Reference Point

Rebreathing anesthetic systems in small animal practice

Phillip Lerche, BVSc; William W. Muir III, DVM, PhD, DACVA; Richard M. Bednarski, DVM, MS, DACVA

Anesthetic breathing systems are designed to deliver inhalant anesthetics and gases, including oxygen and nitrous oxide to the patient and remove exhaled carbon dioxide. Additionally, they facilitate assisted and controlled ventilation. New anesthetic drugs, technical advances in small animal surgery, and a rise in the number of surgical specialists have increased the number of complex and prolonged surgical procedures performed on cats and dogs. Maintenance of anesthesia for surgery lasting several hours is most commonly accomplished by use of inhaled anesthetic drugs that are delivered by precision anesthetic vaporizers and anesthetic breathing systems. All patients, even those receiving anesthesia solely by IV administration for surgical procedures of intermediate duration (15 to 60 minutes), require endotracheal intubation and benefit from supplemental oxygen that may be easily delivered by an anesthetic machine and an anesthetic breathing system.

Modern disposable anesthetic breathing systems have been developed for rebreathing and nonrebreathing approaches to delivery of anesthetics and gases. They are convenient to use, designed to minimize hypothermia, and inexpensive. A review of existing and new breathing systems and terminology used in veterinary anesthetic practice, and a discussion of anesthetic equipment function, criteria for selection, and limitations, is therefore timely.

Classification

Multiple approaches have been used to categorize anesthetic breathing systems, resulting in confusing terminology. Hamilton recognized this shortcoming and recommended that a functional description comprising anesthetic breathing system components and fresh gas flow rate (the rate of gas delivery to the anesthetic breathing system via the flowmeters from oxygen generators or tanks of compressed oxygen and nitrous oxide) be used to describe individual systems.

The method by which carbon dioxide is removed from the anesthetic breathing system provides an alternative means of classification. Carbon dioxide can be directed away from the patient and removed from the breathing system by 1 method or some combination of 3 methods: high fresh-gas flow rates, a series of unidirectional valves, or chemical absorption. Systems using either of the first 2 methods are classified as nonrebreathing, whereas those using the third method alone or in combination with the second are classified as rebreathing.

Unidirectional valved nonrebreathing systems (eg, Fink and Stephens-Slater systems) are rarely used in veterinary anesthesia and will not be discussed further. Valved nonrebreathing self-inflating resuscitation bags (Ambu bag) are routinely used to assist or control ventilation in critically ill patients.

Current commonly used nonrebreathing systems (Mapleson series) do not possess valves and use high fresh-gas flow rates to flush carbon dioxide away from the patient into the scavenging system, thus preventing the patient from rebreathing exhaled gases. By contrast, rebreathing systems make use of a chemical reaction with carbonate-based material (sodium hydroxide lime or barium hydroxide lime) to absorb carbon dioxide, thereby removing it from the system.

Key issues that are important in determining gas exchange and anesthetic delivery to the patient include rebreathing, tidal volume, minute ventilation, and dead space volume. The term rebreathing is defined as inhalation of previously expired gases (ie, anesthetic vapor, oxygen, and carbon dioxide). Rebreathing of alveolar gas implies that a portion of the inspired gas has a reduced inspired fraction (Fi) of oxygen and, unless carbon dioxide has been removed, a higher than normal FiCO₂. Rebreathing can lead to hypercarbia, respiratory acidosis, acidemia, and an unstable plane of anesthesia. Factors that influence the amount of rebreathing of exhaled gases are equipment-related and physiologic. Equipment-related factors include the fresh-gas flow rate, mechanical dead space, and individual system design (eg, location of 1-way valves). Minimal rebreathing will occur if the fresh-gas flow rate is equal to or greater than the peak inspiratory flow rate, or equal to or greater than minute ventilation if expiration into the scavenging system occurs at a point close to the patient.

