Equine Laryngeal Model for Training Surgical Residents

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Background/Motivation

- Upper airway abnormalities can cause distress in horses and exercise intolerance
- Conditions are treated by performing a Transendoscopic Laser Ventriculocordectomy [1]
  - Done with diode laser
  - Diode laser enters respiratory tract and cuts out part of the vocal fold
  - Imperative to cut at least 2-3 mm outside of the vocal process
- Veterinary residents current use cadavers for practice
  - Cadavers do not simulate live equine larynxes well
  - Horse cadavers are scarce
  - 3200 veterinary residents study at universities per year [2]

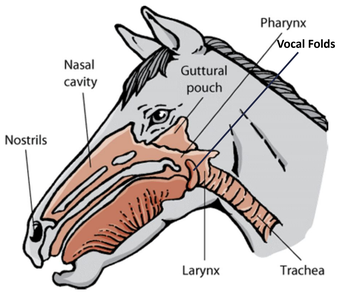

Figure 1. Equine upper respiratory tract anatomy [3]

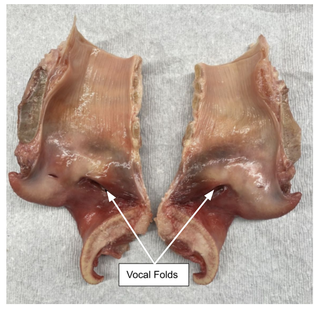

Figure 2: Cut equine larynx

Problem Statement

- **Problem**
  - The design will imitate the anatomy and life-like size of an 4-6 year old adult horse's nostril to larynx
  - The design will accurately replicate the different types of tissues that are present in the larynx of a horse
  - The vocal folds will be replaced after each surgery
- **Goal:** Develop a reusable equine laryngeal model for training surgical residents for Transendoscopic Laser Ventriculocordectomy

Design Criteria

Performance Requirements:
- Anatomically reflective upper respiratory model of mature horse
- Replaceable and static model components

Accuracy and Reliability:
- Inner Larynx Dimensions: Height: 75mm, Width: 55mm [4][5][6]
- Young's Modulus: Cartilage: 0.42-2.51 MPa, Muscle: 1186 KPa [7][8]

Life in Service:
- Vocal fold will be replaced after each surgery
- Replaceable mechanism that holds the vocal folds will last 1 semester
- Static components of model last 20 years
- 14-28 surgeries performed per semester

Safety: materials must safely interact with diode laser
Cost: adhere to target budget of $1000
Competition: other animal models are available, none that replicate horse anatomy

Final Design

Figure 3. Front view of equine larynx provided by client

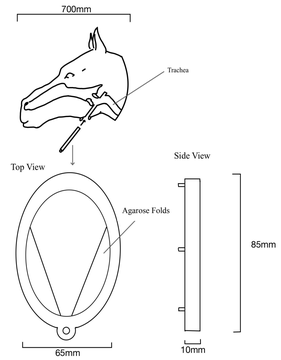

Figure 4. Sketch of Final Design: Replaceable Laryngeal Disk

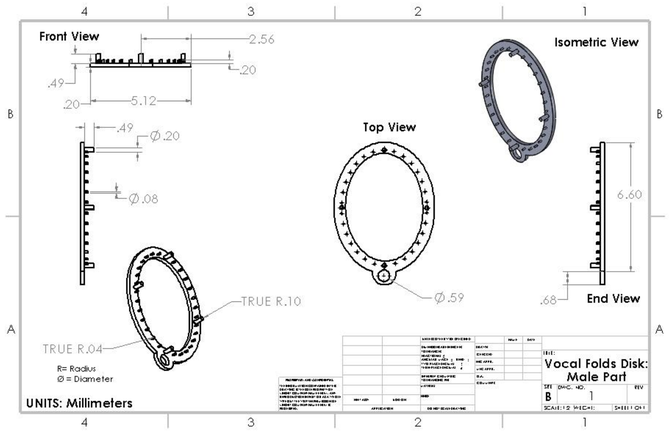

Figure 5. CAD drawing of replaceable laryngeal disk

1. Static Components
Larynx: Flexible 80A Resin
- 3D scanned larynx in two parts, then combined 3D surfaces
- Printed Larynx on Formlabs Printer at UW Makerspace

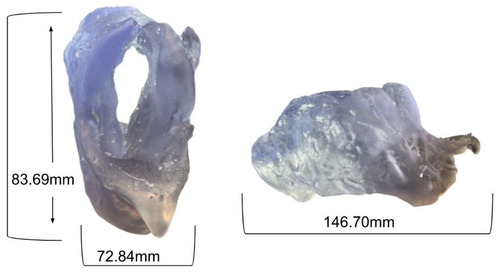

Figure 6. 3D printed equine larynx; front and side view

2. Replaceable Components
Vocal Fold: Agarose
- Molded using 3D printed mold
- Replaced after every procedure

Vocal Fold Disk: Tough PLA Resin
- Designed in SolidWorks
- Prepared in PreForm
- Printed on Formlabs Printer in UW Makerspace

