An effective method of scavenging nitric oxide

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Summary
We report an effective method of scavenging nitric oxide and nitrogen dioxide. We have compared three agents, a commercially available filter, soda lime and activated charcoal, for their effectiveness and duration of action. Complete absorption of nitric oxide and nitrogen dioxide for a period of 170 h was obtained using the commercial filter. However, soda lime and charcoal were unable to successfully scavenge either gas. The resistance characteristics of this filter when dry or humidified were determined. (Br. J. Anaesth. 1996;77:432–434)

Key words

Inhaled nitric oxide can significantly improve oxygenation in both paediatric and adult populations and it is invaluable in the treatment of critically ill patients. Effective scavenging of this gas and its higher oxides may present an obstacle for those wishing to take advantage of this new treatment. Various groups of health care workers looking after patients receiving inhaled nitric oxide have expressed concern over long-term exposure. Many individuals can detect a bitter odour when working with nitric oxide, even at very low concentrations. However, having undertaken a risk assessment, advice from NHS Estates (personal communication, Mr L. W. M. Arrowsmith, Chief Engineer, NHS Estates, Trevelyan Square, Leeds) is that provided there is adequate ventilation, scavenging is not necessary. Despite this reassurance we have continued to search for an effective method of scavenging nitric oxide exhaust. Foubert and colleagues have demonstrated convincingly the limited role of soda lime during administration of nitric oxide, and others have shown that simple activated charcoal is also ineffective. We have found a device available from the chemical industry and have compared it with soda lime and activated charcoal.

Methods
The Evita 2 (Draeger, Hemel Hempstead) ventilator was used under normal clinical conditions with a peak inspiratory flow of 60 litre min⁻¹, frequency of 12 bpm, tidal volume of 0.5 litre, minute volume of 6.1 litre min⁻¹ and 100% oxygen to maximize nitrogen dioxide production. Positive end-expiratory pressure (PEEP) was not used.

We compared the absorbance characteristics of 1 kg of soda lime (Draeger-sorb, PN 6750701, Hemel Hempstead) in a scavenging canister (East Health Care, Littlemore, Oxford), activated charcoal (Carbomix, Penn Pharmaceuticals, Gwent) in a 300-mm length of 22-mm corrugated ventilator tubing (Inter-surgical, Berkshire) and a commercially available filter, ABEK HgCONO-P3 (No. 67-35-813, Drager Industrial Ltd, Kilty Brewster Industrial Estate, Blyth, Northumberland), used in industry to absorb nitric oxide and nitrogen dioxide (fig. 1).

Over a continuous 170-h period, 1% nitric oxide in nitrogen (BOC, Special Gases, Guildford) was introduced into the ventilator circuit containing the ABEK filter (fig. 2) at a flow rate of 0.05 litre min⁻¹. The resultant nitric oxide and nitrogen dioxide concentrations were monitored proximal and distal to the ABEK filter with an electrochemical detector (Micromedical, Kent) at increasing intervals for a total of 170 h continuously. The monitors were calibrated using Spectrasel calibration gases (BOC, Special Gases, Guildford), nitric oxide in nitrogen at 86.1 ppm and nitrogen dioxide in air at 17.6 ppm. The proximal nitric oxide concentration was maintained between 55 and 70 ppm producing nitrogen dioxide concentration between 9 and 12 ppm.

Using the same conditions and experimental design, the 1-kg canister of soda lime and a 300-mm length of 22-mm corrugated tube containing activated charcoal were tested for absorbance. The tests...
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were aborted when no absorption was apparent for either soda lime or charcoal.

In a separate series of experiments, the pressure created by fresh gas flows of 10–120 litre min\(^{-1}\) through the ABEK HgCONO-P3 filter were measured using a pressure meter (Druck, DPI 701, Druck Ltd, Leicester). Humidified gas at 37\(^\circ\)C and 80% humidity was passed at 19 litre h\(^{-1}\) through the filter for 35 h (1.5 litre of water was consumed) making the filter wet, and the expiratory pressures created by the filter at various flows were measured again. Humidity was measured with a relative humidity meter (Vaisala HM34, Cambridge) with an accuracy of ±3%.

Results

With a fresh gas flow of 9.0 litre min\(^{-1}\), the calibration gas of nitric oxide in nitrogen at 86.1 ppm was passed through the soda lime canister and the concentration in the exhaust decreased to a low of 75 ppm, but for only 1 min. After 3 min the concentration had returned to 83 ppm and after 10 min there was no absorption. The test was repeated with a calibration gas of 17.6 ppm of nitrogen dioxide in nitrogen (BOC, Guilford). By 16 min, 14.6 ppm of nitrogen dioxide were detected distal to the soda lime canister. These tests were repeated using activated charcoal and no reduction in exhaust gas concentration was detected at any time.

