ECRI

CLINICAL EVIDENCE ASSESSMENT

Single Ventilator Use to Support Multiple Patients

Mechanical ventilators are intended to support one patient at a time; however, healthcare providers have reported using a single device to support two or four patients during supply shortages driven by disease outbreaks or mass-casualty events. Ventilator sharing may increase ventilation capacity available during a crisis but involves many technical challenges, safety risks, and ethical concerns.

No clinical studies are available on the safety and effectiveness of respiratory support with ventilators shared by two or more patients. In the absence of clinical studies, laboratory and animal studies may at least provide a rationale for action during critical ventilator shortages. Data from four studies using lung surrogates, animals, and healthy humans suggest that sharing a single ventilator appears to be feasible in two to four similar subjects. However, it is challenging and very risky in actual patients whose disease quickly evolves and who require individual airflow adjustments that clinical operators have limited to no control to adjust during sharing. Furthermore, studies involving animals, artificial lungs, or healthy volunteers may not reflect the dynamic nature of ventilation parameters in patients with severe acute respiratory distress. Also, findings may also not generalize across ventilators with different features. Thus, healthcare providers faced with ventilator shortages should critically prioritize patient selection and continuously monitor feasibility when considering using a single device to support multiple patients.

American medical societies recommend against ventilator sharing because of safety, technical challenges, and ethical concerns, and recommend triage-based ventilator allocation during shortages to patients most likely to benefit and survive.

Evidence limitations. No clinical studies are available on split ventilator use for multiple patients. Reporting on actual patients in a clinical setting is not likely feasible because the crisis circumstances that warrant sharing of ventilators typically makes data collection impossible.

Share Your Feedback on how this report answered your question by visiting **ly.ecri.org/rate**

Executive Summary

Findings

Four animal, health human volunteer, and laboratory studies were available to assess.

- 1 laboratory study (Neyman and Irvin 2001) in 4 lung surrogates (elastomer bags) connected to a single Puritan-Bennett™ 840 ventilator set to mandatory breathing (16 breaths/min) with constant volume (0.5 L/lung) or pressure (25 cmH_2O) reported safe airway pressure and tidal volume (VT). However, a similar study using artificial lungs (Branson et al. 2012) found that large and uncontrollable variation in individual VT occurred with either mode when connected lungs have different compliance and resistance.
- 1 animal study (Paladino et al. 2008) in four 70 kg sheep reported that heart rate, arterial pressure, and blood oxygenation remained within safe ranges ventilated for 12 hours with 100% oxygen using a single Servo-I ventilator set to mandatory breathing (16 breaths/min) at fixed volume (6 mL/kg) and positive end expiratory pressure (PEEP) (5 cmH_2O).
- 1 human subject study (Smith al. 2009) in 2 healthy volunteers reported safe end-tidal carbon dioxide ($ETCO_2$) levels ventilated for 10 minutes with a single Evita® XL ventilator using noninvasive patient circuits and mandatory (18 breaths/min), pressure-controlled (30 cmH_2O) respiration mode with 2 cmH_2O PEEP.

Evidence

Search dates: January 1, 2000, to March 27, 2020. We reviewed 2 full-text articles, 1 published abstract, and 1 correspondence article describing laboratory studies.

- Because our searches found no relevant clinical studies, we reviewed laboratory studies of shared commercially available ventilators used on artificial lungs, animals, or healthy human subjects. We reviewed full-text articles available with open access or our library subscriptions and abstracts of other studies.
- 2 studies (Branson et al. 2012, Neyman and Irvin 2001) reported on air pressure and volume delivered to artificial lung sets (4 in each) connected in parallel to a single Puritan Bennett 840 ventilator set to volume- or pressure-controlled mandatory respiration modes.
- 1 study (Smith al. 2009) reported on $ETCO_2$ in 2 healthy volunteers ventilated for 10 minutes with a single Evita XL ventilator using parallel, noninvasive patient circuits and mandatory, pressure-controlled respiration mode.
- 1 study (Paladino et al. 2008) reported on hemodynamic parameters and blood gases in 4 sheep ventilated for 12 hours with a single Servo-I ventilator in mandatory, volume-controlled respiration mode.

