Single lever Humphrey A.D.E. lowflow universal anaesthetic breathing system

Part II: Comparison with Bain system in anaesthetized adults during controlled ventilation

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A clinical trial involving ten anaesthetized adult patients was conducted during controlled ventilation using the Humphrey A.D.E. system in the Mapleson "E" mode (lever down). With each patient acting as his or her own control, the parallel (non-coaxial) and coaxial versions of the single lever Humphrey A.D.E. system were compared, using capnography, to the Bain system (Mapleson D/E). All three systems behaved similarly with predictable patient normocarbia when a fresh gas flow of 70 ml·kg^{-1}·min^{-1} was used. The A.D.E. system has the added advantage that the switch from controlled to spontaneous ventilation (or vice versa) is achieved quickly and simply. Spontaneous, assisted or automatic controlled ventilation could be instituted at any time merely by the appropriate lever position.

Key words
EQUIPMENT: ANAESTHETIC BREATHING SYSTEMS: Bain, Humphrey A.D.E.; VENTILATION: controlled.

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The principles of Mapleson A, D and E anaesthetic breathing systems such as the Magill (Mapleson A), Lack (modified Mapleson A),[1] Bain (modified Mapleson D/E)[2] and T-piece (Mapleson E) have been combined into a single system operated by two levers.[3] A single lever version of this apparatus, known as the Humphrey A.D.E. system, has since been described.[4] The single lever has simplified the switch between spontaneous respiration and controlled respiration modes such that it need be positioned *up* or *down* respectively, all appropriate apparatus such as the ventilator, reservoir bag and expiratory valve being automatically included or excluded (Figures 1–3). A parallel (non-coaxial) and coaxial version are available.

In Part I in this issue a clinical assessment of the function of the coaxial and parallel versions of the single lever A.D.E. system in their Mapleson A modes for spontaneous respiration in adults is presented.[5] Both versions were shown to function similarly, requiring a mean fresh gas flow of

ABBREVIATIONS

A.D.E.	=	Humphrey A.D.E. anaesthetic breathing system
A̲.D.E.	=	A.D.E. set in A mode
A.D̲.E.	=	A.D.E. set in D mode
A.D.E̲.	=	A.D.E. set in E mode
FGF	=	Fresh gas flow
$P\bar{I}CO_2$	=	Minimum inspired carbon dioxide tension
$P\bar{E}CO_2$	=	End-expired (or end-tidal) carbon dioxide tension
$PaCO_2$	=	Arterial carbon dioxide tension

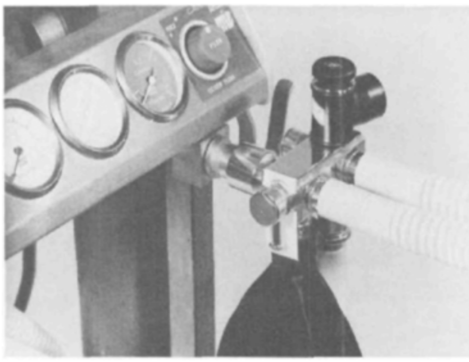

FIGURE 1 Photograph of the single lever parallel (non-coaxial) version of the Humphrey A.D.E. system set in the "E" mode (lever down). Both the reservoir bag and expiratory valve are automatically excluded, thus making simple tubes of the inspiratory and expiratory limbs (see Figures 2–4). While the ventilator remains attached to the expiratory ventilator port on the underside at all times, it is included in circuit only with the lever down. Coaxial tubing can replace the parallel tubes if desired (Figure 3).

only 51 $ml \cdot kg^{-1} \cdot min^{-1}$ to prevent rebreathing of alveolar gases, and to be more efficient than the Magill system which required a mean flow of 71 $ml \cdot kg^{-1} \cdot min^{-1}$. The Bain system was markedly less efficient than both A.D.E. or Magill systems, and required a mean FGF of 150 $ml \cdot kg^{-1} \cdot min^{-1}$.

However, during controlled ventilation, similar function of the A.D.E. and the Bain systems can be predicted, since both are converted into Mapleson E systems* that are functionally two simple tubes (Figure 4). The Bain system has been used extensively in this mode because $PaCO_2$ can be predictably determined by the fresh gas flow set by the anaesthetist. Identical performance of the original *dual* lever A.D.E. system and the Bain system has been confirmed during controlled ventilation.[6] We now present the results of capnograph studies on anaesthetised adult patients during controlled ventilation with both versions of the new *single* lever

*See appendix.