Controlled, limited rebreathing of carbon dioxide and other exhaled gases can be advantageous in that they are warm and saturated with water vapor, whereas fresh anesthetic gases are cold and dry, requiring the patient to expend energy to heat and humidify the fresh gas. Bickler and Sessler demonstrated that...
humans lose as much as 10% of their total metabolic heat by warming and humidifying inspired anesthetic gases. Furthermore, 1 ml of water is required metabolically for every kcal of energy expended, contributing further to fluid loss under anesthesia.  

Minute ventilation (or minute volume) equals breathing frequency (number of breaths per minute) multiplied by tidal volume. Normal tidal volume is approximately 10 to 15 ml/kg (4.5 to 6.8 ml/lb) of body weight, although factors such as metabolic rate, pain, anesthesia, and anesthetic adjuncts may change this value. Respiratory rate varies considerably during anesthesia in cats and dogs. Minute ventilation in cats has been determined to be 174 ml/kg/min (79 ml/lb/min) and 310 ml/kg/min (140 ml/lb/min). Similar values for awake and anesthetized dogs have been reported as 204 ml/kg/min (93 ml/lb/min) and 264 ml/kg/min (120 ml/lb/min), respectively. A practical range for minute ventilation during anesthesia, and anesthetic adjuncts may change this value. Respiratory rate varies considerably during anesthesia in cats and dogs. 

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The greater the dead space volume, the greater the volume of gases rebreathed that contains carbon dioxide. Mechanical dead space (Fig 1) refers to the volume of exhaled gases within the breathing system that is subsequently rebreathed and is produced when equipment is attached to the airway. The 

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rounded by an insulating plastic jacket. This design theoretically decreases heat loss from and condensation formation within the hoses when used in conjunction with a carbon dioxide absorber canister (Fig 3). These insulated hoses connect to the circle system in the same way as conventional breathing hoses.

The Y-piece connects the inspiratory and expiratory hoses to the endotracheal tube or mask connector. The volume within the Y-piece in which mixing of inspired and expired gases occurs (ie, 2-way flow of gases) is equipment dead space. A septum placed in the Y-piece will decrease this volume, thus decreasing dead space (Appendix 1).

**Reservoir bag**—The reservoir or rebreathing bag is most commonly located between the expiratory valve and the carbon dioxide absorber canister so that rebreathing of expired gas does not occur. Rebreathing bags are compliant, which allows visual assessment of respiratory rate and volume and protects the patient from excessive pressure in the breathing system. Rebreathing bags act as dynamic gas reservoirs so that
peak inspiratory flow demands are met when the fresh gas flow is low. They also serve as a method of manually delivering a breath to the patient. The bag volume needs to accommodate a normal tidal breath (10 to 15 ml/kg [4.5 to 6.8 ml/lb]). For convenience, a bag volume 3 to 5 times that of tidal volume is recommended, which also provides ample reserve to accommodate a vital capacity breath. For practical purposes, a 1-L bag is generally used for patients weighing ≤ 7 kg (15.4 lb), a 2-L bag for patients weighing > 7 to 20 kg (15.4 to 44 lb), a 3-L bag for patients weighing > 20 to 60 kg (44 to 132 lb), and a 5-L bag for patients weighing > 60 kg (132 lb). When most mechanical ventilators are used with a circle system, the rebreathing bag is removed and the ventilator hose is attached to the anesthetic circle system in its place (Fig 4).

Pop-off valve (adjustable pressure-limiting valve)—The pop-off valve acts as an interface between the breathing system and the scavenging system (or atmosphere) and allows the anesthetist to control the pressure within the breathing system. When fully open, most valves allow gas to escape from the system when the pressure within the circle exceeds 0.5 to 1.5 cm H2O. During spontaneous respiration, the pop-off valve is left open, although it may be closed partially if the application of positive end-expiratory pressure is desired. The valve is partially closed or left open during low-flow anesthesia. The valve is left partially open or closed during manually assisted breathing, and closed when a mechanical ventilator is used, because anesthetic ventilators have self-contained pop-off valves.

