BME Design-Fall 2022 - PETER WAWRZYN
Complete Notebook

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LILLIAN ZAHN

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Team contact Information

PETER WAWRZYN - Nov 14, 2022, 4:33 PM CST

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Project description

PETER WAWRZYN - Oct 12, 2022, 1:37 PM CDT

Course Number: BME 200/300

Project Name: Optical Imaging of the Small Airway Mucosa

Short Name: Airway Mucosa Optical Imaging

Project description/problem statement:

The goal of this project is to create and validate an optical frequency domain imaging (OFDI) probe for imaging in the airway of small animals. The cells lining the airway play an important role in common airway diseases and new therapeutics are being developed for treatment. A limitation in the work to develop these therapeutics is difficulty of measuring changes over the course of the experiment. Some imaging techniques, including OFDI, are able to monitor changes in the airway, however they are too large for small animal testing. Due to this problem, the aim of this project is to create an effective miniaturized OFDI probe for use in testing on animals.

About the client:

Dr. Allan Brasier is the client and he is the Executive Director of the **UW Institute for Clinical and Translational Research.** He is interested in innate inflammation and pulmonary and cardiovascular disease

9/16/2022 First Client Meeting

PETER WAWRZYN - Sep 21, 2022, 3:56 PM CDT

Title: First Client Meeting

Date: 9/16/2022

Content by: Everyone

Present: Lily, Peter, Andy, Sofia, Yash, Jade

Goals: Discuss initial questions with our client.

Content:

Questions

- When are the best times to meet and could we meet in person (where)?
  - Thursday mornings (9ish) Meeting rooms at Wimmur
- Would it be easier to meet with Melissa more frequently for availability purposes?
  -
- What is the budget for the project?
  - Some imaging equipment might be available. Check about OCT processing computer. Probes can be made available.
  - 5-10k$
- What are the best modes of communication?
  - Email is best
- A brief overview of OFDI system and how it works.
  - Need to talk to Yesilkoy a lot for imaging help. (Suggests OCT?)
- What are any preliminary ideas for how to approach the project from the client's viewpoint?
  - Cells change ECM when they get injured which results in changing of normal physiology of the airway - response to allergens
  - ECM is rich in collagen and is helpful for more cellular processes
  - In human OCT probes people can see collagen precescence not adapted to use in investigations in smaller animals (oct probes are to big to image mouse lung)
  - Oct is approach or if we find anything else
  - measure disease changes in collagen in mouse model
  - Probe to insert into the airway
  - Mouse should be unharmed
- Do you have specific requirements as of now for capabilities or dimensions?
  - Less than 1mm in depth
  - Within the airway mucosa
  - Be able to measure distance changes in mucosa
  - Hand guided is okay for maneuvering
  - Be able to measure how far down into the airway you go for references
- What is the difference between OFDI and OFDR imaging? (skip)
  -
- Are there any standards that you know of that would be important to keep in mind as we begin the project?
  - Approved animal protocols - need to keep that in mind - modify the protocol
  - No standards
- 3d print scaffolds for standards
- Stains for validation

Jeremy rogers BME faculty desktop OCT connect

Conclusions/action items:

As a team, we got a basic understanding of the capabilities our instruments needs to have. We now need to come up with questions to ask Dr. Yesilkoy about the capabilities of different imaging types and which are available to us at the school.

9/14/2022 - Advisor Meeting #1

PETER WAWRZYN - Sep 21, 2022, 3:55 PM CDT

Title: Advisor Meeting 1

Date: 9/14/22

Content by: Peter, Jade

Present: Peter, Jade, Andy, Yash, Sofia, Lily

Goals: To meet with our advisor and go over goals for the semester

Content:

- Create a task list for each week for each individual to accomplish
- Have the communicator share our notebook with progress updates during advisor meetings
- Note major achievements throughout the semester
- Next week to do:
  - Show task list and who is doing what
  - Take meeting minutes
    - include these in notebook
    - can remember everything that has been talked about
  - Each person can talk about what they have done
- Include Optical Imaging in all emails

Conclusions/action items:

In the next week we need to meet with our client and then assign tasks for everyone to complete for the week.

9/21/2022 - Advisor Meeting #2

PETER WAWRZYN - Sep 28, 2022, 12:20 PM CDT

Title: Advisor Meeting 2

Date: 9/21/22

Content by: Andy

Present: Peter, Jade, Andy, Yash, Sofia, Lily

Goals: To meet with our advisor and go over goals for the semester and upcoming week

Content:

- **Meeting Notes**
    - Mucosa and cells will have different optical properties and may require different imaging processing
    - Trying to measure the depth of the mucosa
    - Melissa? Other contact for OCT
    - Yesilkoy will introduce us to Jeremy
    - Yesilkoy has extra “LED camera”
    - Reason how you can measure the mucosa of a mouse (ex: size, etc.)
    - Going to make us meet with other people to understand pros/cons of
    - Autoclavable/disposable material
    - Price can be made lower based on materials/camera Yesilkoy can provide us
    - Specs of optic fiber
    - Need to put a coating around imaging probe and then toss it after use
    - Sofia is taking the materials section on the PDS from Andy
    - There is a new grading scheme including participation (weekly)

Conclusions/action items:

In the next week we hope to meet with Dr. Jeremy Rogers and come up with multiple design ideas to start creating the design matrix.

9/28/2022 - Advisor Meeting #3

PETER WAWRZYN - Oct 12, 2022, 1:26 PM CDT

Title: Advisor Meeting 3

Date: 9/28/22

Content by: Sofia, Yash, Peter

Present: Peter, Jade, Andy, Yash, Sofia, Lily

Goals: To meet with our advisor and go over goals for the semester and upcoming week

Content:

- **Meeting Notes**
    - Meet with Jeremy is something we should definitely do
    - What to do with design matrix in case we don't meet Jeremy
        - Some criteria can be taken from PDS
            - Probe design
            - Light collection
            - Optical fibers
            - Biocompatible
            - Sterilizable
            - Cost is design criteria
        - OCT design idea
        - OFDI design idea
        -
    - May have to adapt image processing code even with commercial products existing
    - Look at specs from pigs studies
    - Multiple Matrices
        - One for probe
            - Or one specifically for probe material
            - Probe geometry
            - Probe sensors?
    - Cc Dr Yesikoy in reminder to Jeremy

Conclusions/action items:

In the next week we hope to meet with Dr. Jeremy Rogers and create a design matrix for different aspects of the imaging probe.

10/19/2022 - Advisor Meeting #4

PETER WAWRZYN - Nov 16, 2022, 2:02 PM CST

Title: Advisor Meeting 4

Date: 10/19/22

Content by: Sofia, Jade, Peter

Present: Peter, Jade, Andy, Yash, Sofia, Lily

Goals: To meet with our advisor and go over goals for the semester and upcoming week

Content:

- **Meeting Notes**
    - Since Last Meeting
        - Met with Dr. Jeremy Rogers
            - Gave us overview of OCT
            - Entire project is deserving of $1 million grant
            - Focus on one aspect of the design for this class
                - Probe Mechanism
                - Spinning of lenses inside airway
            - Willing to meet with us more during semester
                - Email out to discuss our selected design choice
                - Talk about if OCT can be used though clear tube
                    - If not use retractable mechanism
        - Meeting last Friday
            - Difficulty manufacturing something as small as we need
                - Looking into getting a fetal intubation tube for outer catheter and then design inner workings
                - May make first prototype larger scale for ease of fabrication
            - Hope to potentially set up in person Advisor Meeting

Conclusions/action items:

In the next week we hope to meet with Dr. Jeremy Rogers to discuss our design idea and conduct research on small scale manufacturing.

10/27/2022 - Advisor Meeting #5

PETER WAWRZYN - Nov 16, 2022, 2:02 PM CST

Title: Advisor Meeting 5

Date: 10/27/22

Content by: Peter

Present: Peter, Jade, Andy, Yash, Sofia, Lily

Goals: To meet with Dr. Yesilkoy and go over goals for the semester and upcoming week

Content:

- Meeting Notes
    - Lidar imaging also has challenge of spinning
    - Dimensions may be different so not necessarily possible
    - How do they image in different directions in GI
        - Spinning it themself from the outside
        - Could be inspiration
    - LIDAR is a hot research area
        - Similar collection of light light OCT
    - Meet in person 2156 ECB next week wednesday 5:30

Conclusions/action items:

In the next week we plan to continue working on our spinning mechanism and look into existing literature for other ways things are spun.

11/9/2022 - Advisor Meeting #6

PETER WAWRZYN - Nov 16, 2022, 2:10 PM CST

Title: Advisor Meeting 6

Date: 11/9/22

Content by: Everyone

Present: Peter, Jade, Andy, Yash, Sofia, Lily

Goals: To meet with Dr. Yesilkoy and go over goals for the semester and upcoming week

Content:

- Next Steps
    - Focus on spinning mechanism
    - Make mechanism look fancier - more put together than show and tell
    - Incorporate light in final presentation
- What will we order
    - Motor for spinning, motor for resecting
    - Servo motor -
    - Battery for motor power source
    - Gears for slowing motor - lasercut
    - Relays for motors-battery
    - Microcontroller
    - Adult legos to have variability in how we make the motor system
        - Larger optical fiber can be used to make light
            - multi-mode
    - Catheter to use in final presentation
        - Little mirror for end of catheter
            - Optical imaging light redirector
    - Laser pointer

Conclusions/action items:

In the next week we plan to set up a meeting with Dr. Brasier to discuss design idea and talk about what we need to purchase with him. In order to determine what needs to be purchased we split up the items and everyone is researching something we need.

11/16/2022-Advisor Meeting #7

JADE BERGET - Dec 13, 2022, 10:30 AM CST

Title: Advisor Meeting 7

Date: 11/16/22

Content by: Everyone

Present: Peter, Jade, Andy, Yash, Sofia, Lily

Goals: To meet with Dr. Yesilkoy and go over goals for the semester and the upcoming week

Content:

- Send list of items to order through BME department
- Order all items before Thanksgiving break
- Figure out how to test the device
    - Maximize metrics to show that we've designed, built, and tested something

Conclusion/action items:

We need to send items to the BME department to order. We now need to start brainstorming testing options.

12/5/2022 - Advisor Meeting #8

LILLIAN ZAHN - Dec 14, 2022, 10:51 AM CST

Title: Advisor Meeting

Date: 12/5/2022

Content by: Everyone

Present: Everyone

Goals: Discuss final plans for the week before final presentations.

Content: The team updated Dr. Yesilkoy on fabrication plans for the week. Another meeting was planned for 12/7/22 to go over the final poster before printing.

Conclusions/action items: Fabrication will continue. Another meeting is planned for 12/7/22 to go over the final poster draft.

12/7/2022 - Advisor Meeting #9

LILLIAN ZAHN - Dec 14, 2022, 10:57 AM CST

Title: Advisor Meeting

Date: 12/7/2022

Content by: Everyone

Present: Everyone

Goals: Discuss draft for the final poster.

Content: The team discussed improvements for the final poster. It was recommended to include less paragraphs and more bullet points, as well as more descriptive images with labels and connections.

Conclusions/action items: Finish final poster and final prototype by final presentations.

9/19/2022 - Team Meeting #1

PETER WAWRZYN - Sep 21, 2022, 5:55 PM CDT

Title: Team Meeting 1

Date: 9/19/22

Content by: Peter

Present: Peter, Jade, Andy, Yash, Sofia, Lily

Goals: To meet as a team and assign task for the week

Content:

We had a team meeting to assign task for the week. Because the PDS is due this week to assign task we split up the parts of the PDS that needed to be completed as follows:

Peter: Performance Requirements, Safety, Accuracy and Reliability

Sofia: Life in Service, Shelf Life, Operating Environment

Jade: Ergonomics, Size, Weight

Andy: Materials, Aesthetics, Standards and Specs, Customer

Yash: Quantity and Target Cost

Lily: Competing Designs +

Conclusions/action items:

In the next week we need to meet with our client and then assign tasks for everyone to complete for the week.

9/23/22 - Product Design Specifications

PETER WAWRZYN - Oct 12, 2022, 1:34 PM CDT

Title: Preliminary Presentation Slides

Date: 9/23/22

Content by: Whole Team

Goals: To give create design specifications for our project.

Content:

PDS is inserted below

Conclusions/action items:

The next stage of the project is to move forward with the design idea curation.

PETER WAWRZYN - Oct 12, 2022, 1:35 PM CDT

BME Design

Product Design Specification

Optical Imaging of the Small Airway Mucosa

Team Members:
Yash Shah
Jade Berget
Andy Slayton
Sofia Cadagnozzi
Lillian Zahn
Peter Wawrzyn

Client: Dr. Allan Brasier

Advisor: Dr. Filiz Yesilkoy

September 23, 2022

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Optical_Imaging_PDS_1_.pdf (206 kB)

9/30/2022 Meeting with Jemery Rogers

PETER WAWRZYN - Oct 12, 2022, 1:21 PM CDT

Title: Meeting with Dr. Jeremy Rogers

Date: 9/30/2022

Content by: Jade

Present: all

Goals: Learn about potential imaging options and if he has any insight to our project.

Content:

- OCT uses a light source that gets reflected and bounced back to create cross sectional area measurements that can be turned into images.
- Measurements show up in a graph on the screen.
- They use optical fibers for their light source .
- His lab had a contained table top OCT system which he demonstrated how the thickness of a piece of plastic was measured.
- His lab also hand a piece by piece uncovered OCT system that was put together by some students.
- There was a business working on creating a smaller probe but they have sense shut down.
- A light source alone for OCT is $35,000.
- Cheapest probe without any imaging components that he knew of was at least $10,000.
- He hasn't seen one small enough to work through an airway.
- No example of a probe version of OCT was seen.
- Important aspect in human imaging is keeping the airway stable
- Could do initial tests not in-vivo to see efficacy of our imaging/probe design

Conclusions/action items:

We learned a lot as a team about how OCT works and now need to figure out which parts of our project are actually feisable within a semester, and to set realistic goals.

