Work-on-the-Airway: A Useful Concept for Pandemic Ventilators

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Abstract

Mechanical ventilation must do work on the airway in order to inflate the lungs. Considering the work done on the airway may have several uses:

- Computing the maximum required work on the airway in a clinical situation provides engineers a minimum power output requirment by an air drive mechanism.
- Work-on-the-airway is independent of the means of air production, whether by fan, blower, pump, piston, bag-squeezer, or bellows. It therefore may serve as a unifying means of controlling air production to meet a clinical goal independent of the means of production.
- Work-on-the-airway may be used to compute the work of breathing if the work done during expiration can be quantified. This may be a practical means of offerint work of breathing as a clinical metric.

1 Introduction

Let us define the term *air drive* to mean the mechanism that produces air and air/oxygen/medical gas mixtures in a mechanical ventilation system. Because of the COVID-19 pandemic, many humanitarian engineering teams have experimented with squeezing inexpensive Bag Mask Valves (BMVs), or *bag squeezers*. Other mechanisms include pistons, bellows, positive displacement pumps, which tend to produce a fixed volume against a variable pressure. Still other mechanisms such as velocity pumps, fans and blowers tend to produce a fixed pressure against a variable back-pressure leading to the injection of a variable volume. One goal in this paper is to unify these two very different mechanisms.

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MIT has presented a useful computation of the work that must be done on the airway for maximum patient need, from which they conclude a mininum power requirement for an air drive for mechanical ventilation[1]. Expanding on this work is a second goal of this paper.

2 Physical Preliminaries

Roughly speaking, volume times pressure is work. To inject an infinitessimal amount of air in to any air vessel or across any air threshold, the work is the product of the pressure in at the threshold and the volume injected. A threshold into a vessel of fixed size is easy to analyze. A vessel such as a balloon whose volume is dependent on internal pressure is slightly more complicated. A rubber balloon has a *compliance* which is defined to be the change in volume with a change in pressure.

A human lung system is even more complicated, because it has has both static and dynamic compliance `https://en.wikipedia.org/wiki/Lung_compliance`.

Nonetheless, if we use a simplified model, work done over time on an airway is the integral over time of injected volume multipied by pressure, where both injected volume and pressure are a function of time.

However, by considering maximum needs, the problem is simplified.

3 Ventilaiton Modes

Mechanical ventilators offer a number of control modes, the two simplest for invasive ventilaiton being pressure-control mode and volume-control mode. They patient may fight against the action of the ventilator, called dys-syncrhony. However, if we disregard this clinically important problem, the modes are simple.

Pressure control mode create inspiration by providing air at an approximately fixed pressure for a fixed period of time. Volume control mode pushes air at a potentially variable but limited to some maximum pressure into the airway until a volume is acheived.

Volume control mode is easy to acheive with a piston which is powerful enough: use the piston to push the desired volume of air out of a cylinder and into the airway. (A weak piston might not be able to do this.) In so doing we may control the speed of this push which will somewhat control the pressure. A positive-displacement pump with a small chamber may be pumped many times to achieve the desired volume; in this say a piston and positive-displacement pump are similar.

4 Work-on-the-Airway as a Ventilation Mode

We speculate that it might be clinically valuable to define a ventilation mode which control the work-on-the-airway done in a given insipriaiton.

References

[1] MIT Emergency Ventilator: Power Calculation, 2020. [Online; accessed 05-June-2020].