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On behalf of the Rural Health Task Group of the Academy of Family Practice/Primary Care.

This series is also being produced as a booklet for the use of doctors in rural hospitals and will be obtainable from SA Family Practice in 1997.

BREATHING SYSTEMS FOR THE BOYLE'S MACHINE

The series will have the following sections:

1. Introduction to anaesthetics and anaesthetic safety checklist
2. Anaesthesia, intubation and extubation
3. The pre-operative assessment
4. Anaesthetic drugs I
5. Anaesthetic drugs II
6. Spinal anaesthesia
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The main functions of a breathing system are:

- to deliver anaesthetic gas mixture from the fresh gas flow (FGF) outlet of the Boyle's machine to the patient (Figure 1);
- to pass expired air into the atmosphere or into an anti-pollution ('scavenging') system; and
- to provide a method for administering controlled ventilation.

This chapter provides a short and limited guide to breathing systems that are used with the Boyle's machine. It is not a comprehensive text, and must be accompanied by reading a standard anaesthetic textbook, and the manufacturers' manual for the specific breathing system that you use.

INTRODUCTION

Most of the apparatus required for anaesthesia is daunting and can be difficult to understand for the untrained anaesthetist. This is especially the case with breathing systems (previously called breathing *circuits*), of which there are many types. Partly for this reason, the typical rural doctor should keep his/her variation in the use of breathing systems to an absolute minimum.

One of the difficulties with understanding breathing systems is the multiplicity of classifications and terms that are used to describe different systems. This chapter will use the Mapleson classification, which places different types of breathing systems into five categories labelled A to E. The Mapleson classification, however, does not include any of the 'rebreathing systems' such as the 'closed circle system' (or the 'circle absorption circuit').

As a rural doctor or as an occasional anaesthetist, the main criterion for choice of breathing system is safety. For this reason, 'rebreathing systems' (which use soda lime to absorb expired carbon dioxide) are not discussed. Although these systems are more efficient, less polluting and less costly, they are difficult and hazardous in unskilled hands, and should not be used without previous supervised experience. Neither should 'rebreathing systems' be used without a full complement of monitoring devices, especially the capnograph and pulse oximeter.

Other breathing systems that are *not* discussed in this chapter include 'non-rebreathing' systems and 'to-and-fro' systems. These are not required for anaesthesia in the operating theatre setting.

Some underlying concepts

An important feature of breathing systems is *valves*, which are used to ensure the correct direction of gas flow, and to provide an outlet for the gas in the breathing system. For example, most breathing systems have a 'spill valve' through which gas leaves the breathing system (Figure 1). Make a note of where the valves on your breathing system are located, and what their precise functions are.

The workings of a breathing system also depend on whether the patient is spontaneously breathing, or is being ventilated artificially. During *spontaneous ventilation*, the negative pressure generated in the thorax causes fresh gas from the breathing system to flow down a pressure gradient into the lungs. An efficient breathing system would therefore not only minimise the amount of resistance to this flow of gas, but also ensure that gas from

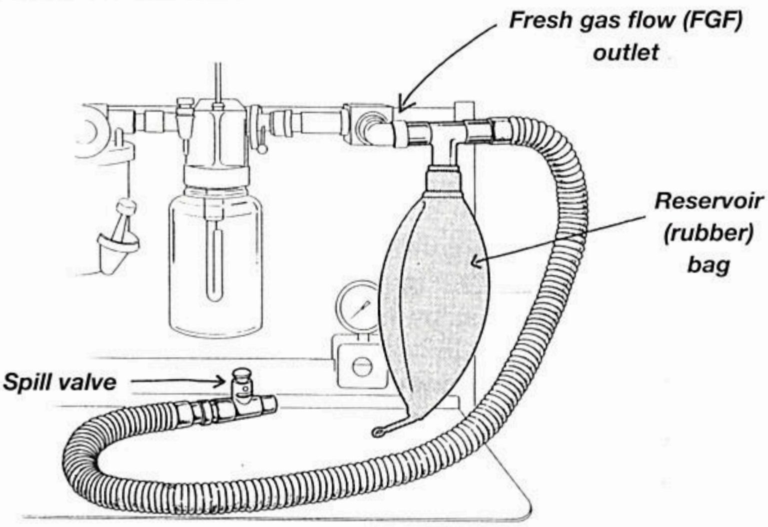


Figure 1: A Magill breathing system attached to a Boyle's machine

outside the system does not flow down the negative pressure gradient generated by the patient.

