Anaesthesia Breathing Systems
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Anaesthesia Breathing System (formerly known as anaesthesia Breathing Apparatus or Anaesthesia Breathing Circuit) is an interface between the anaesthetic machine and the patient. They evolved over 160 years from the open systems used by Morton to the present day closed systems using carbon dioxide absorbents. The main purpose of these systems is to deliver the required oxygen and anaesthetic gases, and maintain carbon dioxide homeostasis. In addition they help us to assess, assist, or control ventilation, and condition temperature and humidity. Present day systems are constructed to facilitate scavenging of exhaled gases as well.

Components
1. Connectors and Adaptors (Figure 1): These connectors ensure quick connection between the breathing systems, and masks or endotracheal tubes. Their sizes are universal and either male or female 15/22 mm connections. Some of them also incorporate gas sampling ports.

   ![Figure 1. Connectors](image)

   1. HME filter with sampling port
   2. T-Piece
   3. Straight connector with a side gas sampling port.
   4. Right angle connection
   5. Right angle swivel connector for insertion of a flexible fibroscope. It can accommodate different sized fibrescopes by changing the diaphragm. The large cap is used if no diaphragm is present.
   6. Right angle connector with gas sampling port.
   7. Flexible corrugated extension

2. Reservoir Bag
   a. Acts as a reservoir for gases to be stored during exhalation
   b. Acts as a reservoir and ensures adequate supply of required flows during inhalation
   c. Helps anaesthesiologist to assess, assist or control ventilation manually
   d. Protects the patient from excessive pressure

3. Corrugated tubes: Flexible, low-resistance, light weight connection from one part to other

4. Valves:
   a. Adjustable Pressure Limiting (APL) Valves: The APL valve is a user-adjustable valve that releases gases to a scavenging system. It is used to control the pressure in the breathing system.
   b. Unidirectional Valves: These valves ensure a required direction of flow in breathing systems.
   c. Non-rebreathing Valves: These valves are used more commonly in manual resuscitators

5. Filters:
   a. **Bacterial filters**: These are meant to prevent transmission of infection to the patient or contamination of the equipment. The recommendations for their use vary for different countries. Generally a new filter should be used for every patient or in the absence of a filter a disposable system should be used for every patient. Filters are generally not preferred for paediatric patients.
   b. **Heat and Moisture Exchange (HME) filters**: Administration of dry gases at room temperature could lead to heat loss and increased pulmonary complication. The function of the nose is to
warm and humidify inhaled gases. When the nose is bypassed it is advisable to use HME filters to achieve this objective. These devices also help to dehumidify the gases that are being sampled for analysis by side stream devices.

**Apparatus Dead Space:** Some components that connect the breathing system to the patient act as an extension of patient’s anatomical dead space. Since this dead space is imposed by a piece of apparatus it is termed as apparatus dead space. **Apparatus dead space** can be defined as that part of the breathing system from which exhaled alveolar gases are rebreathed without any significant change in their carbon dioxide concentration. The volume of the apparatus dead space should be kept to as small as possible or else rebreathing of carbon dioxide could result in hypercapnia.

**Classification of Breathing Systems**

**Historical (Table 1):**

<table>
<thead>
<tr>
<th>Type</th>
<th>Inhalation</th>
<th>Exhalation To</th>
<th>Reservoir</th>
<th>Rebreathing</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open</td>
<td>Air + Agent</td>
<td>Atmosphere</td>
<td>nil</td>
<td>Nil</td>
<td>Open drop T-Piece</td>
</tr>
<tr>
<td>Semi Open</td>
<td>Air + Agent from Machine</td>
<td>Atmosphere</td>
<td>small</td>
<td>minimal</td>
<td>T-Piece with small reservoir</td>
</tr>
<tr>
<td>Semi Closed</td>
<td>From Machine</td>
<td>Atmosphere + Machine</td>
<td>large</td>
<td>possible</td>
<td>Magill attachment Mapleson systems</td>
</tr>
<tr>
<td>Closed</td>
<td>From Machine</td>
<td>Machine</td>
<td>large</td>
<td>Yes + CO₂ absorbent</td>
<td>Circle system</td>
</tr>
</tbody>
</table>

**Recommended (Table 2):** Many classifications used in the literature are a source of confusion and inconsistency. Since it is important for an anesthesiologist to understand carbon dioxide homeostasis while using different systems, it is advisable to classify the systems based on CO₂ elimination. One should also understand whether a system is efficient during spontaneous breathing, controlled ventilation or both, and whether it can be used for paediatric patients, adults or both.