Guidelines, Position, and Consensus Statements

Searched PubMed, EMBASE, ECRI Guidelines Trust® (EGT), and other web-based resources for relevant documents published January 1, 2000, to March 27, 2020: 4 documents were identified.

Position Statement

- A March 2020 position statement by 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, and American College of Chest Physicians addresses ventilator shortages due to the 2019-2020 COVID-19 outbreak. The societies recommends against ventilator sharing because of patient safety, logistical challenges, and ethical concerns and recommend triage and ventilator prioritization to patients most likely to benefit from mechanical support and recover from the disease as an alternative to shared ventilation.

Other Documents

- 3 manufacturers; Drager, Medtronic, and Hamilton Medical, issued letters in March 2020 recommending against multiple patient support with their devices, in response to inquiries during the 2019-2020 COVID-19 outbreak.

Table of Contents

Tables

Background

Mechanical Ventilation

Mechanical ventilators are life-support devices that move gas (i.e., air and/or oxygen) to and from a patient's lungs. These devices are intended to sustain patients who cannot breathe on their own or who require assistance maintaining adequate ventilation because of illness, trauma, congenital defects, or the effects of drugs (e.g., anesthetics). Mechanical ventilation may be delivered noninvasively with a breathing mask or helmet, but patients who cannot protect their airway (e.g., sedated, comatose, with bulbar paralysis) require endotracheal intubation. Clinicians may also choose early intubation for practical reasons (e.g., when patients are expected to worsen or are infected with an airborne pathogen). (For additional information, see the Medscape article Mechanical Ventilation.)

Contemporary ventilators consist of a breath-delivery unit and graphical user interface. The breath delivery unit is an electrically powered, microprocessor-controlled gas-flow system that uses blowers, bellows, or fans to deliver cyclic (inspiratory and expiratory) airflow from a pressurized gas source, such as a compressor, tank, or wall-mounted supply line. The graphical user interface controls the breath delivery unit and provides users with readings and alarms for critical airflow parameters, including volume, pressure, gas composition, and inspired/expired ratios. Patients are connected to the ventilator with a breathing circuit consisting of disposable tubing and valves. Patient circuits typically feature separate inspiration and expiration limbs, but single-limb circuits may be used in patients who do not require controlled expiration. Common accessory devices may include heaters, humidifiers, nebulizers, and additional monitors, such as capnographs. (For additional information, see the ECRI Product Comparison, Ventilators, Intensive Care.)

Contemporary ventilators can use many different algorithms, or ventilation modes, to provide full or partial support depending on the patient's condition and needs. Ventilation modes may broadly be classified according to breath control and sequence. Volume-controlled modes deliver a set VT during each cycle, although breaths are interrupted if they exceed a preset pressure limit. Volume-controlled modes are typically used for adult and pediatric patients. Pressure-controlled modes deliver flow to attain a preset peak inspiratory pressure; delivered volume is variable and depends on airway resistance and lung compliance. Pressure-controlled modes put less strain on lung tissue and are often used with infants and patients with acute lung injury or acute respiratory distress syndrome. Breath sequence may involve continuous breaths regardless of patient effort (mandatory ventilation), continuous ventilation that allows spontaneous breaths (intermittent mandatory ventilation), or fully patient-triggered breaths (continuous spontaneous ventilation).

Ventilator Sharing

Mechanical ventilators are required critical equipment in all emergency and critical care settings. According to a 2010 study, 65,000 full-featured ventilators and 98,000 devices with partial ventilator capabilities (e.g., anesthesia gas machine, transport ventilators, bilevel positive-pressure ventilation devices) are available in the United States. However, crisis situations, such as mass trauma events or disease outbreaks, can temporarily overwhelm mechanical ventilation capacity at acute care centers, sometimes on a countrywide or global scale. At such times, experts have advocated for expanding mechanical ventilation capacity by connecting a single breathing unit to two or four patient circuits, and limited successful experiences have been reported, such as during the 2017 Las Vegas mass shooting.