Several types of pop-off valve are available. A common type uses a spring-loaded disk covered by a threaded screw cap. Fully tightening the screw cap prevents gas from escaping the circle. As the cap is unscrewed, the disk can rise when the pressure exerted beneath the disk (ie, the pressure within the anesthetic circle) exceeds the downward pressure exerted by the spring on the disk. In the fully open position, the disk alone exerts the downward force. A system incorporating a diaphragm valve works in a similar way: the cap and spring push on a diaphragm rather than a disk. A third type with a variable orifice uses a threaded stem with variable contact with the orifice. As the valve is opened, the opening enlarges, allowing more gas to escape.

Location of the pop-off valve in the system may vary. Positioning the pop-off valve on the Y-piece allows for maximal preservation of absorbent because alveolar gas, which contains the highest concentration of carbon dioxide, is preferentially vented to the scavenging system. This location is, however, awkward and potentially wasteful, because fresh gas can escape as well. The pop-off valve is most commonly located above the rebreathing bag near the carbon dioxide absorber canister and between the 1-way valves to avoid venting of fresh gases (Fig 2A and 2B).

Unidirectional (1-way) valves—Unidirectional valves ensure that fresh gas and rebreathed gas (minus carbon dioxide) flows towards the patient and exhaled gas flows away from the patient. During inhalation, the inspiratory valve opens and the expiratory valve closes; the opposite occurs during exhalation. Exhaled gas is directed away from the patient, preventing rebreathing of gas that has not passed through the carbon dioxide absorber. Valve assemblies have traditionally been mounted vertically on the carbon dioxide absorber and consist of a disk covering an annular ring. Disks were originally made of metal, but modern valve assemblies contain lightweight hydrophobic disks that cause minimal resistance to breathing and may be mounted horizontally. Newer valve assemblies contain a retainer that prevents the disk from dislodging laterally or vertically. A transparent dome or ring covering the top of the valve assembly allows visual inspection of the disk. The disks should not stick in the closed position when coated with moisture, because this will increase resistance to breathing. A faulty disk assembly that remains permanently open offers reduced resistance to flow but allows flow to be bidirectional, promoting the build up of carbon dioxy-

![Figure 3](image1.jpg)  Photograph of the THERMH2OSORB® system (A) attached to standard anesthetic machine. Notice RAINCOAT® breathing hoses (B) and empty carbon dioxide absorber canister (C).

![Figure 4](image2.jpg)  Photograph of ventilator attached to circle anesthetic breathing system at the rebreathing bag port.
Carbon dioxide absorption canister and absorbent—The canister assembly consists of a head and base that are usually constructed of metal. A canister containing absorbent is interposed between the head and the base. The canister is usually constructed of clear plastic but may be made of solid metal. Gas may enter the absorbent from below or above. A gap (plenum) located beneath or above the canister allows for adequate dispersal or mixing of gas as it enters or exits the canister, respectively. The plenum also allows dust and moisture to accumulate, which prevents caking of the lower layers of absorbent. Some absorption assemblies have 2 canisters placed in series. When the absorbent is exhausted, the canister nearest the patient is refilled, and the downstream canister is switched to the upstream position.

Sodium hydroxide lime (75 to 80% calcium hydroxide, 14 to 19% water, 4% sodium hydroxide, 1% potassium hydroxide) and barium hydroxide lime (80% calcium hydroxide, 20% barium hydroxide) are 2 alkaline earth compounds commonly used as carbon dioxide absorbents. Silica is added to sodium hydroxide lime, hardening the granules and reducing dust formation. Carbon dioxide reacts with water and the alkali earth compounds, producing water, carbonate compounds (calcium carbonate, sodium carbonate or barium hydroxide, and potassium carbonate), and heat. An actively absorbing canister therefore feels warm unless high fresh-gas flows are used; with use of high fresh-gas flows, much of the carbon dioxide is vented to the scavenging system before reaching the canister. As absorption proceeds, the granules become brittle and clump together, and the contents of the canister become less alkaline. Ethyl violet, a pH-sensitive color indicator contained in the granules, changes from colorless to violet as pH decreases. Color change, although influenced by several factors, is probably the most practical indicator of absorbent exhaustion. Absorbent should be replaced when approximately two thirds of the visible absorbent has changed color. Absorbent that is completely exhausted may have no color change. The most sensitive method for determining exhaustion is through detection of increased FICO₂, which requires a gas analyzer. A much simpler method is to determine whether the granules can be crumbled between the fingers. Alternatively, standard 1-L absorbent canisters should be routinely changed after 6 to 8 hours of use. When filling the canister, a small space should be left at the top to promote even flow through the canister.