9/30/22 - Design Matrix

PETER WAWRZYN - Oct 12, 2022, 1:33 PM CDT

Title: Design Matrix

Date: 9/30/22

Content by: Whole Team

Goals: To give evaluate our probe mechanism and probe material design ideas.

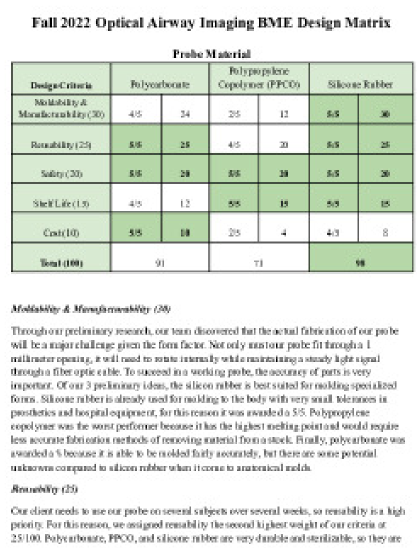
Content:

Design Matrix is inserted below.

Conclusions/action items:

The next stage of the project is to move forward with the our preliminary presentation.

PETER WAWRZYN - Oct 12, 2022, 1:33 PM CDT



Fall 2022 Optical Airway Imaging BME Design Matrix

Probe Material

Design Criteria	Polycarbonate		Polypropylene Copolymer (PPCO)		Silicone Rubber	
Moldability & Manufacturability (30)	4/5	24	2/5	12	5/5	30
Reusability (25)	5/5	25	4/5	20	5/5	25
Safety (20)	5/5	20	5/5	20	5/5	20
Shelf Life (15)	4/5	12	5/5	15	5/5	15
Cost (10)	5/5	10	2/5	4	4/5	8
Total (100)	91		71		98	

Moldability & Manufacturability (30)

Through our preliminary research, our team discovered that the actual fabrication of our probe will be a major challenge given the form factor. Not only must our probe fit through a 1 millimeter opening, it will need to rotate internally while maintaining a steady light signal through a fiber optic cable. To succeed in a working probe, the accuracy of parts is very important. Of our 3 preliminary ideas, the silicon rubber is best suited for molding specialized forms. Silicone rubber is already used for molding to the body with very small tolerances in prosthetics and hospital equipment, for this reason it was awarded a 5/5. Polypropylene copolymer was the worst performer because it has the highest melting point and would require less accurate fabrication methods of removing material from a stock. Finally, polycarbonate was awarded a 4/5 because it is able to be molded fairly accurately, but there are some potential unknowns compared to silicon rubber when it come to anatomical molds.

Reusability (25)

Our client needs to use our probe on several subjects over several weeks, so reusability is a high priority. For this reason, we assigned reusability the second highest weight of our criteria at 25/100. Polycarbonate, PPCO, and silicone rubber are very durable and sterilizable, so they are

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Fall_2022_BME_Design_Matrix.pdf (353 kB)

10/2-5/2022 Team Meeting

JADE BERGET - Oct 12, 2022, 12:57 PM CDT

Title: Team Meeting

Date: 10/2 and 10/5

Content by: Jade

Present: all

Goals: Discuss Preliminary Presentation tasks.

Content:

Divide similar to what everyone did for the PDS.

- Peter: Designs and design matrix
- Jade: Problem statement and Background research
- Andy: Future work
- Yash: Designs and design matrix
- Sofia: Materials matrix
- Lily: PDS and Competing Designs

Conclusions/action items:

Divided up tasks for the preliminary presentation and discussed questions we had on our topic. We now need to finish our presentation and practice it together before presenting.

10/7/22 - Preliminary Presentation Slides

PETER WAWRZYN - Oct 12, 2022, 1:29 PM CDT

Title: Preliminary Presentation Slides

Date: 10/7/22

Content by: Whole Team

Goals: To give a preliminary presentation on our project.

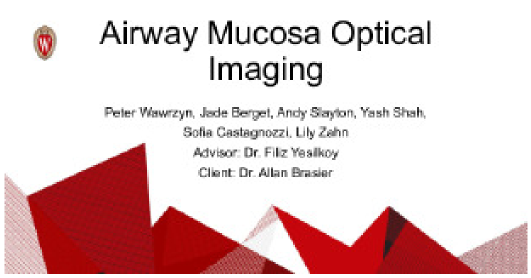
Content:

Slides are inserted below

Conclusions/action items:

The next stage of the project is to move forward with the design of our initial prototype.

PETER WAWRZYN - Oct 12, 2022, 1:35 PM CDT



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Preliminary_Presentation_1_.pdf (1.09 MB)

10/10/2022 - Team meeting

PETER WAWRZYN - Oct 12, 2022, 1:20 PM CDT

Title: Team Meeting

Date: 10/10/2022

Content by: Jade

Present: all

Goals: Discuss Preliminary Report tasks

Content:

Split up report tasks roughly by what we did in the presentation.

- Peter: Abstract, Flexi-Catheter design, Preliminary Design Evaluation
- Jade: Introduction
- Andy: Testing/Future Work
- Yash: Helical balloon design, clear intubation catheter
- Lily: Background
- Sofia: Fabrication/Development Process

A meeting for later this week was also planned to create a outline of the rest of the semester

Conclusions/action items:

We divided up the tasks for the report. We need to finish the report by 10/11 to go over it as a group and answer questions.

10/14-Team Meeting

JADE BERGET - Oct 21, 2022, 1:57 PM CDT

Title: Design Idea Team Meeting

Date: 10/14/2022

Content by: all

Present: all

Goals: Create a plan for the rest of the semester.

Content:

Notes:

-
- Look at manufacturing at such a small scale
- Think of how we can rotate the imaging probe inside the clear catheter
- Solidworks of the design
- Try and see if we can meet in person with Dr. Yesilkoy
- Focus on the apparatus that is used to spin some wire
- Look into 1.9Fr, 22 gauge catheter, 0.63mm to use as the intubation device(silicone)
- Found 3Fr neonatal catheter = 0.9mm for outer (polyurethane)
- Research optical fibers that could be used and are small enough to be
- Motor that is clamped to the outside of optical fiber the rotates on an axis
- https://www.cardinalhealth.com/en/product-solutions/medical/woman-and-baby/neonatal-intensive-care/neonatal-pediatric-peripherally-inserted-central-catheters-and-trays.html
- https://www.heyoptics.net/blogs/wiki/1-mm-optical-fiber
- https://www.vygon.com/catalog/nutriline-3fr_1500_00125315
- https://www.neomedicalinc.com/product/1-9fr-x-40cm-sl-silicone-picc-27ga-sharps-safety-tearaway-sheath/

Next Couple Days:

- Meeting with Dr. Jeremy Rogers
- Metting with Dr. Yesilkoy in person
- Brainstorming ways to spin the probe from the outside
- Look into how to buy catheter

Questions:

For Dr. Rogers:

- Is it possible to image through a clear catheter? (email)
- Do you need a reference plane?

Conclusions/action items:

We finalized what we would like to accomplish by the end of the semester and started brainstorming ideas for how to spin the optical fiber. We now need to meet again with Dr. Roger to do a Q&A and continue coming up with ideas for rotation.

10/21-Team Meeting

PETER WAWRZYN - Nov 16, 2022, 2:13 PM CST

Title: Design Idea Team Meeting

Date: 10/21/2022

Content by: all

Present: all

Goals: Create a plan for the rest of the semester.

Content:

Notes:
Meeting Notes

- Testing
    - Could make larger fake airway to test
- Meeting with Jeremy
    - Plan on meeting on zoom
    - Question for Jeremys
- Spinning Mechanism
    - Use motor to directly spin optical fiber
        - How to adjust the speed?
        - Threaded in order to move forward and backward
        - Attach a cylindrical stabilizer - with holes for breathing
    - Use motor to spin spindle that pulls cord thats pre wound on optical fiber
        - Would this lead to decreased accuracy
    - Pre wind fiber and release to use built up energy have
        - Problems with this (hard to control unwind
    - Ask Jeremy Rogers about how it is done in humans
- Future Questions
    - Have markings that tell how far in to put probe

Conclusions/action items:

Going forward we would like to meet with Dr. Rogers to discuss our idea and we need to continue to finalize our design idea.

10/28-Team Meeting

PETER WAWRZYN - Nov 16, 2022, 2:16 PM CST

Title: Design Team Meeting

Date: 10/28/2022

Content by: all

Present: all

Goals: Prepare for the Show and Tell

Content:

Notes:
Meeting Notes

- Follow up with Jeremy to meet Mon-Wed on Zoom and if that doesn't work send a doc of questions
  - Add question about if we can borrow optical fiber.
- Follow up with Dr. McAdams on Monday during business hours to see if we can pick up catheter
- Change dimensions on Solidworks to match the plastic Andy has over the weekend
  - Peter will add Solidworks files into Shared Drive when complete
- Manufacture the spinning mechanism in team lab during next week before the Show and Tell
  - Andy and anyone who wants to help (need Green Permit probably)
- Get ready for elevator pitch for show and tell
  - Think of ideas before advisor meeting wednesday
  - After advisor meeting wednesday come up with brief outline
    - 30 sec: introduce problem
    - 30 sec: things we want input/advice on
- Look into LiDAR spinning mechanism if people have time/ want something to do

Conclusions/action items:

We now have a plan to get tangible items to use during the show and tell. This week will be about manufacturing or obtaining the items for the show and tell.

11/2/22 - Meeting with Jeremy Rogers

PETER WAWRZYN - Nov 16, 2022, 2:20 PM CST

Title: Meeting with Jeremy Rogers

Date: 11/2/2022

Content by: all

Present: all

Goals: Meet with Jeremy Rogers to discuss our design idea and see what he thinks needs to be done moving forward.

Content:

Notes:
Meeting Agenda

- Show our initial design plans and ask for feedback
- Ask Questions from this doc

Questions

- Important Question: Dr. Yesilkoy mentioned you may have old scrap optical fibers laying around and told us to ask if you were willing to give us one for experimentation.
- Are there any common ways you have heard off to spin an imaging probe inside an airway? - consolidated a couple questions to this one
- Do you have any optical fibers that we could use in a mouse?
- How do you feel about a rotisserie style rotation with a threaded aspect to spin as it inserts and spins backwards while being recessed?
    - This is pretty much our design so when we go over it with him that is asking this question
- Will we need one motor for spinning and one motor for moving vertically or can that be done with one motor?
    - How to deal with movement in the z-direction
- Do we need a way to know where we are in the mouse or can that be handled on the imaging processing end?

Notes

- Optical fibers usually have a structural "jacket", plastic coating for protection, typically 1 mm in diameter (smallest)
    - Can be stripped off, for mechanical purposes
- Inside jacket usually standard 125 microns
- Inner core can be <10 microns
- Multimode fiber has a bigger core diameter
    - Allows for multiple wave modes
- OCT is sensitive to phase
    - Difference in phase encodes depth information
    - Important to have single mode fiber in OCT
- Lumen based imaging using OCT usually has something at the end (lens and/or mirror) that redirects and refocuses light
    - Light must be redirected out sideways and then spun
    - One method of spinning (called "driveshaft")
        - Fiber is fixed, then the optical device is rotated from within the intubation catheter and collects a sideways scan.
            - Challenge with this method is mechanical- must be able to maintain good optical coupling while rotating.

        - Mirror is adhered to the end of fiber s.t. mirror rotates with the fiber
    - Another method is to have a motor embedded at the end of the optical device that rotates a mirror, which redirects the light.
    - In past whole fiber rotates because it is easier to have everything fixed
- Low frequency in ripples is close to reference, high frequency is further away from reference, need reference beam at some point “reference arm”
- Use code to tract how far probe has moved with a gauge
- Thorlabs has optical fibers for purchasing
- Need a broadband light source than can be coupled to use with a single mode optical fiber
- Spectrometer for OCT
  Fiber-based beam splitting

Conclusions/action items:

This meeting was very helpful, we learned a lot about OCT and the things needed to take into account. Moving forward we are planning on finalizing our spinning mechanism in away that would allow future semesters to add on OCT aspect.

11/4/22 - Show and Tell

JADE BERGET - Dec 13, 2022, 9:39 AM CST

Title: Show and Tell

Date: 11/4/2022

Content by: all

Present: all

Goals: Prepare elevator pitch for Show and Tell

Content:

First 30 seconds

- Explain Research
  - Client is testing drug candidates on mouse subjects for airway inflammatory diseases.
  - Need a way to image airway (1mm) and measure the thickness of the airway mucosa without injuring mouse to track drug success
  - Goal is to get a 3D cross section image of airway
    - Need have a way to spin the device to get 360 degrees

Second 30 Questions

- Questions
  - Do people have any experience with fabricating things on the micro fabrication?
  - Do people have any other ideas for how to spin the optical fiber?

Advice From Other Teams

- Adhere the outside of probe to spinning mechanism
- Use magnetism to spin it

Conclusions/action items:

We got some interesting input from other teams and moving forward we need to finalize spinning mechanism and begin material procurement

11/18/22 - Team Meeting

J

Title: Material List

Date: 11/18

Content by: all

Present: all

Goals: Brainstorm materials needed for our prototype.