In keeping with basic principles of critical care, contemporary ventilators are designed to support one patient at a time. The single most important limitation to ventilator sharing is that commercially available ventilators feature a single internal airflow circuit. A ventilator connected to several patient circuits can deliver only a single airflow that is then passively split between patients; thus, operators have no direct control on individual airflow to each patient. Reciprocally, the control circuit can react only to total airflow parameters when pacing breaths; therefore, spontaneous breathing must be suppressed to prevent hyperventilation. Built-in volume and pressure safeguards become unusable for the same reason. In turn, these limitations cause major barriers to ventilator sharing, as follows:

- ***Patient risks:*** In a shared system, volume-controlled breaths are split among patients according to relative lung capacity and compliance. Some patients may receive excessive volumes and pressures, which can result in potentially fatal lung injury. Because size is a primary determinant of lung capacity, experts recommend

grouping patients of similar size when sharing ventilators; however, sudden changes to lung capacity may occur as a result of disease or respiratory arrest. Pressure-controlled modes may partially avoid the risks of overinflation but may provide only suboptimal ventilation to some of the patients; suboptimal ventilation poses complication risks (e.g., alveolar collapse) and may favor disease progression. Patients in shared circuits may also require deep sedation to suppress spontaneous breathing, which carries its own complication risks. Lastly, even in-line filters may not fully remove the risk of patient cross-contamination in the event of infectious disease outbreak. Even if infected patients are grouped, cross-infection is undesirable because it may hinder immune responses and recovery and because multiple pathogen strains with synergistic properties may emerge during outbreaks. (For additional information, see the EmCrit article Splitting Ventilators to Provide Titrated Support to a Large Group of Patients and the 2020 Joint Statement on Multiple Patients per Ventilator by the Society of Critical Care and other medical societies.)

- ***Technical challenges:*** Setting up a shared ventilator system requires a ventilator with internal expiratory valves and sensors. Many in-patient ventilators have internal arrangements, but many portable ventilators feature valves and sensors incorporated in the patient circuit. Mandatory ventilation is required for ventilator sharing but is seldom used in critical care, and newer ventilator may not allow users to turn off breath triggers or to sufficiently reduce their sensitivity. Individual monitoring with in-line capnography is critical during ventilator sharing but may not be available in all settings. Because additional patient circuits increase dead space, overall airflow parameters measured by the breathing delivery unit may not be accurate; therefore, adjustments need to be made empirically with close patient monitoring. Circuit modification, such as use of spigot valves. may allow for rudimentary flow adjustment for individual patients but still on an empirical basis. Last, patient arrangement around a single ventilator should seek to minimize circuit length and dead space, which may prove challenging. (For more information, see the Joint Statement on Multiple Patients per Ventilator.)
- ***Ethical concerns:*** Ventilator sharing poses ethical challenges because it requires some patients to accept greater individual risk in the interest of treating other patients, which may not be acceptable for all patients and may contravene the "do no harm" treatment principle. Healthcare provider liability in case of patient refusal to accept shared ventilation is also unclear. (For more information, see the Joint Statement on Multiple Patients per Ventilator.)

Alternative and Complementary Crisis Ventilation Capacity Management Strategies

Ventilator sharing is intended as a last-resort resource measure. At times when ventilation demand is expected to exceed capacity, healthcare providers may also consider the following measures in advance or in parallel to ventilator sharing:

- Use of non-FDA-cleared ventilators: In the United States, mechanical ventilators are subject to FDA clearance through the 510(k) process. However, equivalent performance and controls are required for ventilators available with a CE mark in Europe and registered with the Australian Trade Goods Registrar. Some manufacturers, such as Medtronic (Dublin, Ireland), have also made their designs available for assembly by third parties, and open-source designs are also available. (For additional information, see the FDA Enforcement Policy for Ventilators and Accessories and Other Respiratory Devices during the Coronavirus Disease 2019 (COVID-19) Public Health Emergency.)
- *Alternative devices:* Anesthesia gas machines and portable ventilators are not intended for extended use and may not provide all possible ventilator modes but may provide basic support to patients until a full ventilator is available. Bilevel and continuous positive airway pressure therapy and high-flow oxygen therapy devices are intended to improve oxygenation in patients with spontaneous breathing and may be used to delay ventilator use in such patients. Risks of airborne disease spread should be considered when using these devices for noninvasive ventilation during outbreaks. (For additional information, see the FDA Enforcement Policy for Ventilators and Accessories and Other Respiratory Devices during the Coronavirus Disease 2019 (COVID-19) Public Health Emergency.)
- *Triage-based allocation*: As a last resort, clinicians can follow triage principles to maximize effective ventilator use by not ventilating or terminating ventilation in patients who are not expected to recover. This approach operates, in principle, in opposition to that of ventilator sharing and raises ethical concerns of its own. (For more information, see the New York State Department of Health's 2015 Ventilator Allocation Guidelines and the review The Toughest Triage — Allocating Ventilators in a Pandemic.)

