

# Using Anesthesia Machines as Critical Care Ventilators During the COVID-19 Pandemic

Paul N Austin and Richard D Branson

**Somewhere between 30% and 89% of patients with COVID-19 admitted to a critical care unit require invasive mechanical ventilation. Concern over the lack of adequate numbers of critical care ventilators to meet this demand led the U.S. Food and Drug Administration to authorize the use of anesthesia machines as critical care ventilators. The use of anesthesia machines for ventilating patients with COVID-19 is overseen by an anesthesia provider, but respiratory therapists may encounter their use. This article reviews the fundamental differences between anesthesia machines and critical care ventilators, as well as some common problems encountered when using an anesthesia machine to ventilate a patient with COVID-19 and steps to mitigate these problems. Key words: COVID-19; anesthesia; mechanical ventilation; critical care. [Respir Care 2021;66(7):1184–1195. © 2021 Daedalus Enterprises]**

## Introduction

Somewhere between 30% and 89% of patients with COVID-19 who are admitted to a critical care unit require invasive mechanical ventilation.<sup>1</sup> Concern over the lack of adequate numbers of critical care ventilators to meet this demand led the U.S. Food and Drug Administration to authorize the use of anesthesia machines (sometimes termed anesthesia workstations) as critical care ventilators.<sup>2</sup> This may occur by repurposing operating rooms as intensive care areas or by relocating anesthesia ventilators to the ICU. In both cases, the stated simplicity belies the important technical differences in devices and skills required for safe and effective operation.

Anesthesia machines are multi-component devices intended to deliver oxygen (O<sub>2</sub>) and other gases (eg, nitrous oxide and air) along with volatile inhaled anesthetic agents. The anesthesia machine often includes a physiologic monitor, capnograph, anesthetic gas monitor, and additional monitors. A

mechanical ventilator is integrated into the anesthesia machine as one of these components. Anesthesia machines may effectively ventilate critically ill patients but differ significantly from critical care ventilators both in design and operation.<sup>3,4</sup> Anesthesia providers (eg, certified registered nurse anesthetists or physician anesthesiologists) should oversee the use of anesthesia machines for patients with COVID-19,<sup>3</sup> but respiratory therapists are likely to be involved in their monitoring and use in the critical care unit.

This article provides critical care respiratory therapists with a review of the fundamental differences between anesthesia machines and critical care ventilators. Also examined are the common problems encountered when using an anesthesia machine to ventilate a COVID-19 patient and steps to mitigate these problems. Volatile anesthetics are sometimes administered to patients with severe asthma<sup>5</sup> and seizure disorder<sup>6</sup> in critical care units. A discussion of this practice is beyond the scope of this article. This information is not intended to replace formal training or manufacturer instructions. Like critical care ventilators, there are many manufacturers and models of anesthesia machines, and readers must follow manufacturer instructions and other guidelines. Readers are referred elsewhere for detailed directions on how to use an anesthesia machine as a critical care ventilator.<sup>2-4</sup>

## Fundamental Differences Between Critical Care Ventilators and Anesthesia Machines

Critical care ventilators deliver breaths containing a variable O<sub>2</sub> concentration (F<sub>IO<sub>2</sub></sub>), typically set from 0.21 to 1.0. Depending on the ventilation mode selected, the flow of gas

---

Dr Austin is affiliated with Texas Wesleyan University, Fort Worth, Texas. Mr Branson is affiliated with the Division of Trauma and Critical Care, Department of Surgery, University of Cincinnati Medical Center, Cincinnati, Ohio.

Mr Branson is Editor-in-Chief of RESPIRATORY CARE. He discloses relationships with Mallinckrodt Pharmaceuticals, Pfizer, Ventec Life Systems, Vyair, and Zoll Medical. Dr Austin has no conflicts to disclose.

Correspondence: Paul N Austin PhD CRNA, 14311 Harvest Moon Rd, Boyds, MD 20841. E-mail: paulaustin5@gmail.com.

DOI: 10.4187/respcare.08799



Fig. 1. A modern anesthesia machine (Aisys, GE Healthcare). There are many design variations.

from the ventilator can be triggered by patient effort, by settings controlled by the operator (eg, delivering a specified number of breaths per minute), or a combination of these 2 options. A critical care ventilator is capable of a number of modes of ventilation as well as volume, pressure, and adaptive pressure breaths. The critical care ventilator also delivers PEEP and allows control of inspiratory flow, inspiratory time, rise time, and flow termination criteria. Critical care ventilators include a dizzying array of alarms and displays of monitored variables based on airway pressure and flow.

An anesthesia machine delivers oxygen and other gases such as air and nitrous oxide (an analgesic that has some anesthetic properties) along with volatile (also called “inhalational”) anesthetics (Fig. 1). Patients may also breathe spontaneously with no ventilatory support. A positive pressure breath can be delivered either manually by squeezing a breathing bag that is part of the machine or by using the integrated mechanical ventilator. The ventilator may range from a simple bellows-in-a-box device to one approaching the sophistication of a critical care ventilator and deliver patient-triggered breaths. The anesthesia machine may contain a gas and anesthetic monitor, analyzing the inspiratory and expiratory concentrations of  $O_2$ ,  $CO_2$ , and the volatile anesthetic as well as a physiologic vital signs monitor. Unlike the critical care ventilator, the anesthesia machine is intended to be operated with an anesthesia provider in attendance at all times.

Two of the 5 major differences between critical care and anesthesia machine ventilators are related: potential for rebreathing of exhaled gases and  $CO_2$  absorption. The third major difference is the use of a scavenging system to prevent pollution of the room with inhaled anesthetics. The fourth major difference is that  $F_{IO_2}$  may be set using gas flow meters on older anesthesia machine, while  $F_{IO_2}$  is directly set on a critical care ventilator or newer anesthesia ventilator. The final major difference is that manual and mechanical ventilation can be delivered using the anesthesia machine.<sup>7</sup> Table 1 contains a summary of these and other differences between an anesthesia machine and a critical care ventilator. These 5 major differences are discussed further below.