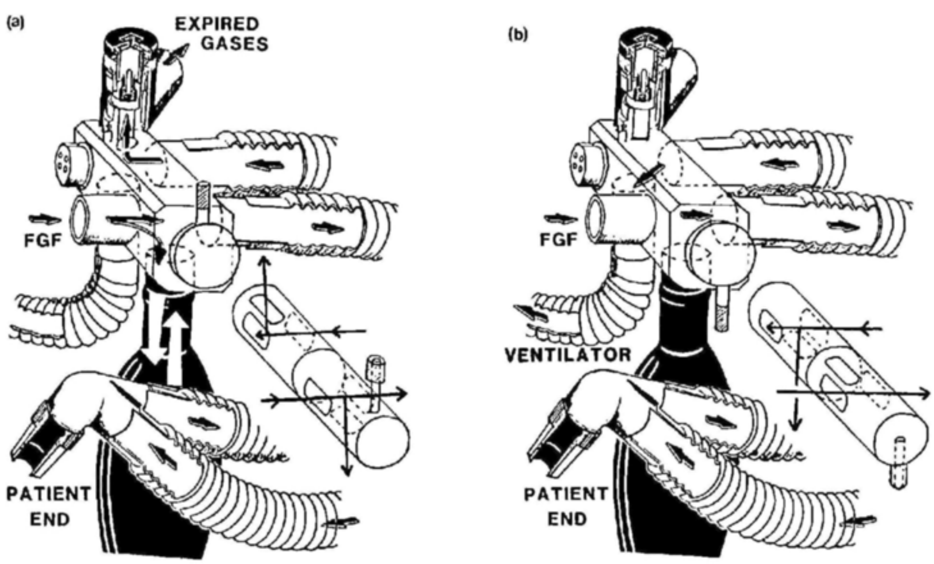

FIGURE 2 Diagram of the *parallel* (non-coaxial) single lever Humphrey A.D.E. system with an exploded view of the cylinder mechanism. (a) When the lever is upright (A mode, spontaneous and manual respiration) and inspiratory reservoir bag and expiratory valve are in circuit, while the ventilator is excluded. (b) When the lever is down (E mode), the ventilator is now included with the exclusion of the reservoir bag and exhaust valve. The system is simply two tubes, as is the Bain circuit during controlled ventilation (see Figure 4). Note that the pressure-limiting device stays in circuit in either mode. FGF = fresh gas flow. (Reproduced from Humphrey,[4] with permission.

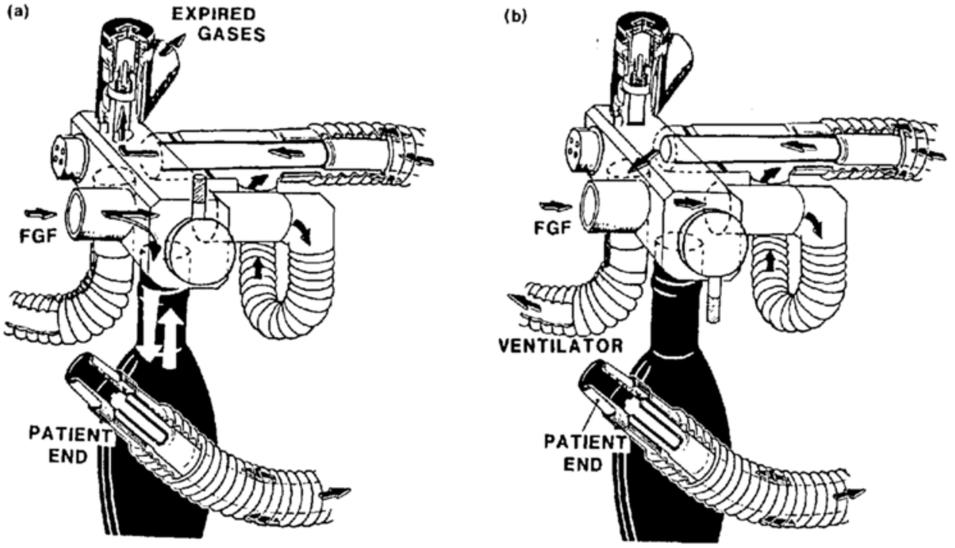

FIGURE 3 Diagram of the single lever *coaxial* Humphrey A.D.E. system. The same main body as in Figure 2 is used but the parallel tubing is replaced by a coaxial set. The position of the lever and function of the system remain identical.

