System Development for Measuring Dynamic Pressure-Area Relationships in Isolated Airways

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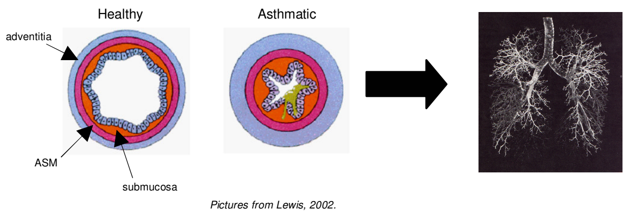
INTRODUCTION

Airways
- The airway tree is a complex 3-D structure with non-symmetric bifurcations
- Mechanics of individual airways, such as pressure-area relationships and compliance, are important because they integrate to affect whole lung function

Asthma
- Airway disease characterized by inflammation, thickening of the airway walls, and luminal secretions
- All three layers of the airway wall (adventitia, airway smooth muscle, and submucosa) become thicker in asthma
- Causes reduction in airway diameter, increased airway resistance, and hyperresponsiveness to a range of stimuli



Pictures from Lewis, 2002.

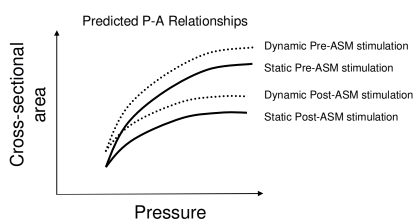
RATIONALE

Past Work on Isolated Airways and ASM
- Previous studies have examined the *static* pressure-area relationships of isolated airways[1]
- Dynamic length cycling of ASM causes it to remodel so as to generate less force than when held at a static length[2]

- Breathing is a dynamic process

➡ An isolated airway with intact ASM examined dynamically will produce pressure-area relationships that more accurately represent the impact of breathing on wall mechanics

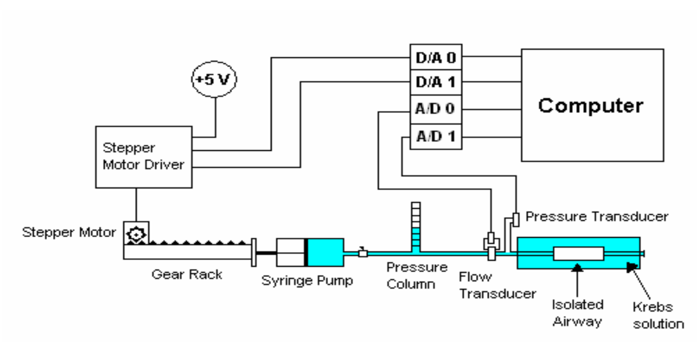
Dynamic Pressure-Area (P-A) Relationships
- As with static P-A relationships, healthy airways should have a higher cross-sectional area than stimulated airways
- Dynamic P-A curves should have a higher CSA than static P-A curves because ASM becomes more plastic when dynamically oscillated
- The slope will be greater for pre-stimulated airways because of a higher compliance



SPECIFIC AIMS

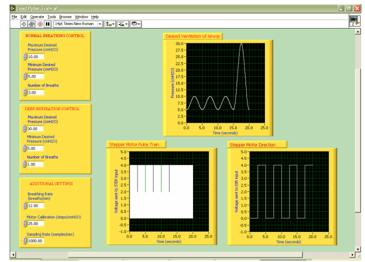
- To develop a system to study the dynamic properties of isolated airways with intact ASM
- System must produce the appropriate pressure changes across the airway wall to simulate normal breathing and deep inspirations
- System must be:
  - User-friendly
  - Computer-controlled
  - Adaptable, in order to produce different breathing patterns

SYSTEM OVERVIEW

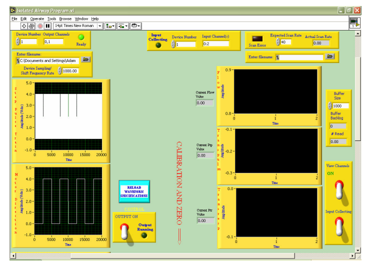


- The system functions as follows:
  1. A computer-controlled stepper motor drives a syringe pump
  2. The syringe pumps Krebs solution into and out of a pressure column
  3. The height of the pressure column determines the pressure of the Krebs solution that is delivered into the isolated airway
  4. The pressure and flow going into the airway are measured
- Additional notes:
  - Airway transmural pressure is the independent variable
  - For a normal breathing case, the system should deliver pressures of 5 to 10 cmH_2O in a sinusoidal manner into the isolated airway
  - Rigid tubing is used to ensure that the system compliance does not effect the measured pressure and flow

SOFTWARE

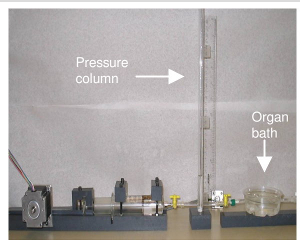


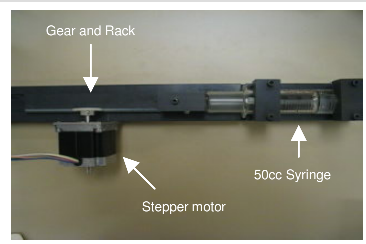
Program 1 – Creating Desired Pressure Waveform
- Labview GUI
- Allows user to make a desired sinusoidal pressure waveform to simulate breathing (5 to 10 cmH2O for normal breaths; 5 to 25 cmH2O for deep inspirations)
- Translates waveform into a corresponding pulse train and step function that drives the stepper motor driver



Program 2 – Outputting Waveform and Collecting Data from Transducers
- Labview GUI
- Outputs pulse train and step function to stepper motor driver
- Inputs and records flow and pressure data from transducers

HARDWARE

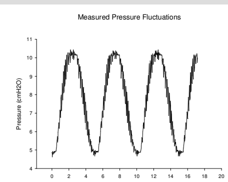




- The side and top view of the system show (from left to right): the stepper motor, the gear and gear rack, the 50cc syringe, the pressure column, and the organ bath

INITIAL TESTING

- Initial testing has shown that the pressures delivered past the pressure column are sinusoidal and oscillate in the correct range
- Some noise is present due to the stepping of the stepper motor



PROJECT END GOAL

- Perform experiments using airways excised from calf lungs
- Using the sampled pressure and flow data, determine the following relationships for pre- and post-activated ASM:
  - Transmural Pressure and Cross-sectional Area

$$Vaw = \int Flowdt \qquad CSA = Vaw / Law$$

  - Transmural Pressure and Compliance

$$Compliance = dVaw / dPtm$$

Where:
Ptm = transmural pressure (cmH_2O)
Vaw = airway volume (cm^3)
Law = airway length (cm)
CSA = airway cross-sectional area (cm^2)

- Improve 3-D computer lung models using dynamic pressure-area relationships

REFERENCES

(1) Gunst, S.J., and J.Q. Stropp, *Pressure-volume and length-stress relationships in canine bronchi in vitro.* American Physiological Society, 1988. 88: 2522-2531.
(2) Latourelle, J., B. Fabry, and J.J. Fredberg, *Dynamic equilibration of airway smooth muscle contraction during physiological loading.* J Appl Physiol, 2002. 92: 771-779.

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