### Non-, Partial, and Complete Rebreathing

The critical care ventilator operates as a non-rebreathing system where exhaled gases are vented to the atmosphere. The anesthesia machine can operate as a non-rebreathing (also called an open) system where all of the exhaled gases are vented to the scavenging system, as a partial rebreathing (also called semi-closed) system where a portion of the exhaled gases are recycled, or a complete rebreathing (also called a closed) system where all of the exhaled gases are recycled. The anesthesia machine is rarely used as a complete rebreathing system in the operating room; in that

Table 1. Important Differences Between an Anesthesia Machine and a Critical Care Ventilator

Anesthesia Machine	Critical Care Ventilator
<b>Major differences</b>	
Can operate as a non-rebreathing, a partial rebreathing, or a complete rebreathing system by using a circle breathing system where exhaled gases can be recycled and reintroduced with fresh gas flow	Operates as a non-rebreathing system; does not use a circle system
Equipped with a CO <sub>2</sub> absorber (if depleted, may result in increased inspiratory CO <sub>2</sub> and hypercapnia)	No need for a CO <sub>2</sub> absorber
Can deliver manual or mechanical ventilation	Delivers only mechanical ventilation
F <sub>IO<sub>2</sub></sub> determined by settings on the gas flow meters or an F <sub>IO<sub>2</sub></sub> control	The operator directly sets the F <sub>IO<sub>2</sub></sub>
Equipped with a scavenger system that prevents pollution of room with anesthetics	No need for a scavenger system
<b>Other differences</b>	
Operated by a continuously present anesthesia provider, maintained by an anesthesia provider or anesthesia technician	Operated and maintained by a respiratory therapist
Delivers O <sub>2</sub> and other gases such as air and nitrous oxide as well as volatile (inhaled) anesthetics (eg, isoflurane, sevoflurane, desflurane)	Typically delivers only O <sub>2</sub> and air
Requires an operator in attendance at all times	Does not require an operator to be with the device at all times
Designed for intermittent use during a single day with multiple patients	Designed for continuous use for days with the same patient
Alarm volume may not be loud enough to be heard in the critical care unit	Alarm volume designed to be heard in a critical care unit
Alarms do not interface with the hospital nurse call alarm system	Alarms may generate alerts in the hospital nurse call alarm system
May contain residual amounts of anesthetic agents in the breathing system (remote risk of malignant hyperthermia)	Does not contain residual amounts of anesthetic agents
Often has an integrated gas and anesthetic monitor	May contain or interface with a gas monitor
May have a physiologic monitor	Typically does not have an integrated physiologic monitor
May interface with an electronic anesthesia record (that ultimately becomes part of the patient record) but not directly with the patient electronic medical record	May interface directly with the patient electronic medical record
Rarely used with a heated humidifier	Commonly used with a heated humidifier

From References 2-4,7.

setting, the anesthesia machine is often used as a partial rebreathing system to help conserve volatile anesthetics, to reduce costs, and to conserve heat and moisture.<sup>7</sup> When used as a partial rebreathing system, the fresh gas flow (ie, the amount of gas in L/min continuously entering the breathing circuit set by the operator, not the flow of gas during inhalation) is less than the patient's minute ventilation, and the CO<sub>2</sub> contained in the portion of the patient's exhaled breath is chemically removed by the CO<sub>2</sub> absorbent.<sup>7</sup> In contrast, the anesthesia machine is used as a non-rebreathing system when used with patients with COVID-19. This is primarily done to mitigate problems resulting from excess moisture buildup in the inspiratory limb of the breathing circuit when the anesthesia machine is used with these patients.<sup>3,4</sup> This is discussed further below.

Factors or controls determining whether the anesthesia machine is operating as a complete, partial, or non-rebreathing system include the fresh gas flow, adjustment of the adjustable pressure-limiting valve if the patient is breathing spontaneously or being manually ventilated (or analogous valve located with the integrated mechanical ventilator), use of one-way inspiratory and expiratory valves, and the presence of the CO<sub>2</sub> absorber.<sup>7</sup> Table 2

contains an explanation of terms used when discussing the anesthesia machine and rebreathing. Fresh gas flow and the circle system are discussed further below.

**Fresh Gas Flow.** Oxygen and other gases such as air and nitrous oxide are supplied from central pipeline sources or tanks mounted on the anesthesia machine. The anesthesia machine is disabled if there is a loss of the O<sub>2</sub> supply pressure. This is a safety system to prevent hypoxic gas mixtures being delivered in the absence of an O<sub>2</sub> supply. Regulators in the anesthesia machine reduce the pressure of the supplied gases prior to delivery. The flow of gases (O<sub>2</sub>, nitrous oxide, air) to the patient are regulated by the anesthesia provider directing setting the flows of the gases on flow meters or by setting variables such as total flow and F<sub>IO<sub>2</sub></sub>.<sup>7</sup> This gas flow is termed the fresh gas flow and is the amount of new gas added to the breathing circuit each minute.

High fresh gas flow is associated with minimal rebreathing. High fresh gas flows (ie, greater than the patient's minute ventilation) are used when the anesthesia machine is operated as a non-rebreathing system, which is recommended for patients with COVID-19 to help minimize excessive moisture production in the breathing circuit.<sup>3,4</sup>

Table 2. Three Operating Modes Anesthesia Machines

	Complete Rebreathing (Closed) System	Partial Rebreathing (Semi-Closed) System	Non-Rebreathing (Open) System
FGF and minute ventilation	"FGF composed only of O <sub>2</sub> with the flow meeting metabolic demand <sup>†</sup> with flow much lower than minute ventilation	FGF does not equal or exceed minute ventilation, gases other than O <sub>2</sub> may be used such as air or nitrous oxide	FGF equals or exceeds minute ventilation
APL valve <sup>‡</sup>	Closed	Partially open	Fully open
Role of CO <sub>2</sub> absorbent	Fully dependent on CO <sub>2</sub> absorbent to remove exhaled CO <sub>2</sub>	Some portion of the exhaled breath is rebreathed; dependent on CO <sub>2</sub> absorbent to remove exhaled CO <sub>2</sub>	Little dependence on CO <sub>2</sub> absorbent to removed exhaled CO <sub>2</sub>
Portion of exhaled breath shunted to atmosphere <sup>§</sup>	All unused portion of the inhaled breath is rebreathed with no portion of the exhaled breath shunted to the atmosphere via the scavenging system	Some of the exhaled breath is shunted to the atmosphere via the scavenging system	Almost all or all of the exhaled breath is shunted to the atmosphere via the scavenging system
Advantages	Conservation of O <sub>2</sub> and volatile anesthetics; less heat and water loss from the respiratory system	Can use other gases with O <sub>2</sub> ; some conservation of volatile anesthetics and some conservation of heat and water loss from the respiratory system; some conservation of CO <sub>2</sub> absorbent, less buildup of moisture in breathing circuit from the CO <sub>2</sub> absorbent	Can use other gases with O <sub>2</sub> , little dependence on CO <sub>2</sub> absorbent to remove CO <sub>2</sub> from exhaled breaths, little buildup of moisture in breathing circuit from the CO <sub>2</sub> absorbent
Disadvantages	Requires use of F <sub>IO<sub>2</sub></sub> = 1.0, technically difficult, little room for error if patient's O <sub>2</sub> requirement increases; excess moisture can build in the circuit due to water production by the CO <sub>2</sub> absorbent <sup>‡</sup> ; toxic accumulation of metabolites is possible; may see quick exhaustion of the CO <sub>2</sub> absorbent with resulting hypercapnia	Excess moisture can build in the circuit due to water production by the CO <sub>2</sub> absorbent, somewhat quick exhaustion of the CO <sub>2</sub> absorbent compared with the non-rebreathing mode with resulting hypercapnia; should ensure an HMEF is used to help conserve heat and reduce moisture loss from the lungs	Quicker depletion of gas and volatile anesthetics, must use an HMEF to help conserve heat and reduce moisture loss from the respiratory system, <sup>  </sup> more rapid depletion of gas supplies

From References 3,4,7.