Response to Ventilation Capacity Shortages during the 2019-2020 COVID-19 Outbreak

- On March 31, 202, Prisma Health, Inc. (Greenville, SC, USA) began distribution of VESper™, a Y-connector intended to facilitate ventilator sharing, under a FDA device Emergency Use Authorization (EUA) listed below.
- On March 24, 2020, FDA issued an EUA covering non-FDA-approved ventilators, alternative devices not approved or cleared for critical respiratory support, and devices intended to facilitate ventilator sharing. The document reflects final adoption for Enforcement Policy Guidelines that FDA issued earlier in March 2020.
- On March 24, 2020, the Columbia University College of Physicians & Surgeons New York-Presbyterian Hospital made available a protocol for dual-patient ventilation based on its clinical experience during the outbreak.
- On March 22, 2020, FDA issued a letter to healthcare providers titled Ventilator Supply Mitigation Strategies: Letter to Health Care Providers that outlines and endorses the strategies discussed on the later EUA and recommends providers consult with manufacturers regarding approved indications and potential device modification and off-label use to face ventilator demands during the outbreak.

Clinical Guidelines, Consensus, and Position Statements

Searches of PubMed, EMBASE, ECRI Guidelines Trust®, and other web-based resources identified a position statement and two letters from manufacturers, all from March 2020, recommending against split use:

- Society of Critical Care Medicine, American Association for Respiratory Care, American Society of Anesthesiologists, Anesthesia Patient Safety Foundation, American Association of Critical-Care Nurses, and American College of Chest Physicians: *Joint Statement on Multiple Patients per Ventilator*. The document states:

  > The above-named organizations advise clinicians that sharing mechanical ventilators should not be attempted because it cannot be done safely with current equipment. The physiology of patients with COVID-19-onset acute respiratory distress syndrome (ARDS) is complex. Even in ideal circumstances, ventilating a single patient with ARDS and nonhomogeneous lung disease is difficult and is associated with a 40%-60% mortality rate. Attempting to ventilate multiple patients with COVID-19, given the issues described here, could lead to poor outcomes and high mortality rates for all patients cohorted. In accordance with the exceedingly difficult, but not uncommon, triage decisions often made in medical crises, it is better to purpose the ventilator to the patient most likely to benefit than fail to prevent, or even cause, the demise of multiple patients.

- Drager. *Letter to Providers of Mechanical Ventilation*. The letter states:

  > We have received many inquiries regarding social media postings and publications that discuss the use of one ventilator to be used on multiple patients. Any such use would be considered "off-label application". The intended use of Dräger ventilators is as a single patient item to ensure safe and reliable management of the respiratory failure patient that requires mechanical ventilation. Dräger has not tested or validated for use any scenario using one ventilator on multiple patients. Further, this concept is not one of the recommendations in the FDA guidance document and such use would seem to be contrary to the CDC's recommendations for proper isolation procedures for treatment of COVID-19 infected patients.

- Hamilton Medical. *COVID-19 Latest Update*. This online information resource states:

  > Hamilton Medical does not recommend the use of one mechanical ventilator for more than one patient. To ensure appropriate and lung-protective ventilation, monitoring and ventilator settings need to apply for one patient only. This is made possible by the proximal flow- and pressure-measurement technology in our devices.

In addition, ECRI member organizations reported receiving a letter from Medtronic in response to inquiries received by the manufacturer. The March 13, 2020, letter states that Medtronic considers multiple patient support with Puritan Bennett 840 and 980 ventilators to be off-label use because of safety concerns. On March 27, 2020, ECRI issued a Health Devices Alert to notify members of Medtronic's position.

Clinical Literature

We searched PubMed, EMBASE, the Cochrane Library, and selected web-based resources for clinical studies published between January 1, 2000, and March 27, 2020, and reporting on outcomes of mechanical ventilation using a single ventilator to support multiple patients. Our search strategies included the following keywords: shared ventilators, simultaneous ventilation, split ventilators. Please see the *Selected Resources and References* section for detailed search strategies.