A prepackaged disposable carbon dioxide absorber incorporating a bacterial-viral filter and an airway humidification and warming system is available. This device is positioned between the inspiratory breathing hose and the anesthetic machine (Fig 3). It replaces the traditional absorbent canister, so when this system is used, it is important to remove the absorbent from the regular canister prior to its use, or resistance to breathing will be excessive. Similar to traditional carbon dioxide absorber canisters, change in color of the indicator or duration of use can be used to determine absorbent exhaustion.

Carbon dioxide absorbents interact with and degrade most volatile anesthetic agents, producing potentially toxic byproducts. Sevoflurane is degraded to an olefin termed compound A. Factors implicated in increased concentrations of compound A are low fresh-gas flows, use of baralyme instead of soda lime, high concentrations of sevoflurane, high absorbent temperature, and dry absorbent. Results of a recent study in dogs indicate that when the fresh-gas flow rate is <15 ml/kg/min (7 ml/lb/min), sevoflurane produces compound A concentrations in the circle that are not >65 µg/g. This value is well below 150 µg/g, a concentration known to be nephrotoxic in rats.

When used in rebreathing systems, the newer inhalants desflurane, isoflurane, enflurane, and, to a lesser extent, halothane, but not sevoflurane, react chemically with carbon dioxide absorbents, and may produce potentially harmful concentrations of carbon monoxide. Although carboxyhemoglobin concentrations reported in humans are low, patients with anemia or reduced total hemoglobin could be at risk for development of hypoxemia. Greater concentrations of carbon monoxide develop with use of barium hydroxide lime than with sodium hydroxide lime, and with high absorbent temperatures, dry absorbent, high anesthetic concentrations, and increased anesthetic duration. Recommended maximum time-weighted mean concentrations of gases have been reported; volatile agents used alone, ≤2 µg/g; volatile agents used with nitrous oxide, ≤0.5 µg/g; nitrous oxide, ≤25 µg/g. Recommended concentration within the circuit for carbon dioxide is ≤30 µg/g and for compound A is <150 µg/g.

Vaporizers—The anesthetic vaporizer is designed to convert volatile liquid anesthetic to vapor and add a specific amount of that vapor to the breathing system. Most vaporizers used today divert a fraction of the total fresh-gas flow through the vaporizing chamber. The remaining gas bypasses the chamber, and the 2 streams unite prior to leaving the vaporizer, resulting in a known, controlled concentration of anesthetic entering the breathing system. Concentration-calibrated, temperature-compensated vaporizers of the variable bypass design (eg, Ohmeda Tec 3") are located outside the circle (ie, vaporizer outside circle [VOC]; Fig 2A). Measured-flow vaporizers, by contrast, are supplied with a measured flow of fresh gas, all of which passes through the vaporizer. This measured flow becomes saturated with the maximum vapor output possible at any given temperature. The measured gas must therefore be diluted by an additional flow of fresh gas supplied to the breathing system. Measured-flow vaporizers (eg, Copper Kettle, Verni-Trols) are no longer manufactured but can be found on older anesthetic machines.

