Animal Ventilator for Hyperpolarized Gas MRI

Ashley Anderson[1], Micah Brown[1], Matt Smith[1] , Chris Wegener[1]

Advisor: Professor Willis Tompkins PhD[1], *Client:* Dr. Sean Fain PhD[1,2]

1 Department of Biomedical Engineering, 2 Department of Medical Physics

Abstract

The use of hyperpolarized Helium (3-He) as a contrast agent in Magnetic Resonance Imaging (MRI) is an emerging technique for diagnosing diseases or abnormalities in the respiratory tract. Current methodology allows for MRI scans to be taken during inhalation of helium every fourth breath to allow adequate oxygen for the subject. A device and/or method is needed to function as an oxygen ventilator and to serve as a means to integrate 3-He into small animals on every breath for Hyperpolarized Helium MRI imaging of the respiratory tract and lung systems.

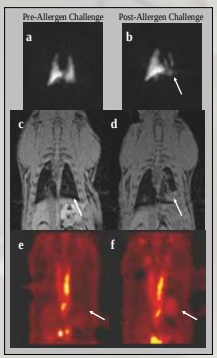
Problem Definition

Create or redesign a small-animal ventilator capable of delivering constant volumes of 3-He and Oxygen gas (1-20 mL) at user-specified frequencies (1-100 cycles/min) for safe and compatible use in an MRI environment.

Objectives for this semester include increasing accuracy and precision of the device with a second-generation prototype. Additionally, the current timing of the valves cause an undesirable "oxygen chaser" after each helium breath, and a solution to this problem is also desired.

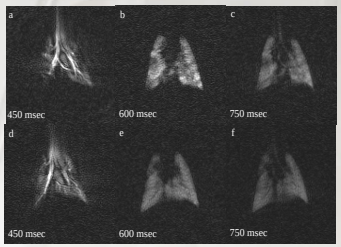
Client Study

If 3-He MRI can accurately image airways and air spaces, one could postulate that respiratory diseases such as asthma could be diagnosed with the use of this process. Ideally, 3-He MRI will successfully reveal information that will lead to diagnoses of respiratory diseases. Physicians will be better able to assess the patient's condition by viewing accurate images of their airway channels and lung systems.



3-He images (a,b). T_1-weighted conventional MRI images (c,d). [F-18]FDG PET images (e,f).

The study assesses the capability of successful diagnoses of respiratory diseases induced in small animals with the use of 3-He MRI.

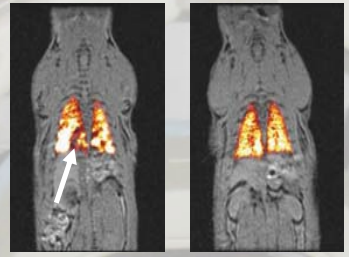


Respiratory phases for asthma-like (top) and healthy (bottom) rat lungs with 3-He MRI.

3-He MRI

Concept

- *3-He is the hyperpolarized isotope of Helium*
- *Conventional MRI scanner*
- *Signal comes from 3-He instead of Hydrogen*
- *Helium is inhaled during imaging*
- *Images allow non-invasive analysis of respiratory structure and function*

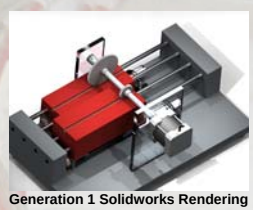


Helium signal overlaid on anatomical (proton) images for control (top) and asthma-like (bottom) rats.

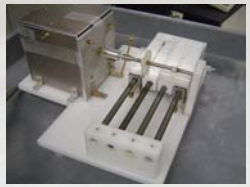
Simultaneous Delivery of O_2/3-He Pros

- *Keep animal alive*
  - *Able to scan over a period of months*
  - *Show progression or regression of diseases*
  - *Show inflammatory response*
- Scan every breath
  - Reduce scan times by a factor of four
  - Animal anesthetized for less time

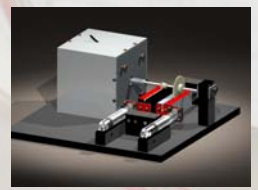
Design Progression



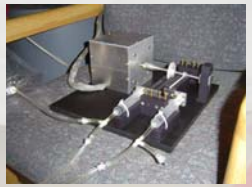
Generation 1 Solidworks Rendering



Generation 1 Prototype



Generation 2 Solidworks Rendering



Generation 2 Prototype

Design Improvements

Hardware

- *Improved materials*
  - *Nylon-66 bulk plastic pieces*
- *New syringe clip design (right)*
- *Smaller scale*
- *Easier access to syringes (right middle)*
- *Adjustable axle support*

Syringe clip design

Software

- *Implemented in LabVIEW*
- *Integrated with pre-existing setup*
- *Enables simultaneous delivery of 3-He and O_2 from syringes*
- *Scan trigger every breath*
- *Eliminates O_2 chaser*

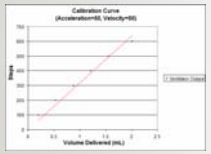
Positioning of syringes

(Left) User interface to enter parameters. (Middle) Counter initialization. (Right) Breath control via communication with stepper motor.

Calibration and Testing

Calibration

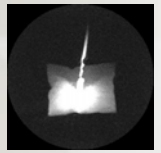
- *Used manometer to measure volume output*
- *Relates volume to number of motor steps (right top)*
- *Linear relationship*
- *$Y = 317.33x$*
- *$R^2 = 0.9732$*



Output calibration

Testing

- *Performed respiratory gated projection 3-He MRI*
- *Ventilated bag with 3-He/O_2 mixture to simulate rat lung*
- *Signal levels were optimal as shown (right bottom)*



Small bag ventilation with 3-He MRI

References

[1] Hedlund, LW.; Moller, H.E.; Chen, X.J.; Chawla, M.S.; Cofer G.P.; Johnson, G.A. (2000) Mixing oxygen with hyperpolarized He for small-animal lung studies. NMR Biomed. (2000). Jun;13(4):202-6

[2] Prince, J.; Links,J.; Medical Imaging Signals and Systems. Pearson Education. Upper Saddle River, NJ. (2006).

[3] Holmes et al. Noninvasive Mapping of Regional Response to Segmental Allergen Challenge Using Magnetic Resonance Imaging and [F-18]Fluorodeoxyglucose Positron Emission Tomography. Magnetic Resonance in Medicine. (2005). 53:1243-1250.

Thanks to Sean Fain PhD, Jim Holmes PhD, and Eric Peterson