<sup>\*</sup> Typically done with only F<sub>IO<sub>2</sub></sub> = 1.0.<sup>†</sup> Metabolic demand for oxygen of a normal size anesthetized adult is ~ 0.2 L/min.<sup>‡</sup> An analogous valve is present on the integrated mechanical ventilator.<sup>§</sup> Water is produced as a by-product of the CO<sub>2</sub> absorbent reaction to remove CO<sub>2</sub> from exhaled breaths. As more CO<sub>2</sub> is removed, more water is produced.<sup>||</sup> HMEF may not prevent thick airway secretions, especially with high minute volumes and thick or bloody secretions.

APL = adjustable pressure-limiting

FGF = fresh gas flow

HMEF = heat-and-moisture exchanging filter

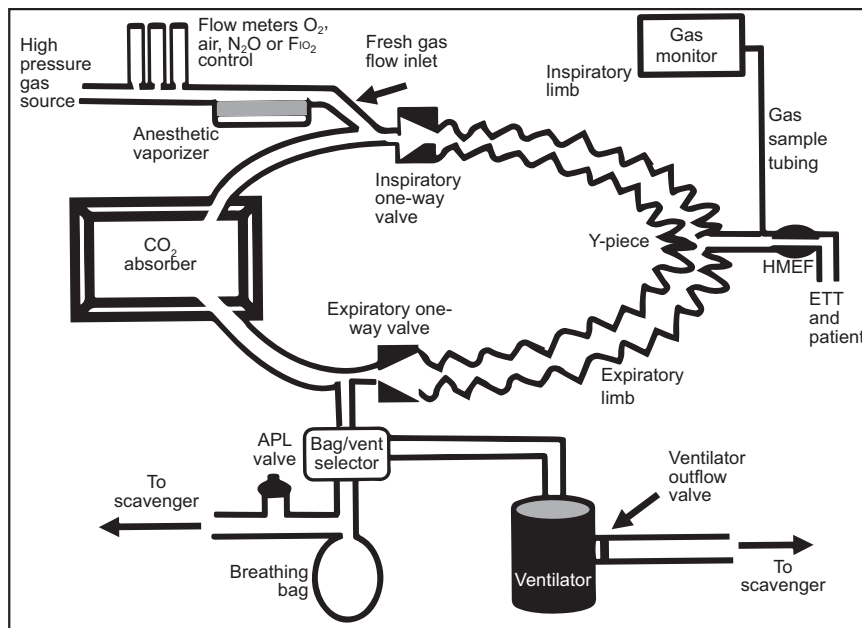


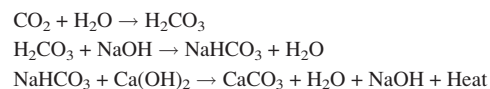
Fig. 2. A simplified drawing of the anesthesia machine circle system. APL = adjustable pressure-limiting; ETT = endotracheal tube; HMEF = heat-and-moisture exchanging filter.

More rebreathing occurs as the fresh gas flow is decreased.<sup>7</sup> To emphasize, fresh gas flow is the amount of gas in L/min continuously entering the breathing circuit set by the operator and not the flow of gas mixture provided by the mechanical ventilator during inspiration. The flow of the gas mixture from the mechanical ventilator during inspiration is determined by the settings on the ventilator.

If desired by the anesthesia provider, the fresh gas flow may pass through vaporizers before entering the breathing circuit. These vaporizers convert the liquid volatile anesthetics to a vapor. The vaporizers allow delivery of the anesthetic at the desired concentration. Vaporizers should be removed or drained on anesthesia machines repurposed as critical care ventilators for patients with COVID-19.<sup>3,4</sup> The fresh gas flow then flows directly into the circle system.<sup>7</sup>

**Circle System.** The circle system is designed to permit rebreathing of exhaled gases while chemically absorbing exhaled CO<sub>2</sub>. The flow of gas to the patient circuit is continuous (ie, the fresh gas flow). The simplified patient circuit or circle system includes the adjustable pressure-limiting valve, breathing bag, CO<sub>2</sub> absorber, one-way inspiratory and expiratory valves, breathing circuit (usually 22-mm corrugated tubing), and a Y-connector with a heat and moisture exchanging filter (HMEF) (Fig. 2). The adjustable pressure-limiting valve prevents pressure buildup in the system if fresh gas flow significantly exceeds the oxygen consumption of the patient. An analogous valve on the integrated mechanical ventilator performs this function if the patient is mechanically ventilated.<sup>7</sup>

Table 3. Series of Chemical Reactions to Remove CO<sub>2</sub> From Exhaled Breaths by Soda Lime



Note that water and heat are by-products of these reactions. From Reference 8.

H<sub>2</sub>CO<sub>3</sub> = carbonic acid  
NaOH = sodium hydroxide  
NaHCO<sub>3</sub> = sodium bicarbonate  
Ca(OH)<sub>2</sub> = calcium hydroxide  
CaCO<sub>3</sub> = calcium carbonate

## CO<sub>2</sub> Absorption

There is no need for CO<sub>2</sub> absorption with a critical care ventilator as no portion of the exhaled gases are recycled. Exhaled gases containing CO<sub>2</sub> can be recycled using an anesthesia machine. The CO<sub>2</sub> in the exhaled breath must be removed to prevent hypercapnia. CO<sub>2</sub> is removed using an absorbent material often soda lime. This commonly used CO<sub>2</sub> absorbent contains primarily calcium hydroxide along with small amounts of additional chemicals such as sodium hydroxide. The exhaled breath passes through the granular absorbent before returning to the patient.<sup>7</sup>

The absorbent does not soak up CO<sub>2</sub> like a sponge. Rather, CO<sub>2</sub> is chemically removed by converting it to calcium carbonate in a series of chemical reactions. These reactions produce heat and water (Table 3). This water production may be excessive in patients with COVID-19 due,



in part, to an increased minute ventilation and elevated CO<sub>2</sub> production. The granules of the CO<sub>2</sub> absorbent typically contain an indicator. This enables the granules to change color (such as from white to blue or purple) when the absorbent's capacity has been exhausted. The life of the absorbent is highly variable, depending on factors including the type of absorbent, manufacturer, minute ventilation, patient CO<sub>2</sub> production, and the fresh gas flow.<sup>7,8</sup>

### Ability to Deliver Manual and Mechanical Ventilation

The critical care ventilator only delivers mechanical breaths. If required, manual ventilation is accomplished using a separate, manual resuscitator. A non-self-inflating bag is part of the anesthesia machine. This bag is kept inflated by the fresh gas flow. Closing the adjustable pressure-limiting valve and squeezing the bag delivers a manual breath to the patient via endotracheal tube or face mask. An O<sub>2</sub> flush valve is present in the anesthesia machine and, when depressed, delivers 100% O<sub>2</sub> into the patient circuit at a flow of 35–70 L/min. This high flow of O<sub>2</sub> helps when manually ventilating a patient using the anesthesia machine with a face mask in the presence of leaks. The anesthesia machine does not initiate mechanical ventilation automatically.<sup>7</sup> The breathing bag/ventilator switch and ventilator controls must be set correctly before mechanical ventilation will begin.