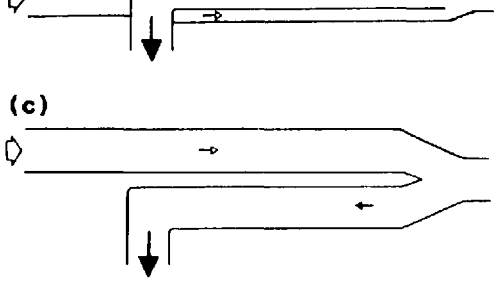

FIGURE 4 Diagrams of the (a) Bain, (b) coaxial A.D.E. and (c) non-coaxial parallel A.D.E. systems showing the functional parts when used for controlled ventilation. All are simply two tubes (Mapleson E systems), since the valve on each system has been closed (Bain) or excluded (A.D.E.) and the reservoir bag removed (Bain) or excluded (A.D.E.).

A.D.E. system compared in their E mode to the Bain system.

Methods

A similar protocol and anaesthetic induction technique as has been previously presented[5] was employed. Ten patients scheduled for elective peripheral surgery and of ASA physical status I were selected. Each patient gave informed consent. Anaesthesia was induced with thiopentone, the trachea was intubated and anaesthesia was maintained with halothane and nitrous oxide with oxygen. However, in this study, the use of narcotic analgesics during anaesthesia was permitted as required. Muscle relaxation was achieved with alcuronium 0.15 to 0.25 $mg \cdot kg^{-1}$ IV as an initial dose, with smaller increments being given as necessary.

Ventilation was controlled using a fluid logic, time cycled, flow generator Nuffield 200 ventilator (Penlon Ltd., Abingdon, Oxon, England) attached to the expiratory valve-bypass outlet of the A.D.E. system via two standard 22 mm corrugated tubes with a total volume of about one litre. This ventilator is of the "bag squeezer" variety and is suitable for Bain type and circle systems. Tidal volumes were calculated as normally recommended for the Bain system at approximately $10\,ml\cdot kg^{-1}\cdot min^{-1}$ with the respiratory rate set between 12 and 15 breaths$\cdot min^{-1}$, and fresh gas flows adjusted to $70\,ml\cdot kg^{-1}\cdot min^{-1}$. Both A.D.E̲. systems and the Bain circuit were compared twice in each patient, the initial order of testing being randomized, six patients being connected to an A.D.E̲. system first.

Clinical trials

Investigations were conducted with both parallel and coaxial versions of the single lever A.D.E̲. systems set in their Mapleson E mode with the lever in the down position (Figures 1–3). With the ventilator connected to the expiratory valve-bypass outlet, tidal volumes, ventilation frequency and fresh gas flows were set, as above. The Bain system was used in the conventional way with the ventilator attached to the expiratory limb with the reservoir bag removed and the exhaust valve fully closed. Within patient comparisons in ten subjects were made between both A.D.E̲. systems and the Bain, without alteration of any of the ventilation or fresh gas parameters.

Both versions of the single lever A.D.E. systems were also examined towards the end of anaesthesia during the change over from controlled to spontaneous respiration. Each A.D.E. system was converted from the "E" to the "A" mode by repositioning the lever from the down to upright position. Following intravenous injection of neostigmine 2.5–3.75 mg with glycopyrrolate 0.8 mg to reverse residual muscle paralysis, controlled ventilation was continued for another 30 to 60 seconds. The ventilator was then switched off (but left attached to the system) and at the same time the A.D.E. system was converted to the "A" mode. The fresh gas flow, anaesthetic gas and vapour concentrations, reservoir bag and valve were all left unaltered. The return of spontaneous respiration was continuously monitored with a capnograph from a stable state before injection of the anticholinesterase and anticholinergic drugs until adequate spontaneous respiration was re-established. It was not considered ethical to conduct the same procedure with the Bain system, since the FGF would be inadequate with consequent carbon dioxide retention and potential hypoxia.[5]

Data were analyzed using a paired Student's t test. P values ≤0.05 were taken as being significant.

