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SHORT COMMUNICATIONS

Preoxygenation in healthy volunteers: a graph of oxygen "washin" using end-tidal oxygraphy

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SUMMARY

End-tidal oxygen fractions (FE'_{O_2}) have been measured in 40 healthy volunteers breathing 100% oxygen. On the assumption that FE'_{O_2} is a good measure of alveolar oxygen, we have drawn a graph of oxygen washin vs time. Clinical applications are discussed. (Br. J. Anaesth. 1994; **72**: 116–118)

KEY WORDS

Oxygen. inspired concentration, uptake. Anaesthetic techniques: preoxygenation.

Preoxygenation is performed routinely before rapid sequence induction of anaesthesia and, in many centres, as an integral part of induction for general anaesthesia [1]. The principle is to reduce the risk of hypoxia by providing a reservoir of 95% oxygen (assuming an obligatory 5% alveolar carbon dioxide) in the patient's lungs for planned or unplanned periods of apnoea during the induction period. This is achieved by alveolar denitrogenation while ventilating the lungs with 100% oxygen. Studies on the period required for preoxygenation have used several end-points, including pulse oximetry [2], arterial blood-gas measurements [3] and mass spectrometry [4]. Only those studies using measurements of alveolar gas may be said to measure the efficacy of alveolar denitrogenation.

Work completed recently in this hospital has shown that FE'_{O_2} is a good measure of alveolar oxygen when end-tidal oxygraphy is used [5]. We have used a convenient and readily available measuring technique to construct an oxygen washin curve for 40 healthy volunteers.

METHODS AND RESULTS

After obtaining Ethics Review Committee approval and informed consent, we studied 40 healthy (ASA I) volunteers. Age, sex, height, weight and smoking habits (1 = smoker, 2 = ex-smoker, 3 = never smoked) were recorded.

A standard circle anaesthetic system (Model Tm 41, Commonwealth Industrial Gases Ltd, Australia) was flushed with 100% oxygen and a flow rate of 8 litre min^{-1} set for the period of the trial. The 2-litre reservoir bag was filled with 100% oxygen before each trial period. A clean black antistatic rubber mask (British Oxygen Co. Ltd, London, U.K.) with pneumatic seal (size 4 or 5) was used.

The Capnomac Ultima gas analyser (Datex Instrumentarium Corporation, Helsinki, Finland) was calibrated and used according to the manufacturer's instructions. The Capnomac Ultima measures oxygen using a rapid detector based on the paramagnetic principle. The 10–90% response time is 150 ms for filtered sampling (20–30 ms if unfiltered) [6]. The gas sampling line of the Capnomac Ultima was placed between the face mask and the Y-piece of the breathing circuit in order to minimize circuit deadspace. The end-point of preoxygenation was defined as FE'_{O_2} 0.90; this corresponds to an alveolar nitrogen concentration of approximately 5% (with 5% carbon dioxide).

All participants had been breathing room air before the study and were asked to lie supine on a standard operating table with their head on one pillow. One of the authors applied the mask to the patient's face in order to produce an air tight seal. Each participant was then instructed to take slow deep breaths.

FE'_{O_2} was recorded at 15-s intervals from the start of preoxygenation. If FE'_{O_2} was not approaching 0.90 after 3 min, further recordings were not obtained. If those subjects who failed to achieve this target had facial hair or a demonstrable air leak around the mask, this was recorded.

Mean FE'_{O_2} and 95% confidence limits (CI) were calculated for each 15-s period using SPSS version 4.0 statistics software (SPSS Inc., Chicago, U.S.A.). Patient characteristics are presented as mean (SD).

Mean age of the 40 volunteers (22 of whom were male) was 33.4 (9.9) yr (range 21–64 yr); mean weight was 69.5 (13) kg and mean height 171 (12) cm. Six volunteers were smokers, 13 were ex-smokers and 21 were non-smokers. All participants had their own teeth.