Content:

Links of things

- Batteries - 9 Volt
- Regular Motor
- Servo Motor
- Relay Shield
- Microcontroller
- Laser
- Optical Fiber
- Bearings

What will we order

- Motor for spinning, motor for resecting
  Regular 2-terminal

Bearings:
https://www.amazon.com/Bearings-Shielded-Miniature-Skateboards-Scooters/dp/B092LGTD9P/ref=zg_bs_3416131_sccl_9/133-7728056-5606644?psc=1
22mm dia. x 7mm
Rated Voltage: DC 12V
Reduction Ratio: 1: 31.6
No-Load Speed: 100RPM
Rated Torque: 4.5Kg.cm
Rated Current: 1.1Amp
D Shaped Output Shaft Size: 6*14mm (0.24" x 0.55") (D*L)
Gearbox Size: 37 x 24.5mm (1.46" x 0.96") (D*L)
Motor Size: 36.2 x 33.3mm (1.43" x 1.31") (D*L)
Mounting Hole Size: M3 (not included)

https://www.amazon.com/Greartisan-Electric-Reduction-Centric-Diameter/dp/B072R57C56/ref=sr_1_7?crid=1LQ84W3JCNMM6&keywords=dc%2Bmotor&qid=1668139499&sprefix=dc%2Bmotor%2Caps%2C160&sr=8-7&th=1

- Servo motor -

Dimensions: 2.4 x 2.4 x 0.63 inches
Operating at 110rpm; 4.8V - can run straight from arduino if only using one
4.8V is1.3kg.cm,

https://www.amazon.com/Feetech-Degree-Continuous-Rotation-Arduino/dp/B079MF1BZS/ref=asc_df_B079MF1BZS/?tag=hyprod-20&linkCode=df0&hvadid=312126267824&hvpos=&hvnetw=g&hvrand=8212896324009313951&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvloc
646852416703&psc=1

- Battery for motor power source
  Start with some 9V batteries in series
  I only see 8 pack and we only need 2, could just go somewhere in madison
  https://www.amazon.com/Amazon-Basics-Performance-All-Purpose-Batteries/dp/B00MH4QM1S/ref=asc_df_B00MH4QM1S/?tag=hyprod-20&linkCode=df0&hvadid=583815642163&hvpos=&hvnetw=g&hvrand=9161696630756996008&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocir
  332122495433&th=1
- Gears for slowing motor - lasercut
  The Makerspace offers a Laser Cutter upgrade through a canvas quiz, followed by an in-person seminar.
  Email maker-laser@engr.wisc.edu for specific help on this equipment.
- Relays for motors-battery
  https://www.amazon.com/HiLetgo-Relay-Shield-Channel-Arduino/dp/B07F7Y55Z7/ref=sr_1_1_sspa?keywords=arduino+relay+shield&qid=1668140142&sı
- Microcontroller
  https://www.amazon.com/Arduino-A000066-ARDUINO-UNO-R3/dp/B008GRTSV6/ref=sr_1_3?crid=28558C81AEOK1&keywords=arduino&qid=1668140059&sprefix=arduino%2Caps%2C162&sr=8-3
- Adult legos to have variability in how we make the motor system

HDPE or 3D print

- Larger optical fiber can be used to make light
  - Multi-mode
  - $80 fiber with connection that matches second amazon link Sofia has for the laser 1 m long with total outer diameter of 0.25 mm should fit ir has outer diameter of 2 mm - Link
  - Ask Dr. Yesilkoy if this connection would work and how this price is.
- Catheter to use in final presentation

- 

-
- Little mirror for end of catheter
    - Optical imaging light redirector
    - https://www.thorlabs.com/newgrouppage9.cfm?objectgroup_id=139
- Laser pointer - light source
    - https://www.amazon.com/Visual-Locator-Include-Adapter-Network/dp/B08Q85W6QJ/ref=sr_1_7?crid=2PXAXZ25YTQ1A&keywords=optic+fiber+laser&qid=1668285242&sprefix=optic+fiber+lasesr%2Caps%2C97&sr=8-7

  Or this one
  - https://www.amazon.com/dp/B09XL2ND4J/ref=sspa_dk_detail_3?psc=1&pd_rd_i=B09XL2ND4J&pd_rd_w=JugFP&content-id=amzn1.sym.46bad5c8a82fa48a54&pf_rd_p=46bad5f6-1f0a-4167-9a8b-c8a82fa48a54&pf_rd_r=GGCB81B0VC12X4RGZQRH&pd_rd_wg=rN23X&pd_rd_r=dba27275-55c29d682952&s=industrial&sp_csd=d2lkZ2V0TmFtZT1zcF9kZXRhaWw

Conclusion/action items:

Came up with a complete list of materials needed for our prototype. Now we need to order them and start building our prototype.

11/30/22 - Team meeting

JADE BERGET - Dec 13, 2022, 10:45 AM CST

Title: Prototype Brainstorm

Date: 11/30

Content by: all

Present: all

Goals: Brainstorm manufacturing for our prototype.

Content:

- Use a 45 degree plastic tube to connect the optical fiber and the mirror.
- Print optical fiber piece - scale down
- Moving Plate
  - Based on solidworks
  - Talk to makerspace about gear - match track to gear we can get (print if needed)
  - Think about connecting servo motor
- Base piece
  - Two holes for the bearing
  - Add indentation to hold the motor
  - Everything else from solidworks
- Axle - get from maker space

Conclusions/action items:

Discussed the pieces we need to 3D print given our solidworks. We now need to start manufacturing our prototype.

12/1/22 - Team meeting

PETER WAWRZYN - Dec 13, 2022, 6:18 PM CST

Title: Initial 3D Printing

Date: 12/1

Content by: all

Present: Jade, Andy, Lily, Peter

Goals: Begin prints needed for final prototype.

Content:

- We began prints today on the spinning piece, base, and movie platform.
- We had to adjust the print for the base to fit into the 3d printing platform and created a semicircular nesting place for the motor to sit in

Conclusions/action items:

We started our prints and they should be ready to be picked up for our fabrication day on Saturday.

12/3/22 - Team meeting

PETER WAWRZYN

Title: Fabrication Day

Date: 12/3

Content by: all

Present: Lily, Yash, Sofia, Andy, Peter

Goals: Begin prototyping our design

Content:

- During the meeting today we began fabricating our design.
- The Makerspace was closed which limited the amount of tools we had.
- We experimented with the optical fiber and the mirror to see if it reflected light which it did. It was also to small so some light went straight forward and was not refl
- The hope is that when we cut the material we can focus the light more so all the light can be redirected.
- We are waiting to cut the optical fiber until we hear from Dr. Yesilkoy to make sure that we don't cut it incorrectly.
- We also don't have an axle yet so Andy is going to look at ECB if they have anything we could use.

Conclusions/action items:

We plan on meeting again on Monday to continue fabrication

12/5/22 - Team meeting

P

Title: Continued Fabrication

Date: 12/5

Content by: all

Present: all

Goals: Continue fabricating our prototype

Content:

- We began assembling the device today
- The string mechanism that moved the moving platform back and forth was created today. It works by wrapping a string around the axle and one end connecting to

This allows for when the axle spins the platform moves forward or backwards depending on the direction

- We decided to switch from the large motor to the second servo motor today because when the code was running we realized that the large motor wou
- Originally we were planning to use gear reduction to slow it down but due to availability of the servo motor and space constraints we made the switch
- We reprinted the spinning piece because the original print was partially capsized and this lead to difficulty inserting the optical fiber.
- We also printed a holder for the new servo motor that fit into the large motor holder.
- We also printed a gear connector for the servomotor and the axle.

Conclusions/action items:

Tomorrow we intend to join together all the pieces including the new prints and get our working final prototype.

12/6/22 - Team meeting

PETER WAWRZYN - Dec 13, 2022, 6:58 PM CST

Title: Fabrication Conclusion

Date: 12/6

Content by: all

Present: all

Goals: Finish making our final prototype

Content:

- Today we finished making our final prototype.
- We cut the optical fiber and glued it into the spinning piece.
- When we cut it the light shined in all directions a lot more then with the connector.
- Due to this we decided to pivot from the mirror idea and use tape to just show the light horizontally in one direction.
- The servo motor worked for retraction and both servo motor code was adjusted.
- We brainstormed potentially laser cutting a box that could act as a see through mouse airway.
- We decided to print a rail to put on the design to stop the spinning optical fiber from hitting the moving platform and bouncing it upward.

Conclusions/action items:

Now that the design is complete we are meeting tomorrow to complete testing and finish the poster.

12/7/22 - Team meeting

PETER WAWRZYN - Dec 13, 2022, 6:59 PM CST

Title: Testing

Date: 12/7

Content by: all

Present: all

Goals: Complete testing and finish the poster first draft

Content:

- We did testing of the device
- Testing looked into retraction distance, full rotation, and horizontal light appearance
- We also worked on the poster

Conclusions/action items:

Going forward we need to meet with Dr. Yesilkoy to go over the poster and then finish and print it to be ready for the poster presentation.

12/9/22 - Team meeting

PETER WAWRZYN - Dec 13, 2022, 7:10 PM CST

Title: Poster Presentation Practice

Date: 12/9

Content by: all

Present: all

Goals: Discuss poster presentation format and present

Content:

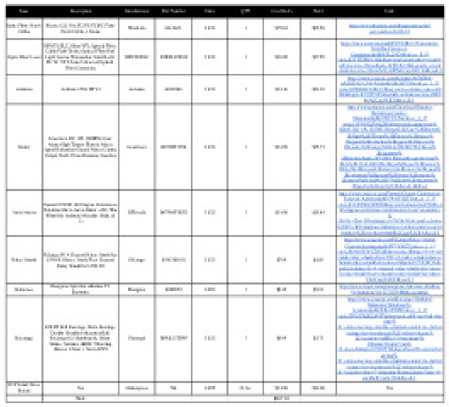
- We met before the presentation to practice and make sure everything was working.

Conclusions/action items:

Next steps are to do the poster presentation and get final deliverables completed.

Team Expenses

SOFIA CASTAGNOZZI - Dec 12, 2022, 5:35 PM CST



Download

Team_Expenses_-_Sheet1.pdf (52.7 kB)

Fabrication

YASH SHAH - Dec 13, 2022, 6:09 PM CST

Title: Fabrication

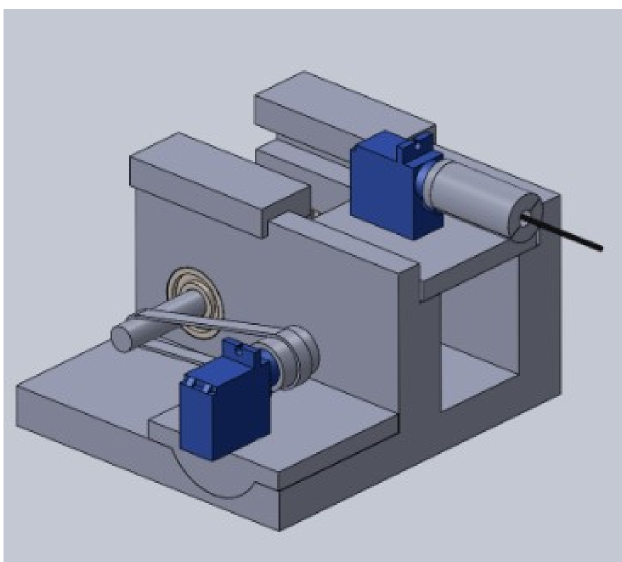
Date: 12/4 - 12/8

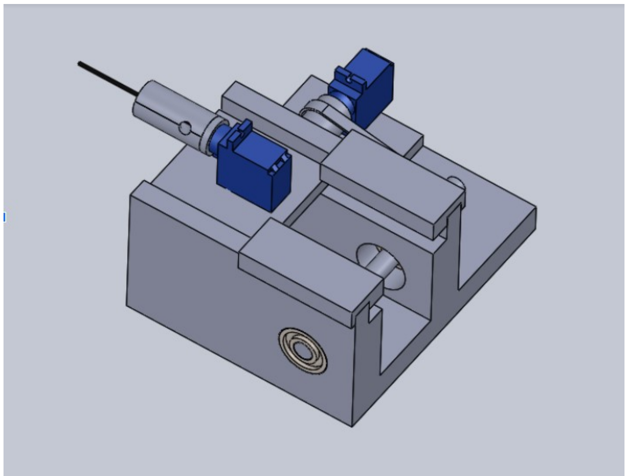
Content by: All

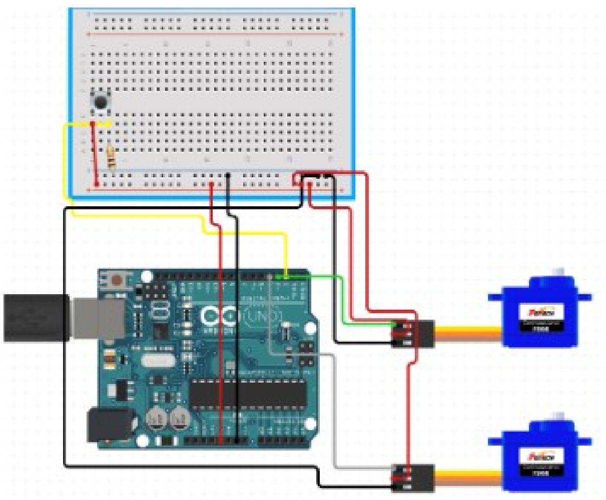
Present: All

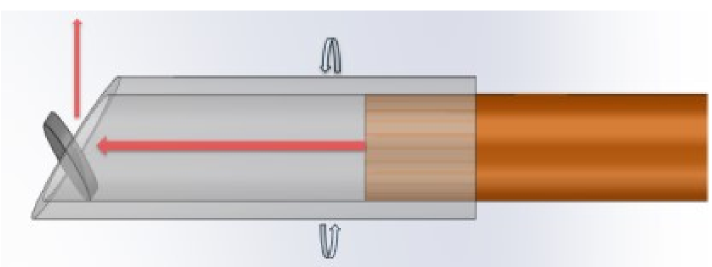
Goals: Fabricate our probe and design mechanism