During expiration, the spontaneously breathing patient generates a positive pressure within the system so that gas will flow along a pressure gradient from within the system to the outside. For this to occur effectively and efficiently, the spill valve should be opened in order to minimise resistance to the expiratory effort. The system also has to ensure that the bulk of gas that is expelled from the system is made up of expired gas, and not fresh gas entering the system from the Boyle's machine.

During *controlled ventilation* a positive pressure is artificially generated to push gas into the patient's lungs. In this instance, the spill valve has to be kept relatively shut so that when the positive pressure is generated, it does not cause gas to be dissipated out of the system through it. However, the spill valve cannot be kept completely shut as this will mean that there is no way for the expired air to leave the system.

Understanding breathing systems also requires an understanding of the mechanics of *rebreathing* expired gas. A breathing system must try to ensure that the patient does not rebreathe expired gas whose oxygen concentration is low, and whose CO_2 concentration is high. The system must therefore devise a way for expired gas to leave the breathing system altogether, or to be diluted or flushed away with a sufficiently high volume of fresh gas. (Note that the circle system provides another alternative to the problem of expired gas, which is to use soda lime to absorb the CO_2.)

Not all the air that is expired, however, is bad to rebreathe. A considerable amount of inspired and expired gas lies in what is called the *respiratory deadspace*, which is made up of the space in the upper respiratory tract, as well as the space in some of the breathing apparatus such as the facemask. The gas in these spaces does not take part in the process of gas transfer, and therefore remains with its original mixture of oxygen and anaesthetic agents.

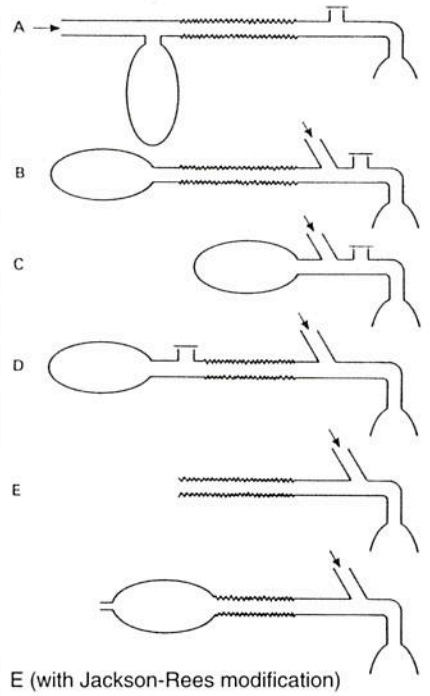
It is therefore acceptable for the patient to inspire this portion of expired gas. In fact it is actually beneficial because the gas has been warmed and humidified. An ideal breathing system would therefore ensure that the expired gas from the respiratory deadspace is kept in the breathing system and rebreathed, but not with the expired gas that has been involved in gas exchange.

Another implication of the respiratory deadspace relates to the relatively small tidal volume of the child: a child is only able to move a relatively small volume of air when he/she breathes. Therefore if the child has to contend with a large respiratory deadspace, there will be less gas movement occurring in the alveolar air spaces where gas exchange takes place.

A large respiratory deadspace would therefore effectively cause a spontaneously breathing child to be hypo-ventilated. This means that the choice of breathing system for small children must be one that does not increase the respiratory deadspace by much, by using large facemasks for example.

Finally, it is important to understand the role of the reservoir *(rubber) bag* in the breathing system (Figure 1). Apart from acting like a set of bellows during manual artificial ventilation, the bag is also a reservoir for fresh gas. This reservoir should be big enough to cope with the intermittently high demand that occurs in normal inspiration. For example, a normal adult breath consisting of a tidal volume of 500ml inhaled over one second, will produce an inspiratory flow rate of 30 litres/min, and will exceed the fresh gas flow rate used in most anaesthetic breathing systems. Therefore, a reservoir of fresh gas is required from which gas can be drawn during the period of inspiration when the inspiratory flow rate exceeds the fresh gas flow rate of the Boyle's machine. During expiration, the reservoir bag is able to refill with fresh gas.