<table>
<thead>
<tr>
<th>Table 2. Classification based on CO₂ Rebreathing (normal working condition)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>No CO₂ Rebreathing</strong></td>
</tr>
<tr>
<td>1. <strong>Non-Rebreathing Valves:</strong> These separate exhaled gases from inhaled gases.</td>
</tr>
<tr>
<td>• Non-Rebreathing circuits.</td>
</tr>
<tr>
<td>• Self inflating resuscitation equipment</td>
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<tr>
<td>2. <strong>CO₂ Absorbent systems:</strong></td>
</tr>
<tr>
<td>• To-and-Fro system</td>
</tr>
<tr>
<td>• Circle system</td>
</tr>
<tr>
<td><strong>CO₂ Rebreathing is possible,</strong> but the CO₂ level in patient is determined by the interaction of:</td>
</tr>
<tr>
<td>1. Minute ventilation</td>
</tr>
<tr>
<td>2. Fresh Gas Flow and</td>
</tr>
<tr>
<td>3. Arrangement of Components</td>
</tr>
</tbody>
</table>

| **Mapleson Systems**                                           |
| a. Efficient for spontaneous respiration Mapleson A, Lack’s   |
| b. Efficient for controlled ventilation Mapleson D, Bain’s    |
| c. Efficient for both spontaneous and controlled              |
|   • A-D switches                                              |
|   • Enclosed Afferent Reservoir System                        |
| **T-Piece Systems:**                                          |
|   • Ayre’s T –piece, Jackson-Rees, Bain’s                    |
**Systems using Non-rebreathing Valves**

These systems have largely disappeared from anaesthetic practice. However, manual resuscitators (Figure 2) are used commonly in the medical practice. Self inflating bags with non-rebreathing valves (Ambu bag is one of the common names) are principally used for transport of patients and for resuscitation of patients by paramedics, emergency room staff, critical care staff, and the operating room personnel.

The non-rebreathing valve allows the gases from the bag to be delivered to the patient and prevents any exhaled gases to enter the self inflating bag and thus prevent CO\textsubscript{2} rebreathing. The bag is filled with oxygen enriched air through another set of unidirectional valves. The inspired oxygen concentration depends on the oxygen flow and size of the reservoir. A PEEP valve can be added to the system at the patient exhalation port to optimize gaseous exchange. A pressure monitoring and limiting valve is also added to prevent any barotrauma.

![Diagram of self inflating resuscitator](image)


These units are available in different sizes to suit different patient populations. Patients breathing spontaneously will either breathe ambient air or oxygen enriched ambient. The equipment is portable, and simple to use. However failure to familiarize oneself with the available equipment can lead to adverse outcomes.

**Systems using CO\textsubscript{2} Absorbents**

These systems were developed to conserve gases, to save costs, minimize pollution, and to some degree retain heat and moisture. All the exhaled gases are rebreathed except the carbon dioxide which is removed by different formulations of carbon dioxide absorbents (Soda lime, Baralyme, Amsorb®, Drägersorb® etc.). Fresh gases are added to the system based on the leaks in the system, uptake of oxygen and inhalational anesthetic agents by the body, arrangements of various components of the system, and clinical state and duration of anesthesia.

The CO\textsubscript{2} from exhaled gases combines with water to become a weak acid, carbonic acid, which reacts with a strong alkali (calcium hydroxide) producing a carbonate and water. This reaction of neutralization is exothermic and steps are as follows:

1. \( \text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{CO}_3 \)
2. \( \text{H}_2\text{CO}_3 + \text{Ca(OH)}_2 \rightleftharpoons \text{CaCO}_3 + 2\text{H}_2\text{O} + \text{Heat} \)
The reaction with calcium hydroxide is slow, hence catalysts are used to improve the performance. Traditionally soda lime has sodium and potassium hydroxides as catalysts. The modern day soda lime has only sodium hydroxide as a catalyst. Baralyme has barium hydroxide octahydrate as a catalyst. Some formulations of Amsorb® and Drägersorb® Free contain calcium chloride, a humectant (hygroscopic substance with the affinity to form hydrogen bonds with molecules of water).

