Kathmandu University Medical Journal (2005) Vol. 3, No. 1, Issue 9, 22-25

Original Article

The oxygen and volatile anaesthetic delivery characteristics during spontaneous ventilation using a non-rebreathing coaxial anaesthesia system

Day SK[1]
[1]Launceston General Hospital, Launceston, Tasmania, Australia

Abstract
The gas delivery characteristics during simulated spontaneous ventilation of a non-rebreathing adaptation of the Bain circuit were examined. Tidal volumes were varied from 200 to 600 ml and respiratory rate from 8 to 20 breaths per minute obtaining characteristics for a minute volume range from 2.4 to 12 litres/minute. The minimum inspired oxygen concentration with 1 litre/minute 100% oxygen fresh gas flow varied between 86 and 43% over the range of minute volumes. . The minimum inspired Sevoflurane concentration with a 4% vaporiser setting and a 1 litre/minute fresh gas flow varied between 3.4 and 1.3% over the range of minute volumes. Increasing minute volume was the primary determinant of decreasing minimum inspired concentrations with increasing respiratory rate having an independent but smaller effect in reducing concentrations. Thus this system was shown to be safe and economical for the use in spontaneous ventilation.

Introduction

Shrestha and colleagues developed a non-rebreathing modification of a Bain coaxial breathing system in 1992 (1) by incorporating an Ambu valve and self-inflating bag. This enabled the safety advantages of draw-over anaesthesia to be replicated with plenum vaporisers and anaesthetic machines while using oxygen and anaesthetic agents sparingly. Extensive clinical experience is available in developing countries with this system using 2 litre fresh gas flows and manual ventilation. This paper reports the characteristics of the system likely to be seen in spontaneous ventilation at a fresh gas flow of 1 litre/minute.

Method

A disposable Bain circuit was modified as described by Shrestha et al (2) with components from a Laerdal Resuscitator. This involved placing the non-rebreathing Laerdal valve at the patient end of the circuit and using a Laerdal self-inflating bag to replace the reservoir bag. The resulting non-rebreathing circuit's outer co-axial tube acted as both a fresh gas reservoir and a conduit for air entrainment.

Spontaneous ventilation was simulated using an Acoma ARF 900II draw-over ventilator that enabled tidal volume and rate to be varied. The ventilator was set to give an inspiration (filling) time half the expiration (emptying) time. The gas was expelled from the ventilator to the gas scavenge system. Though the expired gas did not pass through the Laerdal valve, this did not affect the characteristics of this non-rebreathing circuit. The Tidal Volume (200, 400 and 600 ml) and Respiratory Rate (8, 10, 12, 14, 16, 18 and 20 breaths/minute) were varied to determine the characteristics of this circuit likely to be encountered in spontaneous ventilation.

Oxygen at 1 litre/minute and Sevoflurane 1% and 4% were delivered from the fresh gas outlet of the Siemens KION Anaesthetic workstation using a Siemens KION Vaporizer and a piped oxygen supply. Continuous side stream sampling of Oxygen and Anaesthetic Agent was carried out using the gas bench of a Siemens KION Anaesthetic workstation connected via a Pall HME filter between the Laerdal valve and the ventilator. This resulted in 150 ml per minute being lost from the system. Minimum and Maximum Inspired concentrations of oxygen and Sevoflurane were recorded for each of the set parameters after 2 minutes, when the waveforms and values had stabilised.

Results

The dependence of Oxygen and Sevoflurane concentrations on Minute Volume is illustrated in Figures 1 and 2. An increasing Minute Volume results in entrainment of increasing amounts of air thus decreasing minimum inspired oxygen and Sevoflurane concentrations. The higher Sevoflurane concentration set on the Vaporiser delivered higher inspired Sevoflurane concentrations. Increasing the rate of ventilation slightly decreased the inspired concentration of gases for any given minute volume.