### Setting the F<sub>IO<sub>2</sub></sub>

Anesthesia machines used as critical care ventilators must be able to deliver air due to the consequences of prolonged breathing of 100% O<sub>2</sub>. The F<sub>IO<sub>2</sub></sub> is directly set on the critical care ventilator. This may be done directly on more modern anesthesia machines, but some anesthesia machines require the use of settings on the flow meters to determine the F<sub>IO<sub>2</sub></sub>. For instance, if 1 L/min each of O<sub>2</sub> and nitrous oxide are delivered, the F<sub>IO<sub>2</sub></sub> is 0.5. If there is a flow meter for air, then setting the O<sub>2</sub> and air flow meters will control the F<sub>IO<sub>2</sub></sub> (Table 4, Table 5).

F<sub>IO<sub>2</sub></sub> is continuously monitored using an O<sub>2</sub> analyzer with high and low alarms. Modern anesthesia machines are designed to make it difficult to deliver hypoxic gas mixtures if the system is properly functioning.<sup>7</sup> It is nevertheless possible to unknowingly change the F<sub>IO<sub>2</sub></sub> setting. This underscores the need for the operator to be near the anesthesia machine.

### Scavenging System

There is no need for a scavenging system with a critical care ventilator as the device does not deliver inhaled anesthetics. With an anesthesia machine, exhaled gases that are not rebreathed when operating as a partial or open system

Table 4. Basic Principles for Determining F<sub>IO<sub>2</sub></sub> Using Air and O<sub>2</sub> Flow Meter Settings on an Anesthesia Machine

Basic Principles
Flow meter settings are used on some anesthesia machines to determine the F <sub>IO<sub>2</sub></sub> .*
Fresh gas flow is the total flow per min of all gases (eg, O <sub>2</sub> and N <sub>2</sub> O, or O <sub>2</sub> and air).
21% of air is O <sub>2</sub> .
If <i>only</i> air is used, the F <sub>IO<sub>2</sub></sub> will be 0.21.
F <sub>IO<sub>2</sub></sub> is calculated as follows when using air and O <sub>2</sub> :
$F_{IO_2} = \frac{(\text{Air flow} \times 0.21) + (\text{O}_2 \text{ flow} \times 1.0)}{\text{Fresh gas flow}}$
*For an adult patient with COVID-19, fresh gas flow should be equal to or higher than the patient's minute ventilation. See the manufacturer recommendations. <sup>9</sup> Some have reported using a fresh gas flow of 150% of minute ventilation or 10 L/min with these patients. <sup>3</sup>
N <sub>2</sub> O = nitrous oxide

Table 5. Air and O<sub>2</sub> Flow Meter Settings With Resultant F<sub>IO<sub>2</sub></sub> Using a Fresh Gas Flow of 10 L/min

O <sub>2</sub> Flow Meter Setting, L/min	Air Flow Meter Setting, L/min	O <sub>2</sub> Content of Air at This Flow Meter Setting, L/min	F <sub>IO<sub>2</sub></sub>
9	1	0.21	0.92
5	5	1.05	0.61
4	6	1.26	0.53
1	9	1.89	0.29

exit the circle system. These exhaled gases exit the circle system via the adjustable pressure-limiting valve or another analogous valve in the integrated mechanical ventilator through a system that directs these gases out of the room, as chronic exposure to personnel may be toxic.<sup>7</sup> The scavenging hose leading from the anesthesia machine to the wall should be removed if the anesthesia machine is used to ventilate a patient with COVID-19 unless the machine will not function properly without it attached to a wall suction source.<sup>3</sup>

### Excessive Water Production With Rebreathing

Partial rebreathing with lower fresh gas flows, often done in the operating room, requires the CO<sub>2</sub> absorbent to chemically remove CO<sub>2</sub> from the portion of the exhaled breath that is rebreathed. In the operating room, this side effect of CO<sub>2</sub> absorption increases the temperature and humidity of inspired gases. Water and heat are by-products of the reactions of the chemicals in the absorbent and CO<sub>2</sub>.<sup>7,8</sup> This water production is a major problem in patients with COVID-19 because they are often hypermetabolic (ie, high CO<sub>2</sub> production) and thus require a high minute ventilation. Large amounts of water are produced, which can occlude the patient circuit and interfere with flow sensors in the

<p>United States Food and Drug Administration Ventilator Supply Mitigation Strategies: Letter to Health Care Providers <a href="https://www.fda.gov/medical-devices/coronavirus-disease-2019-covid-19-emergency-use-authorizations-medical-devices/ventilators-and-ventilator-accessories-euas">https://www.fda.gov/medical-devices/coronavirus-disease-2019-covid-19-emergency-use-authorizations-medical-devices/ventilators-and-ventilator-accessories-euas</a></p> <p>Manufacturers Dräger Medical Letter <a href="https://www.draeger.com/Library/Content/Draeger_Customer_Letter-COVID-19-Usage_of_Anesthesia_devices_for_long_term_ventilation-2020-03-18.pdf">https://www.draeger.com/Library/Content/Draeger_Customer_Letter-COVID-19-Usage_of_Anesthesia_devices_for_long_term_ventilation-2020-03-18.pdf</a></p> <p>COVID-19 general information <a href="https://www.draeger.com/en-us/us/Home/novel-coronavirus-outbreak#anesthesia">https://www.draeger.com/en-us/us/Home/novel-coronavirus-outbreak#anesthesia</a></p> <p>GE Healthcare Letter <a href="https://www.gehealthcare.com/-/nssmedia/3c655c83bd6b427_e9824994c12be0da5.pdf?la=en-us">https://www.gehealthcare.com/-/nssmedia/3c655c83bd6b427_e9824994c12be0da5.pdf?la=en-us</a></p> <p>COVID-19 general information <a href="https://www.gehealthcare.com/corporate/covid-19">https://www.gehealthcare.com/corporate/covid-19</a></p> <p>Anesthesia machines <a href="https://www.gehealthcare.com/products/Anesthesia-Delivery-Systems-User-Resources">https://www.gehealthcare.com/products/Anesthesia-Delivery-Systems-User-Resources</a></p> <p>Mindray COVID-19 general information <a href="https://www.mindraynorthamerica.com/covid-19-response/">https://www.mindraynorthamerica.com/covid-19-response/</a></p> <p>Getinge General information <a href="https://www.getinge.com/dam/hospitaldocuments/marketing-sales/customer_letters/english/mcv00103387_reva_covid-19_customer_letter_long_term_ventilation_with_flow-en-us.pdf">https://www.getinge.com/dam/hospitaldocuments/marketing-sales/customer_letters/english/mcv00103387_reva_covid-19_customer_letter_long_term_ventilation_with_flow-en-us.pdf</a></p>	<p>Professional Organizations American Association for Respiratory Care COVID-19 News &amp; Resources <a href="https://www.aarc.org/nn20-covid-19-news-resources/">https://www.aarc.org/nn20-covid-19-news-resources/</a></p> <p>American Association of Nurse Anesthetists Resources <a href="https://www.aana.com/aana-covid-19-resources">https://www.aana.com/aana-covid-19-resources</a></p> <p>SARS CoV-2 Guidance document <a href="https://www.aarc.org/wp-content/uploads/2020/03/guidance-document-SARS-COVID19.pdf">https://www.aarc.org/wp-content/uploads/2020/03/guidance-document-SARS-COVID19.pdf</a></p> <p>American Society of Anesthesiologists COVID-19 Resources <a href="https://www.asahq.org/in-the-spotlight/corona-virus-covid-19-information">https://www.asahq.org/in-the-spotlight/corona-virus-covid-19-information</a></p> <p>Anesthesia Patient Safety Foundation Novel Coronavirus (COVID-19) Anesthesia Resource Center <a href="https://www.apsf.org/novel-coronavirus-covid-19-resource-center/">https://www.apsf.org/novel-coronavirus-covid-19-resource-center/</a></p> <p>Society of Critical Care Medicine Emergency Resources: COVID-19 <a href="https://www.sccm.org/Disaster/COVID19">https://www.sccm.org/Disaster/COVID19</a></p>
---	--