The absorbent is presented as porous granules or pellets with a size between 4-8 mesh. Traditionally silica is added to give hardness to the granules, but the modern technology makes this unnecessary. The absorbents can either be packed into canisters or available as pre-packed canisters.

Theoretically 100 grams of wet soda lime contains approximately 74 grams of calcium hydroxide (one gram molecular weight). This can absorb one gram molecular weight of CO₂ (44 g CO₂ is equivalent to 24 liters at room temperature and pressure according to Avogadro’s principle). Assuming that a resting adult produces CO₂ at the rate of 12 liters/hour (200 ml/min), 100 g of soda lime at 100% efficiency is expected to last for about two hours. However in practice one can never achieve this level of efficiency particularly in single chamber canisters and 100 g soda lime roughly lasts for about 60 minutes. Dual chamber canisters demonstrate better efficiency if canisters are changed one at a time and reversed. However in order to minimize the effects of desiccation of the absorbent, the consensus statement from Anesthesia Patient Safety Foundation recommends that the absorbent from both canisters be changed at the same time. Amsorb® is reported to be 50% less efficient when compared to soda lime.

**Inhaled Anaesthetic agents and CO₂ absorbents**

The absorbents will, to some extent, interact with inhaled anesthetics and result in the production of degradation products.

**Compound A:** Sevoflurane decomposes to form several degradation products. However, only ‘Compound A’ has a dose dependent nephrotoxicity in rats. Human studies have produced contradicting results.

The circumstances that produce higher levels of ‘compound A’ include
1. low total gas flow rate (below 1 L/min),
2. higher concentration of sevoflurane,
3. the use of Baralyme rather than Soda lime,
4. higher absorbent temperatures, and
5. desiccated carbon dioxide absorbent (hence the addition of calcium chloride reduces the production of compound A).

Absorbents free of strong alkali, having smaller concentration of sodium hydroxide, or containing calcium chloride produce little or no ‘compound A’ (Amsorb®, Drägersorb® Free).

**Carbon Monoxide:** Carbon monoxide (CO) is produced when desflurane, enflurane, or isoflurane is passed through dry absorbent containing a strong alkali. The factors that increase the carbon monoxide production include (1) higher anaesthetic concentration, (2) higher temperature, and (3) dry absorbent. The magnitude of CO production from greatest to least is desflurane > enflurane > isoflurane > halothane = sevoflurane. The use of Baralyme produces more CO rather than Soda lime. Amsorb® and Drägersorb® free do not produce significant levels of CO. In view of the above and also because of the production of high temperature with sevoflurane, leading to reports of fires, the manufacturers of Baralyme have stopped the distribution of Baralyme since late 2004.
**Indication of Absorbent exhaustion:**

1. **Capnography:** Appearance of CO\(_2\) in the inspired gas is the best way to detect absorbent exhaustion.

2. **Indicators:** An indicator is an acid or base whose color depends on the pH and the color change is indicative of absorbent exhaustion. Several indicators like Phenolphthalein (White to pink), Ethyl violet (white to purple), Clayton yellow (red to yellow), Ethyl orange (orange to yellow), and Mimosa Z (red to white) are used by different manufacturers. Color change could be misleading in certain circumstances particularly due to regeneration (peaking) after a period of rest. Amsorb® turns purple when desiccated; an additional advantage to prevent use of desiccated soda lime.

3. **Temperature in canister:** Since the CO\(_2\) neutralization is an exothermic reaction, changes in the absorbent temperature occur earlier than color change. Studies have suggested that when temperature of the downstream canister is higher than that of the upstream canister the absorbent should be changed in both canisters.

4. **Clinical signs:** Clinical signs of hypercapnia like tachycardia, hypertension, cardiac arrhythmias, and sweating are usually late signs and are non-specific.