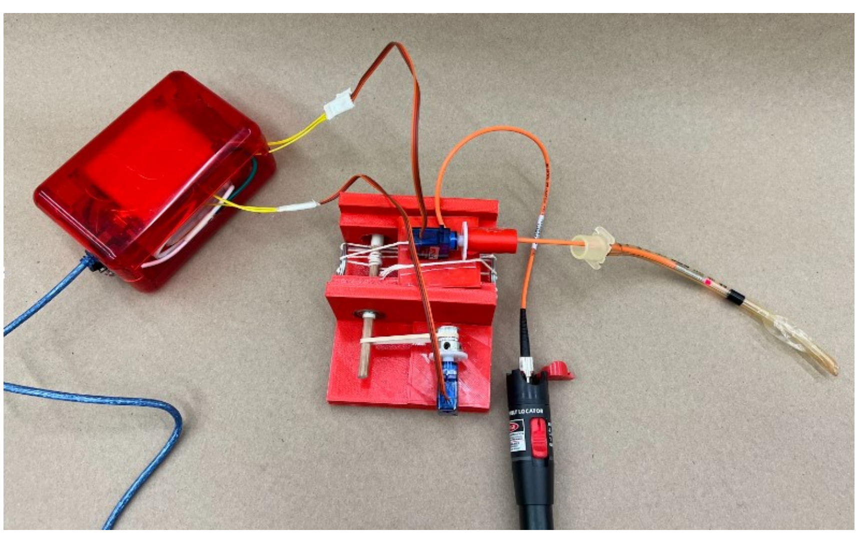
Content: The team created a SolidWorks model of our base for 3D printing. Base contains two walls with holes for the bearings supporting our axle as well as fittings for our servo motors. The base also contains guide rails that were added after testing to prevent our platform from jumping. We separately 3D printed a cylindrical holder that would convert the servo motor rotation to our optical fiber inside the catheter. Our design also consisted of a circuit with a microcontroller that takes inputs from a button and allows servo motors to retract and rotate the probe inside the catheter. This required the team to build a circuit using Arduino and code it to specifically allow a small amount of retraction followed by a complete rotation of our optical fiber. The small retraction occurred using a belt drive to transfer the rotation of the servo motor to the axle used for retraction. At the end of our design there is an imaging probe that is comprised of an optical fiber that runs through a clear intubation catheter. There should also be a reflective surface at the end of our catheter to reflect incoming light perpendicularly out of the catheter, but we were unable to get the light from our light source to reflect high resolution light off of our mirror.