Figure 2: Mapleson classification of breathing systems



→ indicates point at which fresh gas enters the breathing system

The Mapleson system of classification

Of the five categories that are in the Mapleson system, only three need to be discussed here (Figure 2). *Generally speaking*, category A is considered best for spontaneous ventilation, D for controlled ventilation, and E for children. However, since the days of Mapleson, new breathing systems have been developed to allow a combination of the three systems mentioned above.

Category A

The most common breathing system in this category is referred to as the Magill system. While it is very suitable for the spontaneously breathing patient, it is not used with controlled ventilation. Because of the required increase in deadspace and the presence of a spill valve, *the system should not be used in children under the age of four years.*

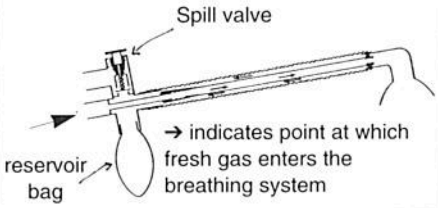
Another modification of this category is called the Lack system, which uses a coaxial arrangement of tubing. This means that the tubing consists of one larger tube with a smaller one running through the middle.

During spontaneous breathing, a fresh gas flow (FGF) rate the equivalent of the patient's minute volume is generally used in order to prevent the rebreathing of alveolar gas (about 6ℓ/minute in a 70kg adult, or about 80ml/kg). However, if the Mapleson A system is used with controlled ventilation, CO_2 accumulation can only be prevented by using unaffordably high FGF rates, of up to 15ℓ/min.

Category D

The difference between this category and the Mapleson A category is that the reservoir bag is on the expiratory limb of the system and not the inspiratory limb. What this creates is an arrangement that is efficient for controlled ventilation, but inefficient for spontaneous ventilation.

Figure 3: The Bain system. This is an adaptation of the Mapleson D category, employing a coaxial system of tubes.



During controlled ventilation, a fresh gas flow rate equivalent to the patient's minute volume is adequate for preventing rebreathing. The most commonly used version of this system is the Bain system, which is also a coaxial system like the Lack system. It has a relatively small inspiratory tube (which carries the fresh gas) passing through the middle of the larger expiratory limb of tubing (Figure 3).

Because the system causes a certain amount of rebreathing, CO_2 retention has to be compensated for by setting the ventilator to deliver a slightly greater than normal minute volume, eg by setting a tidal volume of 10ml/kg at a rate of 10-12 breaths per minute. The drawback of the Bain system, however, is its inefficiency during spontaneous ventilation, where it requires a FGF in excess of 10ℓ/minute (in an adult) in order to prevent CO_2 accumulation and hypoxia. The Bain system can be used for both adults and children.

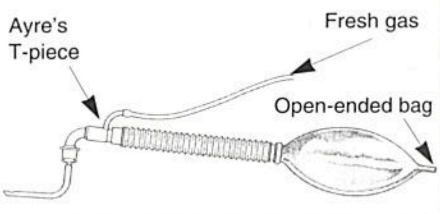
Finally, because the tube that carries the fresh gas is actually on the inside, a disconnection or a leak (which would cause hypoxaemia) is not obvious. The breathing tubes must therefore be checked thoroughly before use.

Category E

The Mapleson E breathing system is nothing more than two tubes converging together at a T-junction, at the patient's end of the system. Because there are no valves involved in the system, there is very little resistance to breathing in or out, and it is therefore the system of choice for spontaneously breathing children.

However, it is with the Jackson-Rees modification of attaching a small *open-ended* reservoir bag to the expiratory limb of the system that the Mapleson E system is

Figure 4: The Mapleson E system with the Jackson-Rees modification. Notice the absence of valves. The system can be attached to a facemask at the patient end as well as to an endotracheal tube.



commonly used (Figure 4). This modification allows for the presence of a bag to act as evidence of air moving in and out, it helps to provide a degree of positive airway pressure at the end of expiration, and it helps to provide a method for assisted or controlled ventilation.

Because the system functions like the Mapleson D system, it is most ideal for controlled ventilation (a FGF rate of 70ml/kg, with an absolute minimum of 3ℓ/min). However, the FGF rate should be between two to three times the minute volume during spontaneous ventilation.