We did not identify any relevant clinical studies. Therefore, we expanded our inclusion criteria to laboratory and animal studies. We identified and reviewed two full-text articles, one published abstract, and one correspondence article, as follows:

- 2 studies reported on air pressure and volume delivered to artificial lung sets (4 in each) connected in parallel to a single Puritan Bennett 840 ventilator (Medtronic) set to volume- or pressure-controlled mandatory respiration modes.(1,2)
- 1 study reported on $ETCO_2$ in 2 healthy volunteers ventilated for 10 minutes with a single Evita XL ventilator (Drägerwerk AG and Company, Lübeck, Germany) using parallel, noninvasive patient circuits and mandatory, pressure-controlled respiration mode.(3)
- 1 study reported on hemodynamic parameters and blood gases in 4 sheep ventilated for 12 hours at fixed volume with a single Servo-I ventilator (Maquet Critical Care, a subsidiary of Getinge Group, Gothenburg, Sweden).(4)

We reviewed full-text articles available with open access or our library subscriptions and abstracts of other studies. We also identified but excluded an animal study involving an experimental ventilation mode (biphasic-flow induced ventilation, a mode that requires a multilumen endotracheal tube) with a premarket prototype device.(5)

Evidence limitations and comments. No clinical studies are available on split ventilator use for multiple patients. Reporting on actual patients in a clinical setting is not likely feasible because the crisis circumstances that warrant shared ventilator use typically make data collection impossible.

In the absence of clinical studies, laboratory and animal studies may at least provide a rationale for action during critical ventilator shortages. Reviewed studies suggest that a single ventilator may support up to four patients, but significant risks exist because individual ventilation parameters are not fixed and are not under direct control for each patient by operators. Furthermore, studies involving animals, artificial lungs, or healthy volunteers may not reflect the dynamic nature of ventilation parameters in patients with severe acute respiratory distress. Findings may also not generalize to other ventilators with different features. Thus, healthcare providers faced with ventilator shortages should critically prioritize patient selection and continuous monitoring feasibility when considering using a single device to support multiple patients.

Table 1. Laboratory Studies

Reference	Study Aims	Setup and Outcomes	Results	Conclusions by Authors
Branson et al. 2012(1) United States Reviewed full text	"We designed a lung model investigation of the concept of one ventilator for 4 patients, using mechanical lung analogues at varying levels of airway resistance and lung compliance."	A Puritan Bennett 840 was connected to 4 artificial lungs (Training and Test Lung, Michigan Instruments, Grand Rapids, MI, USA) using 2 successive Y-piece connectors for the inspiration limb and the same arrangement for the expiration limb. The circuit was set to mandatory ventilation mode (10 breaths/min) with 2 L tidal volume (VT) and 5 cmH^2O positive end expiration pressure (PEEP)	"When [lung] R [resistance] and C [compliance] were equivalent the VT distributed to each chamber of the test lung was similar during both volume (range 428– 442 mL) and pressure (range 528–544 mL) breaths. Changing C while R was constant resulted in large variations in delivered VT (volume range 257–621 mL, pressure range 320–762 mL). Changing R while C was constant resulted in a smaller variation in VT (volume range 418–460 mL, pressure range 502–554 mL) compared to only C changes. When R and C were both varied, the range of delivered VT in both volume (336–517 mL) and pressure (417–676 mL) breaths was greater, compared to only R changes."	"Using a single ventilator to support 4 patients is an attractive concept; however, the VT cannot be controlled for each subject and VT disparity is proportional to the variability in compliance. Along with other practical limitations, these findings cannot support the use of this concept for mass-casualty respiratory failure."
Smith et al. 2009(3) United Kingdom Reviewed correspondence article (available with subscription only)	"One study has shown that sheep can be ventilated simultaneously but as far as we know this has not been tested in humans. We conducted a volunteer study to investigate whether this was a possibility."	2 healthy volunteers received noninvasive ventilation for 10 min with a single Drager Evita XL ventilator using parallel patient circuits and mandatory breathing mode at 18 breaths/min rate, set 30 cmH_2O pressure, and 2 cmH_2O PEEP. End-tidal carbon dioxide ($ETCO_2$) for each patient was monitored with inline capnography.	"Both subjects were comfortable making no spontaneous respiratory movements. The ventilator functioned normally throughout ETCO2 values at 10 min were 4.7 and 5.7 kPa. We noted an inspired carbon dioxide partial pressure of 0.65 kPa in one subject suggesting re-breathing. Combined [VT] was 2–2.2 l, giving an expired minute ventilation of 36–40 lmin-1."	"We have shown that two subjects can be ventilated simultaneously using a single ventilator... Although the subjects achieved different ETCO2 partial pressures both of them were acceptable and well tolerated."

