Endotracheal Tube Intracuff Pressure is Not Equal to Tracheal Wall Pressure on a Simulated Trachea

B. Randall Brenn MD
Associate Professor of Anesthesiology
Medical Director of Perioperative Informatics
Director of Pediatric Clinical Informatics
Vanderbilt Anesthesia & Perioperative Informatics Research

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Research Trajectory

- A Longstanding OR Argument
- Plantar Fasciitis
- Beer and Wings
- Squirrel Monkeys

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The Argument: His side

- CRNA who always measured cuff pressures
- His Belief: The pilot balloon cuff pressure equals tracheal pressure
  - Low-Pressure/High-Volume Cuffs "conform to the trachea"
  - "A significant advantage of these cuffs is that the intracuff pressure closely approximates that on the wall of the trachea…"
    - Dorsch and Dorsch, Understanding Anesthesia Equipment. 2nd Ed. 1984, 364-368
  - Nobody argues with Dorsch and Dorsch

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Table 13.1.
Characteristics of High Pressure and (Idealized) Low Pressure Cuffs (90)

	High Pressure	Low Pressure
Diameter at residual volume	Small	Large (ideally approximates tracheal diameter)
Residual volume	Small (3–6 ml)	Large (usually more than 30 cc)
Area of cuff in contact with trachea with seal	Small	Large
Cuff volume-pressure relationship before seal is achieved	Linear relationship between volume and pressure	No significant pressure until seal is approached
Intracuff pressure at seal	High	Low (less than 30 torr)
Pressure exerted by cuff laterally on tracheal wall	High	Low
Relationship between intracuff pressure and pressure exerted by cuff on tracheal wall	Intracuff pressure exceeds tracheal wall pressure	Equal
Cuff behavior in relation to trachea at seal	Cuff imposes its shape on the trachea, deforming it	Cuff tends to conform to shape of trachea
Rise in cuff pressure per unit volume after seal is achieved	Steep rise	Slow rise (90)
Change of cuff pressure with airway pressure	Some rise with a rise in airway pressure, but no linear relationship (91)	Intracuff pressure automatically cycles in synchrony with airway pressure when airway pressure exceeds intracuff pressure
Cuff wall	Thick, rigid	Thin, pliable

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Dorsch and Dorsch, 2nd Ed. 1984

The Argument: My side

- My Belief: This is not always the case…
  - With multiple size tubes, multiple size tracheas, how always the same?
  - Small cuffed ETT, in a real big trachea, the TWP might be zero!
  - Large cuffed ETT, in a smaller trachea, the TWP might be high!
  - Absolutely No Data…

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What we know

- ETT cuff can cause tracheal mucosal ischemia
  - Knowlson GT, et al. Br J Anaesth. 1970; 42 (10):834-7.
- Low-Vol/High-Press cuffs worse than High-Vol/Low-Press cuffs
  - Mathias DB, et al. Br J Anaesth. 1974; 46: 849-852.
- If TWP does not exceed 30mmHg, low likelihood of mucosal ischemia
  - Seegobin RD, et al, Br Med J. 1984; 288 (6422): 965-8.
- High-Vol/Low-Press cuffs, if not stretched, pilot balloon pressure and intra-cuff pressure should closely correlate.
  - Talekar CR et al. Anaes Int Care 2014; 42 (6): 761-70.
- Things were not looking good for my argument…

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Pediatric Anesthesia

- Infants and Children undergo rapid growth
- Infinite sized tracheas
- We use few sizes of cuffed ETTs 2.0-5.5 mm ID
- Have been using cuffed ETT since mid 1990's
  - Khine HH, et al. Anesthesiology. 1997 Mar;86(3):627-31

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How Could This Question be Answered?

- Literature searches…
- Discussions with colleagues…
- Years of torment…
- Finally I had a breakthrough!
- I developed Plantar Fasciitis…

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The Dr. Scholl's Foot Pressure Kiosk

- Stand on a Pad
- Foot pressure is sensed
- An orthotic is recommended

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Wait how does this work?