Correspondence
Dr Stuart Day
Consultant Anaesthetist
Launceston General Hospital, Launceston, Tasmania, Australia
Email: studay@bigpond.com

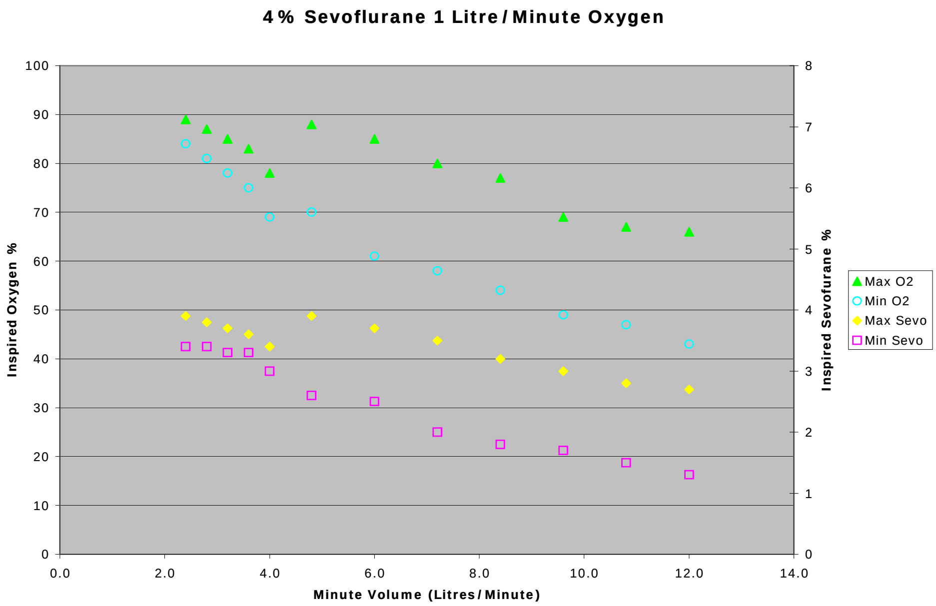

Fig. 1 Vaporiser set at 4% Sevoflurane and 1 litre/minute 100% Oxygen fresh gas flow. Tidal volumes of 200 ml with respiratory rates from 12 to 20 breaths per minute and 600 ml with respiratory rates from 8 to 20 breaths per minute. The fall in Maximum values with increased respiratory rate is likely the result of turbulence in the circuit causing gas mixing with air. The fall in Minimum values with increasing minute volume is the result of increasing air dilution.

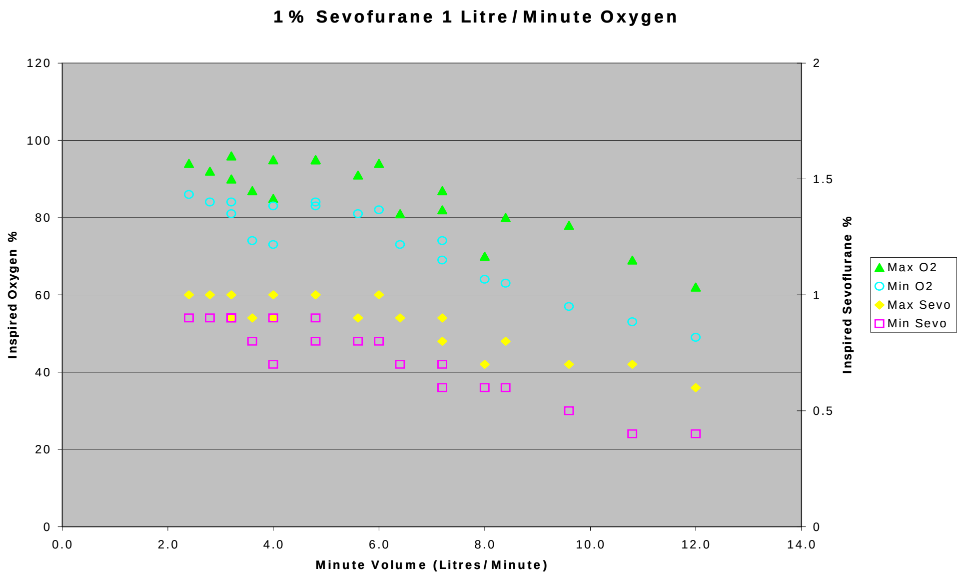

Fig. 2 Vaporiser set at 1% Sevoflurane and 1 litre/minute 100% Oxygen fresh gas flow. Tidal volumes of 200 ml with respiratory rates from 12 to 20 breaths per minute, 400 ml with respiratory rates from 8 to 20 breaths per minute and 600 ml with respiratory rates from 8 to 20 breaths per minute. Similar trends to those seen in Figure 1 are shown. The lowering of inspired gas concentrations due to effect of an increased respiratory rate for a given minute volume is illustrated. An example is the values at a minute volume of 7.2 litres/minute. Lower gas concentrations are seen for 400 ml x 18 breaths compared to 600 ml x 12.