FIGURE 5 Typical capnograph trace recorded from an anaesthetized subject comparing the A.D.E̲. system in its "E" mode to the Bain circuit during controlled ventilation, employing a fresh gas flow of $70\,ml\cdot kg^{-1}\cdot min^{-1}$. Minor but clinically insignificant differences were observed, normocarbia being maintained with both systems. Both versions of the A.D.E̲. system behaved identically.

Results

Comparisons between both parallel and coaxial single lever A.D.E̲. and Bain systems are summarized in the Table and Figure 5. There were no observed differences between any version of the A.D.E̲., and consequently recorded results refer to both versions unless stated otherwise. The mean minimum inspired and end-expired carbon dioxide tensions with the A.D.E̲. were 10.9 and 39.0 mmHg respectively, and 12.0 and 40.0 mmHg respectively with the Bain system. The differences between the A.D.E. and Bain systems with respect to inspired and end-expired CO_2 tensions were statistically significant (both $p < 0.05$). However, these differences were small enough not to be clinically relevant. Normocarbia was predictable with all three systems when using a fresh gas flow of $70\,ml\cdot kg^{-1}\cdot min^{-1}$, a tidal volume of $10\,ml\cdot kg^{-1}$ and a respiratory rate of 12 to 15 breaths$\cdot min^{-1}$.

A typical capnograph trace of events occurring during the change-over from automatic controlled ventilation to spontaneous respiration towards the end of anaesthesia is shown in Figure 6. After the muscle relaxant reversal drugs were administered and the ventilator was turned off, the A.D.E. system was reset for spontaneous respiration by positioning the lever upright, without further alterations to equipment or FGF. Following a period of apnoea of 40 seconds, the subject started to breathe spontaneously, effective respiration being re-

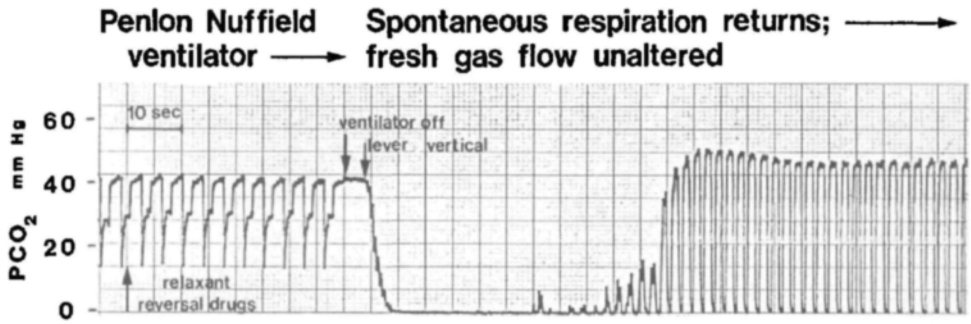

FIGURE 6 A typical capnograph trace of the events during the change-over from controlled ventilation to spontaneous respiration with the A.D.E. system, towards the end of anaesthesia. At the points indicated, muscle relaxant reversal drugs were administered intravenously, the ventilator turned off and the lever altered from its down (Mapleson E mode) to the upright (Mapleson A) position. Fresh gas flow remained unaltered at $70\,ml\cdot kg^{-1}\cdot min^{-1}$. During the return to spontaneous respiration rebreathing did not occur, though some degree of respiratory depression was evident.

established within 30 seconds. No rebreathing was evident, though a minor degree of respiratory depression was detected by the small rise in end-expired CO_2 without a rise in inspired CO_2.