Nine of the 40 volunteers studied (22.5%) did not achieve FE'_{O_2} 0.90 within 3 min. Three of those were noted to have facial hair and one was noted to have

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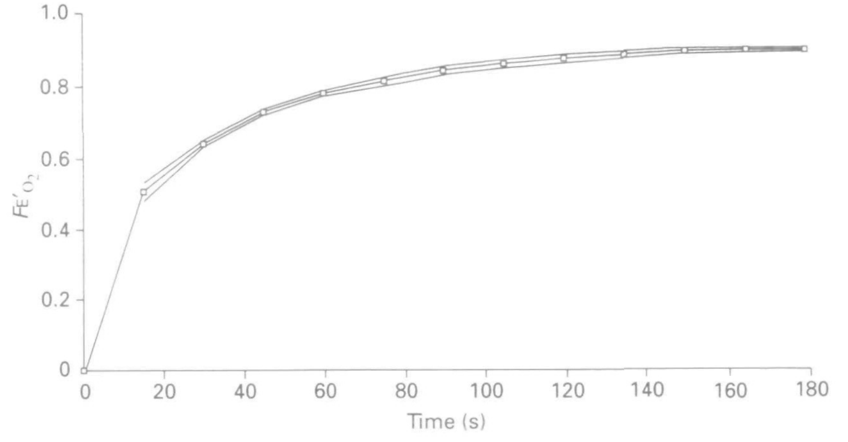

FIG. 1. Graph of mean (95% CI) end-tidal oxygen fraction *vs* time for 40 health volunteers breathing 100% oxygen via a circle anaesthetic breathing system.

a poor mask fit. None of the participants who achieved FE'_{O_2} 0.90 was noted to have facial hair or poor mask fit.

At 60, 120 and 180 s, mean FE'_{O_2} was 0.78, 0.87 and 0.89, respectively (fig. 1)—alveolar denitrogenation was approximately 83% complete at 60 s (allowing for 5% carbon dioxide). This was increased by a further 9% at 2 min. After a further 60 s, only a further 2% denitrogenation was achieved (fig. 1).

COMMENT

The time required for adequate preoxygenation is directly related to the rate at which nitrogen is replaced by oxygen (alveolar denitrogenation). This is subject to factors which include fraction of inspired oxygen, tidal volume and ventilatory frequency. Several studies have considered this subject [2–4, 7, 8] and 3 min of breathing 100% oxygen has been accepted practice after the observations of Hamilton and Eastwood [7], who found denitrogenation of the lungs to be 95% complete after this time. Similar results were obtained by Berthoud, Read and Norman [8] using mass spectrometry in healthy volunteers. Arterial oxygen tension and pulse oximetry have been used in other studies [2, 3] in order to define an end-point for preoxygenation; however, these may be confounded by cardiac output, oxygen consumption and the characteristics of the oxygen–haemoglobin dissociation curve, and so cannot be considered a true measure of the extent of alveolar denitrogenation.

We have used a readily available piece of theatre monitoring equipment to show the rate at which oxygen is washed into the lungs during tidal volume breathing in healthy volunteers. We suggest that this apparatus can be used as a convenient and accurate predictor of effective denitrogenation before anaesthesia is commenced. Mass spectrometry does provide the most direct and accurate means of measuring alveolar denitrogenation, but the equipment is expensive, difficult to maintain and often removed from the anaesthetic environment.

The shape of our oxygen washin curve suggests an exponential function and shows that, after 1 min of breathing 100% oxygen, only limited gains in denitrogenation are achieved. This may then be used as a guide for future clinical practice when the technique of preoxygenation is used during routine or emergency anaesthetic practice. Use of end-tidal oxygen monitoring can apply any desired end-point for denitrogenation and, importantly, detect those whose mask has an air leak preventing complete alveolar denitrogenation.

We have also shown that, even in the hands of experienced anaesthetists using standard breathing circuits, more than 20% of volunteers did not achieve FE'_{O_2} 0.90 in 3 min. This is presumed to be a result of mask leak but, interestingly, obvious causes such as facial hair or a demonstrable leak were found in fewer than 50% of those who did not achieve the target of FE'_{O_2} 0.90. Efficacy of denitrogenation was demonstrated clearly in these subjects using this equipment. Effective mask seal must be achieved before complete denitrogenation can occur.

The apparatus has obvious applications for comparing special groups of patients (e.g. the morbidly obese, pregnant and those with respiratory disease) with regards to the rate at which denitrogenation can be achieved and this work is being planned at present. We would recommend monitoring end-tidal oxygen concentration in any patient who requires optimal oxygen reserve before induction of anaesthesia.

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