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

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Research Trajectory

• A Longstanding OR Argument

• Plantar Fasciitis

• Beer and Wings

• Squirrel Monkeys
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

| Table 13.1. Characteristics of High Pressure and (Idealized) Low Pressure Cuffs (00) |
|---------------------------------------------|---------------------------------------------|
| Diameter at residual volume                | High Pressure                               |
| Residual volume                            | Small (3-6 ml)                              |
| Area of cuff in contact with trachea       | Small                                       |
| Cuff volume-pressure relationship          | High                                        |
| intracuff pressure at seal                 | High                                        |
| Pressure exerted by cuff                   | Equal                                       |
| Cuff behavior in relation to trachea       | Cuff imposes its shape on the trachea, deforming it |
| Rise in cuff pressure per unit volume      | Steep rise                                  |
| After seal is achieved                     | Some rise with a rise in airway pressure, but no linear relationship (91) |
| Change of cuff pressure with airway pressure | Intracuff pressure automatically cycles in synchrony with airway pressure when airway pressure exceeds intracuff pressure |
| Cuff wall                                  | Thick, rigid                                |

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…

What we know

• ETT cuff can cause tracheal mucosal ischemia
  

• Low-Vol/High-Press cuffs worse than High-Vol/Low-Press cuffs
  

• If TWP does not exceed 30mmHg, low likelihood of mucosal ischemia
  

• 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...
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

How Could This Question be Answered?

• Literature searches...
• Discussions with colleagues...
• Years of torment...

• Finally I had a breakthrough!

• I developed Plantar Fasciitis...
The Dr. Scholl’s Foot Pressure Kiosk

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

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,
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.
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
### 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?
Questions?