Discussion

The prediction that both versions of the new single lever version of the Humphrey A.D.E. system would perform similarly to the Bain system during automatic controlled ventilation has been verified, even though small but statistically signficant differences were observed (Table). Normocarbia was maintained with all three systems with a FGF of $70\,ml\cdot kg^{-1}\cdot min^{-1}$, a tidal volume of $10\,ml\cdot kg^{-1}$ and a respiratory rate of 12 to 15 breaths$\cdot min^{-1}$. These observations confirm that the single lever system functions identically to the original dual lever version, since Shulman and Brodsky[6] found in a

TABLE Inspired and end-expired carbon dioxide tensions in anaesthetized subjects comparing the single lever coaxial and parallel A.D.E. and Bain system during controlled ventilation, employing a fresh gas flow of $70\,ml\cdot kg^{-1}\cdot min^{-1}$, a tidal volume of $10\,ml\cdot kg^{-1}$, and a ventilation rate of 12–15 breaths$\cdot min^{-1}$

				*A.D.E.**		*Bain*	
Patient number	*Age yr*	*Weight kg*	*FGF* $L\cdot min^{-1}$	P_ICO_2 *mmHg*	$P\bar{E}CO_2$ *mmHg*	P_ICO_2 *mmHg*	$P\bar{E}CO_2$ *mmHg*
1	54	65	4.5	16	41	19	44
2	27	70	4.9	8	40	9	40
3	39	80	5.6	18	43	13	43
4	55	81	5.7	14	42	15	43
5	24	50	3.5	10	39	10	40
6	73	50	3.5	12	38	14	39
7	36	80	5.6	1	37	2	39
8	23	71	5.0	8	38	13	40
9	37	63	4.5	16	37	17	37
10	28	57	4.0	6	35	8	35
Mean	39.6	66.7	4.7	10.9†	39.0‡	12.0†	40.0‡
SD	±16.5	±11.8	±0.82	±5.3	±2.5	±4.9	±2.8

*The results in the A.D.E. columns apply to both versions as they functioned identically.
†$p < 0.05$.
‡$p < 0.02$.

study of ten anaesthetized patients, a mean $P\bar{E}CO_2$ of 40.7 mmHg (SD ± 2.0) with the dual lever parallel A.D.E. and 41.1 (SD ± 1.8) with the Bain system.

The major advantages of the A.D.E. over the Bain system lie in the simplicity of the switch between the controlled ventilation and spontaneous respiration modes, and the subsequent high efficiency in the latter mode as shown in Part I.[5]

Despite the known inefficiency of the Bain system for spontaneous respiration, apparent convenience and simplicity has tempted many anaesthetists to use the Bain circuit as a "universal" system for both controlled and spontaneous respiration. The Bain circuit, however, may not on close examination be the simple and convenient system it appears to be. During change-over from controlled to spontaneous respiration it requires the following adjustments: the ventilator has to be turned off and disconnected from the expiratory outlet, a reservoir bag reattached at this point, the relief valve opened and the FGF doubled. The reverse procedure is required when ventilating a patient. With the A.D.E. system this change-over is quicker and simpler, especially with the new single lever version. All that is required with the latter is to turn the ventilator on or off and to move the lever to its respective *up* or *down* position (Figures 2, 3 and 6). Only minor adjustment in FGF between 50 and 70 $ml \cdot kg^{-1} \cdot min^{-1}$ is necessary, though some anaesthetists may find it convenient to leave the FGF at the higher flow, allowing a good margin for safety during spontaneous respiration. Unlike the Bain system, the ventilator can remain attached during spontaneous respiration since it becomes functionally excluded when the A.D.E. system is set in its "A" mode. Further, no detachment or reattachment of any reservoir bag is required, nor is it necessary to close the relief valve on the A.D.E. since the rotating cylinder within the A.D.E. system automatically includes or excludes both the reservoir bag and valve in the appropriate mode.

A further limitation of the Bain system is that its function is dependent on "bag squeezer" type of ventilators. Function with the Bain system directly attached to Manley "minute volume divider" ventilators has been shown to be impossible since the inner tube is too narrow and offers too great a resistance to gas flow from the ventilator to the patient.[7] By contrast, the A.D.E. system was found to function well with these ventilators,[7] and moreover the combination allowed normocarbia to be predictably maintained with the same FGF of 70 $ml \cdot kg^{-1} \cdot min^{-1}$ as used in this study. These ventilators are particularly useful because they are simple to use and need no electricity or separate driving gas other than the anaesthetic gas. They are popular in many countries (particularly the United Kingdom and Commonwealth countries), and would generally be the better type of ventilator to use in Third World environments.

