated with higher pulmonary deposition.36

Ultrasonic nebulisers

Ultrasonic nebulisers can be used during all types of mechanical ventilation. They are simpler to use than jet nebulisers as no gas flow is required and many have large capacities. Disadvantages are that in theory some drugs might not be stable during ultrasonic nebulisation and the process may produce erroneous automated measurements of tidal volume. Pulmonary aerosol deposition in vivo associated with ultrasonic nebulisers has been estimated as 1% in infants using the Penta-sonic. In vitro data are lacking in adults but in vitro data indicate that delivery through an endotracheal tube during volume cycled ventilation can be as high as 22% using the Sono-pulmic ultrasonic nebuliser, an 18 ml fill volume, and an aerosol storage chamber.36 Under similar conditions the system 22 Acorn jet nebuliser delivers 10%.36

The factors that appear to improve aerosol delivery using ultrasonic nebulisers include placing the nebuliser in the inspiratory limb of the ventilator circuit rather than at the catheter mount connection or on the expiratory limb, increasing the fill in the nebuliser,26 attaching the nebuliser to a spacer in the inspiratory limb,26,32 and alteration of the ventilator settings for example, decreasing the respiratory rate, increasing the inspiratory time, or decreasing the minute ventilation.36 Drugs have to be shown to be stable during ultrasonic nebulisation.

Recommended practice

Any of the following three methods of aerosol administration currently appear to be appropriate for mechanically ventilated patients:

1. Administration by metered dose inhaler into a spacer connected to the inspiratory limb of the ventilator circuit with actuation at the onset of lung inflation. Humidification should be interrupted for a few minutes before administration.
2. Use of an inspiratory phase activated jet nebuliser connected to an aerosol holding chamber placed on the inspiratory limb of the circuit, or at least connected by a T piece in the inspiratory tubing no more than 30 cm from the Y piece. A high nebuliser gas flow should be used and the drug solution should be diluted to fill the nebuliser to capacity. Humidification should be discontinued for a few minutes before and throughout nebulisation.
3. Use of an ultrasonic nebuliser connected to the inspiratory limb of the circuit. The drug solution should be diluted to fill the nebuliser to capacity and humidification should be discontinued for a few minutes before and throughout nebulisation.

Clinical evidence of benefit from drug aerosols

Evidence that can be used in assessing the potential value of nebulised therapy in ventilated patients, in order of importance, is as follows:25 (1) clinical trials using clinically relevant end points such as survival, length of stay in ITU, length of stay in hospital; (2) clinical trials using physiological measurements such as changes in airway resistance or lung compliance; (3) aerosol deposition and deposition measurements in vivo in man using radio-labelled aerosols; (4) aerosol deposition measurements in animals (these are particularly appropriate for paediatric studies although not all lung conditions affecting infants can be mimicked in the lungs of healthy animals and, furthermore, the airway structure of animals differs from that of human infants and therefore the distribution of aerosol may be different); (5) aerosol delivery measurements made in vivo by measuring urinary excretion of nebulised drugs although measurements may be affected by other factors such as renal or liver function; (6) aerosol delivery measurements made in vitro or using combined in vivo/in vitro methods using radiolabelled or fluorescent aerosols. These are inevitably overestimates of in vivo lung deposition.

An ideal approach is a combination of these methods. In vitro studies can select those nebulisers worthy of consideration for delivering a particular drug, and then deposition and clinical outcome can be demonstrated in a particular clinical situation. The amount of drug deposited is estimated to prove that sufficient drug is being deposited for clinical benefit. There are few published studies proving the efficacy of aerosol drug treatments in ventilated patients and it is often necessary to make clinical judgements on the need for aerosol therapy using clinical trial data from spontaneously breathing subjects. This information is used, together with lung deposition or delivery data from patients receiving mechanical ventilation,
BRONCHOSPASM

Nebulised β₂ agonists are effective for acute severe asthma in spontaneously breathing patients and their use during mechanical ventilation can also improve measurements of pulmonary function (respiratory system resistance, compliance) in adults and infants with acute asthma, although not all studies have shown this. Pulmonary function can also be improved in adults with chronic obstructive pulmonary disease. No clinical trials have been performed to compare different bronchodilators or methods of aerosol administration. In some patients delivery of aerosol to peripheral bronchioles may be particularly poor because of intense bronchospasm and it may often be appropriate to use intravenous as well as inhaled bronchodilators in patients with severe disease. Ipratropium bromide also improves pulmonary function in mechanically ventilated patients with COPD.

RESPIRATORY SYNCYTIAL VIRUS (RSV) INFECTION

Clinical trials have been performed in infants with respiratory failure associated with RSV infection, evaluating the efficacy of continuous nebulisation oftribavirin (20 mg/ml) using the SPAG. This consists of a jet nebuliser coupled to a particle drying tube. In one study, infants treated with nebulised tribavirin had reduced durations of mechanical ventilation, oxygen treatment, and hospital stay compared with infants treated with nebulised water. In a second study, infants treated with nebulised tribavirin had small reductions in the duration of mechanical ventilation, supplemental oxygen use, and hospital stay compared with those receiving nebulised saline. However, the differences were not statistically significant, although a clinically relevant drug effect may have been missed because of reduced study power. Other possible explanations for the apparent differences in the findings of these studies are that the nebulised water used as a placebo in the first study may have had a deleterious effect on lung function. Alternatively, treatment with tribavirin may have been commenced too late for maximum benefit in the second study. Neither study included patients with apnoea and the effects of nebulised tribavirin in this group have not been assessed. Further studies using larger patient numbers, different doses, and different methods of administration will be needed to clarify the role of nebulised tribavirin in severe RSV infection. This topic is discussed further in the chapter on nebuliser treatment in childhood on pages S78-88.

The SPAG, as well as being cumbersome to use, is an inefficient method for delivering aerosol (0.1 ml/min) compared with other methods and its particle size output is comparatively large (mass median aerodynamic diameter (MMAD) 8-8 μm). Other devices may be better for delivering tribavirin but this has yet to be proved.

Tribavirin may deposit in ventilator circuits and block the expiratory valve, leading to expiratory pressures and barotrauma. This should be avoided by appropriate use of filters to protect the ventilator from the effects of the aerosol.

BRONCHOPULMONARY DYSPLASIA

Nebulised beclomethasone 50 μg eight hourly for 28 days reduced airways resistance and increased dynamic compliance in infants with bronchopulmonary dysplasia. Beclomethasone was administered using a Whisper (Marquest Medical Products, Englewood, Colorado, USA) jet nebuliser on the inspiratory limb of the circuit and running at 4-8 l/min of humidified gas. Pulmonary deposition was not measured. Beclomethasone aerosolisation from nebuliser solution is no longer produced but it is to be expected that beclomethasone delivered by metered dose inhaler or an alternative nebulised steroid such as budesonide should provide similar benefit. Further studies confirming the value of this form of treatment are needed.

ADULT RESPIRATORY DISTRESS SYNDROME (ARDS)

Preliminary evidence suggests that nebulised colfosceril palmitate (40-80 mg) given continuously over five days may improve the alveolar-arterial oxygen tension gradient (A–aDO₂) and fractional inspired oxygen (FiO₂) and reduce mortality in adults with sepsis-induced ARDS. Weg et al. also used nebulised colfosceril palmitate in a group of patients with ARDS for 12 or 24 hours per day and found a trend towards improvement in mortality compared with no treatment.

Nebulised orciprenaline (metaproterenol) has been shown to reduce airways resistance in patients with ARDS.

References

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