Reference	Study Aims	Setup and Outcomes	Results	Conclusions by Authors
Paladino et al. 2008(4) United States Reviewed full text	"We conducted a study to determine if a single mechanical ventilator can adequately ventilate four adult-human-sized sheep for 12 h."	4 sedated, 70 kg sheep received mechanical ventilation for 12 hours with a single Maquet Servo-i ventilator with mandatory breathing mode at a 16 breaths/min rate, 1.0 inspired oxygen fraction, 5 cmH_2O PEEP, and set 6 mL/kg VT (combined sheep weight). Arterial gases pressure were monitored with an arterial catheter.	"The ventilator and modified circuit successfully oxygenated and ventilated the four sheep for 12 h. All sheep remained hemodynamically stable."	"It is possible to ventilate four adult-human-sized sheep on a single ventilator for at least 12 h. This technique has the potential to improve disaster preparedness by expanding local ventilator surge capacity until emergency supplies can be delivered from central stockpiles."
Neyman and Irvin 2006(2) United States Reviewed full text	"To determine if a ventilator available in an emergency department could quickly be modified to provide ventilation for four adults simultaneously."	A Puritan Bennett 840 was connected to 4 lung surrogates (elastomer bags) and set to mandatory ventilation mode (16 breaths/min) for 6 hours at fixed VT (2 L) and for 6 hours at fixed pressure (25 cmH_2O), in random order. Airway pressures and VT were monitored at 30-min intervals.	"Using readily available plastic tubing set up to minimize dead space volume, the four lung simulators were easily ventilated for 12 hours using one ventilator. In pressure control (set at 25 mm H2O), the mean [VT] was 1,884 mL (approximately 471 mL/lung simulator) with an average minute ventilation of 30.2 L/min (or 7.5 L/min/lung simulator). In volume control (set at 2 L), the mean peak pressure was 28 cm H2O and the minute ventilation was 32.5 L/min total (8.1 L/min/lung simulator)." "Visual inspection showed roughly equivalent excursion of all lung models. No respiratory stacking was seen." "Pressures did not exceed 35 cm H2O. Airway pressures beyond 35 mmH2O are associated with ventilator-induced lung injury."	"Single ventilator may be quickly modified to ventilate four simulated adults for a limited time. The volumes delivered in this simulation should be able to sustain four 70-kg individuals."

Selected Resources and References

Search Summaries

The following databases were used to identify the literature and related materials.

ECRI Resources [searched January 1, 2000, through March 27, 2020]

Search Strategy: Ventilators

Universal Medical Device Nomenclature System (UMDNS) Codes: Ventilators, Intensive Care [17-429], Ventilators, Intensive Care, Adult [18-792]. Ventilators, Intensive Care, Neonatal/Pediatric [14-361], Ventilators, Transport [18-098]

Results: We identified 5 related reports.

- Emergency Preparedness: Response and Recovery. [Continuing Care Risk Management]. 2019 Feb.
- Evaluation Background: Intensive Care Ventilators. [HD Journal]. 2018 Sep.
- Product Comparison: Ventilators, Intensive Care. [HPCS]. [cited 2020 Mar 27].
- Ventilators, Intensive Care. [HPCS]. 2018 Dec.
- Ventilators: The Essentials. [HD Journal]. 2019 Oct.