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**To and Fro System (Figure 3)**

Ralph Waters (anesthetist in Kansas City) in 1921 described the clinical use of a canister filled with soda lime. Patients exhaled through the canister (placed close to the patient's airway) into a reservoir bag and inhaled the next breath, free of CO\(_2\), from the reservoir bag, passing again through the canister (i.e., a to-and-fro canister). This revolutionary innovation meant that inhalation anaesthesia could be given without dilution by room air. High concentrations of oxygen could be given, heat was conserved, and pollution of the operating room air was avoided (pollution was considered to be a problem even in 1926). The principle of CO\(_2\) absorption using the to-and-fro canister was eventually supplanted by soda lime canisters in circle systems. The to-and-fro canister, however, set the stage for the subsequent introduction of cyclopropane and, even later, halogenated inhalation anesthetics that could not be given using open techniques. The stage was also set for initiation of assisted and, finally, controlled respiration, the need for which did not become apparent for another 25 years.

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**Circle System (Figure 4)**

In 1926, Brian Sword developed a unidirectional rebreathing system, referred to as a circle system. The gases flow in a circle through the soda lime canister to the patient and back. The unidirectional flow is maintained by two separate unidirectional valves one for inspiration (IUDV) and another for expiration (EUDV) mounted on the canister. The placement of the other components like Fresh Gas Flow (FGF), Adjustable Pressure Limiting Valve (APL), and Reservoir bag determine the efficiency of the system.
FGF: The fresh gas flow usually enters the system between the canister and the IUDV. The system is classified into three functional types based on the FGF:

1. High flow: FGF > patient’s Alveolar Ventilation. In an ideal arrangement this results in selective elimination of all the exhaled gases from the patient and hence there is no rebreathing of alveolar gases. The inspired concentration of oxygen and anaesthetic agents will be the same as that are set on the machine. This technique is recommended usually at induction, intermittently during a long anaesthetic, whenever patient’s depth of anaesthesia needs to be changed rapidly, and during recovery.

2. Low flow: FGF < patient’s Alveolar Ventilation (but not basal). These flows result in conservation of part of the exhaled gases. This technique allows for a bit of flexibility, requires less sophisticated technology, and lessens the effects due to accumulation of compound A and carbon monoxide.

3. Closed system or Basal flow: The use of very low FGF makes these systems economical and exciting. FGF supplies only the consumed oxygen and anaesthetic agents by the patients. The currently available sophisticated machines (Zeus, Aisys) make this technique practically easy to master and use. Monitoring of oxygen and inhaled agents between the system and patient is mandatory.

Figure 4. Schematic representation of circle system. (© Cambridge University Press. Reproduced with permission)
**Reservoir Bag (RB):** The reservoir bag should ideally be located between EUDV and the canister. It will be less efficient to have it between IUDV and the canister. It should never be located between either of the unidirectional valves and the patient. During mechanical ventilation the reservoir bag is switched to the ventilator bellows using a switch (Man/Auto).

**APL:** The location of the APL valve in conjunction with the reservoir bag determines the efficiency of expelling exhaled gases out of the system. The ideal location is between the EUDV and the canister along with the RB. This location allows for efficient elimination of exhaled alveolar gases preferentially out of the system. Modifications to the APL valve facilitate scavenging.

**Breathing tubes:** Two corrugated tubes connect the Y-piece at the patient end to either of the unidirectional valves. Corrugated tubes are used to allow flexibility and prevent kinking. These tubes expand and contract during positive pressure ventilation resulting in loss of tidal volume (internal compliance of the tubes). This could be as high as 200 ml at pressures of 20 cm H₂O. Hence appropriate changes should be made particularly for paediatric patients.

**Advantages and disadvantages**
The main advantages of circle system include economy, reduced pollution, and conservation of heat and humidity. The disadvantages include the need for more vigilance, need for extensive monitoring of inspired gases, and accumulation of by-products of anaesthetic agent degradation.

**Mapleson Systems (Figure 5)**

![Mapleson Systems Diagram](mapleson_systems.png)

**Figure 4.** Mapleson Classification. (© Cambridge University Press. Reproduced with permission)

The Magill attachment has been in use since 1928. In 1954 on the advice of William Mushin, Mapleson assembled various components used in the Magill circuit in different ways and reported on the functional
analysis to eliminate rebreathing. Mapleson systems A-E were thus born and system F (Jackson Rees modification of T-piece) was added to the analysis in 1975. The amount of carbon dioxide rebreathing associated with each system is multifactorial, and variables that dictate the ultimate carbon dioxide concentration are as shown in Table 3. The following summarizes the relative efficiency of different Mapleson systems with respect to prevention of rebreathing:

- During spontaneous ventilation: A > DFE > CB.
- During controlled ventilation, DFE > BC > A.

