SPONTANEOUS VENTILATION WITH THE BAIN ANAESTHETIC SYSTEM

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SUMMARY

Measurements of ventilation and of inspired gas composition were made while volunteers breathed a non-anaesthetic gas through a Bain anaesthetic system. It was found that rebreathing occurred when the fresh gas flow was between two-and-a-half and three times the minute volume. Fresh gas flows at least three times the minute volume appear to be necessary to prevent rebreathing when using this system.

The Bain anaesthetic system (Bain and Spoerel, 1972) consists of a length of corrugated tubing, 1.8 m long and 22 mm in diameter, through the length of which runs an inner tube of 7 mm diameter. Fresh gas can be delivered to the subject end of the system by means of this narrow inner tube. The addition of a reservoir bag and expiratory valve to the non-subject end of the system produces a form of Mapleson “D” system, while if an open-ended bag is used without an expiratory valve the system resembles the Mapleson F system (Willis, Pender and Mapleson, 1975). The system has been advocated as an economical and convenient method of administering anaesthetic gases during controlled ventilation. Bain and Spoerel (1973) showed that, providing minute ventilation was high, arterial carbon dioxide concentrations will be a function of the fresh gas flow rate. In adults a fresh gas flow of 70 ml kg\(^{-1}\) min\(^{-1}\) was found to provide normocapnia. Similar findings have been reported by Henville and Adams (1976).

The Bain system has been advocated also as a “universal” anaesthetic system for use during spontaneous, as well as controlled, ventilation (Henville and Adams, 1976). However, in spontaneously-breathing, anaesthetized patients, Goodwin (1976) and Mansell (1976) have shown that marked carbon dioxide retention can occur when a Bain system is used with a low fresh gas flow (70 ml kg\(^{-1}\) min\(^{-1}\)). The arterial carbon dioxide tension is often a poor guide to the presence or severity of rebreathing, especially during anaesthesia since respiratory compensation may maintain near normocapnia in spite of an inspired carbon dioxide load. Conversely, anaesthetic drugs commonly produce respiratory depression and some degree of carbon dioxide retention. The present study was designed to ascertain, by measurements of ventilation and inspired gas concentrations, the fresh gas flow requirements necessary to prevent the rebreathing of alveolar gas when the Bain system was used during spontaneous ventilation.

METHODS

Studies were performed on five healthy volunteers, all of whom were accustomed to studies on respiratory apparatus. The subject of each study lay at rest in a quiet room. At the outset of the study he was connected to a Bain system (M. & I.E. Ltd) by means of a well-fitting mouthpiece and a nose clip was applied. A conventional reservoir bag and a metal shrouded valve (Penlon Ltd) were connected to the non-subject end of the system. Air was used as the fresh gas and supplied from cylinders through a calibrated rotameter (Gapmeter Ltd). Initially, fresh gas was supplied at a rate considerably in excess of the subject’s minute volume. Carbon dioxide concentrations at the mouth were recorded continuously using an infra-red analyser (Godart), sampling at a rate of 150 ml min\(^{-1}\), and minute ventilation was measured at intervals by means of a calibrated Wright’s respirometer interposed between the mouthpiece and the Bain system. Ventilation was monitored also by means of a simple pneumograph placed around the lower part of the chest. Tidal carbon dioxide concentrations and chest movement were recorded continuously on a pen recorder (Brush Clevite) and also on FM Tape (Tandberg 100). The subjects were kept unaware of the level of fresh gas flow and of the times at which it was changed. Following an initial period of acclimatization, the fresh gas flow was reduced in steps of 1 litre min\(^{-1}\). Each level of fresh gas flow was maintained for 10–20
min to allow equilibration to occur. When rebreathing of alveolar gas was detected, indicated by a sustained increase in the minute volume and a detectable and maintained concentration of carbon dioxide in the inspired gas, the fresh gas flow was increased to wash carbon dioxide from the system. Fresh gas flow was decreased then in much smaller steps, towards the rate at which rebreathing had been detected. In this way the fresh gas flow at which rebreathing occurred was estimated to within 250 ml min⁻¹. This flow was assessed in comparison with the subject's average minute ventilation as measured towards the end of the initial period of acclimatization.

At each rate of fresh gas flow, gas was sampled also at various points along the system, in order to study gas disposition. The sampling sites used were 20 cm from the subject end of the system, 100 cm from the subject, and the reservoir bag. The composition of gas vented through the expiratory valve was measured also.

