valve on the expiratory port (Fig. 1). The required components for fresh gas flow and the mushroom valve system are: a mushroom valve, fresh gas flow source, high-pressure relief valve (pop-off valve), and low-pressure alarm. To minimize rebreathing, the fresh gas flow must be introduced as close as possible to the patient's endotracheal tube. In addition, the circuit should contain an alarm for airway pressure loss, and a pressure-relief valve (pop-off valve) to reduce the risk of barotrauma. A PEEP valve can be added to the expiratory port of any patient circuit, and thus individual PEEP can be optimized for each patient (2, 3). The ventilator's PEEP valve can also be engaged, but the same amount of PEEP will be applied to each patient.

Analysis of System. The advantages of this system are that it is inexpensive and easy to assemble, use, and trouble shoot. The number of patients that can be ventilated with this system is determined by the capacity of the ventilator to drive the mushroom valves and the availability of fresh gas sources. Its major disadvantage is its inefficient use of fresh gas flow. During the expiratory phase, the fresh gas flow is vented and thus wasted. For example, considering an inspiratory time of 2 secs, and a tidal volume of 500 mL at 12 breaths/min, a fresh gas flow of 15 L/min is required, of which only 6 L is used to ventilate the patient.

Secondary Circuit System. Fresh gas flowing during the expiratory phase of ventilation stays within the secondary circuit and makes up part of the inspired volume. In this instance, the required fresh gas flow would be equal to the minute ventilation.

Assembly. Figure 2 is a schematic diagram of two secondary circuits attached to one ventilator. Table 1 lists the components required to double the ventilator capacity using this system. The ventilator should ideally be a volume- or pressure-cycled ventilator, using a mushroom valve on the expiratory port. The ventilator circuit is attached to each secondary circuit.

Secondary Circuit. The "box" should be transparent to allow visualization of the bag. It should have two ports, one port attached to the ventilator circuit, and the other port attached to the bag inside the "box"

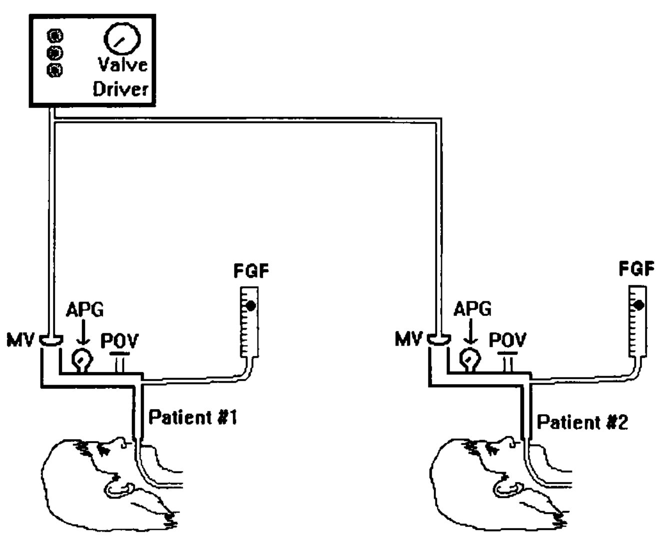

Figure 1. Fresh gas flow and mushroom valve ventilator showing a T-piece configuration. The fresh gas flow should enter the circuit as close as possible to the patient to avoid rebreathing. *MV*, mushroom valve; *APG*, airway pressure gauge; *POV*, "pop-off" valve; *FGF*, fresh gas flow.