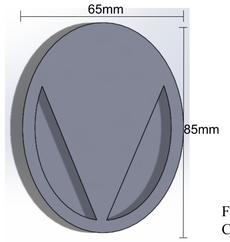

Figure 8. Vocal Fold mold CAD model

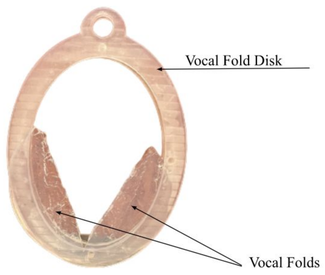

Figure 7. Final Design of 3D printed disk holding agarose mixture vocal folds

Testing and Results

1. Anatomical Accuracy Test
   - 3D Printed Laryngeal Model
   - Dissected Equine Larynx
   - Literature Values
2. MTS Machine Compression Test
   - Agarose
   - Equine Laryngeal Tissue
   - Flexible 80A Resin

Anatomical Accuracy Test Results

	Length (mm)	Width (mm)	Height (mm)
3D Printed Model	146.70	72.84	83.69
Actual Equine Larynx	182.88	72.97	81.10

3D Printed Model to Equine Larynx ANOVA p-value = 0.0468

Table 1. Measured Anatomical Values

MTS Machine Compression Test Results

Material	Avg. Young's Modulus (MPa)	Standard Deviation
Agarose	0.0976	0.0197
Equine Tissue	2.7857	2.9447

Agarose to Equine Tissue T-test p-value: 0.2524

Table 2. Material Mechanical Properties

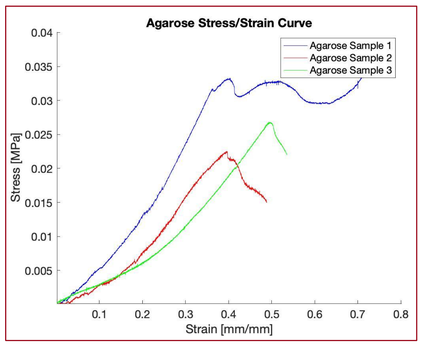

Figure 9. Agarose sample stress/strain curve

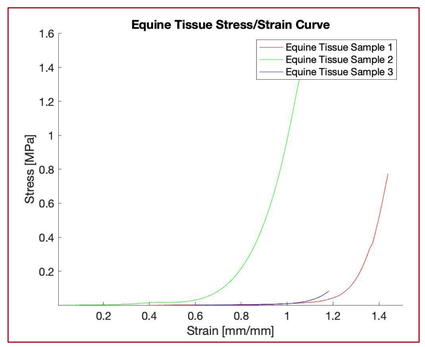

Figure 10. Equine tissue stress/strain curve

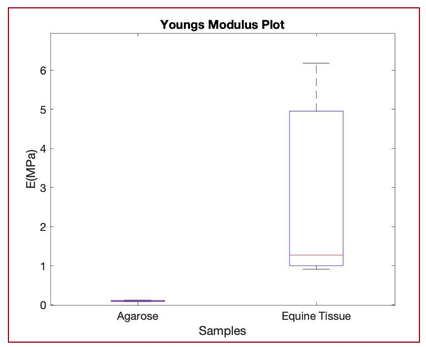

Figure 11. Box plot of equine tissue vs Agarose stress/strain curve

Discussion

- The difference between the elastic modulus of the agarose samples and the equine tissue samples are not statistically significant
  - $p > 0.05 \rightarrow$ statistically insignificant
  - 2800% difference
    - There is an outlier in the muscle tissue samples
      - Qexp = 1.636 ; Qcrit = 0.970 ; Qexp < Qcrit
      - Equine tissue sample 1 is an outlier
    - The statistical insignificance could be due to:
      - Low sample robustness
      - Poor sample control
      - Agarose mechanical property was not tailored using cross-linking agents
- The difference between the anatomical measurements and 3D printed measurements are statistically significant
  - $p<0.05 \rightarrow$ statistically significant
  - Inaccuracy of the measurements could be due to the use of 3D scan instead of CT scan converted STL file
- Ethics considerations
  - The accuracy of the model will affect the number of successful laser ventriculocordectomy performed by the residents in the future

Future Work

3D Printed Larynx
- Smooth CT scan surface and use to fabricate accurate laryngeal structures
- Cut the 3D Laryngeal Model laterally for disk insertion
- Extend model on both ends to include static nasal passage that simulates surgical condition
- After model completion, have surgical residents complete an ease of vocal fold fabrication test and a procedural similarity test

Vocal Folds
- Add cross linking agents to agarose to alter the mechanical properties to more accurately represent Equine tissue
- Fabricate various vocal fold molds to provide more realistic procedures

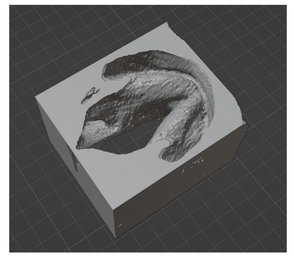

Figure 12: Unsmoothed 3D surface of larynx generated from CT scans

Acknowledgements

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Sources

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