COMPARISON OF THE MAGILL AND LACK ANAESTHETIC BREATHING SYSTEMS IN ANAESTHETIZED PATIENTS

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The fresh gas flow rate required to prevent rebreathing in the Mapleson A (Magill) anaesthetic breathing system has been studied extensively in anaesthetized patients [1] and conscious volunteers [2, 3]. These authors agreed with the conclusions of the theoretical analysis performed by Mapleson [4] and found that rebreathing did not occur until fresh gas flow was reduced to approximately alveolar minute volume. More recently, Humphrey [5] has reported that a fresh gas flow rate of 71.5 (SEM 2.70) ml kg\(^{-1}\) min\(^{-1}\) is required to induce rebreathing in anaesthetized patients. However, Dixon, Chakrabarti and Morgan [6] reported the onset of rebreathing at a mean fresh gas flow rate of 69.3 (SD 12) ml kg\(^{-1}\) min\(^{-1}\) in conscious volunteers and 56.5 (SD 15.9) ml kg\(^{-1}\) min\(^{-1}\) in lightly anaesthetized subjects.

The fresh gas flow rate required to prevent rebreathing with the coaxial version of the Mapleson A (Lack system) has also been the subject of controversy. Barnes, Conway and Purcell [7] noted that the Lack system was somewhat less efficient than the non-coaxial A system in conscious volunteers. Norman, Nott and Walters [8] showed the two systems to be equally efficient. Humphrey [5] claimed that the Lack system is considerably superior to the conventional A system, requiring a mean fresh gas flow rate of 51.30 (SEM 2.01) ml kg\(^{-1}\) min\(^{-1}\) to induce rebreathing. Because controversy exists concerning the fresh gas flow rate required to prevent rebreathing in the conventional and coaxial A systems, we have compared them at fresh gas flow rates of approximately 50 and 70 ml kg\(^{-1}\) min\(^{-1}\) in lightly anaesthetized patients.

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SUMMARY

The Magill and Lack anaesthetic breathing systems were compared by measuring inspired and expired carbon dioxide concentrations and expired minute volumes in lightly anaesthetized, unstimulated subjects. There were no significant differences between the two breathing systems at fresh gas flow rates of approximately 50 and 70 ml kg\(^{-1}\) min\(^{-1}\). Inspired carbon dioxide concentrations increased in one of six subjects at the higher fresh gas flow rate using the Magill system and in two using the Lack system. Inspired carbon dioxide concentrations increased in one of six subjects at the lower fresh gas flow rate with both systems. Expired carbon dioxide concentrations and expired minute volume increased in the majority of subjects at both fresh gas flow rates using each system. We conclude that a fresh gas flow rate greater than 70 ml kg\(^{-1}\) min\(^{-1}\) (which approximated to alveolar minute volume in our subjects) should be supplied to the Magill and Lack breathing systems.

PATIENTS AND METHODS

Twenty-four healthy adults (ASA I) were included in the study. They required general anaesthesia and tracheal intubation. They gave informed consent to the study, which was approved by the Hospital Ethics Advisory Committee. Premedication was with diazepam 10 mg by mouth 2 h before surgery and anaesthesia was induced with thiopentone 5 mg kg\(^{-1}\). Suxamethonium 1 mg kg\(^{-1}\) was administered and the larynx and trachea were sprayed with 4% lignocaine 3 ml. Tracheal intubation was performed using a cuffed tracheal tube.

The patients breathed 1% halothane and 70% nitrous oxide in oxygen for a period of 10–20 min.
During this time the gas mixture was delivered at a rate in excess of 100 ml kg⁻¹ min⁻¹, via a Magill attachment, to all subjects. End-tidal carbon dioxide concentration was measured continuously using a capnograph (Hewlett-Packard), expired minute volume using an electronic spirometer (Wright) and ventilatory flow using a pneumotachograph (Fleisch). The total apparatus deadspace was 34 ml. Measurements were displayed on a pen recorder (Brush) and recorded on FM tape. When stabilization had occurred, shown by a constant value of expired minute
volume, fresh gas flow was reduced to either 50 ml kg\(^{-1}\) min\(^{-1}\) or 70 ml kg\(^{-1}\) min\(^{-1}\). The subjects had previously been assigned randomly to one of four groups: Magill, 70 or 50 ml kg\(^{-1}\) min\(^{-1}\); Lack, 70 or 50 ml kg\(^{-1}\) min\(^{-1}\). Fresh gas was supplied from a Boyle anaesthetic machine with the rotameters set to the graduation which approximated most nearly the above flows. Rotameter calibration was checked using a dry gas meter. The subjects breathed at the designated flow rates for a period of 20 min. After completion of the study, surgery commenced. A single Magill breathing system and a single Lack breathing system were used throughout the study.

