Coronavirus Tech Handbook

Ventilators

✏️ Edit this document to make it better ✏️

Join the Whatsapp Chat for deep dive discussions

[“Ventilators” CoronavirusTechHandbook Whatsapp Chat]

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link dump

https://github.com/alitarraf/covent19

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Xñqqpqp of Contentsjq:

Overview of Ventilators

Corona Virus and ARDS (Acute Respiratory Distress Syndrome)

A Chief Anesthesiologist from St. Olavs Hospital Trondheim, Norway has pointed out: lation), longer inspiration time and low pressure (low tidal volume) to avoid additional lung damage. I am not sure how this will work with an iron lung, this is quite fine-tuned respirator-work." "What we know so far about COVID patients is that they have failure of oxygenation. They have what we call ARDS, and have trouble getting enough oxygen, not necessarily getting CO2 out/in. On our respirators this means they need high PEEP (Positive End-Expiratory Pressure, pressure remaining in the lung after exhalation.

Treating ARDS
ARDS are treated with a combination of:

1. Low Tidal Volume (long inspiration time)
2. High PEEP (Positive End-Expiratory Pressure)
3. Prone Position (chest down, back up)

For hospitals without special prone beds, they usually use Swimmers position in the hospital beds. This is less than ideal. In this page, the benefits and risks of prone positions are addressed. In short, prone position can reduce mortality by half because gravity assists in the removal of fluid in the lungs.:
Source : Prone positioning for severe ARDS advised by major societies

However, using this type of positioning can be difficult and has some risks. Hospital personnel need experience supporting the patient in prone position or special

prone-beds to minimize the risks of prone positioning, and collect the reduced mortality rate of prone positioning.

Prone positioning is not being used for Covid patients because of physician preference, but because it is necessary. It is only used when supine ventilation is not working well enough because of the risks highlighted above.

Do we need more ventilators? - Yes.

Overview of Ventilators

First, we may define **what** a ventilator is and what it is not. Second, we may consider **why** ventilators are uniquely applicable to health care needs. Third, we might consider **how** to develop and deploy solutions that precisely solve the Corona Virus issue.

Ventilator - A ventilator is a medical-grade device fully capable of mechanically pressurizing the lungs with humidified, oxygenized, and temperature-controlled air with precise volume and breath cycles to replace or augment lung function.

There are other types of breathing apparatus that can not be considered a ventilator (such as a nasal cannula or a CPAP device).

Application - A mechanical ventilator forces air into a patient via a tube which passes into the trachea and has an inflatable cuff which sits below the vocal cords creating a seal. Tracheal tubes can be inserted through the mouth or nose - this is known as intubation. Some people require a tracheostomy. A shorter tube is inserted through a stoma in the front of the neck directly into the trachea. The ventilating gas needs to be supplemented with medical grade oxygen to maintain normal oxygen levels and to be humidified. Warming is desirable. Endotracheal tubes are now always connected to ventilators via heat and moisture exchange (HME) filters which passively heat and humidify gases passing in and out of the tube. These filters can also act to prevent passage of bacteria and virus from patient to ventilator. The volume delivered into the lungs from one cycle of a ventilator is known as the tidal volume. The number of breaths per minute is described as the rate or frequency. Ventilators are set to deliver to a set tidal volume or set to deliver to a set lung pressure. It can be assumed that a mechanical ventilator is for patients who are deemed in *critical condition* and are in a hospital ICU (intensive care unit) setting. personnel. Such a device would not be called a ventilator and have reduced constraints such as time-to-market and fewer liabilities.

Ventilator - Background Information

Operation - Typically, only specifically trained medical personnel who are in a hospital ICU should operate a mechanical ventilator. A mechanical ventilator is highly intrusive to the human body, and patients are not routinely attached to a ventilator without being anaesthetised first. They require constant monitoring.

Assumptions

It is widely believed that the CoronaVirus (CV) complicates the health of patients who already have *underlying health concerns*.