Fig. 3. Resources for using anesthesia machines as critical care ventilators for use with patients with COVID-19.

anesthesia machine.<sup>3</sup> The anesthesia machine should be operated as a non-rebreathing (open) system to mitigate the problem of excess water production from the CO<sub>2</sub> absorbent.<sup>3,4</sup>

Fresh gas flows greater than the patient's minute ventilation (such as 1.5 times higher) are recommended for patients with COVID-19. Manufacturers and others offer guidance on setting the fresh gas flow (Fig. 3). Some rebreathing may occur even with high fresh gas flows, and the CO<sub>2</sub> absorbent should be monitored for color change indicating depletion and replacement as needed. Using a capnograph to detect excess inspiratory CO<sub>2</sub> may help determine whether there is unwanted CO<sub>2</sub> rebreathing.<sup>3,4,7</sup>

### Heated Humidifiers, HMEFs, and the Anesthesia Machine

Heated humidifiers are rarely used with anesthesia machines. It may not be possible to attach a heated humidifier to an anesthesia machine because the moisture produced may interfere with its operation. Therefore, an HMEF is placed between the endotracheal tube and the patient connector to help conserve heat and moisture (Fig. 4). Importantly, when using an anesthesia machine with a COVID-19 patient, a heat-and-moisture exchanger with an integrated bacterial and viral filter should be used. This positioning helps protect the anesthesia machine from contamination with COVID-19 and from excessive moisture that can affect flow sensors in the machine. This positioning also protects the small-bore



Fig. 4. Proper location of heat-and-moisture exchanger protecting the anesthesia machine and gas monitor.

sample tubing leading to the gas monitor, thus helping protect the monitor from contamination. The HMEF may become occluded due to copious secretions or by the added moisture from the process of CO<sub>2</sub> absorption. This may result in a slow increase in resistance. The HMEF should be routinely inspected and replaced as needed. Protection of the anesthesia machine is also facilitated by placing a filter on the end of expiratory limb where it connects to the anesthesia machine. Decontamination of the anesthesia machine is described in the manufacturer's instructions.<sup>3,4</sup>

## The Anesthesia Machine Ventilator

### Older Anesthesia Machines

Older anesthesia machines were equipped with simple ventilators that solely delivered controlled ventilation. These ventilators were pneumatically powered and controlled. These devices used compressed gas (usually oxygen) to squeeze the bellows to deliver the gas mixture to the patient. These are commonly referred to as bag-in-the-box or bellows-in-the-box ventilators. Older anesthesia ventilators were not capable of delivering spontaneous breathing ventilation modes.<sup>7</sup> Many of these anesthesia machines are still in use today and perform well in the operating room with anesthetized patients.<sup>7</sup>

### Newer Anesthesia Machines

Newer anesthesia machines are often equipped with sophisticated, electronically controlled ventilators capable of delivering many ventilation modes. Like older anesthesia machine ventilators, some of these devices use compressed O<sub>2</sub> to squeeze a bellows, so demand on the compressed O<sub>2</sub> supply is a consideration.<sup>7,9-14</sup> Others use an electrically powered piston or turbine to generate inspiratory flow.<sup>7,15-17</sup> There is tremendous variability in the features included on these devices, and manufacturers are constantly updating the machines, so the user must consult the manufacturer's description and directions for use for a specific anesthesia machine (Table 6).

Reports suggest that anesthesia machine ventilators may, however, not perform as well as critical care ventilators for patients with COVID-19. For example, asynchrony and its accompanying problems, including excess airway pressure and patient discomfort, may occur; the asynchrony resolved when the anesthesia machine was replaced with a critical care ventilator.<sup>18,19</sup> This evidence suggests that anesthesia machines should be used only if critical care ventilators are not available and should not be used with complicated patients. In addition, experts and experienced providers suggest a critical care ventilator may have to be used if there is difficulty ventilating the patient with an anesthesia machine.<sup>3,19</sup>

### Considerations When Using an Anesthesia Machines For Patients With COVID-19

Stakeholders should consider triage planning such as using anesthesia machines with patients suffering from non-respiratory conditions (eg, trauma, neurologic conditions) and using critical care ventilators with patients with challenging respiratory conditions such as COVID-19. Providers should consider replacing an anesthesia machine with a critical care ventilator if the patient with COVID-19

is ineffectively ventilated when steps such as adjusting ventilator settings (eg, inspiratory time), increasing sedation, and paralysis are not effective.<sup>3,4,18,19</sup>

Discussed below are general considerations when using an anesthesia machine to ventilate a patient with COVID-19 in a critical care unit. Many agencies, manufacturers, and organizations provide detailed instructions for repurposing an anesthesia machine as a critical care ventilator for such scenarios (Fig. 3). Information includes specific details for determining proper fresh gas flow, preventing contamination, and disinfection of the anesthesia machine. This list is not all inclusive and, like many aspects of this pandemic, resources are frequently revised and new resources become available.

### General Planning

All stakeholders, including respiratory therapists, nursing personnel, critical care providers, and anesthesia providers must work together to formulate the policy for using an anesthesia machine for patients with COVID-19 in the critical care unit. Their use must be overseen by an anesthesia provider.<sup>2</sup> The policy should include such things as how often the anesthesia provider rounds on the patients, how often an anesthesia machine checkout procedure is required by anesthesia provider, key alarms the non-anesthesia providers must be aware of, and methods of communication with the anesthesia provider.