In veterinary anesthetic practice, nonprecision, draw-over vaporizers (eg, Ohio #8 glass bottle) are also encountered. These vaporizers are located in the anesthetic breathing system (ie, vaporizer in circle [VIC]; Fig 2B).
VOC—Measured-flow vaporizers and concentration-calibrated vaporizers are capable of delivering a fairly precise concentration of anesthetic vapor but have high resistance to gas flow and are therefore positioned out of the breathing circuit (Fig 2A). Patient ventilation and ambient temperature do not affect vaporizer output, except at extremes of heat or cold or if the fresh-gas flow rate is less than the calibrated limits of the vaporizer (usually <100 ml/min).22 Controlled ventilation can be used without risk of generating excessively high concentrations of anesthetic gas.

VIC—All VIC vaporizers have low resistance to gas flow, because the patient is required to breathe through the vaporizer (Fig 2B). Nonprecision draw-over type vaporizers can be placed in the inspiratory limb of the circle. Calibrations have little meaning, because concentrations delivered vary with changes in patient ventilation and ambient temperature. Increased spontaneous ventilation, assisted or controlled ventilation, increases in temperature, and decreased fresh-gas flow rate lead to increased inspired anesthetic concentration. The Ohio 8 vaporizer, at one time relatively popular, and other draw-over vaporizers are still used with Stephens and Komasaroff anesthetic systems. Their use has diminished with the desire for better knowledge of the anesthetic vapor concentration that is delivered to the patient.

Administering anesthetic agents with high vapor pressures such as sevoflurane, isoflurane, and halothane by use of nonprecision vaporizers located in the breathing circuit has been described.19,26,27 Safe use requires removal of the wick (Ohio 8 vaporizer), vigilant patient monitoring, and a thorough understanding of the factors influencing vaporizer output.26,28 Some authors have expressed concern that there is a greater risk of the patient inspiring a dangerously high concentration of anesthetic unless inspired and end-tidal gas concentrations are measured.29 Vaporizers located in the breathing circuit are not suited to deliver anesthetic vapor to nonrebreathing systems or to-and-fro systems.

It is possible, through a technique known as liquid injection, to introduce inhalant anesthetic agents into a closed circle system without the need for vaporization.20,31 This technique is not widely used, and its explanation is beyond the scope of this article.

Fresh gas inlet—The fresh gas inlet conveys oxygen, nitrous oxide, and volatile anesthetic vapor to the breathing system, and is most typically located between the canister and the inspiratory valve. This location minimizes fresh-gas loss from the pop-off valve and helps to prevent absorbent dust from being forced toward the patient when ventilation is controlled or the emergency oxygen flush button is operated.

Fresh-gas flow rates—After the carbon dioxide is removed from the rebreathing system by chemical absorption, the amount of remaining exhaled gas (oxygen, nitrous oxide, water vapor, anesthetic agent) returning to the patient is a function of the fresh-gas flow rate. The minimum oxygen flow rate delivered from the flowmeter is then determined by the minute oxygen consumption of the patient (approx 3 to 10 ml/kg/min [1.4 to 4.5 ml/lb/min], depending on the patient's individual metabolic rate, which is based on body surface area).32 Advantages of a low fresh-gas flow rate include decreased cost (inhalant anesthetics and delivery gases), decreased operating room and environmental pollution, conservation of heat and moisture within the breathing system, and decreased consumption of natural resources. During closed-system anesthesia the fresh-gas flow rate is equal to the uptake and metabolism of oxygen by the patient. The pop-off valve is left open, unless assisted or controlled breathing is required. The major disadvantage of closed-system anesthesia is the inability to change the inspired concentration quickly. To do so requires the fresh-gas flow rate to be increased simultaneously with the change in vaporizer setting. The volume of fresh gas entering the circle system every minute during closed-system anesthesia is small, compared with the total volume in the circle, so the time required to change the concentration of the system is relatively long. For example, a 13-kg (33-lb) dog may only require 10 ml/kg/min (4.5 ml/lb/min) of oxygen (150 ml) to enter the circle each minute. If a 2-L reservoir bag is used, the approximate volume of the circle is 6 L, or 6,000 ml. The time constant (time required for a 63% change to a new concentration) is circuit volume divided by flow rate (6,000 ml divided by 150 ml/min), or 40 minutes. Rapid changes in anesthetic concentration can therefore only be made by simultaneously altering the vaporizer setting and increasing the fresh gas flow rate.