1. A mechanical ventilator is needed for life-sustaining lung function for patients with complications beyond CV and are confined to a critical care hospital environment.
2. It is not possible to attach or operate a mechanical ventilator without specially trained medical personnel that can prescribe lung function.
3. A medical-grade mechanical ventilator would require certification and testing by an authority. And, it would carry liability concerns.
4. Alternative breathing apparatus may be suitable for mild CV symptoms where a forced mechanical ventilator to act as lung function is not entirely necessary. Such devices could be used in a home or hospital environment without medical

Mechanical Ventilation Explained Clearly - Ventilator Settings & Modes (1/5)
Mechanical Ventilation Explained Clearly by MedCram.com | 2 of 5 (2/5)
Mechanical Ventilation Explained Clearly by MedCram.com | 3 of 5 (3/5)
ttps://www.youtube.com/watch?v=KHpJ21UWbhgh (4/5)
Mechanical Ventilation Explained Clearly of MedCram.com | 5 of 5 (5/5)
Ventilator Pearls Explained Clearly (6/5)
Ventilator Pearls Explained Clearly by MedCram.com | Part 2 (7/5)

Ventilator subtypes

There are two main types of ventilator. Positive pressure, and negative pressure ventilators.

Positive pressure ventilators

Most ventilators used today are positive pressure. They involve inserting a tube into the trachea or into the windpipe via tracheoctomy. They are electronic, and blow air (positive pressure). They support:

1. PEEP (Positive End-Expiratory Pressure)
2. Duration of inspiration
3. Duration of exhalation
4. Tidal volume (how much air)

Drawbacks

1. The only drawbacks are ventilator induced complications.
2. Damage to lung tissue due to aggressive ventilator settings.
3. Limited number available, shortage imminent.

Negative pressure ventilators

Negative pressure ventilators were common in the past. They were used during the Polio epidemic, and were called “Iron Lungs”. These are mechanically simple devices that can be built quickly. Today, Hayek Medical produces a ventilator based on this principle called “Biphasic Cuirrass Ventilator” which is a negative pressure ventilator that does not enclose the entire body, but only such onto the torso. Imagine a cup

placed on your chest with a vacuum attached, it will suck your chest into the cup and you draw your breath naturally.

Advantages

- Iron Lungs are closer to the real breathing pattern and may not harm lungs in the same way as invasive ventilator types.
- Can be built quickly due to very simple design.

Drawbacks

As of 18.03.2020, current feedback from medical personnel relating to Negative Pressure ventilators are:

1. They are lacking important functions for treating patients with CoronaVirus, such as adjustable PEEP (Positive End-Expiratory Pressure).
2. Personnel are not used to working with the devices.

Some health professionals incorrectly believe that Iron Lungs *are **only suitable*** when the patient has neurological damage to lungs musculature, such as with ALS or Polio. This is ***not correct***, and studies show that Iron Lung ventilators are equal or better than invasive mechanical ventilators for treating COPD and Acute Respiratory Failure.

Source : https://erj.ersjournals.com/content/23/3/419

However, what is correct is that healthcare workers prefer to work with ventilator types they know. Also they need to be able to adjust PEEP when treating Covid-19 patients with ARDS. An avenue for exploration could be to combine CPAP machines with Iron Lung or Biphasic Cuirass Ventilation (BCV) to ensure positive airway pressure on exhalation. For more details on this avenue, please see CovidIen project below.

Continuous Positive Airway Pressure (CPAP and BiPap)

A CPAP device assists the patients/people in breathing normally with a slight boost of air pressure on the inhale portion of the breath. It can be used in a home or hospital setting.

A CPAP device may suffice when a mechanical ventilator is not yet fully needed or it may reduce the time needed on the mechanical ventilator.

CPAP devices are also used in the home typically to aid breathing cycles for sleep apnea. As such, there is an entire industry of CPAP devices and knowledge that can be leveraged.

Assumption: CPAP devices can augment or reduce the need for mechanical ventilators as it pertains to the Coronavirus. It is assumed that patients with fewer underlying health concerns may benefit from a CPAP device to assist with breathing in ways that don't require a full mechanical ventilator.

CPAP and Oxygen-Helmets

In Italy in late March, they have addressed the shortage of ventilators by using CPAP machines (and possible other

ways of generating positive pressure) together with a plastic bulb, with an mostly airtight collar. The collar is attached under the arms with a harness. This allows oxygen and CPAP/BiPap without the invasive ventilators. Crucially, the exhaust can be filtered so that coronavirus is not released into the hospital en masse.
This approach scales much better than trying to find more ventilators, but when the patient isn't able to breathe themselves, they will need to be transferred to mechanical ventilators. In Italy now (22.03.2020), if you are above the age-threshold of about 60, you are not prioritized, the transfer never happens and the patient dies. This device has saved a lot of people already, and it also buys time. However, many people on these devices consume a lot of oxygen, and a supply chain for creating enough oxygen should also be considered in the event of scaling this for example in UK, Germany or USA:
We do not know if this is working, but we do know that Italy has been doing this. When countries that haven't seen their ventilator capacity run out yet realize they need something fast that scales, there is a decent chance this is what they would go for.