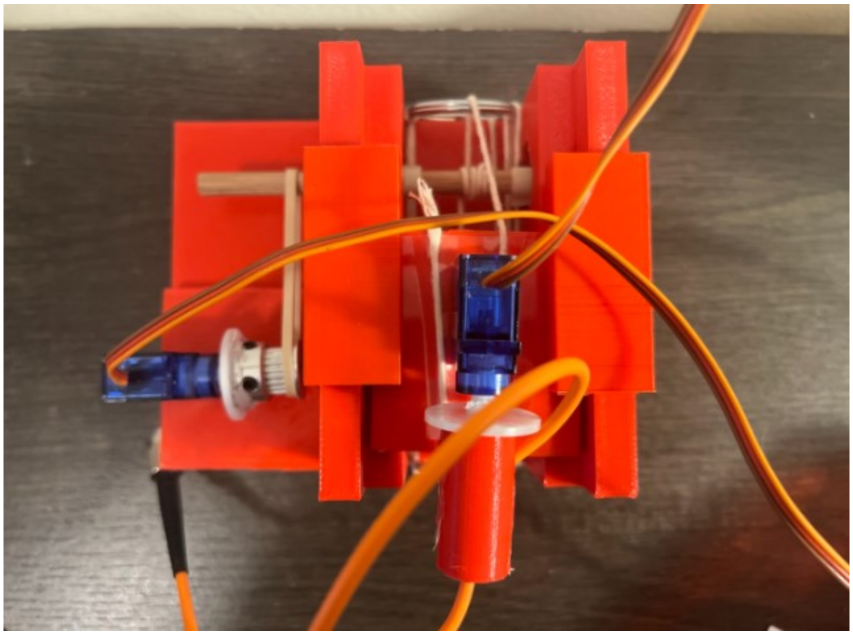


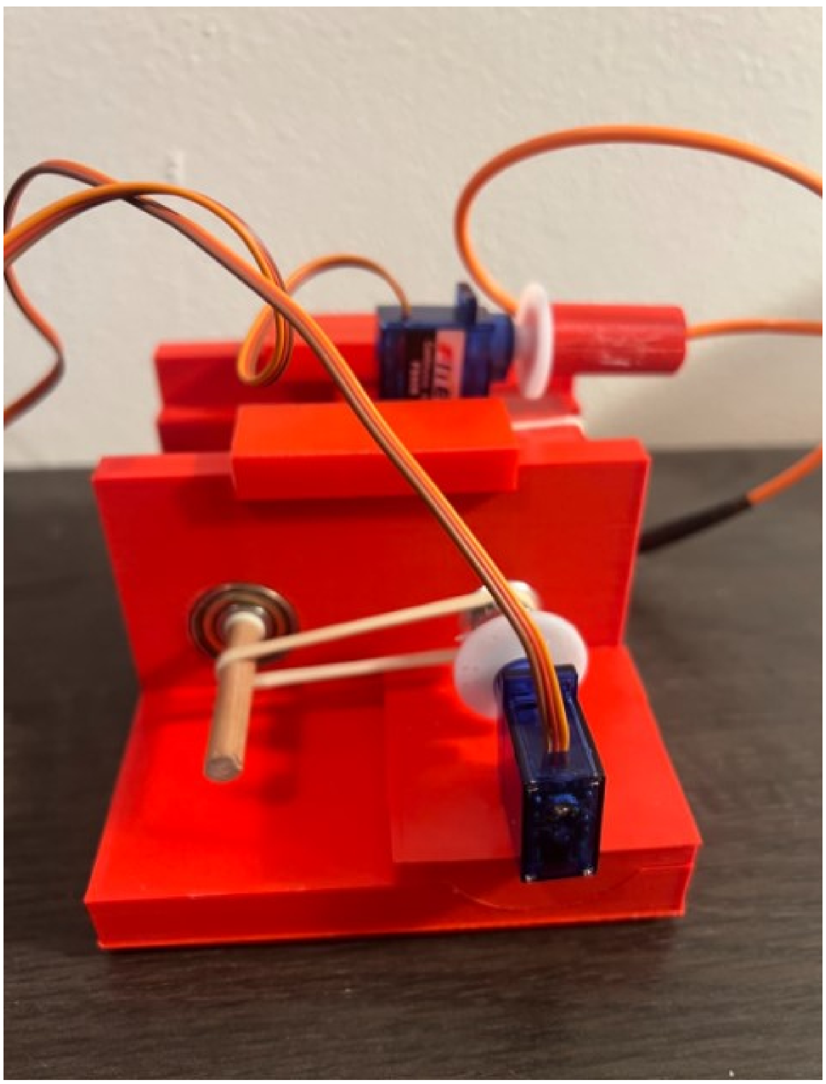


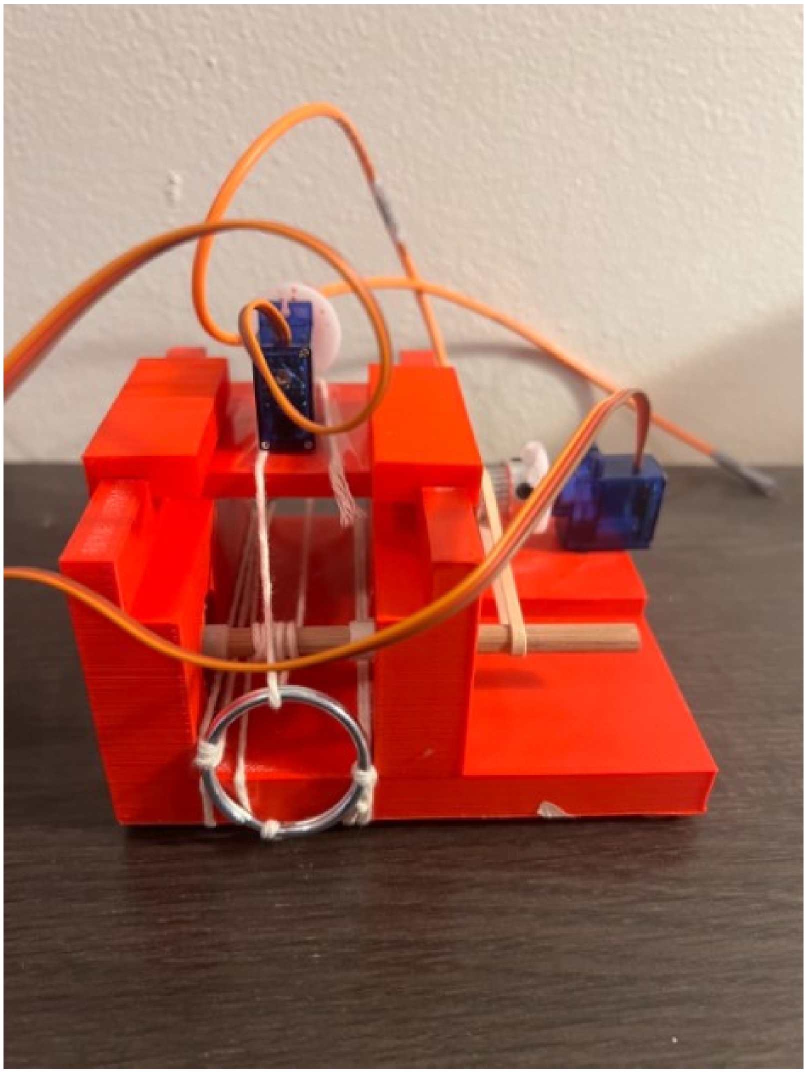


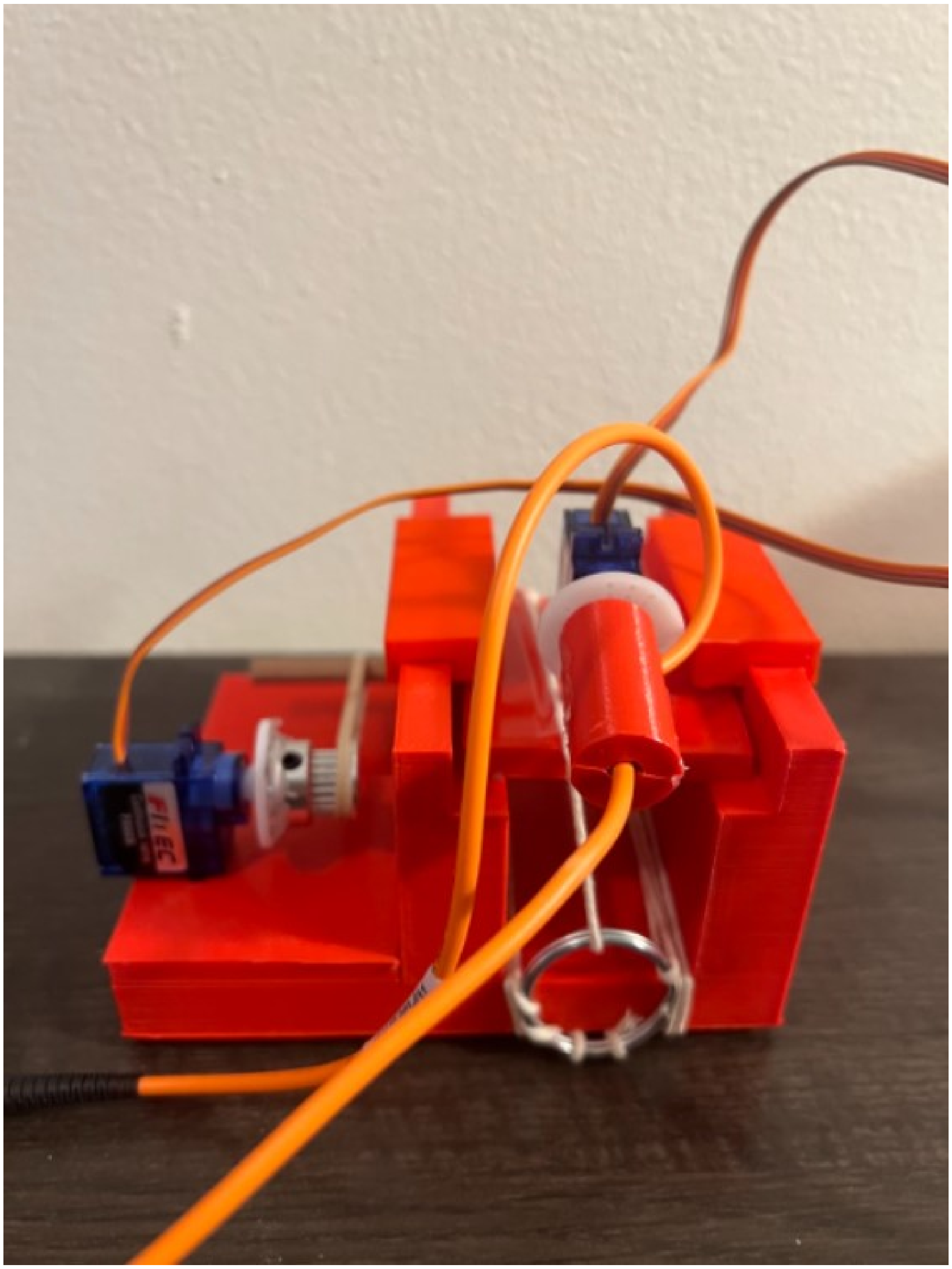


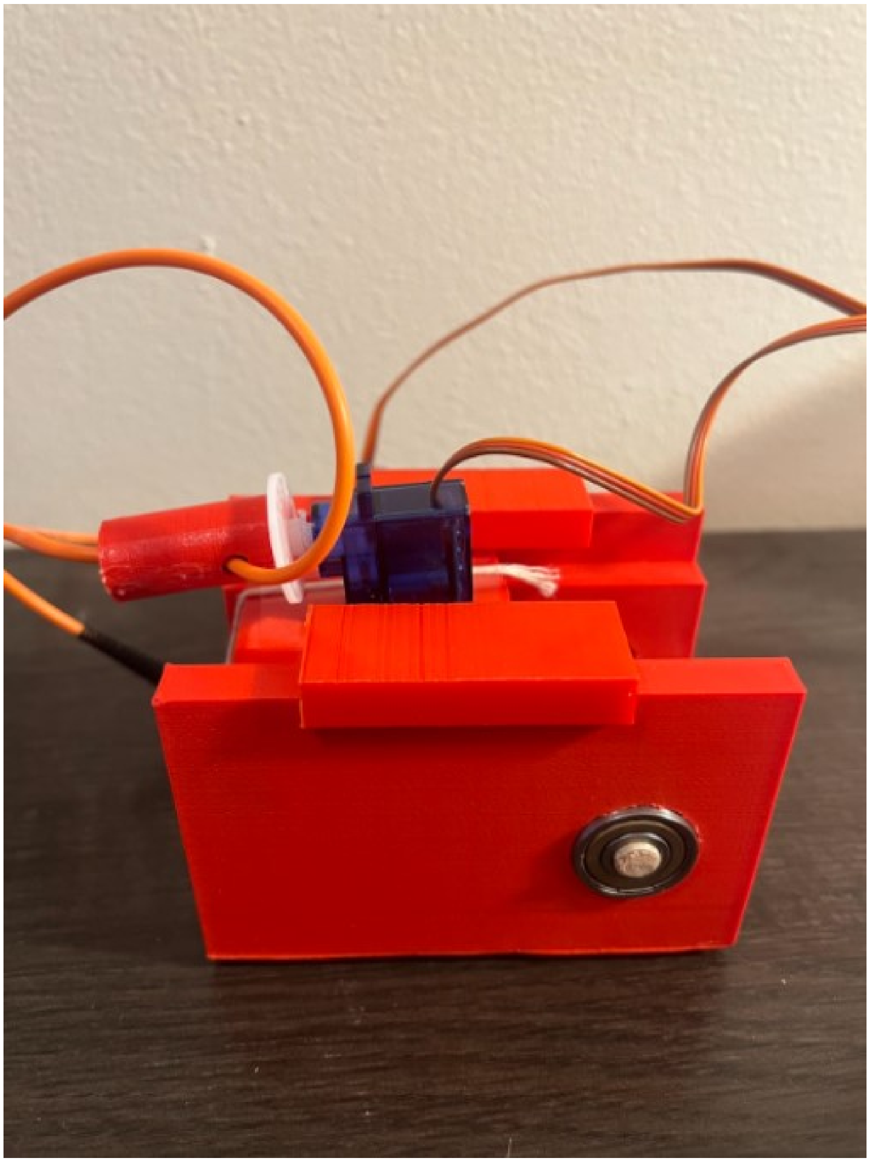












Conclusions/action items:

Our team was able to fabricate our probe and design mechanism to allow rotation and retraction of our optical fiber with the intubation catheter. In the future the team plans to scale down the prototype to fit a mouse airway, connect an imaging system to record and process high-resolution images, use more advanced safety features, attach an angled reflective surface at the end of the catheter, and use more effective circuitry for the most accurate results.

Retraction Protocol

JADE BERGET - Dec 13, 2022, 11:42 AM CST

Title: Retraction Protocol

Date: 12/7

Content by: all

Present: all

Goals: Create protocols for retraction tests.

Content:

Retraction test:

Retraction depth consistency testing was done using a standard setup and measuring the distance the probe was retracted for every slice. This consisted of securing the catheter and placing the optical fiber tip at a marked location to start every trial. The optical fiber was then retracted four times, measuring the total distance from the marked start after each retraction. The total distance traveled was then calculated using the change in distance from the marked position after each retraction. This procedure was repeated for a total of 10 trials. This test was intended to measure the operational consistency of the optical fiber retraction both within one trial and over many separate trials. The intended results of the test would include a consistent retraction depth among all measurements taken. Notably, this would suggest that measurements will have a consistent total distance and the image slice distribution would be uniform.

Conclusions/action items:

Created a protocol for how we tested the retraction consistency. Now we need to include our testing protocols in our poster and report.

Rotation Protocol

JADE BERGET - Dec 13, 2022, 11:43 AM CST

Title: Rotation Protocol

Date: 12/7

Content by: all

Present: all

Goals: Create protocols for rotation and light tests.

Content:

Light Rotation and dispersion:

Both 360° rotation and 90° light appearance were assessed during the testing of the retraction depth consistency. Full probe rotation was assessed by placing the light source in the vertical position (0 degrees) and observing it during testing to ensure it would rotate completely and return at least as far as the vertical position. Intended results of this test would be for the probe to fully rotate everytime signaling the design is effective allowing for the acquisition of a complete radial image. Horizontal light appearance was measured during the retraction testing. Measurement consisted of noting the direction of the visible light coming from the probe as either horizontal, coming out of the probe perpendicular to the probe direction, or vertical, coming out of the probe parallel to the probe direction. This was noted for all testing trials. Intended results of this test would be horizontal light appearance for every trial, signifying the capacity to image the airway mucosa.

Conclusions/action items:

Created a protocol for how we tested the rotation and the light source direction. Now we need to include our testing protocols in our poster and report.

Testing

JADE BERGET - Dec 13, 2022, 11:50 AM CST

Title: Testing Results

Date: 12/7

Content by: all

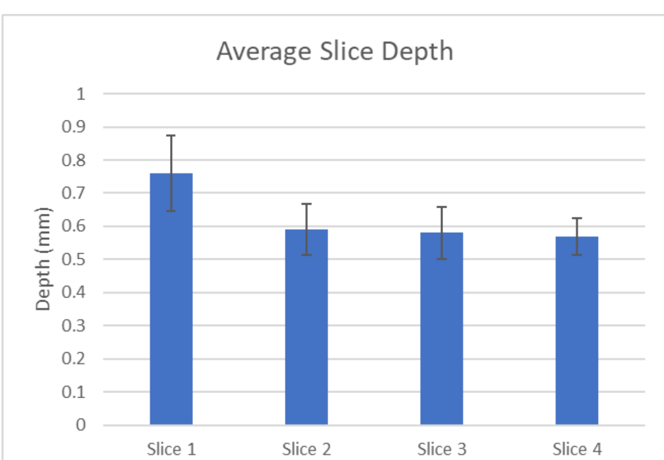
Present: all

Goals: Complete tests to evaluate our prototype.

Content:

- Overall there was consistency with clicks 2, 3, and 4.
- Click 1 the optical fiber occasionally hit the platform during rotation which caused the platform to jump and led to the 1st click average being higher than the other 3.
- need to add rails on top to keep the platform in place.

	Retracted Distance										
Trial	1 click	2 click	3 click	4 click	360 spin?	light?					
1	0.7	1.4	2	2.5	yes	perpendicular	0.7	0.7	0.6	0.5	
2	0.5	1.5	2	2.4	yes	perpendicular	0.5	1	0.5	0.4	
3	1.4	2.2	2.6	2.9	yes	perpendicular	1.4	0.8	0.4	0.3	
4	0.5	1.2	2.1	2.7	yes	perpendicular	0.5	0.7	0.9	0.6	
5	1.3	2	2.4	2.9	yes	perpendicular	1.3	0.7	0.4	0.5	
6	0.4	0.6	1	1.9	yes	perpendicular	0.4	0.2	0.4	0.9	
7	0.4	0.7	1.4	2.2	yes	perpendicular	0.4	0.3	0.7	0.8	
8	0.6	1.2	2.2	2.8	yes	perpendicular	0.6	0.6	1	0.6	
9	0.9	1.4	2.1	2.7	yes	perpendicular	0.9	0.5	0.7	0.6	
10	0.9	1.3	1.5	2	yes		0.9	0.4	0.2	0.5	
avg											
	0.76	1.35	1.93	2.5		avg each	0.76	0.59	0.58	0.57	0.625
	0.36	0.49	0.49	0.37			0.36	0.24	0.25	0.18	



Conclusions/action items:

We completed tests on 3 different criteria to get accurate measurements for our prototype. We now need to work on our poster and get ready for our poster presentation.

Product Design Specifications

LILLIAN ZAHN - Oct 12, 20

Product Design Specification

Optical Imaging of the Small Airway Mucosa

Team Members:
Yash Shah
Jade Berget
Andy Slayton
Sofia Castagnozzi
Lillian Zahn
Peter Wawrzyn

Client: Dr. Allan Brasier

Advisor: Dr. Filiz Yesilkoy

September 23, 2022

Function:
The goal of this project is to create and validate an optical frequency domain imaging (OFDI) probe for imaging in the airway of small animals. The cells lining the airway play an important role in common airway diseases and new therapeutics are being developed for treatment. A limitation in the work to develop these therapeutics is the difficulty of measuring changes over the course of an experiment. Some imaging techniques, including OFDI, are able to monitor changes in the airway; however, they are too large for small animal testing. Due to this problem, the aim of this project is to create an effective miniaturized OFDI probe for the use in animal testing.

Client requirements:

5cfThe imaging device must be able to visualize the airway mucosa of mice in vivo.
5cfThe device must be able to be maneuvered through a mouse airway for imaging.
5cfThe project's budget is up to $10,000 depending on availability of already purchased resources

Design requirements:

1. Physical and Operational Characteristics

a. Performance Requirements: The imaging device must be able to image the airway mucosa of a murine test subject. The device should be able to measure up to 1 mm in depth of the airway mucosa and should have a resolution of 5 - 20 μm, which is comparable to existing OCT systems [1]. The device should not harm the mouse when sedated to allow for testing throughout a drug testing protocol.

b. Safety: The device must come with clear and concise instructions for device usage and must only be used by a trained operator with animal subjects training [2]. The device material must not cause biological harm to the mouse or the user and no sharp edges should be exposed as part of the device that could user and no sharp edges should be exposed as part of the device that could cause internal injury to the mouse subject during imaging.

c. Accuracy and Reliability: The device must have a Signal to Noise Ratio (SNR) of 80 or more, which is a baseline for imaging biological targets [3]. The imaging device must also demonstrate significant correlation ($p < 0.01$) between calculated airway wall layer areas using histology, ex-vivo, and in-vivo approaches [4].

d. Life in Service: The imaging probe should be reusable on different subjects, operating at least 10 minutes per use, averaging 2 minutes per data set with OFDI technology, [5] or 4 minutes with OCT technology [6]. The material of the probe will be sterilized by autoclaving.

e. Shelf Life: The shelf life will be dependent on quality of materials, e.g. fiber optic cable, biocompatible finish.

f. Operating Environment: The imaging probe must withstand temperatures between 20°C (68 °F) and 135°C (275 °F) for storage and sterilization conditions. The probe must also avoid corrosion from in-vivo testing and sterilization chemicals.

g. Ergonomics: The imaging probe must be made out of a material that can be used safely inside an organism with no reaction and can be sterilized. It must be able to maneuver the cartilage rings in the upper part of the trachea and measure within the airway mucosa [7].

h. Size: The probe must be able to fit inside the airway of a mouse. Its diameter must be less than 1.5mm, the diameter of a mouse trachea [8].

i. Weight: The probe must be light enough to be hand maneuvered by the same hand and weigh no more than 5.1 pounds [9].

j. Materials: Potential materials that may be included are fiber-optic cables, polycarbonate plastic, and a camera and lens. The materials will all be biocompatible and autoclavable if the design is made to be reusable.

k. Aesthetics, Appearance, and Finish: The finish must be smooth to limit physical interference of the sample. The finish must be biocompatible. The appearance and aethstetic of the device does not contribute meaningfully to its efficacy .

2. Production Characteristics:

a. Quantity: We will manufacture one final design and test it in the small airway mucosa of a small mouse.

b. Target Product Cost: The manufacturing cost may be more expensive due to the specialized style of optical imaging necessary. The total cost should be approximately $5,000-$10,000. Although this cost is high, the total cost can be made lower based on materials already readily available to our team.

3. Miscellaneous

a. Standards and Specifications: Must avoid or minimize discomfort, distress or pain consistent with sound scientific practices [10]. Animals that are subject to prolonged discomfort or distress must be given proper sedation [10]. Animals must be humanely and safely handled, treated and transported [11].

b. Customer: The customer is asking for a device which can image the mucosa in lab mice to record the effects of trial drugs. Mice are sedated prior to imaging. Perturbation of the mucosa and other tissue by the probe would negatively impact the accuracy of the data taken. The customer would like a feature of the probe to indicate the depth of the probe in the mouse.

c. Subject-related concerns: The materials and maneuverability of the probe must ensure the mouse is unharmed and procedures follow lab animal safety protocol while using the product.

d. Competition: Hariri et. al. published a study in 2012 recording the use of OFDI on human lung imaging. The study described two methods, one of bronchoscopy airway-centered imaging and one of parenchymal imaging. A custom-built bronchoscope was used with a diameter of 0.8 - 1.7 mm. The OFDI methods were only performed on human lungs [12].

Templin et. al. published a study in 2010 that successfully used OFDI for stent healing evaluation in vevo on pigs. The study described using a Terumo-OFDI catheter on a 0.014-inch guidewire. The study successfully used OFDI on the animals 1, 3, 10, 14, and 28 days after the stents were implanted [13].

Vakoc et. al. published a study in 2006 where OFDI was successfully performed on the distal esophagus of two swine using a 4.5 cm long inflatable balloon. The study successfully acquired cross sectional imaging of the mucosal vascular network within two living swine [14].

No patents were found for a product that could successfully use OFDI in the airways of any animals smaller than pigs.

References:

[1] S. Aumann, S. Donner, J. Fischer, και F. Müller, 'Optical Coherence Tomography (OCT): Principle and Technical Realization', στο High Resolution Imaging in Microscopy and Ophthalmology: New Frontiers in Biomedical Optics, J. F. Bille, Επιμ. Cham: *Springer International Publishing*, 2019, σσ. 59–85.