Using the ABEK HgCONO-P3, we were able to completely scavenge both nitric oxide and nitrogen dioxide from levels of 55–70 ppm and 9–12 ppm, respectively, to less than 0.4 ppm for both gases for a continuous period of 170 h. By multiplying nitric oxide/nitrogen dioxide concentrations by the time intervals between readings, the volume of nitric oxide absorbed over this 170-h period was estimated to be 3.92 litre, and 0.67 litre for nitrogen dioxide.

The ABEK filter produced a linear increase in pressure with increasing flow rate when both dry and wet; when dry, resistance was 0.086 kPa litre min\(^{-1}\); when wet, having been humidified for 35 h, resistance was 0.091 kPa litre min\(^{-1}\) (fig. 3). At 10 litre min\(^{-1}\), the pressure generated within the test circuit was 0.1 kPa and at 60 litre min\(^{-1}\) 0.45 kPa.

Discussion

Current recommendations state that in a well ventilated environment, administration of nitric oxide poses no health hazard and that scavenging is not necessary. However, there are situations where nitric oxide may be delivered in less than ideal circumstances; in ambulances during transport of neonates; in a catheter laboratory; and in isolation cubicles with inadequate ventilation. For these situations scavenging of nitric oxide is desirable.

We have tested three methods and have found a commercially available filter which removes all nitric oxide and nitrogen dioxide. We can also support previous reports that soda lime and charcoal are of little value. The initial reduction in nitric oxide concentration we observed in the first minute of exposure to soda lime may have been caused by oxidation of nitric oxide to nitrogen dioxide by residual oxygen in the absorber rather than true absorption. Alternatively, the indicator dye within the soda lime may be independently involved in scavenging\(^4\)\(^-\)\(^6\). Charcoal from organic sources, for example coconut, can be activated by heating to high temperatures to create...
absorptive pockets of varying size on the charcoal particles. Larger molecules are removed more easily, ethanol being at the lower limit of effective removal and smaller molecules such as nitric oxide are not effectively scavenged.

We found the ABEK HgCONO-P3 filter the most effective method of scavenging nitric oxide and nitrogen dioxide. The ABEK HgCONO-P3 filter contains microglass fibres coated with copper and chromium salts. The filter also contains manganese dioxide and copper oxide as catalysts. Scavenging nitric oxide itself is difficult; it is much easier to scavenge nitrogen dioxide. The filter oxidizes nitric oxide to nitrogen dioxide which may then be absorbed by the copper and chromium salts.

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2NO + O_2 \rightarrow 2NO_2 \\
2NO_2 + H_2O \rightarrow HNO_2 + HNO_3 \\
2HNO_3 + Cu/X/Cr/X \rightarrow Cu(NO_3)_2/Cr(NO_3)_3 + H_2O
\]

It is estimated by the manufacturers that the filter can take up to 4–5 litre of nitric oxide and nitrogen dioxide in total, at a flow rate of 8 litre min\(^{-1}\).

All our ventilators, Evita 1 and Evita 2 (Draeger Medical, Hemel Hempstead, Herts) Servo 900c (Siemens, Bracknell, Berkshire) and Brompton Manley (Porton, Denmark) are now fitted with the filter on the expiratory port whenever nitric oxide is used. The extra expiratory resistance introduced of approximately 0.01 kPa litre\(^{-1}\) min\(^{-1}\) or 0.6 kPa at 60 litre min\(^{-1}\) is an acceptable level for the advantage of complete removal of nitric oxide and nitrogen dioxide from the environment. Although the filter lasts for up to 170 h we change it every 96 h. The current price is approximately £20.00.

Having performed a risk analysis, the recommendation of the NHS Estates is that scavenging is not necessary in an adequately ventilated environment (personal communication, Mr L. W. M. Arrowsmith, Chief Engineer, NHS Estates). This view is supported by other clinical reports where nitric oxide has been found to be negligible in the environment during inhaled treatment. However, by using the ABEK filter we are guaranteed a nitric oxide free environment. Although we accept that exposure to nitric oxide in a well ventilated area may carry no significant risk, we suggest the use of the ABEK filter on the expiratory exhaust limb of ventilators when delivering nitric oxide to further reassure all those working with nitric oxide.

References