RESULTS

Expired minute volumes immediately before reduction of fresh gas flow to experimental values and at the end of the experiment, and exact fresh gas flow rates in terms of body weight, are listed in table I.

At the higher fresh gas flow rate, one patient in the Magill group and two in the Lack group had carbon dioxide in the inspired gas. At the lower fresh gas flow rate, inspired carbon dioxide did not increase in only one patient in each group (Magill and Lack) (fig. 1). Minute volume (fig. 2) and end-tidal carbon dioxide concentration (fig. 3) increased in the majority of patients in all four groups. A representative capnograph with pneumotachograph signal for a patient without an increase in inspired carbon dioxide at a fresh gas flow of 70 ml kg\(^{-1}\) min\(^{-1}\) is shown in figure 4.

The results were analysed using non-parametric statistics (Mann–Whitney \(U\) test and Fisher Exact probability test). There were no significant differences between the Magill and Lack systems.

DISCUSSION

The functional characteristics of simple breathing systems without carbon dioxide absorption have been defined by the fresh gas flow rate required to prevent rebreathing. Although some rebreathing is possible potentially in all but truly open breathing systems, it has little physiological consequence until the degree of rebreathing is such that carbon dioxide re-enters the alveolar space. In lightly anaesthetized subjects this causes an increase in minute volume to maintain normal alveolar carbon dioxide concentration \([9]\). In more deeply anaesthetized subjects this response is obtunded, so alveolar carbon dioxide concentration increases if the fresh gas flow rate is less than that required to prevent rebreathing.

In spontaneously breathing anaesthetized subjects, the presence or absence of rebreathing cannot be detected merely by measuring arterial
carbon dioxide tension, or be recognized easily by monitoring inspired carbon dioxide concentration. In order to detect rebreathing, it is necessary to monitor both inspired carbon dioxide concentration and expired minute volume. In this study we have not attempted to determine the fresh gas flow at which rebreathing can be detected. We have determined only changes in end-tidal carbon dioxide concentration and expired minute volume at two fresh gas flow rates. These were selected because Humphrey [5] reported that the Lack system required approximately 51 ml kg⁻¹ min⁻¹, and the Magill 72 ml kg⁻¹ min⁻¹, to just induce rebreathing (as defined by an increase of 0.27 kPa in inspired carbon dioxide concentration).

When the fresh gas flow rate approximated to 70 ml kg⁻¹ min⁻¹, rebreathing (demonstrated by an increase in the minimum inspired carbon dioxide concentration) occurred in one subject breathing through the Magill attachment and two using the Lack system. However, changes in end-
tidal carbon dioxide concentration and expired minute volume occurred at this fresh gas flow rate in the majority of patients. The attainment of zero inspired carbon dioxide concentration does not indicate that rebreathing is not taking place. Figure 4 is a representative example of the change in the capnograph that occurs when fresh gas flow approximates to 70 ml kg\(^{-1}\) min\(^{-1}\), in each breathing system. Although the inspired carbon dioxide concentration reaches zero, it does so for a smaller percentage of the inspiratory period when fresh gas flow is 70 ml kg\(^{-1}\) min\(^{-1}\) (fig. 4b) than it does when compared with control (fig. 4A). This inspired carbon dioxide load may be the cause of the reported increases in minute volume and end-tidal carbon dioxide concentration. Although the changes in end-tidal carbon dioxide concentration and expired minute volume were not statistically significant, a fresh gas flow rate of approximately 70 ml kg\(^{-1}\) min\(^{-1}\) may represent a threshold below which frank rebreathing commences. When the fresh gas flow rate was approximately 50 ml kg\(^{-1}\) min\(^{-1}\), the inspired carbon dioxide concentration was variable in both the Magill and Lack groups.