The Mapleson A, B, and C systems are rarely used today, but the D, E, and F systems are commonly used.

<table>
<thead>
<tr>
<th>Table 3. Factors affecting CO₂ rebreathing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. the fresh gas inflow rate,</td>
</tr>
<tr>
<td>2. the minute ventilation,</td>
</tr>
<tr>
<td>3. the mode of ventilation (spontaneous or</td>
</tr>
<tr>
<td>controlled),</td>
</tr>
<tr>
<td>4. the tidal volume,</td>
</tr>
<tr>
<td>5. the respiratory rate,</td>
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<tr>
<td>6. the inspiratory to expiratory ratio,</td>
</tr>
<tr>
<td>7. the duration of the expiratory pause,</td>
</tr>
<tr>
<td>8. the peak inspiratory flow rate,</td>
</tr>
<tr>
<td>9. the volume of the reservoir tube,</td>
</tr>
<tr>
<td>10. the volume of the breathing bag,</td>
</tr>
<tr>
<td>11. ventilation by mask,</td>
</tr>
<tr>
<td>12. ventilation through an endotracheal tube, and</td>
</tr>
<tr>
<td>13. the carbon dioxide sampling site.</td>
</tr>
</tbody>
</table>

Mapleson A (Magill attachment – 1928; Lack system – 1972): This is the most efficient system during spontaneous respiration. FGF equalling minute ventilation eliminates rebreathing, while PaCO₂ is determined by the patient’s minute ventilation. The following figures depict plug type movement of gases from various compartments, however, mixing of gases at various interfaces occurs all the time. The apparatus dead space in this system extends from the APL valve to the patient.

During spontaneous ventilation the APL valve is kept in the fully open position, however it remains closed till its opening pressure is exceeded. As the patient exhales, the dead space gases followed by alveolar gases enter the corrugated tube and travel towards the reservoir bag. Simultaneously the fresh gas also flows into the bag. Once the bag is full the pressure in the system rises and the APL valve opens. From this point the alveolar gases from the patient are vented through APL valve. The fresh gas entering the corrugated tube forces the alveolar gases in the corrugated tube out through the open APL valve. If the FGF is equal to or higher than patient’s minute volume, all the alveolar gases and the dead space gases will be vented through APL valve (Figure 6). At the beginning of next inspiration patient inhales alveolar gases from apparatus dead space followed by fresh gases from the corrugated tube. If the FGF is equal to the alveolar ventilation then the gas from the dead space that entered the corrugated tube will be conserved (Figure 7). Since these gases do not contain any CO₂, rebreathing of these dead space gases will not result in CO₂ accumulation in patient. However if the FGF were to be less than the alveolar ventilation, then significant rebreathing of CO₂ containing alveolar gases could result in hypercapnea (Figure 8).

During controlled ventilation the Mapleson A is the least efficient system (Figure 9). The APL valve has to be partially closed to inflate the lungs. Hence the opening pressure of the APL valve is high and the gases are not vented out of the system during exhalation. At the end of exhalation the patient end of the corrugated tube is filled with alveolar gases. The reservoir bag and the machine end of the corrugated tube contain fresh gases. During the early part of the next inspiration a portion of the alveolar gases enters the patient and some is vented out through the APL valve. During the later part of inspiration fresh gases enter the patient’s lungs and some are vented out. This results in wastage of fresh gases and significant rebreathing of alveolar gases making this system unsuitable for controlled ventilation.
However enclosing the reservoir bag and APL valve as done in Enclosed Afferent Reservoir System (EARS) makes the system efficient both for spontaneous and controlled ventilation.