- Not the Orthotics…
- What is the technology behind the pressure sensing pad?
- Beer and Wings at Kennett Brewing Company, Kennett Square PA
- Force Sensitive Resistor
  - "Material that changes its resistance when a force or pressure is applied"
  - "Sensor can be designed that can detect force, pressure, strain or weight"
  - Customizable, Low Cost, Sensitive,

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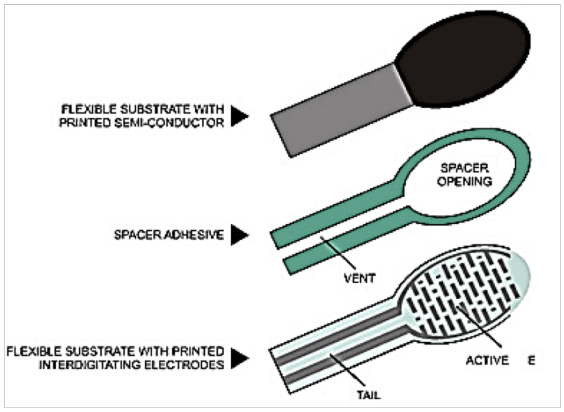
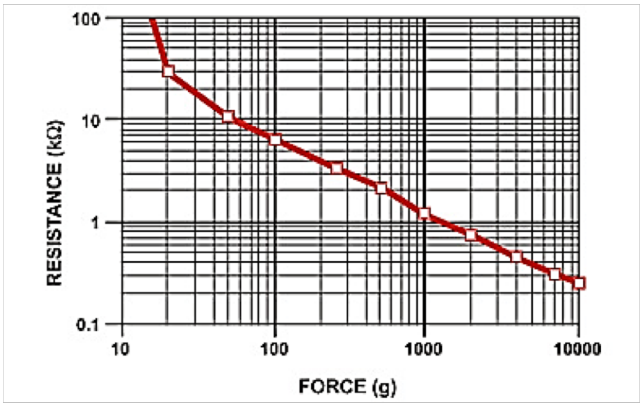
Force Sensitive Resistor Construction

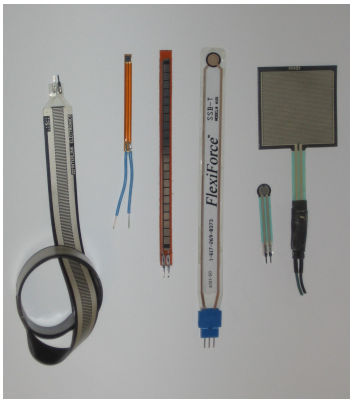


- Semiconductor Substrate
- Thin Insulated spacer
- Semiconductor Substrate with printed electrodes
- Pressure causes connection with electrodes reducing resistance

FSR Functionality

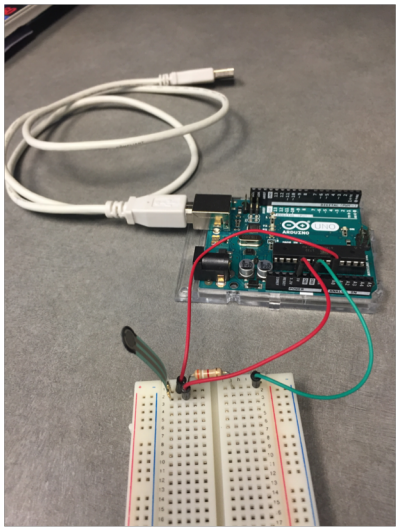


- No pressure-infinite resistance
- High pressure-Low resistance
- Logarithmic scale-wide dynamic range



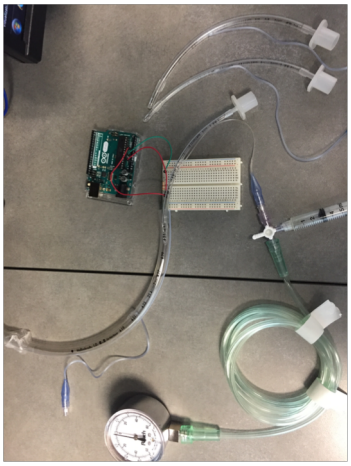
Very Customizable depending on application