While the concept of combining the advantages of Mapleson A, D and E principles into a single apparatus appears to be generally accepted, concern has been expressed over potential hazards in the use of such systems, especially by inexperienced anaesthetists.[8,9] With this in mind, the simplicity of and clear labelling on the improved single lever A.D.E. system ensure that misuse is unlikely to occur. The labelling specifies the correct set-up prior to anaesthesia, the method of use, and the FGF. It is, however, apparent that even the simple Bain system can be incorrectly assembled with disasterous results.[10]

Once the A.D.E. is correctly set up, accidental displacement of the lever from the selected position is prevented by a simple self-locking spring-loaded sleeve around the central lever spindle. This makes an audible click as the sleeve locates its recess in the upright or down position. To move the lever, the sleeve has to be lifted out of this recess. This can only be achieved by *deliberate* manipulation. Furthermore, the parallel (non-coaxial) A.D.E. system would appear to answer the call for a solution to the problems of kinking, twisting or disconnection of the inner tube associated with the Bain system.[11] The inclusion of a pressure-limiting device *separate* from the expiratory valve will prevent barotrauma from whatever cause, in either mode, and allow any type of exhaust valve to be used. An in-line pressure manometer on either the inspiratory or expiratory limb allows a simple leak test to be performed prior to each anaesthetic in addition to continuous airway pressure monitoring. Further leak tests similar to those recommended for the Lack system can be used for the coaxial system. Since the A.D.E. system has been manufactured to the British Standard 3849 and the draft recommendations of the International Standards Organisation (I.S.O.), it can be readily attached to any

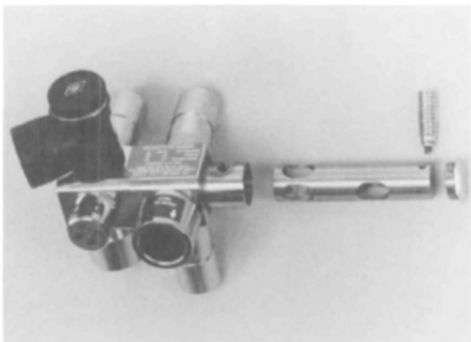

FIGURE 7 The main body of the Humphrey A.D.E. system with the rotating cylinder removed. Periodic lubrication requires undoing the lever spindle and the capping nut; the cylinder cannot be replaced incorrectly.

anaesthetic machine which also conforms to these standards. Maintenance of the A.D.E. system would appear to be minimal as essentially only the cylinder requires periodic lubrication. The latter slides out after undoing only one nut and the lever spindle (Figure 7); it cannot be replaced incorrectly.

While all the potential problems of the dual lever system[8,9] appear to have been solved, the single lever A.D.E. system further avoids the pitfalls of other alternative single lever "universal" systems.[12–14] The latter can all be used in a potentially lethal Mapleson A mode during controlled ventilation without the anaesthetist being aware that anything is amiss.[15] This can occur even if the system has been properly assembled and with the ventilator correctly connected. These systems also involve removal of the reservoir bag and adjustment of the valve during the switch from one mode to the other, becoming inconvenient and generally adding to the chances of error.

In the description of yet another universal system, Salkield[16] claimed that the MultiCircuit system improved on the single lever Humphrey A.D.E. system on which it was based. After examining and using a prototype MultiCircuit system, we made the following comparisons. The overall appearance was remarkably similar, but several differences were apparent. While the MultiCircuit system also employed a single lever, a complex interlocking dual cylinder mechanism was involved in which half rotated through 90° and half through 180°. While this caused some confusion in understanding how the system worked, it introduced the possibility of incorrect lever position despite clear marking. The mechanism caused a doubling of the resistance to rotation after moving the lever half way; if relying on feel, the junior anaesthetist might well be convinced, as initially we were, that the lever had travelled to its full extent on reaching this increased resistance. The physical effort to complete the switch subsequently had to be doubled. Disaster would have been imminent if the lever had been left in this half-way position since the fresh gas supply to the patient would have been cut off. The A.D.E. system, in contrast, offered an even resistance with a smooth action throughout rotation.