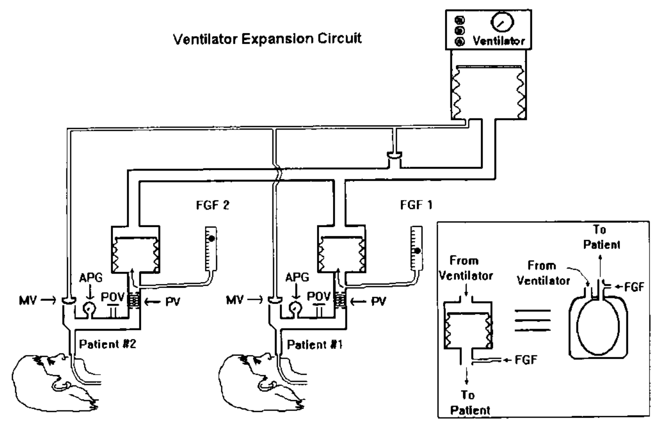

Figure 2. A schematic of the secondary circuit ventilator. Each secondary circuit is T-pieced to a volume-cycled ventilator circuit. The ventilator's mushroom valves are configured in parallel to the primary ventilator circuit and each secondary circuit. The "bag in box" is diagrammatically simplified as a bellows. *MV*, mushroom valve; *APG*, airway pressure gauge; *POV*, "pop-off" valve; *PV*, positive end-expiratory pressure valve; *FGF*, fresh gas flow.

Table 1. Apparatus for secondary circuit system required to double ventilatory capacity

"Bag in Box"
Two "boxes" e.g., 4-L suction bottles
Two 3-L bags
Two in-line spring-loaded PEEP valves
Mushroom Valves and Connectors
Two mushroom valves
1/8" ID tubing (4 m)
Two 4-mm "Y" connectors
Circuit Tubing and Connectors
Two 15-mm ID "T" connectors
Two nebulizer "T" connectors (as FGF inlet)
Two oxygen tubes
Four straight connectors
Nine meters of 22-mm corrugated aerosol tubing
Safety Monitors
Two aneroid manometers
Two pressure-relief valves (pop-off valves)
Two low-pressure alarm monitors

PEEP, positive end-expiratory pressure; ID, inner diameter; FGF, fresh gas flow.

Blood gas measurements can be performed as necessary.

In the event of a power or gas source failure, the patients must be disconnected from the circuits and ventilated manually, as is the practice when standard ventilators are used.

Trouble-Shooting. A system malfunction is normally detected by an aberrant filling and emptying motion of one or more of the bags in the secondary circuits. The patients affected should be disconnected from the circuit, ventilated manually with a self-inflating bag, and the circuit attached to a rubber anesthesia bag until the problem is identified. Malfunctions are classified according to one of the following three conditions: a) primary circuit malfunction; b) mismatched fresh gas flow; c) secondary circuit malfunction.

Trouble-shooting consists of differentiating between these three conditions. In a primary circuit malfunction, all patients and bags are affected simultaneously. Problems that appear to be affecting predominantly one patient reflect a fresh gas flow mismatched to minute ventilation, or a malfunction in any interdependent secondary circuit. The adequacy of fresh gas

