COMPARISON OF THE BAIN AND THE ADE SYSTEMS DURING CONTROLLED VENTILATION IN ADULTS

N. K. SHAH, C. J. LOUGHLIN AND R. F. BEDFORD

Since Ayre's original description of the "T-piece" system [1], anaesthetists have introduced modifications to facilitate different aspects of anaesthetic management. One variation on this theme is Humphrey's "ADE" system [2] (Mercury Enterprise, Ft. Lauderdale, FL) designed to facilitate changing from a "Mapleson D or E" configuration during controlled ventilation to a "Mapleson A" mode for spontaneous ventilation [3]. A recent study [4] suggested that, when a fresh gas flow (FGF) of 70 ml kg\(^{-1}\) min\(^{-1}\) was used, this device was as effective for controlled ventilation in adult patients as the Bain system, which is another variant of the Mapleson D. Because an FGF of 70 ml kg\(^{-1}\) min\(^{-1}\) is considerably in excess of the FGF requirements for maintaining normocapnia during controlled ventilation with the Bain system in adults [5], we have studied the efficiencies of the two systems at the minimum FGF required to maintain normocapnia.

PATIENTS AND METHODS

We studied 20 adult patients (mean (SD) age 52 (19) yr; 15 males), ASA class I, undergoing elective surgery. The study was approved by the local Institutional Review Board and written informed consent was obtained. Anaesthesia was induced with thiopentone and maintained with 0.5-0.6% isoflurane and 60% nitrous oxide in oxygen. Tracheal intubation was facilitated with a competitive neuromuscular blocking drug and ventilation was controlled using a Drager Narcomed II anaesthesia ventilator with an in-circle carbon dioxide absorber. Tidal volume was set at 10 ml kg\(^{-1}\) and a 1:3 inspiratory to expiratory ratio. Inspired and end-tidal gas concentrations were measured with a calibrated Perkin-Elmer mass spectrometer with sampling from a catheter placed in the lumen of the tracheal tube (rate of sampling 200 ml min\(^{-1}\); the sample was not returned to the system); minute ventilation was determined with a calibrated respirometer (Boehringer Corp. of Pennsylvania, U.S.A.) placed at the tracheal tube adaptor. Heart rate was determined from the cardiotachometer of a standard electrocardiograph lead II. Arterial pressure was measured by sphygmomanometry, temperature with a nasopharyngeal thermocouple, and arterial blood-gas tensions with a Corning Model 178 blood-gas analyser.

During controlled ventilation with the circle system, the rate of ventilation was adjusted to maintain end-tidal carbon dioxide partial pressure between 4.7 and 5.3 kPa (mean frequency \(f = 5.9\) kHz).
FRESH GAS FLOW WITH BAIN AND ADE SYSTEMS

Ventilator — Patient

Bain system

FGF

Ventilator — Patient

ADE system, "E" mode

FGF

FIG. 1. Comparative configurations of the Bain and ADE systems.

(2.5) ml kg⁻¹ min⁻¹). Patients were allocated randomly to receive anaesthetic gases via either the Bain or the ADE system. The configurations of the systems are shown in figure 1. Both systems were connected directly to the tracheal tube. The apparatus deadspace was approximately 40 ml with both systems. The Bain system was connected to the anaesthesia machine using a simple adaptor with a pressure manometer and bagmount. The ventilator was attached to the expiratory limb of the system with the exhaled gas "pop-off" located in the ventilator. Thus there was no return of waste gases from the ventilator to the system. The non-coaxial version of the single lever ADE system was set in the "E" mode, with the lever in the "down" position. As with the Bain system, the ventilator was attached to the expiratory limb. The Drager anaesthesia machine has an audible low pressure sensor, which was connected to the FGF tube for both the Bain and the ADE systems. Minute ventilation (mean 58 (SEM 2.0) ml kg⁻¹ min⁻¹) was kept constant while FGF was adjusted to maintain end-tidal carbon dioxide partial pressure constant between 4.7 and 5.3 kPa with both systems. After 30 min, each patient received anaesthetic gases from the alternative system. FGF and \( \dot{V}_E \) were held constant for an additional 30 min. At the end of the study, all patients were returned to ventilation with the circle system at the same FGF and \( \dot{V}_E \) as had been used with either the Bain or the ADE system. Cardiovascular and ventilatory measurements were recorded at 10-min intervals during each 30-min observation period. These values and blood-gas tensions were tabulated at the end of each 30-min period. Mean values were obtained at the end of 30 min with the first valveless system and were compared with those obtained after 30

\[
\begin{align*}
&\text{FIG. 2. Differences in carbon dioxide partial pressures associated with changing from the ADE (A) to the Bain (B) system (---)} \quad \text{and vice versa (----). Fresh gas flow was held constant in each situation: FGF for B to A = 54 (SEM 2.5) ml kg⁻¹ min⁻¹; FGF for A to B = 67 (3.8) ml kg⁻¹ min⁻¹. The Bain circuit proved to be more efficient than the ADE circuit.}
&\text{RESULTS}
\end{align*}
\]