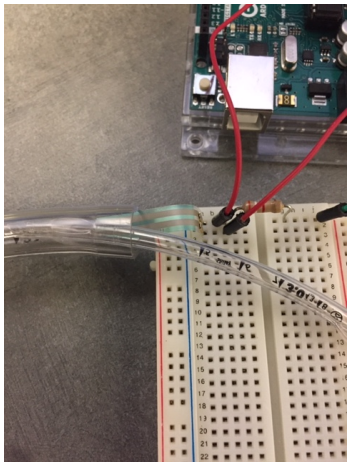
Experimental Setup



- Kit Specifications
  - 4 mm FSR Sensor (Sparkfun.com)
  - Current Limiting Resistor
  - Voltage divider circuit
- Analog to Digital Converter
  - Arduino Microcontroller
  - (Arduino Uno-R3)
  - (Software Version: Arduino 1.8.5)
  - USB connection to PC

Experimental Set Up





- ETT (3.0, 3.5, 4.0 mm ID)
- Faux Trachea (ETT 8.0 mm ID)
- Airtight Setup
  - Pilot Balloon
  - Three Way Stopcock
  - Respiratory Tubing
  - Manometer
- 4mm FSR placed between the cuff and faux tracheal wall

Research Plan

- Inflate the cuffs in 0.5cc increments, hold for 5 sec
- Record resulting manometer cuff pressures
- Record Force exerted on the Trachea via FSR
- Data then transferred to Excel for graphical output.

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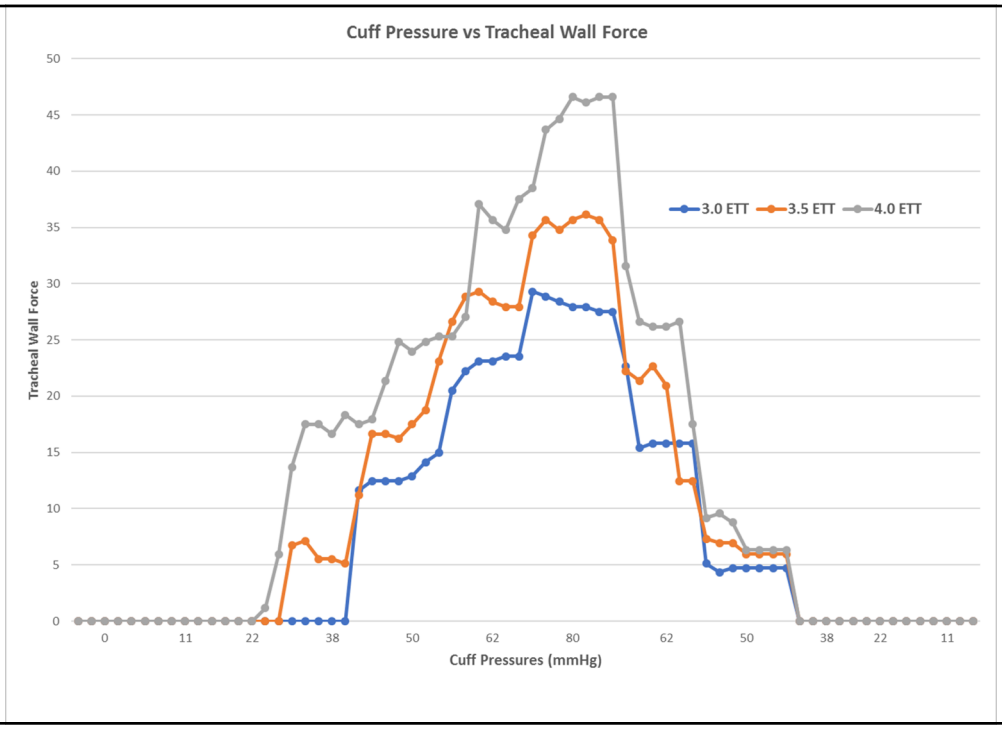

Findings

- With each 0.5cc increment, each ETT exerted a different force plateau at the same cuff pressure.
- Therefore, intracuff pressure was not equal to TWP in vitro.
- Limitations:
  - Exaggerated example, may not be directly clinically applicable
  - System used was homemade, therefore confounding variables

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Future Study

- Explore further applications of FSRs
- Neuropathology Research group at Vanderbilt
- Squirrel Monkey model for spinal cord injury and recovery
- Went from 1500gm to 900gm subjects
- Used same uncuffed 3.0 mmID ETTs
- Post intubation respiratory difficulties!

Future Study

- We have may have a model of neonatal ETT mucosal injury
- Currently looking at FSR on ETTs for SM
- Measure mucosal forces/pressure
- Correlate with mucosal injuries
- Translate to Premature infants?

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Questions?

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