Hypercapnic gas stimulus in ventilators:
First step towards CVR imaging in ventilated patients

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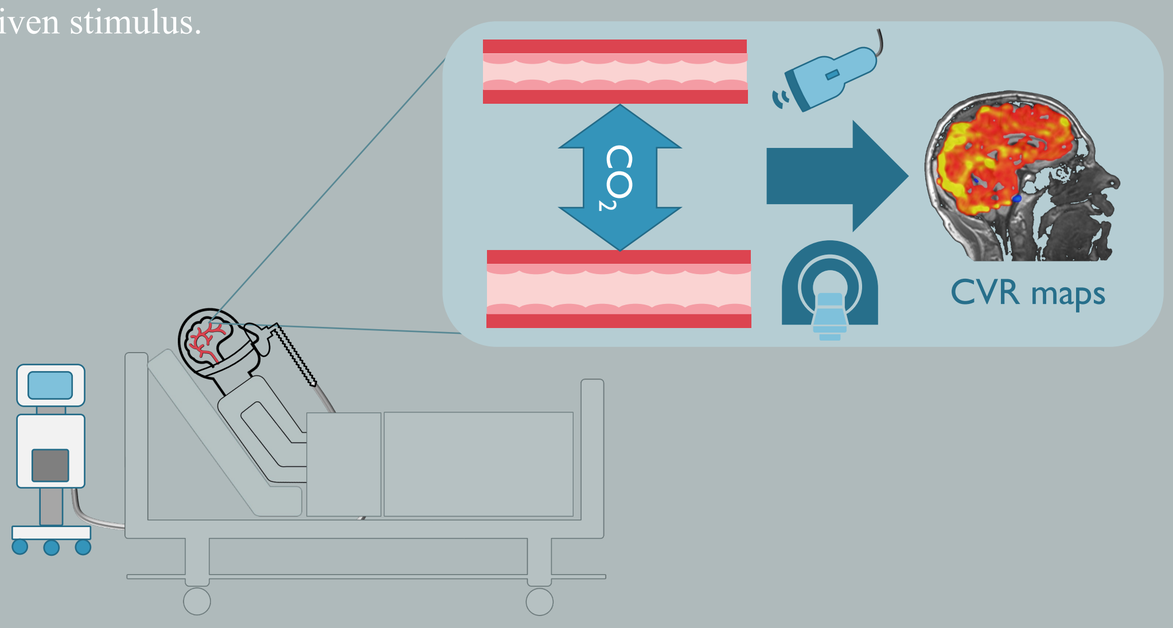
1 Cerebrovascular Reactivity

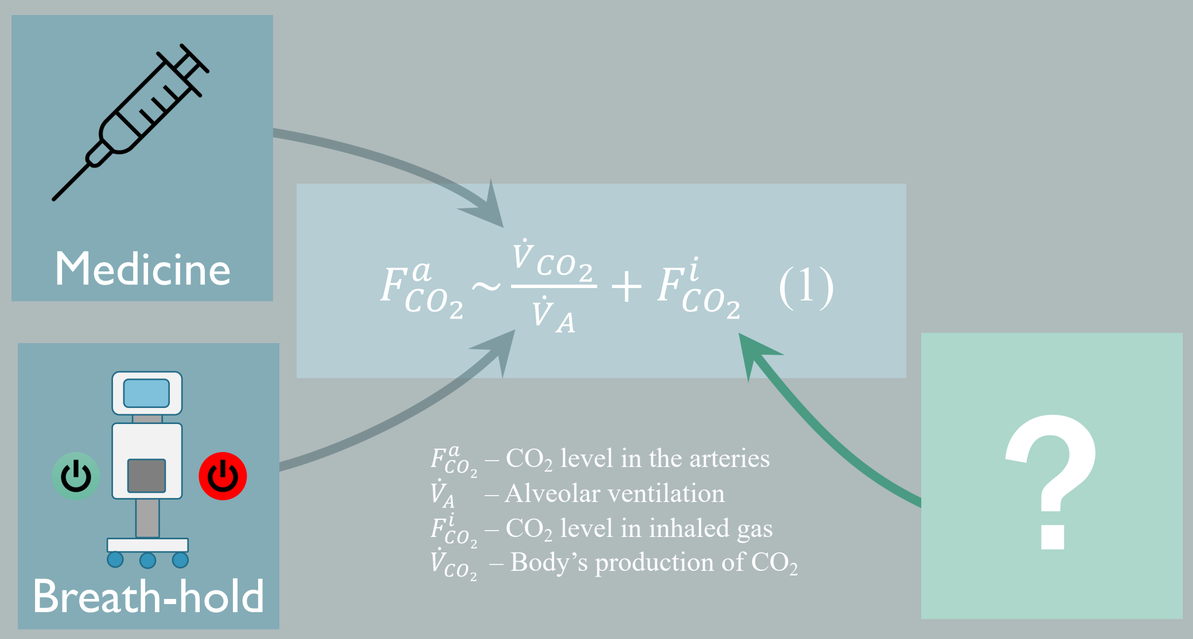
The brain has an advanced system for regulating its blood flow, termed cerebral autoregulation. One way to probe this system is to use a technique called Cerebrovascular Reactivity (CVR) which measures the change in blood to a given stimulus.