Continuous Mechanical Ventilation (CMV)

A CMV device is considered a *mechanical ventilator* (MV) that replaces or augments the normal breathing rhythm (tidal breath) by pressurized inhale and the vacuum exhale. Breathe too rapidly/fully, and the patient may hyperventilate. Breathe too infrequently/shallow and the patient may asphyxiate. If some lung function is retained, the patient may end up "fighting" the ventilator's prescribed settings. The continual effort to avoid one or the other over a varied range of activities involves feedback loops such as a pulse oximeter. Trained medical personnel who specialize in the use of CMVs typically determine the proper settings in a critical care setting.

Other Types/Modes of Ventilators

Ventilators have a spectrum of complexity:
https://www.openanesthesia.org/modes_of_mechanical_ventilation/
https://twitter.com/OSVentilator
https://twitter.com/coronadenktank
https://web.mit.edu/2.75/projects/DMD_2010_Al_Husseini.pdf

Models and brands (class II or III)

(the purpose of this is to validate the specs we are building the ventilator to are somewhat in the ballpark of existing ventilators used by the ICU)

- Siemens Servo I ventilator
- Hamilton Medical - C1
- Neumovent Advance (Tecme S.A.)

Basic Requirements of the Ventilator Prototype

Requirements validated by MHRA (the UK's FDA) curated in this document

- UK Government published specifications here: https://www.gov.uk/government/publications/coronavirus-covid-19-ventilator-supply-specification
- Also UK gov email for companies who may be able to produce ventilators: For ventilators, email ventilator.support@beis.gov.uk and register here https://www.gov.uk/government/news/production-and-supply-of-ventilators-and-ventilator-components (*NOT* for questions - only for firms that may be able to support)

Ventilation Parameters:

1. Tidal volume 2~2000ml
2. Rate 1~50 bpm
3. Synchronized intermittent mechanical ventilation (SIMV) rate 2 ~ 20 bpm
4. Oxygen concentration output adjustable 21% ~ 100%
5. I:E 4:1~1:4
6. IInspiratory trigger pressure -1.0~2.0 kPa
7. PEEP 0 ~ 3.0 kPa
8. Pressure range 1.0 ~ 6.0 kPa
9. SIGH 0 (off) 1/100 - 5/100

Parameters for ventilation monitoring:

- tidal volume, ventilation volume, IPPV rate, SIMV rate, total respiratory rate, I/E, peak pressure of airway, pressure - time waveform, flow rate - time waveform, PEEP, inspiratory trigger pressure

Airway pressure alarm :

- upper limit setting range 1.0~6.0 kPa
- low limit setting range 0.4~2.0 kPa

Per-minute ventilation volume alarm :

- upper limit setting range 3.0~30L/min
- low limit setting range 1.0~10L/min
-

Sustained high-pressure alarm:

- it will give alarm when stress have consistently been higher than 2.5 kPa

Suffocation alarm :

- it will give sound and light alarm if there is no tidal volume input for 15 seconds

Invasive Ventilation:

Inspiratory tidal volume
Adult 100–2000 ml
Infant 2–350 ml
Inspiratory flow ≤200 l/min
PEEP 0–30 cm H2O
Pressure above PEEP

Adult 0– (30-PEEP) cm H2O
Infant 0 –(20-PEEP) cm H2O

Non-invasive Ventilation:

PEEP 2–20 cm H2O
Pressure above PEEP 0– (62-PEEP) cm H2O
Leakage compensation
Adult Inspiratory, up to 200 l/min
Adult Expiratory, up to 65 l/min
Infant Inspiratory, up to 33 l/min
Expiratory, up to 25 l/min
Nasal CPAP, up to 20 l/min

Graphical patient data - Waveforms graphs: Pressure, Volume, Flow, PCO2 1 , FCO2 , Plethysmogram2
Trends 1-, 6-, 12-, 24-, or 72-h trend data for a selected parameter(s)
Cycle data: Pressure/Volume, Pressure/Flow, Volume/Flow, Volume/PCO21 , Volume/FCO21

Outstanding questions

- Can you name the brands & models of modern ventilators used currently in ICUs ?