Figure 6. Disposition of gases at the end of spontaneous exhalation when FGF equals or slightly more than minute ventilation. During next inspiration patient breathes gases from apparatus dead space and fresh gas. (© Cambridge University Press. Reproduced with permission)

Figure 7. Disposition of gases at the end of spontaneous exhalation when FGF equals alveolar ventilation. During next inspiration patient breathes gases from apparatus dead space, dead space gas and fresh gas. (© Cambridge University Press. Reproduced with permission)
Figure 8. Disposition of gases at the end of spontaneous exhalation when FGF is less than alveolar ventilation. During next inspiration patient breathes alveolar gas, dead space gas, and fresh gas. (© Cambridge University Press. Reproduced with permission)

Figure 9. Disposition of gases at the end of exhalation (controlled ventilation). During next inspiration patient is ventilated with alveolar gas, dead space gas, and fresh gas. There will be significant wastage of fresh gas. (© Cambridge University Press. Reproduced with permission)
**Lack System:** This system is a co-axial version of Mapleson A. The expiratory tube runs coaxially within the inspiratory limb and the APL valve is situated at the machine end of the system, facilitating easy access and scavenging. In view of the expiratory limb running inside the inspiratory limb, the system is bulky and imposes a higher resistance.

![Lack System](Image)

**Figure 10.** Lack System. (© Cambridge University Press. Reproduced with permission)

**Mapleson D:** The Mapleson D, E, and F systems function as T-piece systems. The apparatus dead space in these systems extend from the patient to the point of entry of FGF.

All through the exhalation the dead space gases and alveolar gases mix thoroughly with fresh gases and collect in the reservoir bag and corrugated tubing. During the expiratory pause the fresh gases collect at the patient end of the corrugated tube (Figure 11). During the next inspiration the fresh gas flowing from the machine and fresh gas in the corrugated tube enters the patient first. The contribution of this to the tidal volume will depend upon the FGF and the expiratory pause. The functional analysis is similar in both spontaneous and controlled ventilation. Hence this system can be used safely during both spontaneous and controlled ventilation. Fresh gas flow of 1.5 to 2 times the minute ventilation of the patient was reported to produce adequate \( \text{PaCO}_2 \), which depends primarily on the minute ventilation.

The system is slightly more efficient during controlled ventilation because of the control over the expiratory pause. When high FGF (> 2 times the minute volume) is used, there is no rebreathing and the minute ventilation determines the arterial \( \text{CO}_2 \) levels. This principle is commonly employed in paediatric population. Whereas, in adults, the patient is hyperventilated (minute Volume > 150 ml/Kg/min with normal to low respiratory rate) and \( \text{CO}_2 \) levels are controlled by adjusting FGF and hence the rebreathing. Studies using Bain circuit have demonstrated that a FGF of 70 ml/Kg/min maintains normocapnia, whereas a FGF of 100 ml/Kg/min maintains mild hypocapnia.
Figure 11. Disposition of gases at the end of exhalation. The patient end of the corrugated tube is filled with fresh gases and the remaining part of corrugated tube and reservoir bag is filled with a mixture of fresh gas, dead space gas, and alveolar gas. (© Cambridge University Press. Reproduced with permission)

Bain Circuit (Figure 12): The Bain circuit is a modification of the Mapleson D system and was introduced in 1972. It is a coaxial circuit in which the fresh gas flows through a narrow inner tube within the outer corrugated tubing. Traditionally the length of the system is 1.8 meters. The length can be increased by adding additional corrugated tube at the machine end without altering its functionality. This may be of particular benefit for remote anaesthesia in magnetic resonance imaging units.

Advantages: It is lightweight, convenient, easily sterilized, and reusable. Scavenging of the gases from the expiratory valve is facilitated because the valve is located away from the patient. Exhaled gases in the outer reservoir tubing add warmth to inspired fresh gases.

Hazards: Kinking, leakage or disconnections in inner tube can cause severe hypercapnia. The outer tube should be transparent to allow inspection of the inner tube. The integrity of the inner tube should be checked by the following tests:

1. Set a low flow on the oxygen flowmeter and occlude the inner tube (with a finger or the barrel of a small syringe) at the patient end while observing the flowmeter indicator. If the inner tube is intact and correctly connected, the indicator will fall slightly.
2. Activate the oxygen flush and observe the bag (Pethick test). A Venturi effect caused by the high flow at the patient end will create a negative pressure in the outer exhalation tubing, and this will cause the bag to deflate. If the inner tube is not intact, this manoeuvre will cause the bag to inflate slightly.