RESULTS

In all subjects the onset of rebreathing was sudden, and no difficulty arose in determining, from ventilation values and inspired carbon dioxide concentrations, the points at which rebreathing occurred. The almost immediate development of a high inspired carbon dioxide concentration following a small decrease in fresh gas flow is illustrated in figure 1.

The resting minute volumes of the five subjects and the flows at which rebreathing was detected are shown in table I. The fresh gas flow at which rebreathing commenced varied from just over two-and-a-half times minute ventilation to just under three times minute ventilation. If both ventilation and fresh gas flow are corrected to STPD the ratio increases to a mean of 3.04 (SD = 0.20).

Gas concentrations within the system when fresh gas flow to one subject was decreased are shown in figure 2.

DISCUSSION

While there are some situations in which rebreathing of alveolar gas combined with passive hyperventilation may be useful, rebreathing of alveolar gas in the anaesthetized and spontaneously breathing subject is a state which has few virtues and two potential dangers. The first and most obvious danger concerns the possible retention of carbon dioxide in the face of an inspiratory carbon dioxide load. If ventilation is unchanged rebreathing will produce an increase in alveolar carbon dioxide concentration which will be a direct function of the mean inspired carbon dioxide concentration. Unless the inspired carbon dioxide load is great, this mild hypercapnia will be of little importance. However, as alveolar carbon dioxide increases, alveolar oxygen concentration decreases.

![Fig. 1. Ventilation (upper tracing) and tidal carbon dioxide concentrations during a stepwise reduction of fresh gas flow (VF) from just over three times resting minute volume to 2.9 times resting minute volume. There is a progressive increase in inspired carbon dioxide concentration which starts two breaths after the change in fresh gas flow. Ventilation becomes less even, and there is a marked increase in tidal volume.](image-url)
and, usually, at equilibrium the absolute value of the decrease in alveolar oxygen concentration will be rather greater than the absolute value of the increase in alveolar carbon dioxide concentration. Almost invariably, alveolar anaesthetic concentrations will be decreased during such rebreathing.

However, marked carbon dioxide retention will not be seen commonly, as the onset of rebreathing will usually be associated with an increase in ventilation. In this study the conscious volunteers, who all breathed air, increased their ventilation by at least 50% as soon as their inspired carbon dioxide concentrations increased. In one subject a decrease of fresh gas flow by 500 ml to a critical value produced a threefold change in ventilation within 2 min. In the present studies rebreathing was terminated soon after its detection. In a previous study upon the Magill circuit during spontaneous ventilation (Conway et al., 1976) in which mild rebreathing was maintained for up to 1 h, sixfold or greater increases in ventilation were seen commonly in response to moderate carbon dioxide loading. While anaesthetized patients may show a lesser respiratory response to rebreathing than do conscious volunteers an increased respiratory drive during rebreathing can be expected in any lightly anaesthetized subject. Hyperventilation may limit the changes in alveolar gas concentration which would otherwise occur. Vigorous hyperventilation is not usually a desirable attribute of anaesthesia with spontaneous ventilation. As ventilation increases there is a disproportionate increase in the oxygen cost of ventilation and an increased metabolic production of carbon dioxide. Thus there is an ever increasing ventilatory requirement in order to maintain alveolar oxygen and carbon dioxide concentrations at a near constant level.

In the present study rebreathing was found to occur as the fresh gas flow approached two-and-a-half to three times minute volume. A fresh gas flow of at least thrice the minute volume appears necessary if rebreathing is to be prevented with this system. The system as used in these studies was a modified...
Mapleson D system, and the unmodified Mapleson D system requires rather smaller flows than this to prevent rebreathing. The difference in performance is probably a result of the coaxial nature of the Bain system promoting gas mixing within the corrugated tubing. During spontaneous ventilation with the Mapleson D system, gas vented from the expiratory valve will consist of fresh and expired gases passing along the system during expiration. Because the expiratory valve is closed for an initial period during expiration, the first portion of expired gas enters the reservoir bag and is retained in the system. As fresh gas enters the system at a constant rate while expiratory flow is high initially but decreases to low values at the end of expiration, gas leaving the valve soon after it opens will consist mainly of expired gas. At end-expiration, gas remaining in the subject end of the tubing of the system will be mainly fresh gas and this will form the first portion of the next inspirate. If gas mixing occurs in the corrugated tubing, this tendency towards a selective venting of alveolar gas and retention of fresh gas will largely disappear. Evidence of gas mixing within the Bain system as fresh gas flow is decreased is presented in figure 2. Fresh gas flows of 16 and 14 litre min\(^{-1}\) are of the same order as the subject's peak inspiratory flow, and little if any gas from within the system is inspired by the subject. A bolus of carbon dioxide is seen within the system early in expiration, but this is rapidly washed along the system by fresh gas. At end-expiration, gas within the system and vented from the system consists of fresh gas. At both of these high flows, appreciable amounts of expired carbon dioxide well mixed with fresh gas have accumulated in the reservoir bag. Indeed, at these flows this bag is superfluous, for the system is behaving as a T-piece with some added resistance.