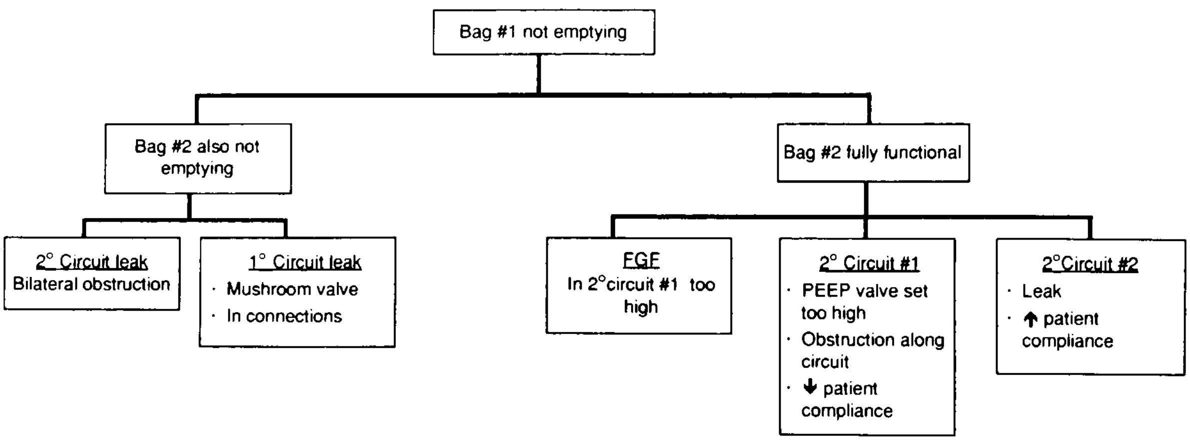

Figure 4. Chart for trouble-shooting when the bag in the secondary circuit on the index patient (*Bag #1*) is not emptying. *FGF*, fresh gas flow; *PEEP*, positive end-expiratory pressure.

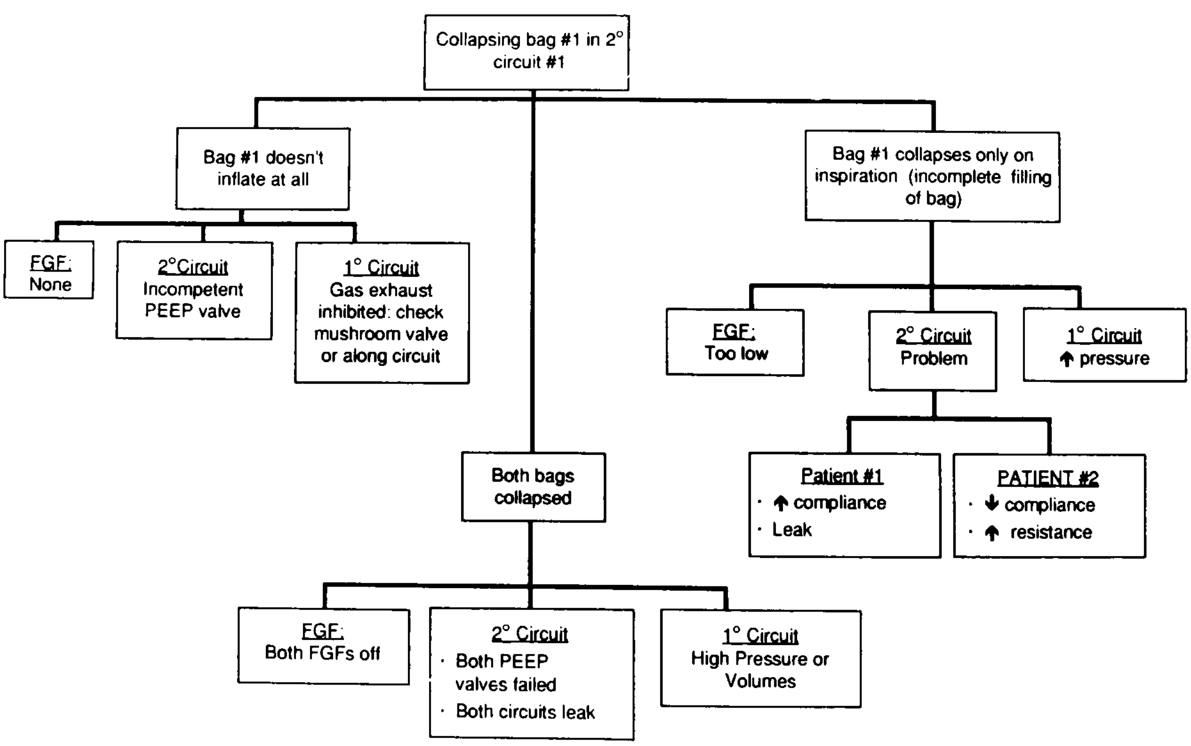

Figure 5. Chart for trouble-shooting when the bag in the secondary circuit on the index patient (*Bag #1*) is collapsing inappropriately. *FGF*, fresh gas flow; *PEEP*, positive end-expiratory pressure.