Sources

🔗HAMILTON-C1 Technical Specifications v2.2.x
🔗Siemens Servo - I Ventilator - Centurion Direct
🔗https://www.alibaba.com/product-detail/MY-E004H-N-Hospital-Medical-Mobile_60825329269.html?spm=a2700.galleryofferlist.0.0.235c36a6E9S3qw

Projects

One Ventilators for Multiple Patients

🇺🇸🔗https://www.ncbi.nlm.nih.gov/m/pubmed/16885402/
A single ventilator for multiple simulated patients to meet disaster surge.
Criticisms of this: that it hasn't been tested in real patients. Patients' lung compliances change during ARDS. This makes it hard to match 4 patients who have similar lung compliances, for any length of time.
A possible solution: have a set of ventilators each optimized for a range of lung compliances, match patients to the optimal ventilator based on their oxygenation needs (ie. higher PEEP). More info here: https://emcrit.org/pulmcrit/split-ventilators/

🇧🇪🔗https://docs.google.com/document/d/1CZ-T7wNdqYMjM_eCRC94_yUBd9ZyAjy1NcGn0wFBWdA/
One ventilator multiple patients- A literature review of related efforts and possible designs

Open Source Ventilators

🔗https://drive.google.com/drive/folders/1TrHL40-RwSL_yWivaRF8GyKmLVJMr63j
🔗https://docs.google.com/document/d/1RDihfZIOEYs60kPEIVDe7gmsxdYgUosF9sr45mgFxY8/edit#
Helpful engineering- Open source project for ventilators and oxygen concentrators. Very comprehensive.

🔗Oxygen Concentrator Design Decision Document
O2 Concentrator Project- Trying to generate a set of instructions that allow for people with only mild DIY skills to build an oxygen concentrator.

🔗 https://www.youtube.com/watch?v=l4asKo9-ejU
The CovidLung Iron Lung - One of the fastest ventilator types to quickly construct, based on a proven design is without a doubt the Iron Lung Design. Jens Tandstad (jens.tandstad@gmail.com) has proposed a possible Iron Lung ventilator to treat Corona patients. But feedback from health professionals has been that this isn't suitable for Covid-19 patients due to missing key features. Evaluated and ***abandoned***. However, the design might be useful for other conditions in low income countries.

🔗https://www.projectopenair.org/
Project Open Air- "working on medical devices, such as open-source ventilators, to have a fast and easy solution that can be reproduced and assembled locally worldwide."

🔗https://panvent.blogspot.com
The Pandemic Ventilator Project- This blog documents our attempt to construct a ventilator design for use in a Flu Pandemic that can be made from readily available materials at the last minute. Hopefully, the situation never arrives where this device will need to be used for a pandemic. But just in case... The Post below is the most recent. See the right-side panel for other posts. This Blog was started on Feb 22, 2007

🔗https://www.bbc.co.uk/news/business-40498395
🔗http://www.thelancet.com/journals/lancet/article/PIIS0140-6736(15)60249-5/fulltext
The Frugal Ventilator- 10 minutes to make a $1.25 shampoo bottle DIY ventilator, with a 2-year lancet-published randomized control trial finding that it improves outcomes in infants, especially when coupled with oxygen. No evidence on use with adults
Bubble CPAP (continuous positive airway pressure) demo vids here and here.

🔗https://response4life.org/

Response 4Life- Website of a nonprofit modifying and distributing a ventilator developed in a graduate course at MIT in 2010 that is less than $200 in hardware components (see Umbulizer below) for use in the coronavirus pandemic. Looking to get in contact with leadership in shipping companies, electronics distributor companies, and in government to help with the distribution process. Looking for volunteers in software development, epidemiology, PR and marketing and other specialties.

🔗https://www.notion.so/c4af6b72b11142448ecac082174a86e2?v=2a0bf15d99b240c7ae3afd301dee05fa&p=38888f74a5b4424db422a35b4aadfe15
List of projects - but warning from https://panvent.blogspot.com/2020/02/im-back.html saying "Be very cautious with the article from Mechanical Engineering Group at MIT"

🔗https://www.instructables.com/id/The-Pandemic-Ventilator/
The Pandemic Ventilator : 6 Steps (with Pictures)

🔗https://medium.com/@brucefenton/we-need-ventilators-we-need-you-to-help-build-them-30805e5ee2ea
The EndCoronavirus.org Ventilator- The ventilators subgroup of EndCoronavirus.org (@endcovid19), an effort by The New England Complex Systems Institute, staffed with scientists from Harvard and MIT and others who have an understanding of pandemics, medicine, systems, risk and the key numbers and data behind this threat.