PubMed. Bethesda (MD): National Library of Medicine [searched January 1, 2000, through March 27, 2020]. Available from: http://www.pubmed.gov

Search Strategy:

- #1 ("Ventilators, Mechanical"[Mesh] OR ventilator[tiab] OR ventilators[tiab] OR ventilation[tiab] OR ventilated[tiab]) AND ("disaster surge" OR "Surge Capacity")
- #2 (“multiple output” OR “multi output” OR “multiple patients” OR “multi patient”) AND ("Ventilators, Mechanical"[Mesh] OR ventilator[tiab] OR ventilators[tiab] OR ventilation[tiab] OR ventilated[tiab])
- #3 “simultaneous ventilation” OR “shared ventilator*” OR “ventilator sharing” OR “split ventilator*” OR “ventilator splitting”
- #4 ("Ventilators, Mechanical"[Mesh] OR ventilator[tiab] OR ventilators[tiab] OR ventilation[tiab] OR ventilated[tiab]) AND (modified OR modify) AND (capacity AND (double* OR increase* OR quadruple* OR triple*))
- #5 ("Ventilators, Mechanical"[Mesh] OR ventilator[tiab] OR ventilators[tiab] OR ventilation[tiab] OR ventilated[tiab]) AND (modified OR modify) AND (disaster OR influenza “low resource*” OR “mass casualty” OR "mass casualty care" OR "mass casualty respiratory failure" OR military OR pandemic OR surge)
- #6 #1 OR #2 OR #3 OR #4 OR #5

Results: We identified 9 records.

EMBASE. Amsterdam (The Netherlands): Elsevier B.V. [searched January 1, 2000, through March 27, 2020]. Available from: www.embase.com. Subscription required.

Search Strategy:

- #1 ('intensive care ventilator'/exp/mj OR ventilat*:ti) AND ("disaster surge" OR "Surge Capacity")
- #2 ('multiple output' OR 'multi output' OR 'multiple patients' OR 'multi patient') AND ('intensive care ventilator'/exp/mj OR ventilat*:ti)
- #3 'simultaneous ventilation' OR 'shared ventilator*' OR 'ventilator sharing' OR 'split ventilator*' OR ‘ventilator splitting’
- #4 ('intensive care ventilator'/exp/mj OR ventilat*:ti) AND (modified OR modify) AND (capacity AND (double* OR increase* OR quadruple* OR triple*))
- #5 ('intensive care ventilator'/exp/mj OR ventilat*:ti) AND (modified OR modify) AND (disaster OR influenza “low resource*” OR “mass casualty” OR "mass casualty care" OR "mass casualty respiratory failure" OR military OR pandemic OR surge)
- #6 #1 OR #2 OR #3 OR #4 OR #5

Results: We identified 2 records.

Cochrane Library. Hoboken (NJ): John Wiley & Sons [searched January 1, 2000, through March 27, 2020] Available from: http://www.thecochranelibrary.com. Subscription required

Search Strategy:

- #1 ventilat* AND (share* OR split* OR multiple OR simultaneous)

Results: We did not identify any relevant publications.

Guidelines and Standards [searched January 1, 2000, through March 27, 2020]

Search Strategy: mechanical ventilation, ventilators

Results: We identified two relevant documents.

Selected Standards and Guidelines

- American Association for Respiratory Care (AARC). SARS CoV-2 Guidance Document. [Guidelines]. 2020 Mar.
- The Society of Critical Care Medicine (SCCM), American Association for Respiratory Care (AARC), American Society of Anesthesiologists (ASA), Anesthesia Patient Safety Foundation (ASPF), American Association of Critical-Care Nurses (AACN), and American College of Chest Physicians (CHEST). Joint Statement on Multiple Patients Per Ventilator. [Guidelines]. 2020 Mar.

Medicare Coverage Database. Baltimore (MD): Centers for Medicare & Medicaid Services (CMS) [searched March 27, 2020]. Available from: http://www.cms.gov/medicare-coverage-database/search/advanced-search.aspx

Search Strategy: mechanical ventilation; ventilators

Results: We did not identify any national or local pending coverage analyses, determinations, articles, or policies.

Selected Web Resources. [searched March 27, 2020]

Manufacturers

- Drager, Inc. Letter to providers of mechanical ventilation. 2020 Mar 22.
- Hamilton Medical. COVID-19 Update. [cited 2020 Mar 27].
- Prisma Health. VESper. [cited 2020 Mar 27].
- FDA gives emergency use authorization of "Y" splitter tubing to allow a single ventilator to assist up to four patients. [Press Release]. 2020 Mar 25].