Discussion

The anaesthesia system developed by Shrestha enables the use of high-pressure plenum vaporisers and anaesthetic machines in developing countries, which usually do not have access to the many components (e.g. Oxygen, Soda Lime, Regular servicing, Agent and Gas monitoring) that enable safe use of circle systems. Of great importance in developing countries is the economical use of Oxygen, which in cylinders is both expensive and difficult to transport. Though draw-over systems have many advantages and are possibly better suited to developing country anaesthesia the initial cost of the vaporiser is often prohibitive. Shrestha's simple, safe and economical system allows available equipment to be used for anaesthesia in developing countries. It has both experimental and a large body of clinical experience in ventilated patients at fresh gas flows of 2 litres per minute. It has had no reported experience in spontaneous ventilation and 1 litre gas flows.

Shrestha in his original paper [2] reported the theoretical gas flow characteristics of this circuit during respiration. He assumed that the early inspired gas would be only fresh gas and the latter gas would be diluted with air dependent on minute ventilation. He was unable to measure this in real time due to limitations with equipment. This is the first time a detailed analysis of inspired gas values has been reported. My study confirms Shrestha's predictions, however mixing with air does occur early in inspiration resulting in lower values. Tweed published waveforms [3] show similar results.

The gas concentrations at the end of inspiration declined as predicted with increasing minute volumes as this determines the amount of air that is mixed with the fresh gas flow. Shrestha [2] stated that the functional characteristics of the system are virtually independent of respiratory rate or pattern. My study showed that for a given minute volume increasing respiratory rates resulted in lower maximum and minimum inspired concentrations. The decrease in gas values at the beginning of inspiration was approximately the same as the decrease at the end of inspiration. Tidal volume was shown (as predicted) to have minimal effect on the concentration at the beginning of inspiration. Thus respiratory rate (but not tidal volume) independent of minute volume does have a smaller secondary effect of further decreasing gas concentrations. This is likely the result of turbulence within the breathing circuit causing greater mixing with entrained air. This effect was small and probably would have minimal effect on end tidal values but this was not studied.

The minimum oxygen concentration delivered by this system varied between 86 and 43% at the end of inspiration and was primarily determined by the minute volume. These values are higher than those obtained by Shrestha [2] (average of 34%) with a 2 litre fresh gas flow. This is explained by the slow response time of Shrestha's oxygen analyser and that many of his patients had higher minute volumes than used in my study (12 litres per min). Tweed's study [3] details the respiratory oxygen waveform from one of his patients, which showed similar oxygen concentration variations, however he does not report the conditions that these were collected. Jarvis [4] examined the oxygen delivery characteristics of a standard draw-over circuit at varying oxygen flows from an oxygen concentrator with varying I:E ratios. The predicted and actual concentrations from their draw over circuit were very close. At a fresh gas flow of 1 litre per minute and a minute volume of 12 litres per minute an inspired oxygen concentration of 28% was predicted. The circuit I tested delivers a significantly higher percentage of oxygen indicating more efficient use of oxygen.

The anaesthetic agent delivery mirrors oxygen with its dependence primarily on minute volume and secondarily on respiratory rate for its inspired concentrations. However it also is dependent on the vaporiser setting. This distinguishes this system from a draw-over system with its inspired anaesthetic agent minimally affected by the minute volume. Despite this I showed that adequate anaesthetic agent could be delivered abet with higher settings required on the vaporiser. Increasing fresh gas flow as shown by Tweed [3] could also increase anaesthetic delivery. He also showed that end tidal anaesthetic concentrations fell with increasing ventilation but did not quantify the minute ventilation.

A practical problem of the system as tested was that during the expiratory phase of the respiratory cycle the pressurisation of the system by the fresh gas flow could cause the Laerdal valve to stay open causing a forward leak of gas and increasing resistance to expiration. This problem is greater with increasing fresh gas flows. Tweed reported similar problems with the Ambu-E valve. This can be minimised during spontaneous ventilation by either opening the APL valve incorporated into the Bain system or disconnecting the Laerdal bag, both of which have no effect on the gas delivery or the characteristics of the system.

Acknowledgements
Dr Hadyn Perndt for technical advice and assistance.

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