Patients ventilated using an anesthesia machine should be located in the same unit to facilitate the anesthesia provider's supervision of their use.<sup>2</sup> Room size is a consideration as anesthesia machines are often larger than critical care ventilators. Central O<sub>2</sub>, air, and suction outlets must be at the bedside. While there usually are 1–2 small O<sub>2</sub> cylinders for emergency use on the anesthesia machine, these will become quickly exhausted. Oxygen use is dramatically increased if the anesthesia machine ventilator is pneumatically powered by compressed O<sub>2</sub>.<sup>3,4</sup>

### Selection and Preparation of the Anesthesia Machine

The anesthesia machine must be capable of delivering patient-triggered breathing modes and air/O<sub>2</sub> mixtures, as well as a constant level of PEEP. Personnel from the anesthesia department should prepare the anesthesia machine, including removing or disabling all vaporizers and removing the high-pressure nitrous oxide hose. Flushing the anesthesia machine with high-flow O<sub>2</sub> or air helps ensure removal of any residual anesthetic.<sup>3,4,20</sup> If the anesthesia machine has an integrated monitor, including a capnograph and anesthetic gas monitor, these monitors should remain intact.



Table 6. Features of Various Modern Electronically Controlled Anesthesia Ventilators\*

	Dräger Fabius GS Premium <sup>15</sup>		Dräger Apollo <sup>16</sup>	Dräger Perseus A500 <sup>17</sup>	Datex-Ohmeda Aestiva With 7900 Ventilator <sup>12</sup>		GE Avance CS <sup>9</sup>	GE Aespire 7900 <sup>10</sup>	GE Aisys Carestation CS <sup>11</sup>	Mindray A5 and A7 Advantage <sup>† 13,14</sup>
Drive mechanism	Piston	Piston	Piston	Turbine	Ascending bellows	Ascending bellows	Ascending bellows	Ascending bellows	Ascending bellows	Ascending bellows
Powered Standard ventilation modes	Electric Manual/spontaneous	Electric Manual/spontaneous	Electric Manual/spontaneous	Electric Manual/spontaneous	Pneumatic Volume control	Pneumatic Volume control	Pneumatic Volume control	Pneumatic Volume control	Pneumatic Volume control	Pneumatic Manual/spontaneous
	Volume control	Volume mode	Volume mode	VC-CMV, PC-SIMV+	Pressure control	Pressure control	Pressure control	Pressure control	Volume with tidal volume compensation	Volume control
		Pressure mode	Pressure mode	VC-CMV, VC-CMV/autoflow, VC-SIMV/autoflow	SIMV PSVPro	SIMV PSVPro	SIMV PSVPro	SIMV PSVPro	CPAP/PSPC-VG	PCV-VC
Optional ventilation modes	Pressure control	Synchronization	Synchronization	PS-CPAP PC-SIMV		Pressure control	Pressure control	Pressure control	SIMV-PC	SIMV-PC
	Pressure support	Pressure support	Pressure support	+PS and VC-SIMV/autoflow/PSPC-APRV		PCV-VG	PCV-VG	PCV-VG	APRV	Lung recruitment
PEEP, cm H <sub>2</sub> O	0–20	2–35	2–35	Off; 2–35	Electronically controlled Off; 4–30	Electronically controlled Off; 4–30	Electronically controlled Off; 4–30	Electronically controlled Off; 4–30	CPAP + PSV	Off, 0–30
Maximum inspiratory flow, L/min	75 in volume and pressure control modes; 85 in pressure support mode	Maximum of 150 in pressure mode	Maximum of 150 in pressure mode	180	120	120	120	120	120	120 plus fresh gas flow

\* Information in this table serves as a guide. Consult the manufacturer.

† A4 Advantage capable of delivering spontaneous ventilation modes with fewer standard ventilation modes.

PC = pressure control

VC = volume control

CMV = continuous mandatory ventilation

SIMV = synchronized intermittent mandatory ventilation

PSVPro = pressure-support ventilation with apnea backup

PS = pressure support

VG = volume guarantee

PCV = pressure control ventilation

SV-CV-PS = synchronized volume control ventilation with pressure support

APRV = airway pressure-release ventilation

Table 7. Potential Problems When Using an Anesthesia Machine to Ventilate a Patient With COVID-19

Problem	Possible Cause	Steps to Help Mitigate the Problem
Respiratory therapist and critical care physician lack of familiarity with anesthesia machines	It is not expected for respiratory therapists to be familiar with anesthesia machines	All stakeholders should be involved with the policy and procedure of using the anesthesia machine as a ventilator, including their responsibilities and methods of communication
Excess water in the breathing circuit	Water production from CO <sub>2</sub> removal by the CO <sub>2</sub> absorbent	FGF should be higher than minute ventilation (ie, $\geq 1.5$ times minute ventilation) to decrease the need for the absorbent to remove CO <sub>2</sub> and decrease the resultant water by-product*; monitor closely
Occlusion of HMEF located between the endotracheal tube and patient	Patient secretions and water	Monitor the condition of the HMEF; change periodically and as needed, keeping in mind the possible need to conserve supplies
Frequent exhaustion of the CO <sub>2</sub> absorbent	Insufficient FGF	FGF should be higher than minute ventilation (ie, $\geq 1.5$ times minute ventilation) to decrease the need for the absorbent to remove CO <sub>2</sub> from the exhaled breath*
Alveolar de-recruitment and possible hypoxemia when changing HMEF; breathing circuit or removing the patient from the anesthesia machine for anesthesia machine check out procedure	Decrease in airway pressure, FIO <sub>2</sub> , or minute ventilation	Plan and rehearse procedures when the patient will be separated from the anesthesia machine
Excessive airway pressure and patient discomfort	Patient-ventilator asynchrony	Adjust the ventilation mode; may have to switch to a critical care ventilator as it may not be possible to set the desired inspiratory time in a high minute ventilation scenario
Gas monitoring sample line tubing or water trap contamination or occlusion	HMEF not in a position to protect the gas monitoring sample line	Reposition HMEF appropriately; monitor closely
Anesthesia machine flow sensor malfunction	Excess moisture in the patient circuit	Be sure the HMEF is placed between the endotracheal tube and the patient connector on the breathing circuit; use adequate FGF to limit the amount of water production from the CO <sub>2</sub> absorbent
Use with inline nebulizer	Not designed for use with an inline nebulizer	Closely monitor if a nebulizer is used
Leak compensation	Likely no leak compensation	Monitor closely if a breathing circuit leak is suspected; NIV with the anesthesia ventilator is not recommended
Quick emergency activation to deliver FIO <sub>2</sub> = 1.0	Not present on an anesthesia machine	Must adjust the flow meters to deliver FIO <sub>2</sub> = 1.0
Unwanted activation of the oxygen flush valve with resulting increased airway pressure	Accidental activation of the valve by personnel	Orientation of non-anesthesia providers to the basic components and function of the anesthesia machine
Loss of electrical power to the anesthesia machine	Overloaded circuit breaker dedicated to the patient room	Carefully monitor the demands of the devices in the patient room
Lack of procedures for documentation of anesthesia machine settings and output from machine and physiologic monitors	Current documentation procedures may be problematic; anesthesia machine does not interface directly with the patient electronic medical record	Consult information technology personnel to determine if the anesthesia machine and physiologic monitors can interface directly with the patient record; identify a documentation procedure

From References 18,19,24-27.