- CVR is calculated as: $\frac{\Delta Blood\ Flow}{\Delta Stimulus}$ and can be seen as an indirect measurement of the vascular reserve of the brain.
- Hypo-/hypercapnia is often used as stimulus as the brain has several mechanisms sensing the CO_2 level and alter its blood flow accordingly.
- The changes in blood flow is usually monitored with transcranial doppler or magnetic resonance (MR) imaging to produce CVR maps.
- CVR is today used as a diagnostic tool for multiple patient groups such stroke, brain tumor and small vessel disease.[1]

2 Research question

The steady state CO_2 level in the blood is controlled by equation (1) below.



To perform hypo-/hypercapnic CVR measurement there exist therefore three main strategies:

- Use medicine, such as acetazolamide, to alter $\dot{V}_{CO_2}$.
- Change the ventilation $\dot{V}_A$, for example through breath-holding.
- Alter $F^i_{CO_2}$ in the inhaled gas.

The last alternative is considered to be most reliable and reproducible. [2]

Problem formulation:

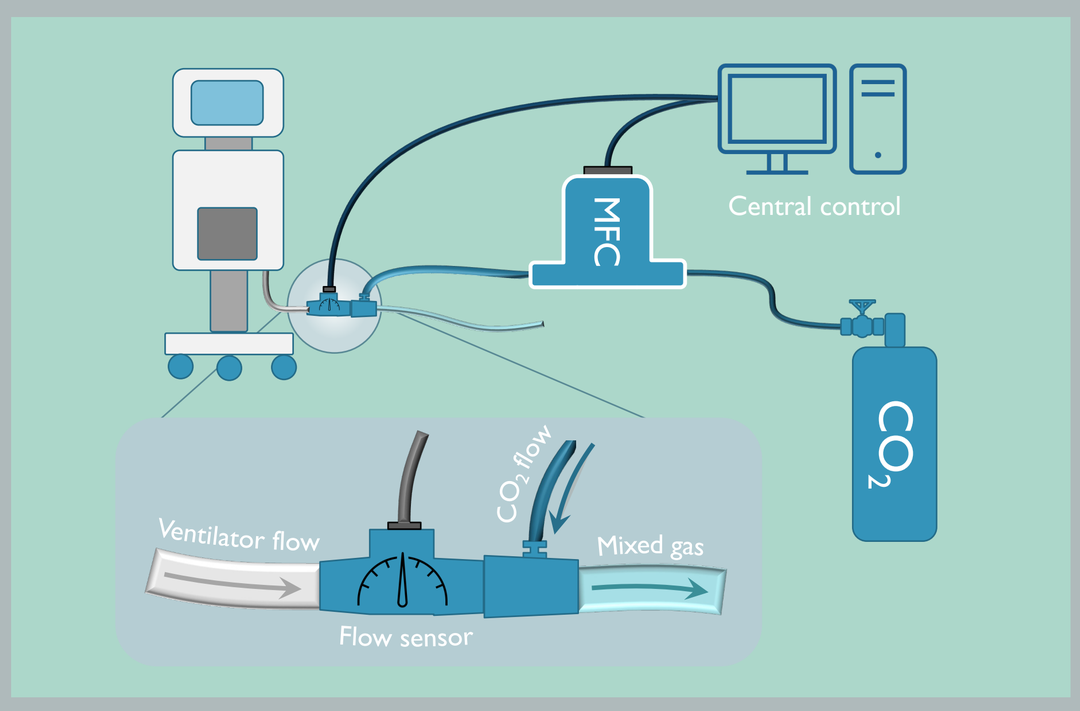
- For ventilated patients there exists today, to our knowledge, no straightforward way to alter $F^i_{CO_2}$.
- Therefore, the only option is to administer drugs or use breath-holding (turning on and off the ventilator).