Nitrous oxide should not be used with closed-system anesthesia unless an in-circuit oxygen analyzer is used, because it does not serve as an oxygen source, and, after the first few minutes of anesthesia, the rate of nitrous oxide uptake by the patient decreases. Unless the ratio of oxygen to nitrous oxide is adjusted with time, nitrous oxide can accumulate within the circle and result in the development of a hypoxic gas mixture. It is possible to overcome the disadvantages of closed-system anesthesia while maintaining some of its advantages by using fresh-gas flow rates slightly greater than closed-system rates. Commonly used fresh-gas flow rates for low-flow anesthesia vary between 22 and 44 ml/kg/min (10 to 20 ml/lb/min).30,32 As fresh-gas flow increases, gas is exhausted through the pop-off valve, increasing waste, pollution, and cost. Nitrous oxide can be used safely with a low-flow technique in a 1-to-1 ratio with oxygen, if the total fresh-gas flow is at least 8 ml/kg/min (3.6 ml/lb/min) and the pop-off valve remains open.33 Regardless of the chosen fresh-gas flow rate, relatively high fresh-gas flow rates are required during the induction phase of anesthesia to compensate for increased anesthetic uptake at this time, and to promote nitrogen washout from the patient and the anesthetic breathing system. Similarly, higher flow rates of oxygen during recovery from anesthesia aid in removing the inhalant anesthetic from the circle, and help prevent diffusion hypoxia if nitrous oxide is used.
Leak test—The circle system has approximately 10 connection points and must be tested for leaks prior to each use. The pop-off valve is closed and the patient port (Y-piece) occluded. With the flowmeters and vaporizer(s) turned off, the system is pressurized to 30 cm H2O by depressing the oxygen flush valve. The system should hold a pressure of 30 cm H2O for at least 10 seconds. The pop-off valve is then opened and the circle pressure should rapidly decrease immediately, indicating a functioning pop-off valve.

To-and-fro systems—The to-and-fro system was first described by Waters in 1936; it is not commonly used in veterinary anesthesia and is discussed here because it is used for field anesthesia and in biomedical research laboratories. It consists of a carbon dioxide absorption canister placed between the endotracheal tube connector and the reservoir bag. A pop-off valve and fresh-gas inlet are positioned between the patient connector and the canister (Fig 2E). Gas flows back and forth through the absorber canister during ventilation. Similar to the circle system, carbon dioxide is absorbed, and fresh-gas flow rates of oxygen approximating the patient’s metabolic oxygen consumption can be used.

Advantages of the to-and-fro system are its simplicity and ease of cleaning. The system is, however, cumbersome, and the proximity of the canister to the patient makes it awkward to use. There is also potential for soda lime dust to be inhaled. Heat produced by carbon dioxide absorption can easily be transferred to the patient unless the canister is made of thermally conductive material such as steel or brass, precluding the ability to observe the color change of absorbent when it becomes exhausted. Furthermore, a horizontally positioned canister can lead to channeling of gases along the walls of the canister, resulting in inefficient removal of carbon dioxide. If the canister is too small, exhaled gases pass through with insufficient contact time for carbon dioxide absorption. If the canister is too large, exhaled gases concentrate near the patient, resulting in rapid absorbent exhaustion and an increase in equipment dead space. A modified to-and-fro system with the fresh-gas inlet placed between the reservoir bag and canister (Fig 2F) has been reported to make more efficient use of fresh gas.

