Circuits without Valves

Circuits with One Valve
- Bain Circuit

Circuits with Three Valves

Airway Humidification

Of all the types of anesthesia equipment, breathing circuits for children are the most different from those for adults. Therefore, they are a continual source of controversy and investigation. These differences are most pronounced for neonates and young infants, whose unique anatomic and physiologic characteristics warrant different equipment from adults. Even though we use these on a daily basis, anesthesiologists don’t normally think about the “physiology” of the different types of breathing circuits (unless required under the duress of a written board exam). Thus, details of these differences are difficult to learn, and more importantly, to retain in one’s mind during a typical anesthesia case.

This chapter reviews types of available anesthesia breathing circuits, with an emphasis on the differences between children and adults. To aid in learning about the differences in breathing circuits, they will be presented here in an order based on the number of valves in the circuit, from zero to 3. The two-valved circuit, which is essentially closed-circuit anesthesia (circle system with the pop-off valve completely closed), will not be covered because closed-circuit anesthesia is rarely utilized in pediatric anesthesia and only by a talented few in the anesthesia community (that does not include this author). Airway humidification will also be reviewed.

CIRCUITS WITHOUT VALVES

A circuit without valves is commonly referred to as an “open” circuit. The ether open-drop technique is the classically-described example. In the author’s institution we use open systems on a daily basis in the form of T-pieces, especially for patients in the postanesthesia care unit (PACU) or when transporting patients between locations within the hospital. Another name for the T-piece is a Mapleson E system (see below).

The T-piece was developed and described by Ayre in the middle of the twentieth century. It consists of:

- An inspiratory limb through which oxygenated air, and possibly anesthetic agents, are delivered
- A connection to the patient
- An expiratory limb for egress of expired air and to act as a reservoir for rebreathing air that contains oxygen (Fig. 13-1).

Since there are no valves in the circuit, inspired air may be derived from either the inspiratory or expiratory limb. However, rebreathing of expired CO₂ can be prevented if the fresh gas flow (FGF) is approximately twice the minute ventilation and if the volume of the expiratory limb is limited to one-third the tidal volume. During the patient’s expiratory pause, the fresh gas flow will flush the expired air from the expiratory limb of the circuit.

![Figure 13-1 Ayre’s T-piece breathing system.](image-url)
When using the open T-piece system, there are a number of parameters that can be manipulated to increase the $P_{aO_2}$ or decrease the $P_{aCO_2}$ (Box 13-1).

Advantages of open circuits are simplicity and portability. Disadvantages include the inability to precisely control the level of delivered oxygen or anesthetic agent, environmental pollution with anesthetic gases, and the inability to deliver positive-pressure ventilation.

**CIRCUITS WITH ONE VALVE**

Valved systems are a result of the need for controlled ventilation. Gordon Jackson-Rees, a pediatric anesthesiologist from Liverpool, England, is credited with altering Ayre's T-piece to administer positive-pressure ventilation by adding a double-ended bag (with openings at each end) to the reservoir tubing (expiratory limb). An adjustable expiratory valve is placed at the end of the bag and can be manually adjusted to regulate the amount of delivered inspiratory pressure and positive end-expiratory pressure (PEEP) during controlled ventilation (Fig. 13-2). Positive-pressure ventilation is achieved by partially closing the valve while simultaneously squeezing the bag. When the valve is completely open, the circuit functions identically to a T-piece and can be used during spontaneous ventilation. Partially closing the valve during spontaneous ventilation provides an adjustable method for delivering continuous positive airway pressure (CPAP). The Jackson-Rees circuit (also called a modified Mapleson E circuit or a modified Ayres T-piece) is most commonly used during transport between the operating room and the PACU, or other areas of the hospital. During transport, it allows the anesthesiologist to easily switch between spontaneous and controlled ventilation depending on the clinical status of the patient.

