3D Printed Airway Trainers

UW-Madison Biomedical Engineering Design; Fall 2024

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Problem Statement

A novel airway trainer device is needed for clinicians to practice intubation procedures. The custom trainer must reflect the complexity of a specific patient's airway anatomy for realistic simulation. These devices are critical to ensure adequate training for clinicians during difficult intubations.

Motivation/Background

Background

- Every year, close to 400,000 airway management procedures are performed to restore patient airway patency [1]
- Overall intubation success rate approximately 78.8%

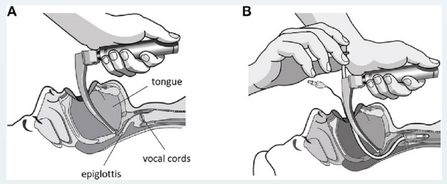


Figure 1: Intubation Procedure [2]

- Critical condition first-pass success is 68.5% [3]
- Complications due to patient abnormalities are rare (0.0015% of cases) but account for 25% of anesthesia related deaths [4]
- Extensive training via airway trainers required for first-pass success in "can't intubate, can't ventilate" situations where surgical interventions are the only next option

Competing Designs

- Popular Laerdal trainer offers healthy airway anatomy [5]
- Not reflective of patient specific pathologies (complications due to abnormal anatomy, edema, previous surgeries)
- Models are expensive ($3,000 average) [6]

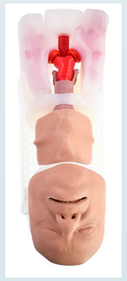


Figure 2: Decent Simulators Airway Trainer [7]

Figure 3: Laerdal Airway Trainer [5]

Design Criteria

- Swappable patient specific anatomy
- Durability measured by minimum Young's Modulus of 16 MPa ∓ 8 MPa and Shore A hardness of 80 [8, 9]
- Material is water-based lubricant resistant
- Successful intubation at least 96.8% of the time [10]
- Budget of $750
- Adaptable in less than one week lead time for new patient

Final Design

Final Design of Airway:

- Utilized auto segmentation capabilities in 3D Slicer
  - CT scans chosen due to availability and simplification
  - Eliminated manual-segmentation for model throughput
  - Removed anatomy after primary bronchi
  - Solid model representing inner wall of airway anatomy
  - Post processing in OnShape to create "negative"

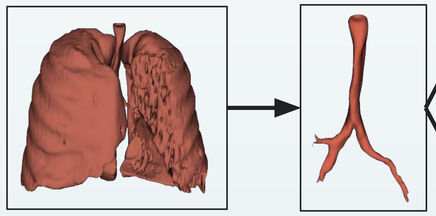
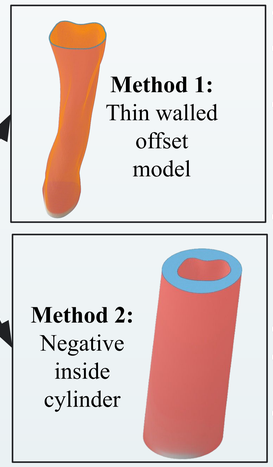


Figure 4: Model processing workflow



Two Paths for Model to Trainer:

- Difficult due to airway model representing air instead of tissue
- 1: Replicate thin tissue lining trachea using offset surfaces
  - Variable thickness per model
  - Constraints due to CAD
- 2: Subtract model from cylinder
  - Replicates anatomy internally
  - Thicker model for more accurate biomechanics of airway
- Both require experience in CAD
- No commercial software available to speed or simplify model creation
- Requires additional post processing to work with upper airway features

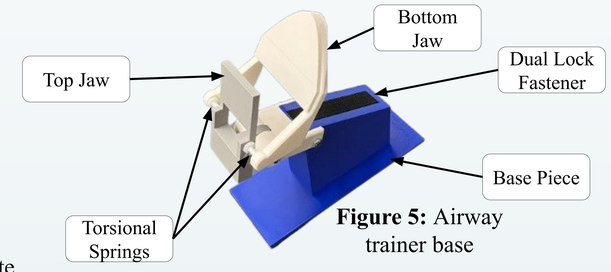


Figure 5: Airway trainer base

Final Design of Airway Trainer Base:

- Sloped platform to mimic anatomical airway placement
- TPU torsional springs that replicate physiologically accurate range of motion in the jaw
- Dual Lock fasteners used to allow for versatility in airways compatible with the design

Results and Discussion

Finite Element Analysis (FEA) Test

Goal: Determine if the pieces of the airway trainer base will fail under the force exhibited during intubation

- Maximum force during intubation is 63 N [11]
- Force applied to base pieces using SOLIDWORKS FEA software
- Factor of Safety (F.O.S.) ≤ 5 was considered a failure
- Since Top Jaw and Bottom Jaw failed, modeling with stronger materials, such as ABS, should be considered

Area Force Applied	Base Piece	Neck Hinge	Top Jaw	Bottom Jaw
Top	✓	✓	X	X
Right	✓	✓	✓	✓
Both	✓	✓	X	X

Table 1: Results of FEA Test - Green indicates passing and red indicates failing

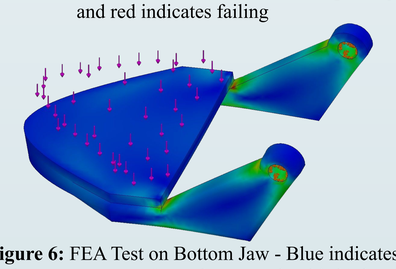


Figure 6: FEA Test on Bottom Jaw - Blue indicates low stress, green is moderate, and red is high

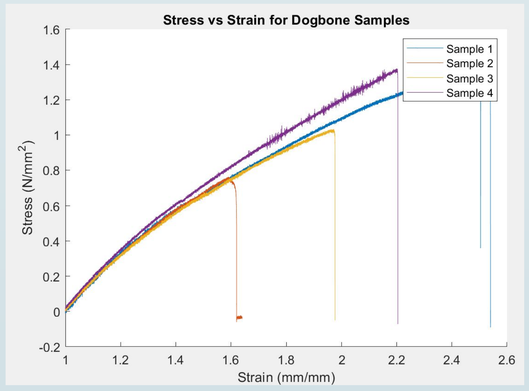


Figure 7: Graphed tensile testing data

Neck Range of Motion (ROM) Test

Goal: Determine if the trainer accurately represents the ROM of a patient's neck

- Testing the modeling of the neck by two hinges
- Angles and measurements were taken from AirSim trainer prior to disassembly to compare values
- Limiting or increasing ROM will decrease realism
- Incorrect ROM can lead to harm caused to patient because of clinician training on the model
- AirSim: 50°, 45°; Our trainer: 55°, 27° (flexion and extension respectively)

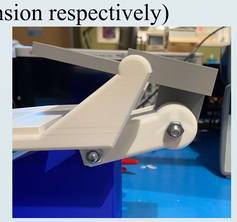


Figure 8: Final hinge maximum flexion

Figure 9: Final hinge maximum extension

Material Tensile Test

Goal: Determine the Young's Modulus (YM) of the Formlabs 50A resin to ensure proper biomechanical properties and realism in trainer

- Significant support required leads to variability in material strength
- YM calculated from tensile testing of ASTM-D838 Type IV Dogbone sample and compared to datasheet from Formlabs
- Calculated Young's Modulus: 0.91 MPa, Stated as 1.59 MPa [12]
- Differences arise from support removal harming model

Future Work

- Collaborate with client to ensure prompt access to scans
  - Receive IRB approval or dataset access
- Work with Radiology for segmentation support
- Explore Materialise availability inside UW Health [13]
- Utilize MeshMixer to process STL files [14]
- Improve the trainer's facial anatomy to allow for compatibility with NPAs and other advanced airways [15]
  - Create mouth, nose, and teeth for realistic intubation
- Contact 3D printing companies to explore improvements in model production to eliminate client processing prints

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