A disposable circle (carbon dioxide absorber canister, 1-way valves, coaxial inspiratory and expiratory limbs, rebreathing bag, pop-off valve) for single use in human anesthesia has been compared with a to-and-fro system in 19 dogs undergoing ovariohysterectomy. Heart rates and end-tidal carbon dioxide concentrations were comparable between groups during a 1-hour period, and rectal temperature was well maintained, decreasing by 1.0 and 1.1 C (1.8 and 1.98 F) in dogs anesthetized with the disposable circle (n = 10) and the to-and-fro system (9), respectively.

Selecting an Anesthetic System

Factors to consider when selecting an anesthetic system include but are not limited to patient-related issues (eg, body weight), type and duration of procedure (eg, dentistry, endoscopy), familiarity with anesthetic equipment, technical competence, facilities, applied knowledge of anesthetic drugs, monitoring capabilities, and economic considerations. Although the valves, hoses, and carbon dioxide absorption canister, combined with large mechanical dead space typical of most rebreathing systems, may cause resistance to breathing, small healthy patients (cats that weigh 2.5 to 4.3 kg [5.5 to 9.5 lb]) have been safely anesthetized by use of a circle system. System dead space should be kept to a minimum in all dogs and cats, particularly those that weigh < 5 kg (11 lb). Serious consideration should be given to the use of pediatric hoses (internal diameter, 15 mm) and endotracheal tube connectors when anesthetizing small patients (< 7 kg [15 lb]) if a circle system is selected because they create less resistance to breathing, conserve body heat, and minimize mechanical dead space.

References

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10. Davies A, Moyle JTB, Ward CS. Breathing systems and their


**Appendix 1**

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Dead space volume (ml)</th>
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<tbody>
<tr>
<td>Circle: standard T-piece</td>
<td>17</td>
</tr>
<tr>
<td>Circle: standard Y-piece, no septum</td>
<td>5.4</td>
</tr>
<tr>
<td>Circle: standard Y-piece, swivel-type</td>
<td>5.4</td>
</tr>
<tr>
<td>Circle: standard Y-piece with septum</td>
<td>2.8</td>
</tr>
<tr>
<td>Bain</td>
<td>4.4</td>
</tr>
<tr>
<td>T-piece</td>
<td>4</td>
</tr>
<tr>
<td>Elbow connector</td>
<td>7.4</td>
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<tr>
<td>End-tidal carbon dioxide connector</td>
<td>6.8</td>
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**Appendix 2**

Advantages and disadvantages of rebreathing anesthetic systems

<table>
<thead>
<tr>
<th>Disadvantages</th>
<th>Advantages</th>
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</thead>
<tbody>
<tr>
<td>* Composed of many parts, which increases risk of incorrect arrangement, malfunction, disconnection, and development of leaks</td>
<td></td>
</tr>
<tr>
<td>* Some components are difficult to clean and sterilize</td>
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<tr>
<td>* Initial cost is high and cost of carbon dioxide absorbent material is ongoing</td>
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<tr>
<td>* Changes in vaporizer setting for percentage of inhalant are not rapidly reflected by changes in percentage of inspired inhalant</td>
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<tr>
<td>* Rapid changes of anesthetic depth are only accomplished if changes in vaporizer setting are accompanied by increased fresh-gas flow rate</td>
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<tr>
<td>* Use of nitrous oxide in closed-system anesthesia may lead to development of a hypoxic gas mixture</td>
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<tr>
<td>* Flowmeters that are not calibrated to deliver low flow rates make accurate delivery of gases difficult during low-flow or closed-system anesthesia</td>
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</tr>
<tr>
<td>* Output of precision vaporizers may be inaccurate at low fresh-gas flow rates (&lt; 100 ml/min)</td>
<td></td>
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<tr>
<td>* Associated with higher resistance to breathing than nonrebreathing systems, which increases the work of breathing</td>
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</table>

* Low fresh-gas flows can generally be used, which are more economical |
* Conservation of heat and moisture |
* Atmospheric and operating room pollution can be minimized |
* PaO2 depends only on ventilation and not fresh-gas flow |
* Easily used with mechanical ventilators