Inspired carbon dioxide concentrations did not increase in one subject in each group, even at the lower fresh gas flow rate. However, the inspired carbon dioxide concentration reached zero for only a fraction of the inspiratory period. The wide variation of inspired carbon dioxide concentration may indicate that factors other than fresh gas flow rate determine the onset and degree of rebreathing.

In respect of the Magill attachment our study is consistent with the findings reported by Dixon, Chakrabarti and Morgan [6], who found that rebreathing (as defined by increases in carbon dioxide concentration and expired minute volume) commenced when the fresh gas flow rate reached a mean of 56 ml kg\(^{-1}\) min\(^{-1}\) in anaesthetized subjects. In their study, one patient rebreathed at a fresh gas flow rate of 100 ml kg\(^{-1}\) min\(^{-1}\), but the remainder did not rebreathe until the fresh gas flow rate was well below 70 ml kg\(^{-1}\) min\(^{-1}\). In contrast, Humphrey [5] reported that a mean fresh gas flow rate of 71.5 ml kg\(^{-1}\) min\(^{-1}\) was required to induce rebreathing in anaesthetized patients. These two studies were performed on patients during surgery, and the anaesthetic techniques differed. In our study all measurements were made before surgery commenced. In five of six patients, inspired carbon dioxide concentrations did not increase when fresh gas flow rate was approximately 70 ml kg\(^{-1}\) min\(^{-1}\).

These findings are not difficult to reconcile. It can be misleading to report mean figures. If Humphrey’s data are examined, it may be seen that four of 10 patients did not begin to rebreathe until fresh gas flow rate was 65 ml kg\(^{-1}\) min\(^{-1}\) or less and, of the remainder, five began to rebreathe at fresh gas flow rates of just over 70 ml kg\(^{-1}\) min\(^{-1}\). It is not possible to relate the fresh gas flow rates quoted to the control minute volume, and hence alveolar minute volume, in either of the above studies. In our study a fresh gas flow rate of 70 ml kg\(^{-1}\) min\(^{-1}\) approximated to 70% of resting minute volume and, hence, was equivalent to alveolar minute volume.

With respect to the Lack system, our study refutes the findings of Humphrey. Five of our six patients had evidence of rebreathing when the fresh gas flow rate approximated to 50 ml kg\(^{-1}\) min\(^{-1}\). Humphrey reported that fresh gas flow rate could be reduced with the Lack system to 51 ml kg\(^{-1}\) min\(^{-1}\), to equal the efficiency of the Magill with a fresh gas flow rate of 71 ml kg\(^{-1}\) min\(^{-1}\). Jonsson [10] has also examined the fresh gas flow rate required to prevent rebreathing when the Lack system is in use, with an experimental model and in anaesthetized patients. He found that a fresh gas flow rate of 85 ml kg\(^{-1}\) min\(^{-1}\) was required in the model to prevent rebreathing. In anaesthetized subjects, he found evidence of rebreathing in 55% of subjects when the fresh gas flow rate was 70 ml kg\(^{-1}\) min\(^{-1}\) and in 92% of subjects when the fresh gas flow rate was 55 ml kg\(^{-1}\) min\(^{-1}\). He expressed difficulty reconciling his findings to those of Humphrey, and agreed with Conway [11] that the differences probably demonstrated variation in experimental technique. Certainly differences in experimental technique may account for some of the discrepancies between the reported results. On the basis of our present study, we suggest that the fresh gas flow rate needed to prevent rebreathing in both the Magill and Lack systems approximates to alveolar minute volume. We recommend that fresh gas flow rate in excess of 70 ml kg\(^{-1}\) min\(^{-1}\) should be used in both systems.

One of the features of the studies reported is that the fresh gas flow rate (ml kg\(^{-1}\) min\(^{-1}\)) needed to prevent rebreathing appears to differ in conscious and anaesthetized subjects. This is demonstrated in the study reported by Dixon and his colleagues [6], who showed that there was a
marked difference in the fresh gas flow rate needed to prevent rebreathing in conscious volunteers and anaesthetized patients.

There is also a difference from our reported findings with the Lack system in awake volunteers, in whom the fresh gas flow rate needed to prevent rebreathing was of the order of minute volume [7], whereas in the present study fresh gas flow rates approximating to alveolar minute volume were adequate. This difference may be caused by anaesthesia, change in breathing pattern or because of differences in carbon dioxide production.

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