🔗https://opensourceventilator.ie/
🔗 https://gitlab.com/TrevorSmale/OSV-OpenLung
OpenSourceVentilator.ie- 3D printed design with the goal of a cost under $100, based in Ireland.

🔗 https://youtu.be/afFWwEcIBW4
The Vortran Automatic Resuscitator- This device which is manufactured commercially is the closest to what we could build.

🔗 https://OpenRvolunteeringespirator.org
OpenRespirator.org- Open source hardware project focused on ventilators, intubation kits, and whatever else can help close the gap. Not tied to a specific solution.

🔗https://www.youtube.com/watch?v=n57u1NvXBgw
🔗https://github.com/jcl5m1/ventilator
Johnny Lee DIY project- “Low-Cost Open Source Ventilator-ish Device” (video)

🔗http://www.pchrd.dost.gov.ph/index.php/news/6410-ginhawa-reliefvent
ReliefVent -(still active, led by Prof Abundio Balgos, UP College of Medicine, University of the Philippines - but short of funding).

🔗https://www.umbulizer.com/
🔗https://innovationlabs.harvard.edu/current-team/umbulizer/
Umbulizer- This is the basis for the technology of Response4Life.
🔗http://diyvetilators.com/
DIY Ventilators- Building a design library for DIY respirators.

🔗http://archive.rubicon-foundation.org/xmlui/bitstream/handle/123456789/3033/3907085.pdf
Trivially Modified Scuba Regulator- An old paper describing a method of modifying a Scuba regulator (mouthpiece) for intermittent positive pressure ventilation.

🔗https://simulation.health.ufl.edu/technology-development/open-source-ventilator-project/
Open Source Ventilator Project

ROARA Ventilator
🔗https://grabcad.com/library/roaera-ventilator-covid-19-1

MUR / Minimal Universal Respirator
🔗https://sraswars.cquest.org/

Other Communities working on Open Source solutions

🔗https://www.reddit.com/r/OpenSourceVentilators/

🔗https://en.wikipedia.org/wiki/Ventilator#Open-source_ventilator

🔗https://www.facebook.com/groups/670932227050506/about

3D Printed Valves for Ventilators

In Italy, a replacement valve was modeled and printed using 3D Printers for roughly $1 a valve. This was done to save lives. The technologist who designed the 3D file was threatened with a lawsuit by the manufacturer that normally makes the valves, and thus has refused to share the valve designs with others, despite the desperate need for the valves at other hospitals. More of these valves may be needed outside of Italy, and already are at hospitals outside of Brescia.
🔗Image of the Original Valve
🔗Image of the 3D design for the Valve
🔗Image of the Printed Valves - Additional Image

Update 2020-03-23: This patented device has just been released, along with some design to fit it to one specific model of snorkeling mask to turn it into a full ventilator system https://www.isinnova.it/easy-covid19-eng/

Open Calls and Hackathons

Open Calls

🇨🇦🔗https://www.agorize.com/en/challenges/code-life-challenge
Code Life Ventilator Challenge- The $200k challenge to design a 3D printable ventilator for COVID-19 patients everywhere

🇬🇧🔗https://medium.com/frontier-technology-livestreaming
✉️COVIDaction@hellobrink.co
DFID's Frontier Technologies Hub is looking for existing and proven low-cost ventilator technologies from across the globe, especially emerging markets, that can be rapidly adapted to be manufactured in the UK. The winning technology will be adapted for manufacture and use in the UK by a team at UCL's Institute for Healthcare Engineering with GDI Hub, and will receive a licensing fee.
📢**Call for applications:** 16th of March 2020
📄**Applications close:** 24th of March 2020
🏆**Final Selection:** 25th of March 2020

🔗https://www.coventchallenge.com/
CoVent-19 Challenge- An Open Innovation Effort to Design a Rapidly Deployable Mechanical Ventilator

🔗https://www.ifm.eng.cam.ac.uk/manufacturing-and-covid-19-ways-your-company-could-help/
Cambridge University Institute for Manufacturing - list of initiatives which manufacturing organisations can support (mentions this handbook :-))

Hackathons

🔗https://hackaday.com/2020/03/12/ultimate-medical-hackathon-how-fast-can-we-design-and-deploy-an-open-source-ventilator/?fbclid=IwAR2oIOeqWPOib1u04HnJB8zN_GWC9XRxs9XeNdNkpiISKPHUm128DTY-W3o
Ultimate Medical Hackathon- "How fast can we design and deploy an open source ventilator?" This led to the development of a facebook group, called Open Source COVID19 Medical Supplies.