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[3] Z. Yaqoob, J. Wu, και C. Yang, 'Spectral domain optical coherence tomography: a better OCT imaging strategy', *BioTechniques*, τ. 39, τχ. 6S, σσ. S6–S13, 2005.

[4] J. N. S. d'Hooghe, A. W. M. Goorsenberg, D. M. de Bruin, J. J. T. H. Roelofs, J. T. Annema, και P. I. Bonta, 'Optical coherence tomography for identification and quantification of human airway wall layers', *PLoS One*, τ. 12, τχ. 10, σ. e0184145, Οκτωβρίου 2017.

[5] M. J. Suter, B. J. Vakoc, P. S. Yachimski, M. Shishkov, G. Y. Lauwers, M. Mino-Kenudson, B. E. Bouma, N. S. Nishioka, and G. J. Tearney, "Comprehensive microscopy of the esophagus in human patients with optical frequency domain imaging," *Gastrointestinal Endoscopy*, 26-Sep-2008. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0016510708018361. [Accessed: 22-Sep-2022].

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Paunovic, R. Corti, S. P. Hoerstrup, T. F. Lüscher, and U. Landmesser, "Coronary optical frequency domain imaging (OFDI) for in vivo evaluation of Stent Healing: Comparison with light and electron microscopy," *European heart journal*, Jul-2010. [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2903715/. [Accessed: 20-Sep-2022].

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Preliminary Presentation

LILLIAN ZAHN - Oct 12, 2022, 2:49 PM CDT

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Preliminary_Presentation.pdf (1.09 MB)

Design Matrices

LILLIAN ZAHN - Oct 12, 2022, 2:50 PM CDT

Fall 2022 Optical Airway Imaging BME Design Matrix

Probe Material

Design Criteria	Polycarbonate		Polypropylene Copolymer (PPCO)		Silicone Rubber	
Moldability & Manufacturability (30)	4/5	24	2/5	12	**5/5**	**30**
Reusability (25)	**5/5**	**25**	4/5	20	**5/5**	**25**
Safety (20)	**5/5**	**20**	**5/5**	**20**	**5/5**	**20**
Shelf Life (15)	4/5	12	**5/5**	**15**	**5/5**	**15**
Cost (10)	**5/5**	**10**	2/5	4	4/5	8
Total (100)	91		71		**98**	

Moldability & Manufacturability (30)

Through our preliminary research, our team discovered that the actual fabrication of our probe will be a major challenge given the form factor. Not only must our probe fit through a 1 millimeter opening, it will need to rotate internally while maintaining a steady light signal through a fiber optic cable. To succeed in a working probe, the accuracy of parts is very important. Of our 3 preliminary ideas, the silicon rubber is best suited for molding specialized forms. Silicone rubber is already used for molding to the body with very small tolerances in prosthetics and hospital equipment, for this reason it was awarded a 5/5. Polypropylene copolymer was the worst performer because it has the highest melting point and would require less accurate fabrication methods of removing material from a stock. Finally, polycarbonate was awarded a ⅘ because it is able to be molded fairly accurately, but there are some potential unknowns compared to silicon rubber when it come to anatomical molds.

Reusability (25)

Our client needs to use our probe on several subjects over several weeks, so reusability is a high priority. For this reason, we assigned reusability the second highest weight of our criteria at 25/100. Polycarbonate, PPCO, and silicone rubber are very durable and sterilizable, so they are all fairly reusable. We assigned PPCO to a 4 out of 5 due to its tendency to degrade due to exposure to UV light, but polycarbonate and silicone rubber were kept at 5/5 for reusability.

Safety (20)

The safety of the animals is an extremely high priority to both our team and our research lab. We assigned safety to a weight of 20/100 in our matrix. All three materials we reviewed were biosafe and are commonly used in biomedical technology, including other probes and medical implants. For this reason, we assigned polycarbonate, PPCO and silicone rubber a safety rating of 5 out of 5.

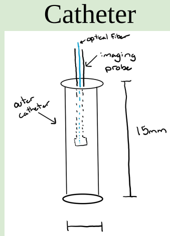
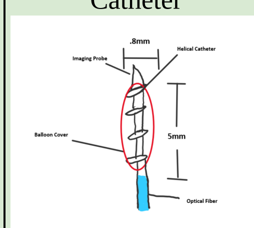
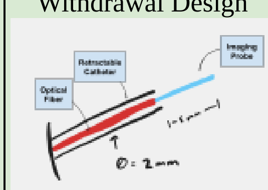
Shelf Life (15)

Our team determined that the shelf life of our probe was the second lowest weighted criteria at 15 as the probe is not anticipated to be operated for long periods of time. The shelf life of the probe material determines how long the probe can be in use before deterioration. All three of our chosen materials are commonly used for biomedical purposes, meaning they will be durable enough to withstand use inside the airway of a living animal. With this in mind, the materials were ranked highly with Polypropylene Copolymer and Silicone Rubber at a 5/5, and Polycarbonate at a 4/5. Polycarbonate was deducted one point because it risks discoloration with some forms of sterilization.

Cost (10)

Cost was the lowest weighted criteria at 10 because the size of the probe will not require much material and the design itself does not include the imaging technology. Polycarbonate was the highest ranked material at 5/5 due to it being an easily accessible plastic. Silicone Rubber was next in our rankings at a 4/5, slightly lower as it is a more expensive material, but still affordable. Polypropylene Copolymer was ranked the lowest at a 2/5 as it is more difficult to machine and therefore less accessible.

Probe Mechanism

Design Criteria	Clear Intubation Catheter 		Helical Balloon Catheter 		Flexi-Catheter Withdrawal Design 	
Stability (30)	**5/5**	**30**	4/5	24	2/5	12
Manufactuability (25)	**5/5**	**25**	3/5	15	4/5	20
Accuracy (25)	3/5	15	**5/5**	**25**	**5/5**	**25**
Safety (15)	**5/5**	**15**	4/5	12	3/5	12
Cost (5)	**5/5**	**5**	4/5	4	**5/5**	**5**

Total (100)	**90**	80	74

*****Images shown larger below

Stability (30)

The stability of the probe was ranked as our highest weighted category because keeping the airway open and stable while imaging is the most important aspect. The Clear Intubation Catheter scored the highest with a 5/5 because with the outer catheter in place the airway will be completely open during the entire imaging process with the probe free to move and rotate inside. The Helical Balloon Catheter was ranked next with a 4/5 because the entire airway does not stay open while you image but the portion around the tip of the probe does which allows for some stability. The Flexi-Catheter Withdrawal Design was ranked last with a 2/5 because there is no outer component that guarantees the airway to stay open around the probe and offers no stability but as the probe is guided the airway will open up which is why it did not receive a 0.

Manufacturability (25)

The manufacturability of the probe mechanism was tied for our second highest weighted criteria at 25. This category measured the ease at which the probe mechanism could be manufactured. The Clear Intubation Catheter scored the highest with a 5/5 due to the simplicity of the design. The Flexi-Catheter Withdrawal Design scored second highest with a 4/5. This design was judged to be more difficult to manufacture due to the mechanism needed to withdraw the outer catheter. The lowest scoring design was the Helical Balloon Catheter with a score of 3/5 due to the complex nature of manufacturing a balloon small enough for a mouse airway.

Accuracy (25)

The accuracy that the probe mechanism allows for was tied for our second highest weighted criteria at 25. This was intended to measure the accuracy and resolution that the probe design would allow for an OCT system. The Flexi-Catheter Withdrawal Design and Helical Balloon Catheter both scored a 5/5 for this category because they both allowed for unobstructed visualization of the airway mucosa during imaging. The Clear Intubation Catheter scored a 4/5 on this category because it would require imaging through a clear catheter which could lead to artifacts in imaging.

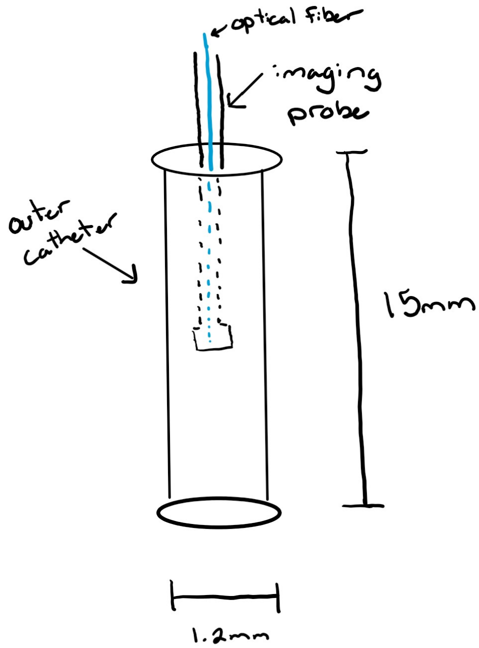
Safety (15)

The safety of the probe was weighted at a criteria of 15. This is to reflect the need for a device that is inserted in a mouse to be held to relatively safe standards. When trying to image a mouse in vivo it is essential to have the mouse unharmed after the imaging probe is removed from its airway. In rating designs we looked at if the design had any parts that could potentially be damaged during imaging. We also considered the materials that would likely be needed to create a design and how easily they could be brought up to biocompatible standards. We rated our intubation catheter design at the highest because it had little to know chance of being damaged during imaging. Our balloon design was ranked a little lower due to a possible rupture of the balloon in a very small opening that could be damaging to the mouse. The safety was a 3 due to a possibility of harming the airway mouse. The safety was a 3 due to a possibility of harming the airway when retracting the outer catheter.

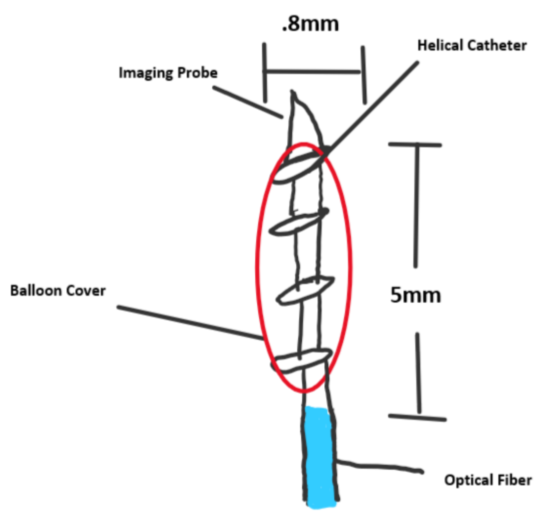
Cost (5)

The cost was weighted relatively low at a criteria of 5. This component was included in the design matrix because expense is typically a large influence in choosing a final design. However, with a budget of up to $10,000, cost is not a huge factor in picking a design for this project. If the final product does not include any imaging component to it then the cost will be significantly cheaper. The cost for all 3 of our potential products does not take into account imaging components so the catheters themselves are relatively cost effective and don't require lots of material itself in the catheter. The helical balloon catheter received a 4 due to an added cost of keeping the balloon stable for it to not rupture during imaging.

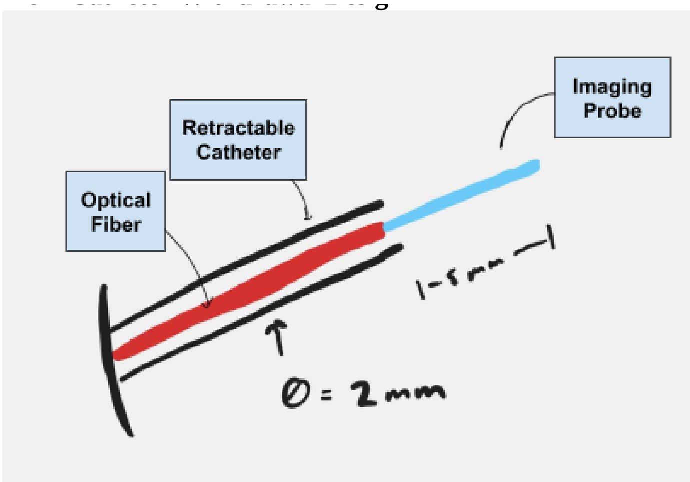
Clear Intubation Catheter



Helical Balloon Catheter



Flexi-Catheter Withdrawal Design


Imaging Probe
Retractable Catheter
Optical Fiber
1-5 mm
Ø = 2mm

Preliminary Report

LILLIAN ZAHN - Oct 12, 20

Optical Imaging of the Small Airway Mucosa

Biomedical Engineering Design 200/300
Department of Biomedical Engineering
University of Wisconsin-Madison
October 12, 2022

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Jade Berget (Communicator)
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Client:

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UW Madison College of Engineering - BME

Abstract

Airway diseases are an increasingly common issue in many humans and the need for effective treatments has never been greater. In order to effectively test these treatments, accurate imaging of the airway mucosa is required. In humans this has been done effectively using Optical Coherence Tomography (OCT) imaging; however, using OCT in mouse test subjects for visualization of the airway mucosa has yet to be demonstrated. The goal of this project is to create and validate a method of imaging the airway mucosa of a mouse test subject in vivo. Specifically, this semester the goal is to create an imaging probe that can access the airway mucosa without damage to the airway and obtain accurate images. The probe must be designed to access the airway of the mouse and allow for stable accurate images. The design team generated three preliminary designs and after evaluation chose the Clear Intubation Catheter. This design uses a clear catheter shell to allow for access and then imaging of the airway mucosa. Multiple materials were considered for design fabrication and silicone was deemed to be the most appropriate. Future work for the team includes manufacturing and testing a prototype of the design based on input from the client and other experts in the field.