Familiarity with the Mapleson E breathing system and the Jackson-Rees modification is strongly encouraged for all doctors who care for infants and small children. Rural doctors are encouraged to develop this skill from a trained anaesthetist, and to learn of its uses both for anaesthesia and for the management of small children in intensive care situations.

Combined systems – the ADE system

The ADE system was designed to combine the separate merits and advantages of the individual Mapleson A, D and E systems, in a way that is simple and user-friendly (Figure 5). The Humphrey ADE system is said to be the most popular example of this type of 'combined system'. When this system was first introduced by its originator (a South African), he highlighted the fact that its safety, simplicity and economy made it an ideal breathing system for the third world and rural hospital scenario.

The ADE system is now used in many places throughout the world, and it is the opinion of this author that it should be considered as the first choice system for all forms of inhalational anaesthesia in rural hospitals.

The system consists of a metal block inside of which there is a set of valves controlled by a lever. On one side of this metal block is a connection for fitting it onto the fresh gas flow outlet of the Boyle's machine, and on the other side are two outlets which are connected to the two tubes of the breathing system. One tube carries fresh gas to the patient (inspiratory limb), and the other carries expired gas away from the patient (expiratory limb). It therefore does not have the advantage of the Bain or Lack system which consists of only one length of coaxial tubing.

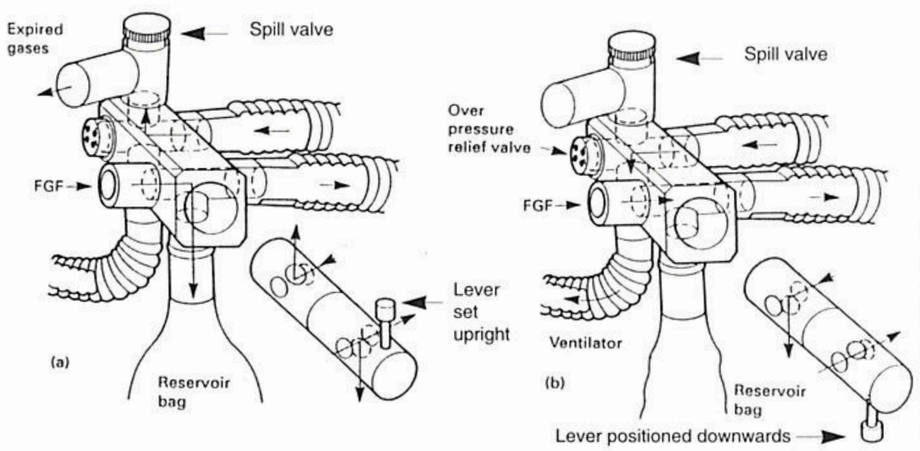
At the bottom of the metal block is another port to which is attached a reservoir bag, and which can also be used for providing artificial ventilation. Finally, at the top of the metal block is the spill valve onto which an anti-pollution (scavenging) system can be attached.

The mode of use of the ADE system depends on the position of the lever. When in the upright position, the breathing system approximates that of a Mapleson A, and can therefore be used for spontaneous ventilation. When the lever is positioned downward, the system approximates a Mapleson D/E system, and even allows the breathing system to be automatically connected to the ventilator.

Interestingly enough, after the system was designed, experiments found that it was in fact a more efficient system than some of the individual systems it tried to combine. Therefore, even when it is in its Mapleson A configuration for spontaneous ventilation, it was also found to be completely satisfactory for manual ventilation by partially closing the spill valve and squeezing the reservoir bag.

The great beauty of the system, therefore, is that the anaesthetist needs only one system for all scenarios. The ADE system can also be used for children, but with smaller tubing and with a smaller reservoir bag. With spontaneous ventilation, the FGF rate needs to be set at about 50ml/kg/min, and at 70ml/kg/min for controlled ventilation. However, the minimum FGF rate must always be 3ℓ per minute.

Figure 5: Humphrey ADE system



With the lever set upright (a) the system functions in its Mapleson A mode as efficiently as the Lack system for spontaneous respiration. Without changing the FGF rate setting, manual ventilation is easily instituted by partially closing the spill valve and squeezing the reservoir bag. For mechanical ventilation the lever is positioned downwards (b) in its E mode. The ventilator is now included while the reservoir bag and exhaust valve are excluded. The system now functions identically to the Bain. For children, the lever settings are identical.