\*See the manufacturer and other resources in Figure 3 for guidance on setting the FGF. Reports of using FGF of 10 L/min has been effective in limiting water production from the CO<sub>2</sub> absorbent.<sup>18</sup>FGF = fresh gas flow (flow per minute of O<sub>2</sub> and other gases such as nitrous oxide)

HMEF = heat-and-moisture exchanging filter

## Anesthesia Machine Checkout Procedure

The anesthesia machine may require completion of a checkout procedure prior to use and periodically during use, perhaps as frequently as every 24–72 h. The device may malfunction if this checkout procedure is not performed, and the anesthesia provider should monitor the need for this checkout and perform the checkout preemptively. An alternative ventilation method (eg, another ventilator, a self-inflating bag) should be available because the anesthesia machine cannot be used during the checkout procedure, which may last a few minutes. Considerations include preventing alveolar de-recruitment while using an alternative ventilation method.<sup>3,4,18,21</sup>

## Alarms

Alarms on anesthesia machines typically include alerts for disconnect, high pressure, and high and low  $F_{IO_2}$ , among others. These should be tested and set appropriately, and all personnel should be aware that these audible alarms are not as loud as those on a critical care ventilator. The alarms will likely not interface with the nurse call system or connect with the electronic health record. Personnel must remain close enough to patients ventilated with an anesthesia machine to hear the alarms.<sup>2–4</sup> Care of critically ill patients in an operating room repurposed as an ICU presents significant logistical issues. If the patient is provided critical care in an operating room, the ability for caregivers to hear alarms is further diminished.

## Setting the Fresh Gas Flow and the $F_{IO_2}$

As previously mentioned, an anesthesia machine should be used as a non-rebreathing system. This helps prevent the  $CO_2$  absorbent from having to remove as much  $CO_2$  and reduces the resultant water by-product. Use as a non-rebreathing system will also extend the supply of  $CO_2$  absorbent. Some rebreathing can occur even with high fresh gas flows, so the  $CO_2$  absorbent must be left in place and monitored. Fresh gas flow (ie, a combined amount of  $O_2$  and air) will determine the  $F_{IO_2}$ , which should be higher than the patient's minute ventilation. This difference may be as much as 1.5 times the minute ventilation, but recommendations vary between anesthesia machine manufacturers (refer to the manufacturer resources in Fig. 3).<sup>3,4</sup> Others report using a fresh gas flow of 10 L/min for adult patients with COVID-19.<sup>18</sup>  $F_{IO_2}$  is determined by the flow meter setting, or it can be set directly (Fig. 2). All personnel must take care not to accidentally alter the desired settings, underscoring the need for a qualified operator to be with anesthesia machine at all times.

## HMEF and Breathing Circuit Filter

As discussed above, an HMEF should be placed between the endotracheal tube and breathing circuit patient connector (Fig. 4). A filter should be placed between the exhalation limb of the breathing circuit where it attaches to the anesthesia machine.<sup>3,4</sup> In the presence of excess humidity, this filter should be monitored for increases in resistance, and it should be changed as needed. The importance of frequent monitoring of this filter cannot be overstated.

## Sharing Anesthesia Machines

Authors of a small case series described ventilating 3 groups of patients (2 patients with COVID-19 per group) using a single critical care ventilator.<sup>22</sup> The patients were sedated and paralyzed. The authors concluded this could be feasible as a stopgap measure, but safety requires careful patient selection and patient monitoring.<sup>22</sup> In one of these 3 pairs of patients, an anesthesia machine was used to provide shared ventilation. In this case, the authors noted that increased HME resistance due to moisture accumulation further exacerbated volume maldistribution between patients. In a 24-h period, they reported changing the HMEF 4 times due to excess water accumulation, as well as issues related to rapid exhaustion of the  $CO_2$  absorbent.<sup>22</sup> No large studies have been conducted examining ventilator sharing, including anesthesia machine sharing. A consensus statement authored by multiple critical care professional organizations warns against sharing mechanical ventilators. Reasons include volumes preferentially going to the most compliant lung segments, monitoring difficulties, and risking life-threatening treatment failure of the involved patients.<sup>23</sup>

## Potential Problems and Mitigation Methods

Potential problems and those reported when using an anesthesia machine to ventilate patients with COVID-19 are described in Table 7, along with possible causes and mitigation methods. All stakeholders must be keenly aware of the potential for excess water in the breathing circuit. This can lead to obstruction of the circuit and occlusion of the HMEF. Other problems include frequent exhaustion of the  $CO_2$  absorbent filter and resulting hypercapnia, ineffective ventilation, and alveolar de-recruitment when the anesthesia machine is disconnected from the patient for various reasons, as well as inability to hear alarms.<sup>18,19,24–27</sup>

## Summary

Anesthesia machines are being repurposed as critical care ventilators during the COVID-19 pandemic.<sup>18,24–26,28,29</sup> Their use should be overseen by an anesthesia provider; however, respiratory therapists will be involved in their

monitoring and use. Anesthesia machines are fundamentally different than critical care ventilators, and respiratory therapists should be familiar with these differences. All providers must be aware of the potential problems and limitations when using these devices with patients with COVID-19.

#### ACKNOWLEDGMENTS

Special thanks to Michael Dosch PhD CRNA and Shari Burns EdD CRNA for their input and review of this manuscript.