I. Introduction

Common airway diseases include asthma, chronic obstructive pulmonary disease (COPD), pulmonary fibrosis, pneumonia, bronchiectasis and lung cancer. These are diseases that most people have been affected by, whether themselves or someone they know. Each of these diseases can affect any gender, race, or age and have varying harmful effects. Asthma affects about 14% of children 5 and under and COPD accounts for about 55% of respiratory diseases in both men and women. In 2017 there were 3,914,196 deaths due to chronic respiratory diseases which accounted for 7% of total deaths globally. This put chronic respiratory diseases as the third leading cause of death in 2017, just behind cardiovascular diseases and neoplasms. These rates have only increased since 1990 [1] and the only way to combat this issue is by developing treatments.

The cells lining the airway play an important role in common airway diseases. The mucosa will change thickness as the body's reaction to certain diseases or infections. When the mucosal lining in the airway thickens it restricts airflow and breathing becomes more difficult [2]. Part of testing treatment effectiveness is to measure that change in thickness of the mucosa.

New therapeutics are being developed for treatment, but a limitation in the work to develop these therapeutics is the difficulty of measuring changes over the course of an experiment in small animal studies. Some imaging techniques being used now are Optical Frequency Domain Imaging (OFDI) and Optical Coherence Tomography (OCT) which are comparable in technique and resolution. Both these options are able to monitor changes in the airway; however, the current probes used with these imaging modalities are too large for small animal testing. B. J. Vakoc et.al. developed and used a balloon stabilization device for OFDI imaging in the distal esophagus of swine [3]. However, a similar approach within a mouse airway would exert excess pressure on the esophagus, potentially harming the mouse. L. P. Hariri et. al developed a custom bronchoscope for use of OFDI imaging in human lungs, however, the device is too large to use in mice and difficult to scale [4]. Due to this problem, the goal of this project is to create and validate an miniaturized OFDI or OCT probe for imaging in the airway of small animals; specifically, creating an imaging probe to be utilized on mice.

II. Background

Client Information and Preliminary Research:

Our client is researching treatments for inflamed and diseased airways. In their research, the lab is testing the effectiveness of treatments on the airways of small animals. The airway mucosa, which consists of epithelial cells lining the esophagus, varies in thickness between healthy and diseased airways. Monitoring the thickness of the airway mucosa can indicate the effectiveness of treatments for lung diseases [5]. Our client is looking to monitor changes in the thickness of the mucosa of mice while testing the effectiveness of their lung disease treatment. One method of measuring the mucosa thickness is to use optical imaging, specifically OFDI with a probe device.

Optical frequency domain imaging, or OFDI, uses infrared light to generate cross-sectional images of tissue with a resolution between 10 and 20 micrometers [6]. The theory behind OFDI imaging is to direct light waves at tissue and measure the delays of the back-reflected light to estimate the thickness of the tissue [6]. To produce accurate imaging, the device must be stable and able to collect and transmit data to an external imaging device.

Design Specifications:

The goal of this project is to create a probe capable of performing OFDI imaging on the

The goal of this project is to create a probe capable of performing OFDI imaging on the small airway mucosa of mice. The device must be small enough to fit within the mouse airway, which is approximately 1.5 mm in diameter. [7] The device must be kept stable enough to use OFDI to create a 3D map of the airway, measuring the depth of the airway mucosa up to 1 mm and resolution between 5 and 20 micrometers [6] with a Signal to Noise Ratio of at least 80 [8]. The device will be used several times on living mice over several weeks, so it must be reusable and meet our clients lab animal testing policies along with federal regulations [9]. The project has a budget up to $10,000, but that can vary depending on the availability of optical imaging equipment.

III. Preliminary Designs

1. **Clear Intubation Catheter:**

The clear intubation catheter design contains a clear outer catheter that is designed to hold the mouse airway in place during imaging. The imaging probe, that will be connected to an optical fiber, will be inserted inside this clear catheter. The outer clear catheter will ensure that the airway is not only stable, but also keep the airway safe from potential damage. Figure 1 shows an imaging probe being inserted into a clear catheter which will be in the airway. The diameter of this catheter will be 1.2mm and the length of the catheter will be 15mm to precisely fit into the airway of a mouse.

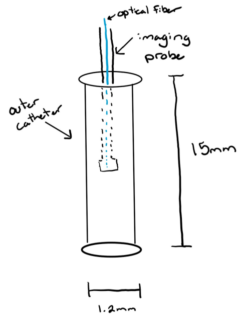


Figure 1: *Clear intubation catheter with probe insertion.*

2. **Helical Balloon Catheter:**

The helical balloon catheter design contains a small deflated balloon covering on the outside of a helical shaped catheter during insertion. Once the helical catheter has been inserted into the mucosa, the balloon is then inflated in order to stabilize the airway for accurate and safe imaging. The balloon would only cover the body of the catheter, leaving the tip exposed for the imaging probe. With nothing covering the imaging probe, there will be higher resolution with no extra artifacts. The dimensions of this catheter with an inflated balloon would be 1.0mm in diameter and 5.0mm in length. Figure 2 shows an image of the overall design of the catheter during insertion, where the balloon surrounds the body of the catheter waiting to be inflated for imaging. Figure 3 shows how the catheter will look during imaging with the balloon inflated to stabilize the airway.

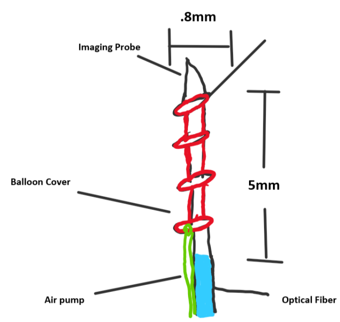


Figure 2: *Helical Balloon Catheter with balloon deflated for insertion.*

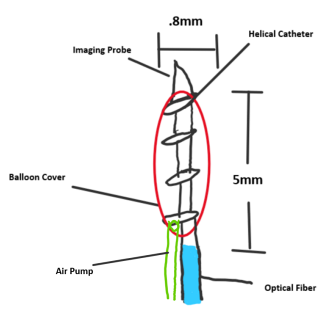


Figure 3: *Helical Balloon Catheter with balloon inflated for stabilization during imaging.*

3. **Flexi-Catheter Withdrawal Design:**

The Flexi-Catheter Withdrawal design consists of an outer catheter and an imaging probe. The outer catheter acts as a normal catheter but contains the imaging probe housed inside of it. The outer catheter is used as a mechanism to guide the imaging probe into the mouse airway. The outer catheter is then retracted exposing the imaging probe which allows for imaging of the mouse airway mucosa. Figure 4 shows an image of the probe mechanism at the time of imaging. In Figure 4 the outer catheter is retracted exposing the imaging probe to the airway mucosa for imaging.

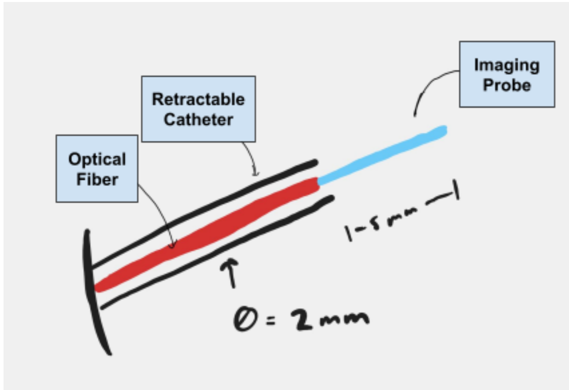


Figure 4: *Flexi-Catheter Withdrawal Design with the outer catheter in the retracted position***.**

Figure 5 shows the probe mechanism with the outer catheter advanced forward. This configuration would be used when the probe is being navigated into and out of the mouse airway.

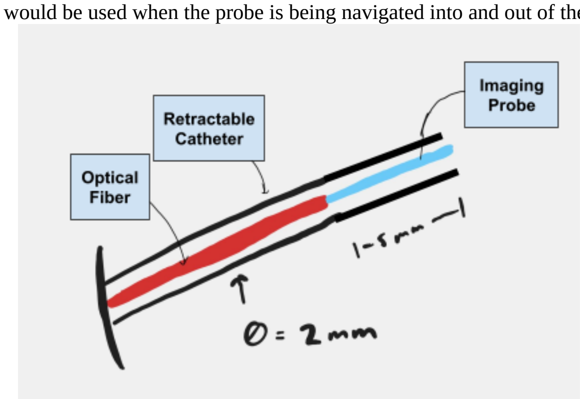


Figure 5: *Flexi-Catheter Withdrawal Design with the outer catheter in the advanced position***.IV.**

Preliminary Design Evaluation

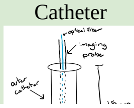
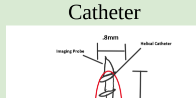
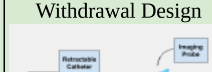
In order to evaluate the three different designs, a design matrix shown in Table 1 was created. All three designs were judged based on their anticipated Stability (30), Manufacturability (25), Accuracy (25), Safety (15), and Cost (5).

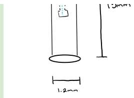
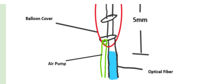
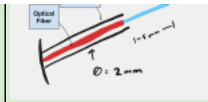
The stability of the probe and airway was our highest weighted category at 30 because keeping the airway open and stable while imaging is a key for accurate imaging. The Clear Intubation Catheter scored 5/5 because with the outer catheter in place the airway will be completely open during the entire imaging process with the probe free to move and rotate inside. The Helical Balloon Catheter scored 4/5 because the entire airway does not stay open during imaging but the balloon can add stability around the tip of the probe. The Flexi-Catheter Withdrawal Design scored the lowest at 2/5 because there is no outer component that guarantees the airway to stay open around the probe.

Manufacturability of the probe mechanism was tied for our second highest weighted criteria. This category measured the ease at which the probe mechanism could be manufactured. The Clear Intubation Catheter scored the highest with a 5/5 due to the simplicity of the design. The Flexi-Catheter Withdrawal Design scored second highest with a 4/5 due to the potential difficulty manufacturing the mechanism needed to withdraw the outer catheter. The lowest scoring design was the Helical Balloon Catheter with a score of 3/5 due to the complex nature of manufacturing a balloon small enough for a mouse airway and incorporating that into a helical catheter.

Table 1: *The Design Matrix used to rank the preliminary designs across five weighted criteria. Green highlights are the winner of that section*

Probe Mechanism

	Clear Intubation Catheter 	Helical Balloon Catheter 	Flexi-Catheter Withdrawal Design 

Design Criteria						
Stability (30)	**5/5**	**30**	4/5	24	2/5	12
Manufactuability (25)	**5/5**	**25**	3/5	15	4/5	20
Accuracy (25)	3/5	15	**5/5**	**25**	**5/5**	**25**
Safety (15)	**5/5**	**15**	1/5	3	3/5	12
Cost (5)	**5/5**	**5**	4/5	4	**5/5**	**5**
Total (100)	**90**		71		74	

The accuracy that the probe mechanism allows for was tied for our second highest weighted criteria at 25. This category intended to measure the accuracy and resolution that the probe design would allow for an OCT scanning system. The Flexi-Catheter Withdrawal Design and Helical Balloon Catheter both scored a 5/5 for this category because they both allowed for unobstructed visualization of the airway mucosa during imaging. The Clear Intubation Catheter scored a 4/5 on this category because it would require imaging through a clear catheter which could lead to artifacts in imaging and would lead to increased complexity in obtaining accurate imaging.

Safety of the probe was weighted at 15 due to the use with live mouse subjects. This category intended to judge how safely the device could be inserted into a mouse airway. During in vivo imaging of a mouse subject it is important to not damage the airway for proper testing of airway mucosa medications. During the rating of designs the possibility of potentially harmful parts and materials was considered. The Clear Intubation Catheter scored 5/5 due to the lack of complicated parts that could lead to injury. The Flexi-Catheter Withdrawal Design scored 3/5 due to the possibility of injury during the outer catheter withdrawal. The Helical Balloon Catheter scored a 1/5 due to potential for injury from inflating a high pressure balloon in the airway.

Cost was the lowest weighted criteria at 5 due to the high budget for the project. Additionally, the probe mechanism is a small portion of the project cost compared to the imaging component. Due to this all designs scored highly with, the Clear Intubation Catheter and the Flexi-Catheter Withdrawal Design both scoring 5/5 and the Helical Balloon Catheter scoring ⅘, due to added expense of the balloon mechanism.

The Clear Intubation Catheter scored the highest with 90 total points. This was largely due to the simplicity of the design which leads to easier manufacturability and increased stability compared to other designs.

IV. Fabrication/Development Process

Materials:

For the creation of the imaging probe, our team focused on the outer material that would encase the OFDI technology. To evaluate possible materials, a design matrix shown in Table 2 was created. All three materials were ranked based on their anticipated Moldability and Manufacturability (30), Reusability (25), Safety (20), Shelf Life (15) and Cost (10).

Table 2: *The Design Matrix used to rank the probe materials across five weighted criteria. Green highlights are the winner of that section*

Probe Material

Design Criteria	Polycarbonate		Polypropylene Copolymer (PPCO)		Silicone Rubber	
Moldability & Manufacturability (30)	4/5	24	2/5	12	**5/5**	**30**
Reusability (25)	**5/5**	**25**	4/5	20	**5/5**	**25**
Safety (20)	**5/5**	**20**	**5/5**	**20**	**5/5**	**20**
Shelf Life (15)	4/5	12	**5/5**	**15**	**5/5**	**15**
Cost (10)	**5/5**	**10**	2/5	4	4/5	8
Total (100)	91		71		**98**	

To fabricate the probe, our team will use the silicone rubber as the outer material for the imaging technology as it ranked the highest in total for our criteria, and has many properties that make it favorable for biomedical applications. It is a firm and flexible material that can withstand a wide range of temperatures, chemicals, and UV exposure, making it ideal for sterilization conditions. It is also readily available, easy to manufacture inert, nontoxic, and nonbiodegradable, making it a suitable option for invivo biotechnology. [10]

Methods:
1) Design Clear Intubation Catheter on Solidworks
2) A model of the probe will be created using the Formlabs Form 3 printer at the UW Madison Makerspace. The material that will be used to print the probe is the Formlabs flexible resin
    a) Flexible resin will be used to resemble the silicone material used on the prototype
3) Model will be tested and modified for final dimensions
4) The team will send finalized design to a biotechnology company for custom silicone molding

V. Testing/Future Work

Moving forward, the team will construct a prototype probe following the winning design and material evaluated in the design matrices. Despite not having the probe attached to the rest of an imaging machine, there are still relevant tests our probe needs to undergo. The most important of these tests is to measure the force imparted on the airway by our probe. This will be done by measuring the coefficient of friction between the silicone catheter and a biologically similar material. The team can also test the silicone as a testing medium by using an existing OCT device; our research suggests silicone wouldn't interfere with imaging, but our fabrication process could affect this.