We therefore set out to construct a system that works together with a ventilator to administer a fix amount of CO_2 in the inhaled gas in order to enable reliable and safe CVR measurements for ventilated patients.

3 Method

We used a solution inspired by INOmax, a system to administer small amounts of Nitric Oxide together with a ventilator.[3] The idea is relatively simple:

- Measure the flow from the ventilator and control an additional flow of high concentration CO_2 which is added to the ventilator flow.
- By controlling the proportion of the additional flow, a target CO_2-concentration can be achieved.



Our system: iCO_2 CVR System, was built with three main components:

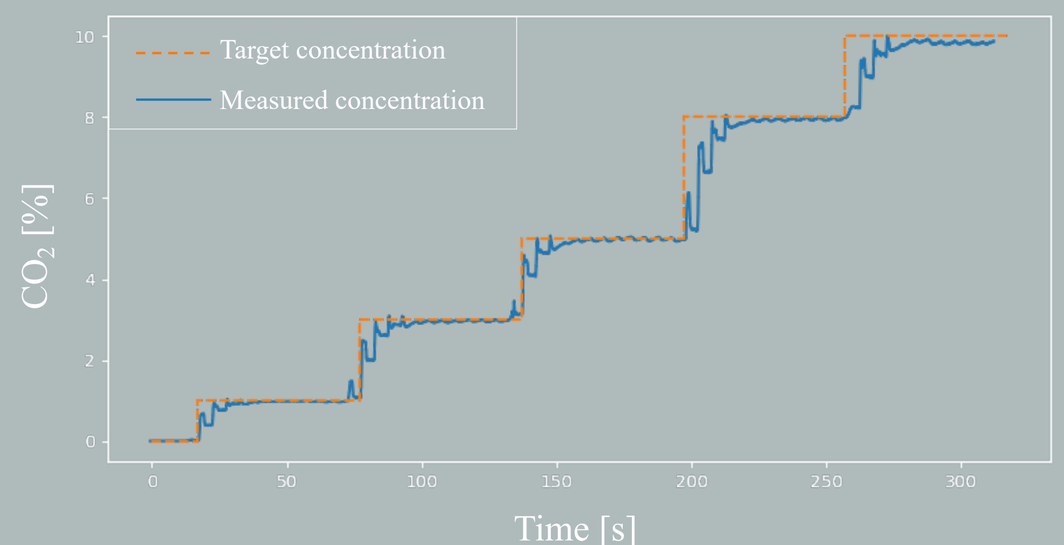
- Flow sensor – Honeywell AWM720P
- Mass Flow Controller (MFC) – Brooks SLA5850
  - Attached to a gas tube containing 10% O2 + 90% CO2
- Central control – Computer running a control program written in Python

4 Results and discussion

The iCO_2 CVR System was completed with satisfactory results.

- We were able to achieve target CO_2-concentration ranging from 1–10% with a mean error less than 1% when ventilating a test lung.

Below is an example showing the target CO_2 in orange and the measured CO_2 in blue.



Discussion:

- The timing of the additional CO_2 flow to the ventilator flow turned out to be crucial since the gases mixed very little in the ventilator tube.
- By adding some additional elements to the ventilator circuit, such as a humidifier, mixing of the gases could be increased.
- The length of the CO_2-delivery-tube is a limiting factor since too large compressible volume in the tube will affect the accuracy of the system.

References

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