Among the patients randomly allocated first to the Bain system, the mean (SEM) FGF required to maintain an end-tidal carbon dioxide partial pressure in the range 4.7–5.3 kPa was 54 (2.5) ml kg⁻¹ min⁻¹, as was suggested originally by Bain and Spoerel [8]. In contrast those anaesthetized first with the ADE system required an FGF of 67 (3.8) ml kg⁻¹ min⁻¹ (P < 0.05) to maintain the same end-tidal carbon dioxide partial pressure. During anaesthesia with the ADE system, the mean (SEM) end-tidal isoflurane concentration was 0.57 (0.04) %. During anaesthesia with the Bain system, the end-tidal isoflurane concentration was 0.58 (0.04)%. No change in any cardiovascular measurement was observed.

The changes in carbon dioxide tensions observed 30 min after patients were switched from either the Bain to the ADE system or vice versa are shown in figure 2. Arterial carbon dioxide increased significantly when patients were
changed from the Bain system to the ADE circuit. The opposite effect (a decrease in \( P_{a\text{CO}_2} \)) was observed when patients were switched from the ADE circuit to the Bain system. As expected, end-tidal and inspired carbon dioxide partial pressures paralleled the changes in arterial carbon dioxide partial pressures as patients were changed from one system to the other.

**DISCUSSION**

Valveless anaesthetic systems are used widely for paediatric anaesthesia and for some specialized procedures such as diagnostic imaging of the head (CT and MRI scanning) where there is a long distance between the anaesthetic machine and the patient’s airway. In addition, these systems can be used in place of expensive anaesthesia machines, they are extremely popular in the third world [6]. As expense has become a significant consideration both in the U.S. and elsewhere, it seems reasonable to use these devices in a manner that conserves expensive anaesthetic gases.

Controlled ventilation as used in this study, with a large tidal volume and a long pause between ventilatory cycles, permits wash-out of exhaled gases and creates a “buffer” of fresh gas for the next inspiratory cycle, as postulated by Mapleson [3] and documented by Harrison [7]. It is this combination, and the availability of carbon dioxide monitoring devices, that makes the use of the traditional 70 ml kg\(^{-1}\) min\(^{-1}\) FGF rate for these systems wasteful in adult patients receiving controlled ventilation.

Most published studies of the Bain system have utilized minute ventilation of 120–140 ml kg\(^{-1}\) min\(^{-1}\) based on requirements predicted by the Radford nomogram [8]. These values are far in excess of those required for maintenance of normocapnia when a carbon dioxide absorber is used. Because of the high minute ventilation used in these previous studies, a high fresh gas flow (70 ml kg\(^{-1}\) min\(^{-1}\), equal to 0.6 of expiratory minute volume, \( V_E \)) was thought necessary to maintain normocapnia [9]. In the present study, where required minute ventilation during general anaesthesia was first established with a circle absorber system, we were able to maintain normocapnia with a much lower fresh gas flow, even though the ratio of FGF to \( V_E \) was 0.9 for the Bain, and 1.2 for the ADE system.

The data indicate clearly that, during controlled ventilation, the Bain system permits a 24\% lower minimum FGF rate than does the ADE circuit. During an anaesthetic procedure of long duration, this could account for a considerable saving in the volume and cost of anaesthetic gases utilized. When the ADE system is used at an FGF rate of 70 ml kg\(^{-1}\) min\(^{-1}\) as has been recommended for the Bain circuit [4], it is not surprising that its performance does not differ from that of the Bain system. It is only when FGF is reduced to its lowest safe limits that the greater efficiency of the Bain system becomes apparent. Presumably, if still lower FGF and higher carbon dioxide partial pressures were studied, the greater efficiency of the Bain system would become even more obvious, but this study was designed specifically to maintain carbon dioxide partial pressures within the physiological range.

In conclusion, the Bain system may be used safely with an FGF that is significantly lower than has been suggested previously, provided controlled ventilation with a long expiratory pause is used. Furthermore, we found that the Bain system is 24\% more efficient than the ADE circuit at conserving anaesthetic gases.

**REFERENCES**