Other selected web resources

- EmCrit. Splitting ventilators to provide titrated support to a large group of patients. 2020 Mar 15.
- Johns Hopkins Center for Health Security. Ventilator Stockpiling and Availability in the US. 2020 Feb 14.
- Menes K, et al. How One Las Vegas ED Saved Hundreds of Lives After the Worst Mass Shooting in U.S. History. 2017 Nov 3.
- New York Times. 'The Other Option Is Death': New York Starts Sharing of Ventilators. 2020 Mar 26.
- SaasCEO.com. How to Share a Ventilator across Multiple Patients with Patient Independent Ventilation Settings, Monitoring, and No Cross-Contamination. [updated 2020 Mar 27].
- U.S. Food and Drug Administration. [cited 2020 Mar 27].
  - Emergency Use Authorization. 2020 Mar 24.
  - Enforcement Policy for Ventilators and Accessories and Other Respiratory Devices During the Coronavirus Disease 2019 (COVID-19) Public Health Emergency. 2020 Mar.
  - Ventilator Supply Mitigation Strategies: Letter to Health Care Providers. 2020 Mar 22.

References Reviewed (PubMed and EMBASE search dates were January 1, 2000, through March, 27, 2020)

1. Branson, RD, Blakeman, TC, Robinson, BR, and Johannigman, JA. Use of a single ventilator to support 4 patients: laboratory evaluation of a limited concept. *Respir Care*. 2012;57(3):399-403. PubMed abstract | Full text

2. Neyman, G, and Irvin, CB. A single ventilator for multiple simulated patients to meet disaster surge. *Acad Emerg Med*. 2006;13(11):1246-1249. PubMed abstract | Full text

3. Smith, R, and Brown, JM. Simultaneous ventilation of two healthy subjects with a single ventilator. *Resuscitation*. 2009;80(9):1087. PubMed abstract | Full text

4. Paladino, L, Silverberg, M, Charchaflieh, JG, Eason, JK, Wright, BJ, Palamidessi, N, Arquilla, B, Sinert, R, et al. Increasing ventilator surge capacity in disasters: ventilation of four adult-human-sized sheep on a single ventilator with a modified circuit. *Resuscitation*. 2008;77(1):121-126. PubMed abstract | Full text

5. L'Her, E, Boulesteix, G, Moriconi, M, Rouvin, B, Renault, A, and Saïssy, JM. Biphasic-flow induced ventilation allows simultaneous ventilation in several animals, using a single multiple output ventilator--a preliminary report. *Eur J Emerg Med*. 2001;8(1):27-31. PubMed abstract

Policy Statement

The information presented in this Clinical Evidence Assessment is highly perishable and reflects the state of the literature on this topic at the time at which searches were conducted and the Clinical Evidence Assessment was prepared. Clinical Evidence Assessments provide a guide to the published clinical literature and other information about a topic on which we received a client inquiry. The scope is customized to address the specific information needs of the requestor. The content reflects the information identified from searches of the available, published, peer-reviewed scientific literature, gray literature, and websites at the time the searches were conducted. Publications referenced in this Clinical Evidence Assessment are generally limited to the English language. Clinical Evidence Assessments are developed by a multidisciplinary staff of doctoral level research analysts, clinicians, and medical librarian information specialists. For quality assurance, all reports are subject to review within ECRI before publication. Neither ECRI nor its employees accept gifts, grants, or contributions from, or consult for medical device or pharmaceutical manufacturers. The Clinical Evidence Assessment may be based on review of abstracts of published articles as well as full text articles. Abstracts do not always accurately reflect the methods and findings of full-length articles and limit full interpretation of published data. This Clinical Evidence Assessment is not intended to provide specific guidance for the care of individual patients. ECRI implies no warranty and assumes no liability for the information contained in the Clinical Evidence Assessment.

ECRI provides Clinical Evidence Assessment and many other forms of information support to help governments, hospitals, health systems, managed care organizations, health insurers, health professionals, and the public meet the challenge of evaluating healthcare technology objectively and rationally. Clinical Evidence Assessment is a service of ECRI, a nonprofit health services research agency. ECRI has been designated an Evidence-based Practice Center by the U.S. Agency for Healthcare Research and Quality. ECRI's mission is to provide information and technical assistance to the healthcare community worldwide to support safe and cost-effective patient care. The results of ECRI's research and experience are available through its publications, information systems, databases, technical assistance programs, laboratory services, seminars, and fellowships.