A fresh gas flow of 12 litre min\(^{-1}\) cannot satisfy all inspiratory requirements and some gas from the subject end of the system will be inspired at mid-inspiration. At a minute volume of 4.5 litre min\(^{-1}\) and a frequency of 12 b.p.m., if a sinusoidal respiratory waveform is assumed, the volume of gas withdrawn from the system will be in the order of 20 ml per breath. At this fresh gas flow, marked rebreathing has occurred, and considerable gas mixing is evident within the system. At no time within the respiratory cycle does carbon dioxide concentration within the system decrease to zero.

The lack of plug flow within this system and the considerable degree of gas mixing that can occur unless fresh gas flow is very high explain the sudden onset of rebreathing seen when fresh gas flow was decreased (fig. 1). This behaviour is in contrast to the behaviour of similar non-coaxial systems when used with spontaneous ventilation. Willis, Pender and Mapleson (1975), when testing a Mapleson F (Jackson–Rees T) system, found a more gradual increase in ventilation as fresh gas flow was decreased to low values. Conway and others (1976) showed that rebreathing in the Magill circuit caused usually only moderate changes in both ventilation and inspired gas concentrations. Marked changes in ventilation and inspired gas concentrations with the Magill circuit were associated with considerable degrees of gas mixing with the system.

The major advantages of the Bain system depend upon its convenience. Its construction from lightweight tubing and the siting of an expiratory valve remote from the patient are attractive attributes, especially during surgery on and around the head. During spontaneous ventilation the efficiency of the Bain system, in terms of the flow of fresh gas needed to prevent rebreathing, is greatly inferior to that of a conventional Magill circuit. A conventional “D” or “E” system would also require a lesser fresh gas flow. The convenient siting of the expiratory valve of the Bain system for gas scavenging is offset by the high volumes of gas that have to be scavenged from it when used during spontaneous ventilation.

ACKNOWLEDGEMENTS

We are grateful to Mr R. Tennant and Mr H. Birdi for technical co-operation and to Mrs B. R. Lister for secretarial assistance.

REFERENCES


SPONTANEOUS VENTILATION WITH BAIN CIRCUIT

VENTILATION SPONTANEE A L'AIDE DU SYSTEME D'ANESTHESIE BAIN

RESUME
On a procedé à une prise de mesures de la ventilation et de la composition des gaz inspirés pendant que des volontaires respiraient un gaz non anesthésiant à l'aide d'un système d'anesthésie Bain. On a trouvé qu'il se produisait une re-respiration lorsque le débit de gaz frais se situait entre deux fois et demi et trois fois le débit cardiaque. Des débits de gaz frais d'au moins trois fois le débit cardiaque semblent être nécessaires pour éviter la re-respiration lorsqu'on utilise ce système.

SPONTANEE BELÜFTUNG BEIM BAIN-NARKOSESYSTEM

ZUSAMMENFASSUNG

VENTILACION ESPONTANEA CON EL SISTEMA ANESTESICO BAIN

SUMARIO
Se tomaron mediciones de ventilación y composición de gas inspirado mientras que voluntarios respiraban un gas no anestésico a través de un sistema anestésico Bain. Se descubrió que se producía una respiración repetida cuando la circulación de gas fresco se hallaba entre dos y medio y tres veces el volumen-minuto. Parecen ser necesarias circulaciones de gas fresco por lo menos tres veces el volumen-minuto para evitar la respiración repetida cuando se emplea este sistema.