A further observation was that the MultiCircuit system did not automatically exclude the expiratory valve during controlled ventilation as does the A.D.E.; the anaesthetist had to remember to close it, otherwise ventilation would have been ineffective. The automatic exclusion of the expiratory valve of the A.D.E. might have been expected to interfere with manual ventilation in the D mode in which this valve had to be in circuit together with a reservoir bag on the expiratory limb. However, the D mode has been found to be unnecessary since manual ventilation in the "A" mode of the A.D.E. system has been shown not only to be more effective than the Magill system, but also more so than the D mode.[17] This seemed to be a logical possibility following our own[5] and independent[18] observations that the A.D.E. system functioned more efficiently than the Magill system during spontaneous respiration and might therefore also behave differently for manual ventilation. Thus the automatic exclusion of the exhaust valve during controlled ventilation by the A.D.E. mechanism offered a valuable simplification. Indeed the whole A.D.E. apparatus has been simplified to an "A" mode with the lever *up* for spontaneous and manual ventilation and, *without further alteration*, an "E" mode with the lever *down* for controlled ventilation.

Finally, but of considerable importance to maintenance engineers, is the simplicity of the A.D.E. cylinder mechanism (Figure 7). This compares to that for the MultiCircuit which is more difficult to dismantle and service. The only remaining claimed advantage of the MultiCircuit is that it can be mounted on a post. However, the A.D.E. can also be mounted separately on a swivel bracket at any place convenient to the anaesthetist. This is particularly useful with anaesthetic machines in which the fresh gas outlet is at the side instead of at the front.

In conclusion, the parallel and coaxial versions of the single lever Humphrey A.D.E. system function similarly, and include all the advantages of the Bain system during controlled ventilation. Several other benefits have been described. In Part I[5] both versions of the A.D.E. have also been shown to be highly efficient for spontaneous respiration in their Mapleson A mode, more so than even the Magill system and three times that observed with the Bain system. The overall function and efficiency of the A.D.E. system appear to offer a solution to the controversy over the use of the Bain system as a multipurpose system, especially for spontaneous respiration. In paediatric practice, similar advantages for the A.D.E. system over the T-piece have been reported.[19] The A.D.E. appears to meet Nunn's criteria for the function of the ideal breathing system,[20] and to perform the function of a "universal" system simply and safely.

Appendix

The Bain breathing circuit as sold is a modified Mapleson D system. However, when used for controlled ventilation, the reservoir bag is removed while the expiratory valve is closed and functionally excluded. This results in the Bain system being two simple tubes (Figure 4) and therefore functionally identical to Ayre's T-piece. Hence, for the way in which the Bain is most effectively used, it should correctly be called a Mapleson "E" system. During manual ventilation with the Bain system it is used, as supplied, in the "D" mode. There are functional differences between the D and E mode since expired gases escape from the system during *inspiration* during manual ventilation in the D mode, while they escape during *expiration* in the E mode. We have found statistically significant changes in $P\bar{E}CO_2$ between the two modes (unpublished observations). While the differences in $P\bar{E}CO_2$ were only about 2–3 mmHg and therefore not significant in clinical practice, it is important not to confuse nomenclature. Hence the Bain circuit is referred to as a Mapleson "D/E" system but is used in its "E" mode during controlled ventilation in the trial reported in this paper.

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Commercial availability: enquiries should be sent directly to the manufacturers or their agents and not to the authors: Medical and Industrial Equipment (M&IE) Ltd, Falcon road, Sowton Industrial Estate, Exeter EX2 7NA, England, Dentsply Canada, Lode Star Road, Downsview, Ontario or Ohmeda Canada, 172 Belfield Road, Toronto, Ontario. The system is protected by worldwide patents.

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Résumé

Une étude clinique de dix patients adultes anesthésiés en ventilation contrôlée utilisant le système de Humphrey A.D.E. en mode "E" est présentée. Chacun des patients se présentant comme son propre contrôle, on a comparé la version parallèle (non coaxiale) et la version coaxiale du système Humphrey A.D.E. à levier unique utilisant le capnographe, au circuit de Bain (Mapleson D/E). Tous les trois systèmes se sont comportés d'une façon identique en tenant un patient en normocarbie lorsqu'un flot de gaz frais de 70 $ml \cdot kg^{-1} \cdot min^{-1}$ était utilisé. Le système A.D.E. présentait l'avantage additionnel d'un interrupteur pouvant permettre simplement et facilement le changement d'une ventilation spontanée en contrôlée (ou vice versa).