Figure 12. Bain Circuit. (© Cambridge University Press. Reproduced with permission)
**T-Piece Systems**

Ayre’s T-piece was introduced in 1937. It is light weight, simple and has no valves. The resistance was considered to be lower than systems containing valves. Numerous modifications of the T-piece system were made. The Jackson-Rees modification is widely used in paediatric anaesthesia (Figure 13). In this system the APL valve is replaced by open ended reservoir bag.

Functionally the Jackson-Rees attachment performs like Mapleson D. Rebreathing is prevented by using FGF about two times the minute ventilation. This system is used in children for both spontaneous and controlled ventilation. The T-piece systems are widely used for paediatric anaesthesia, oxygen therapy, paediatric and neonatal resuscitation, and in paediatric ventilators.

![Figure 13. T-Piece system - Jackson-Rees modification. (© Cambridge University Press. Reproduced with permission)](image)

**Monitoring**

**Inspired Oxygen Concentration**

The current recommendations require that all modern machines must have inspired oxygen concentration monitoring along with low O₂ and high O₂ alarms. Most units incorporate oxygen concentration monitor either at the CGO or in the inspiratory limb of the circle system to ensure that hypoxic mixtures are not delivered. In addition inspired oxygen concentration is also monitored at the patient end using paramagnetic analysers. Causes of inadequate O₂ concentration in the breathing system include:

1. a hypoxic gas being delivered via the pipeline or tanks,
2. disconnected fresh gas hose during use of a hanging bellows ventilator,
3. O₂ flow control valve turned off,
4. failure of oxygen fail-safe system,
5. proportioning system failure,
6. O₂ leak in the low pressure system of the machine, and
7. a closed system with inadequate O₂ inflow rate.

**Airway Pressure**

Airway pressure monitoring warns the user about high pressures, low pressures, and disconnections. Many traditional anaesthesia breathing systems incorporate an analogue pressure gauge, as well as an electronic pressure monitoring and alarm system. Most currently used anaesthesia machines incorporate low pressure, high pressure, sustained pressure, or disconnection alarms. Airway pressure monitoring can give us an approximate idea of changes in airway resistance, and lung and thoracic compliance. The modern anaesthesia machine can give us real time pressure tracing plotted against time. During volume controlled ventilation, when inspiratory pause is used, changes in plateau pressure indicate changes in lung and thoracic compliance, whereas changes in the peak to plateau pressure gradient indicate changes in airway resistance provided there are no alterations in tidal volume.
**Spirometry**

Spirometry is used to monitor the tidal volume, compliance, resistance, and breathing system integrity. These values provide valuable information regarding changing pulmonary mechanics during anaesthesia. The ventilator bellows are marked to give us an approximate idea of tidal volume. In traditional anesthesia machines monitoring of expired tidal and minute volumes is achieved using a spirometer placed in the vicinity of the expiratory unidirectional valve. The modern machines use flow sensors (D-lite flow sensor, heated wire anemometer, ultrasonic flow sensor etc.) between the patient and breathing system, and give an accurate idea of minute volume, compliance and resistance. These modules enable us to monitor flow-volume and pressure-volume loops as well.

**Capnography**

It is interesting and essential to have a good understanding of functional analysis of breathing systems. However for all practical purposes one depends on capnography to maintain CO₂ homeostasis. Monitoring end tidal carbon dioxide levels (PETCO₂) gives us an estimate of PA CO₂, and hence the FGF and minute ventilation can be manipulated to maintain desired CO₂ levels. Evaluation of the inspiratory phase of the capnogram gives us an idea of rebreathing of exhaled CO₂ (Figure 14). The ideal site to sample gases is between the patient and the elbow adaptor after the breathing system.

![Figure 14. Capnography and rebreathing](image)

**A:** Normal capnogram. PETCO₂ is normal

**B:** Exhaustion of soda lime. Base line is elevated above zero indicating rebreathing (shaded area during inspiration). PETCO₂ is increased

**C:** Camel hump during inspiration indicating rebreathing of mixed gas (alveolar and fresh) during later part of inspiration. This is typical of Mapleson D in controlled ventilation. The PETCO₂ may remain normal despite rebreathing.

**D:** Rebreathing during controlled ventilation with Mapleson A or malfunctioning inspiratory unidirectional valve in circle system. The expiration appears prolonged due to rebreathing of alveolar gases without any change in CO₂ content. PETCO₂ is increased.
References / Further Reading


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Websites