#### REFERENCES

- Wunsch H. Mechanical ventilation in COVID-19: interpreting the current epidemiology. *Am J Respir Crit Care Med* 2020;202(1):1-4.
- US Food and Drug Administration. Ventilator supply mitigation strategies: letter to health care providers. March 22, 2020. Available at: <https://www.fda.gov/medical-devices/letters-health-care-providers/ventilator-supply-mitigation-strategies-letter-health-care-providers>. Accessed December 20, 2020.
- American Society of Anesthesiologists and Anesthesia Patient Safety Foundation. APSF/ASA guidance on purposing anesthesia machines as ICU ventilators. May 7, 2020. Available at: <https://www.asahq.org/in-the-spotlight/coronavirus-covid-19-information/purposing-anesthesia-machines-for-ventilators>. Accessed December 20, 2020.
- Dosch M. Using the anesthesia workstation as a ventilator for critically ill patients: technical considerations. *AANA J* 2020;83(3):13-17. Available at: [https://www.aana.com/docs/default-source/aana-journal-web-documents-1/dosch-2.pdf?sfvrsn=b2aa1640\\_6](https://www.aana.com/docs/default-source/aana-journal-web-documents-1/dosch-2.pdf?sfvrsn=b2aa1640_6). Accessed November 22, 2020.
- Louie S, Morrissey BM, Kenyon NJ, Albertson TE, Avdalovic M. The critically ill asthmatic—from ICU to discharge. *Clin Rev Allergy Immunol* 2012;43(1-2):30-44.
- Wilkes R, Tasker RC. Intensive care treatment of uncontrolled status epilepticus in children: systematic literature search of midazolam and anesthetic therapies. *Pediatr Crit Care Med* 2014;15(7):632-639.
- Riutort KT, Eisenkraft JB, et al. The anesthesia workstation and delivery systems for inhaled anesthetic. In Barash PG, Cullen BF, Stoelting RK, Cahalan MK, Stock MC, Ortega R, editors. *Clinical Anesthesia*, 8th Edition. Philadelphia: Wolters Kluwer; 2017:644-705.
- Feldman JM, Hendrickx J, Kennedy RR. Carbon dioxide absorption during inhalation anesthesia: a modern practice. *Anesth Analg* 2021;132(4):993-1002.
- GE Healthcare. Avance CS2 Brochure. Available at: [https://www.vingmed.dk/wp-content/uploads/sites/3/2020/06/ANE\\_EMEA\\_English\\_Avance\\_CS2\\_Spec\\_sheet\\_102013.pdf](https://www.vingmed.dk/wp-content/uploads/sites/3/2020/06/ANE_EMEA_English_Avance_CS2_Spec_sheet_102013.pdf). Accessed December 7, 2020.
- Datex-Ohmeda, Inc. Aespire 7900 User's Reference Manual - Part 1. 2004. Available at: <https://www.medwrench.com/documents/view/10907/datex-ohmeda-aespire-7900-user-manual-pdf>. Accessed December 7, 2020.
- GE Healthcare. Aisys CS2 Brochure. 2013. Available at: <http://www3.gehealthcareturkiye.com/~media/documents/turkey/products/anesthesia%20delivery/product%20specification%20sheets/aisys%20cs2/aisys%20cs2%20spec%20sheet.pdf?Parent=%7B4EAD3924-0CD3-4A07-B9EF-FC1F9B92A68A%7D>. Accessed December 7, 2020.
- Datex-Ohmeda, Inc. Aestive/5 Operation Manual Part 1. 2003. Available at: [http://www.meditegic.com/wp-content/uploads/pdfs/Aestiva\\_User\\_Manual\\_part1.pdf](http://www.meditegic.com/wp-content/uploads/pdfs/Aestiva_User_Manual_part1.pdf). Accessed December 7, 2020.
- Mindray. A7 Workstation. 2017. Available at: <https://www.mindrayuk.com/wp-content/uploads/2020/07/A7-Specifications.pdf>. Accessed December 10, 2020.
- Mindray North America. A Series Advantage Product Comparison. 2018. Available at: <https://www.mindraynorthamerica.com/wp-content/uploads/2018/11/A-Series-Comparison-Chart.pdf>. Accessed December 7, 2020.
- Draeger, Inc. Drager Fabius GS Premium (brochure). Available at: <https://www.draeger.com/Products/Content/fabius-gs-premium-br-9066189-us.pdf>. Accessed December 7, 2020.
- Draeger Medical, Inc. Drager Apollo Anesthesia Workstation (brochure). Available at: <https://www.draeger.com/Products/Content/apollo-br-9050390-us.pdf>. Accessed December 7, 2020.
- Draeger Medical, Inc. Drager Perseus A500 Brochure. 2015. Available at: <https://www.draeger.com/Products/Content/perseus-mechanical-pi-9069004-en-1506-2.pdf>. Accessed December 7, 2020.
- Haina KMK. Use of anesthesia machines in a critical care setting during the coronavirus disease 2019 pandemic. *A A Pract* 2020;14(7):e01243.
- Xi AS, Chang MG, Bittner EA. Rapid establishment of an ICU using anesthesia ventilators during COVID-19 pandemic: lessons learned. *Crit Care* 2020;24(1):388.
- Austin PN, Dosch MP. Transporting anesthesia workstations to hospitals for use as ventilators. *AANA J* 2020;83(3):24-28. Available at: [https://www.aana.com/docs/default-source/aana-journal-web-documents-1/austin-r.pdf?sfvrsn=d12b6728\\_6](https://www.aana.com/docs/default-source/aana-journal-web-documents-1/austin-r.pdf?sfvrsn=d12b6728_6). Accessed December 7, 2020.
- Greig PR, Dixon T, McCorkell S. A process for daily checks when using anaesthetic machines to ventilate the lungs of COVID-19 patients: the 'domino switch' technique. *Anaesthesia* 2020;75(7):973.
- Beitler JR, Mittel AM, Kallet R, Kacmarek R, Hess D, Branson R, et al. Ventilator sharing during an acute shortage caused by the COVID-19 pandemic. *Am J Respir Crit Care Med* 2020;202(4):600-604.
- The Society of Critical Care Medicine, American Association for Respiratory Care, American Society of Anesthesiologists, Anesthesia Patient Safety Foundation, American Association of Critical-Care Nurses, American College of Chest Physicians. Consensus statement on multiple patients per ventilator. March 26, 2020. Available at: <https://www.sccm.org/Disaster/Joint-Statement-on-Multiple-Patients-Per-Ventilator>. Accessed December 7, 2020.
- Canelli R, Spence N, Kumar N, Rodriguez G, Gonzalez M. The ventilator management team: repurposing anesthesia workstations and personnel to combat COVID-19. *J Intensive Care Med* 2020;35(9):927-932.
- Fullick J, Oliver M. Water, water, everywhere: a challenge to ventilators in the COVID-19 pandemic. *Br J Anaesth* 2020;125(1):e188-e190.
- Panchamia RK, Piracha MM, Samuels JD. Desperate times: repurposing anesthesia machines for mechanical ventilation in COVID-19. *J Clin Anesth* 2020;66:109967.
- Levin MA, Burnett G, Villar J, Hamburger J, Eisenkraft JB, Leibowitz AB. Anesthesia machine as an ICU ventilator: a near miss. *APSF Newsletter*. 2020. Available at: <https://www.apsf.org/article/anesthesia-machine-as-an-icu-ventilator-a-near-miss/>. Accessed December 20, 2020.
- Orser BA, Byrick R, Cooper R, Henry E, Lau P, Rittenberg B, et al. Locating and repurposing anesthetic machines as intensive care unit ventilators during the COVID-19 pandemic. *Can J Anaesth* 2020;67(8):1066-1067.
- Gouel-Cheron A, Couffignal C, Elmaleh Y, Kantor E, Montravers P. Preliminary observations of anaesthesia ventilators use for prolonged mechanical ventilation in intensive care unit patients during the COVID-19 pandemic. *Anaesth Crit Care Pain Med* 2020;39(3):371-372.