In 1954, Mapleson categorized several one-valved circuits based on their “anatomy” and “physiology,” which are determined by the locations of the fresh gas inflow, release valve, reservoir bag, and size of the corrugated tubing (Fig. 13-3). The Mapleson A circuit functions best when used during spontaneous ventilation, whereas the Mapleson D circuit is most efficacious when used during controlled ventilation. The Mapleson B and C circuits provide no advantages and are so not in use today. Each system has the potential for rebreathing CO$_2$, depending on the respiratory rate, fresh gas flow, tidal volume, and inspiratory-to-expiratory time ratio of the patient. However, if the FGF is sufficiently high (two to three times the minute ventilation), rebreathing of CO$_2$ will not occur. Thus, these are commonly referred to as “non-rebreathing” circuits. Disadvantages to the use of these circuits include loss of heat and humidity, and wastage of anesthetic gases. Therefore, in the OR environment, these systems are largely of historical interest, as most pediatric centers in the United States have abandoned their use in favor of the circle system (see below). Mapleson A and D circuits, however, are still occasionally used in non-OR settings, and for transporting patients between locations within the hospital.

**Bain Circuit**

The Bain circuit is a modified Mapleson D circuit that is ideally suited for pediatric patients. Its physiology is the same as that of the Mapleson D, but its anatomy is different, in that the inspiratory (fresh gas) limb is contained within the expiratory limb in a coaxial relationship (Fig. 13-4).
abnormality of the internal inspiratory tubing can remain undetected and cause a decrease in the delivered oxygen concentration and unintentional rebreathing of CO₂.

CIRCUITS WITH THREE VALVES

Circuits with three valves are commonly referred to as semiclosed circle systems and are included in the circuitry of all modern anesthesia machines. The three valves are the pop-off valve, the one-way inspiratory valve, and the one-way expiratory valve. The major distinguishing characteristic of this type of circuit is the presence of a canister containing a CO₂-absorbent material (e.g., soda lime) that prevents rebreathing of CO₂ while allowing rebreathing of the inhaled gases. This reduces cost and OR pollution, and conserves heat and humidity.

The use of three-valved circle systems in pediatric anesthesia was slow to evolve. Pediatric anesthesiologists preferred simple, one-valved circuits because of the small compression volume, the ability to prevent rebreathing of CO₂, and the lack of one-way valves, which may increase the work of breathing in neonates and small infants. However, in the second half of the twentieth century, improvements in technology decreased the airway resistance (and thus work of breathing) caused by the CO₂ canister and the heavy inspiratory and expiratory valves. In addition, smaller, low-compliance tubing was developed for use in pediatric patients to facilitate changes in alveolar gas concentrations relative to the smaller tidal volumes. Ventilators became more sophisticated so that spontaneous ventilation in pediatrics was rarely used. Therefore, in the 1990s, most children’s hospitals in the United States discontinued using Mapleson rebreathing circuits in favor of circle systems.

AIRWAY HUMIDIFICATION

Humidification of gases within the anesthesia breathing circuit is thought to prevent respiratory tract damage and promote maintenance of body temperature by decreasing evaporative losses. There are several ways to increase the relative humidity of the breathing circuit. The use of low fresh gas flows will facilitate the rebreathing of gases that are already humidified and have previously passed through the respiratory system and the CO₂ absorber. Low FGFs are possible only when using a circle system, as high FGFs are required to prevent rebreathing when using the Mapleson circuits.

Humidification devices that are added to the anesthesia breathing circuit are classified as passive or active. A passive device is a heat and moisture exchanger (HME), which contains a fine mesh that humidifies the inspired gases by condensation. In most patients, these devices...
are equal in efficacy to active humidification devices for preventing hypothermia, but at much lower cost. An active device is a hot-water humidifier that is inserted into the anesthesia breathing circuit to add heat and moisture to the gases within the circuit. These devices are reserved for use in small neonates and patients with hypothermia who do not respond to more conservative measures. Nevertheless, despite concerns for adequate humidification of anesthetic gases, there are no data to indicate optimum humidification levels within the anesthesia breathing circuit.

ARTICLES TO KNOW