VI. Discussion

The probe must be minimally invasive in order to protect the test subjects and to ensure the highest accuracy in the images produced. If the probe itself is contributing to the inflammation response in the mucosa then it will skew if not invalidate the results. Aspects like these will be assessed if Dr. Brasier tries to take a drug into clinical trials, therefore the final machine must limit physical contact as much as possible. As mentioned previously, testing will be conducted to ensure the probe's safety. Specific figures will be discussed with the client once the final design has been fabricated. There are also animal care standards and regulations relevant to our design, however, the restraints due to data accuracy require a much higher degree of animal protection than is required by regulation[9][11].

VII. Conclusions

Imaging tools are intricate and expensive machines that provide scientists and medical professionals an essential insight into biological organisms. Our team will design and manufacture a probe to help afford this insight to our client, Dr. Brasier, in his research using lab mice. Specifically, Dr. Brasier intended to measure the inflammation of the airway mucosa in mice, an indicator or deteriorating health to assess the efficacy of novel drugs. For this task, optical coherence tomography (OCT) is well suited to produce high resolution volumetric images to completely image the mucosa. We learned from our professional advisors that to make a device like this would traditionally take a team of graduate students and much more than our budget. In spite of this, we believe that through several courses of BME design, a completed OCT imaging device can be delivered to Dr. Brasier.

Our team will continue with the intubation tube design, using silicone rubber. The intubation tube will be the simplest and most effective way to stabilize the source of light in the airway. We will conduct imaging tests on the silicone sheath that we fabricate in order to ensure that the optical properties do not interfere with the imaging process. We will focus our research on the manufacturing process of small, precision instruments. Fabrication at this scale is challenging because there is a lot of precision required to successfully rotate an imaging fiber steadily and avoid damage to the airway. When the prototype is completed, we will test the probe's impact on a simulated airway to ensure that it does not contribute to any perturbation recorded by the probe.

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IX. Appendix

<u>A: Product Design Specification</u>

Function:
The goal of this project is to create and validate an optical frequency domain imaging (OFDI) probe for imaging in the airway of small animals. The cells lining the airway play an important role in common airway diseases and new therapeutics are being developed for treatment. A limitation in the work to develop these therapeutics is the difficulty of measuring changes over the course of an experiment. Some imaging techniques, including OFDI, are able to monitor changes in the airway; however, they are too large for small animal testing. Due to this problem, the aim of this project is to create an effective miniaturized OFDI probe for the use in animal testing.

Client requirements:

5cfThe imaging device must be able to visualize the airway mucosa of mice in vivo.
5cfThe device must be able to be maneuvered through a mouse airway for imaging.
5cfThe project's budget is up to $10,000 depending on availability of already purchased resources

Design requirements:

1. Physical and Operational Characteristics

a. Performance Requirements: The imaging device must be able to image the airway mucosa of a murine test subject. The device should be able to measure up to 1 mm in depth of the airway mucosa and should have a resolution of 5 - 20 μm, which is comparable to existing OCT systems [1]. The device should not harm the mouse when sedated to allow for testing throughout a drug testing protocol.

b. Safety: The device must come with clear and concise instructions for device usage and must only be used by a trained operator with animal subjects training [2]. The device material must not cause biological harm to the mouse or the user and no sharp edges should be exposed as part of the device that could cause internal injury to the mouse subject during imaging.

c. Accuracy and Reliability: The device must have a Signal to Noise Ratio (SNR) of 80 or more, which is a baseline for imaging biological targets [3]. The imaging device must also demonstrate significant correlation ($p < 0.01$) between calculated airway wall layer areas using histology, ex-vivo, and in-vivo approaches [4].

d. Life in Service: The imaging probe should be reusable on different subjects, operating at least 10 minutes per use, averaging 2 minutes per data set with OFDI technology, [5] or 4 minutes with OCT technology [6]. The material of the probe will be sterilized by autoclaving.

e. Shelf Life: The shelf life will be dependent on quality of materials, e.g. fiber optic cable, biocompatible finish.

f. Operating Environment: The imaging probe must withstand temperatures between 20°C (68 °F) and 135°C (275 °F) for storage and sterilization conditions. The probe must also avoid corrosion from in-vivo testing and sterilization chemicals.

g. Ergonomics: The imaging probe must be made out of a material that can be used safely inside an organism with no reaction and can be sterilized. It must be able to maneuver the cartilage rings in the upper part of the trachea and measure within the airway mucosa [7].

h. Size: The probe must be able to fit inside the airway of a mouse. Its diameter must be less than 1.5mm, the diameter of a mouse trachea [8].

i. Weight: The probe must be light enough to be hand maneuvered by the same hand and weigh no more than 5.1 pounds [9].

j. Materials: Potential materials that may be included are fiber-optic cables, silicone rubber, and a camera and lens. The materials will all be biocompatible and autoclavable if the design is made to be reusable.

k. Aesthetics, Appearance, and Finish: The finish must be smooth to limit physical interference of the sample. The finish must be biocompatible. The appearance and aesthetic of the device does not contribute meaningfully to its efficacy .

2. Production Characteristics:

a. Quantity: We will manufacture one final design and test it in the small airway mucosa of a small mouse.

b. Target Product Cost: The manufacturing cost may be more expensive due to the specialized style of optical imaging necessary. The total cost should be approximately $5,000-$10,000. Although this cost is high, the total cost can be made lower based on materials already readily available to our team.

3. Miscellaneous

a. Standards and Specifications: Must avoid or minimize discomfort, distress or pain consistent with sound scientific practices [10]. Animals that are subject to prolonged discomfort or distress must be given proper sedation [10]. Animals must be humanely and safely handled, treated and transported [11].

b. Customer: The customer is asking for a device which can image the mucosa in lab mice to record the effects of trial drugs. Mice are sedated prior to imaging. Perturbation of the mucosa and other tissue by the probe would negatively impact the accuracy of the data taken. The customer would like a feature of the probe to indicate the depth of the probe in the mouse.

c. Subject-related concerns: The materials and maneuverability of the probe must ensure the mouse is unharmed and procedures follow lab animal safety protocol while using the product.

d. Competition: Hariri et. al. published a study in 2012 recording the use of OFDI on human lung imaging. The study described two methods, one of bronchoscopy airway-centered imaging and one of parenchymal imaging. A custom-built bronchoscope was used with a diameter of 0.8 - 1.7 mm. The OFDI methods were only performed on human lungs [12].

Templin et. al. published a study in 2010 that successfully used OFDI for stent healing evaluation in vevo on pigs. The study described using a Terumo-OFDI catheter on a 0.014-inch guidewire. The study successfully used OFDI on the animals 1, 3, 10, 14, and 28 days after the stents were implanted [13].

Vakoc et. al. published a study in 2006 where OFDI was successfully performed on the distal esophagus of two swine using a 4.5 cm long inflatable balloon. The study successfully acquired cross sectional imaging of the mucosal vascular network within two living swine [14].

No patents were found for a product that could successfully use OFDI in the airways of any animals smaller than pigs.

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Final Poster

JADE BERGET - Dec 13, 2022, 12:02 PM CST

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Final Report

LILLIAN ZAHN - Dec 13, 2022, 6:07 PM CST

Embedded private docs from Google Drive cannot be displayed in PDF

09/14/2022-Volumetric Optical Frequency Domain Imaging of Pulmonary Pathology With Precise Correlation to Histopathology

PETER WAWRZYN - Sep 14, 2022, 3:47 PM CDT

Title: Volumetric Optical Frequency Domain Imaging of Pulmonary Pathology With Precise Correlation to Histopathology

Date: 9/14/22

Content by: Peter

Goals: Read introductory paper about the general project area

Content: Notes on research article given by the client

Other methods to obtian imaging of airway

-bronchoscopy > only visualizes the surface of the airway

-Lung biopsy and fine needle aspiration > limited by smaller amounts of tissue obtained and sampling error

-Larger tissue volumes require more invasive procedures

Optical coherence tomography (OCT)

- noninvasive, noncontact, optical imaging modality
- generates high resolution cross-sectional images of tissue microstructure
- penetration depths of 2 to 3 mm
- comparable resolution to a microscope

Optical frequency domain imaging (OFDI)

- second generation OCT with faster acquisition time
- able to capture large area volumetric images
    - ideal for evaluating long segments of the tracheobronchial tree

Conclusions/action items:

This article introduces what OFDI is well and talks more about the validation process that needs to be done to show that OFDI can effectively help diagnose conditions. It may be important to revisit when we need to validate our design.

9/21/2022 - PDS Research

PETER WAWRZYN - Sep 21, 2022, 5:08

Title: PDS Research

Date: 9/21

Content by: Peter

Present: Peter

Goals: To do research to complete my part of the PDS

Content:

Optical Coherence Tomography (OCT): Principle and Technical Realization

https://link.springer.com/chapter/10.1007/978-3-030-16638-0_3#Sec1

- Book talks about basics of OCT
- Resolution of OCT is between 5 - 20 micro meters
- Axial resolution is determined by the light source not the focusing optics

Optical coherence tomography for identification and quantification of human airway wall layers

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5628810/#:~:text=OCT%20is%20an%20accurate%20and,remodeling%20in%20obstructive%20lung%20dis

- Article is used to validate use of OCT in imaging of human airway
- Tested correlation between histology, in vivo, and ex-vivo measurements using OCT
- Did this buy measuring airway wall area
  - Seems like this could be a way for us to validate our device to ensure accurate results
- Process of imaging
  - in-vivo
  - ex-vivo
  - histological with stains for ground truth

What Investigators Need to Know Who Must Comply With the PHS Policy?

https://olaw.nih.gov/sites/default/files/InvestigatorsNeed2Know.pdf

- Talks about the different approval processes needed for Animal Testing

Spectral domain optical coherence tomography: a better OCT imaging strategy

https://www.future-science.com/doi/10.2144/000112090

- Talks about signal to noise ratio
- Measurement in dB depends on different imaging parameters
  - on a log scale
- Minimum needed SNR for imaging biological tissues is generally thought to be 80

Conclusions/action items:

This was a good start for research of the PDS. We will need to meet as a team to discuss potential areas of the project we are missing and add to and edit PDS more based on those discussions.

9/30/2022 - OCT Technology Explained

PETER WAWRZYN - Sep 30, 2022, 11:35 AM CDT

Title: OCT Technology Explained

Date: 9/30/22

Content by: Peter

Present: Peter

Goals: Learn more in depth about OCT imaging

Content:

- Waves from similar tissues will reflect at same index and remain coherent - in line
- Waves from different tissue reflect differently and become incoherent
- Waves can either constructively interfere or destructively interfere
    - Coherent will constructively interfere
    - Incoherent will destructively interfere
- Light source sends info into a coupler which splits light into the sample arm and reference arm
- Light is reflected back from both arms back through the coupler and a detector reads incoming signal
    - Light undergoes constructive or destructive interference
- Why do we need a reference arm
    - Light moves to fast to calculate distance of light traveled so you can compare to the reference arm
- Time domain OCT
    - uses a monochromatic light source 840nm
    - reference mirror moves over time to get different depths
    - 400 Axial scans per second
    - Resolution is 8-10 micrometers
    - Can have motion artifacts
- Fourier Domain (Spectral Domain)
    - fixed reference arm
    - broadband light source 840nm-850nm
        - Spectrum of wavelengths is sent at once and different wavelengths bounce back at different layers
    - Fourier transform - converts into signal into individual frequencies the signal is made of
    - Very fast (10,000s scans per second)
    - Higher resolution
- Swept Source OCT
    - tunable frequency swept laser (1050nm)
    - can quickly change wavelength to get a signal at every wavelength
    - extremely fast (100,00s scans per second)
    - can see deeper structures more clearly

https://www.youtube.com/watch?v=dd0hdPbozJU

Conclusions/action items:

This is helpful information about the basics of OCT imaging that can be used to help understand multiple aspects of the project moving forward.

PETER WAWRZYN - Oct 10, 2022, 3:52 PM CDT

9/30/2022 - Flexi-Catheter Design Idea

PETER WAWRZYN - Oct 12, 2022, 1:18 PM CDT

Title: Flexi Catheter Design Idea

Date: 9/30/22

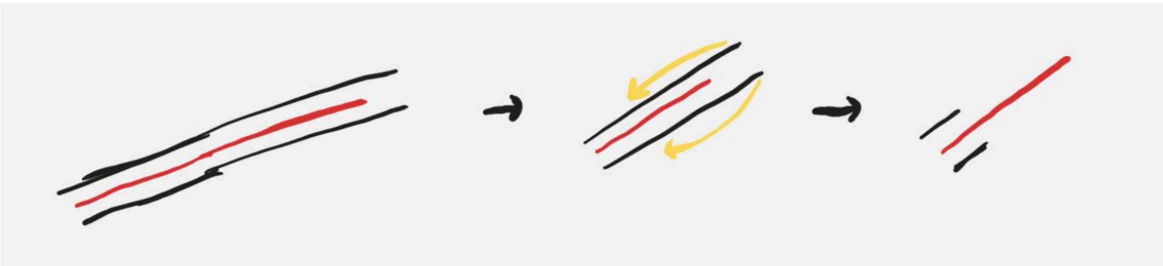
Content by: Peter

Present: Peter

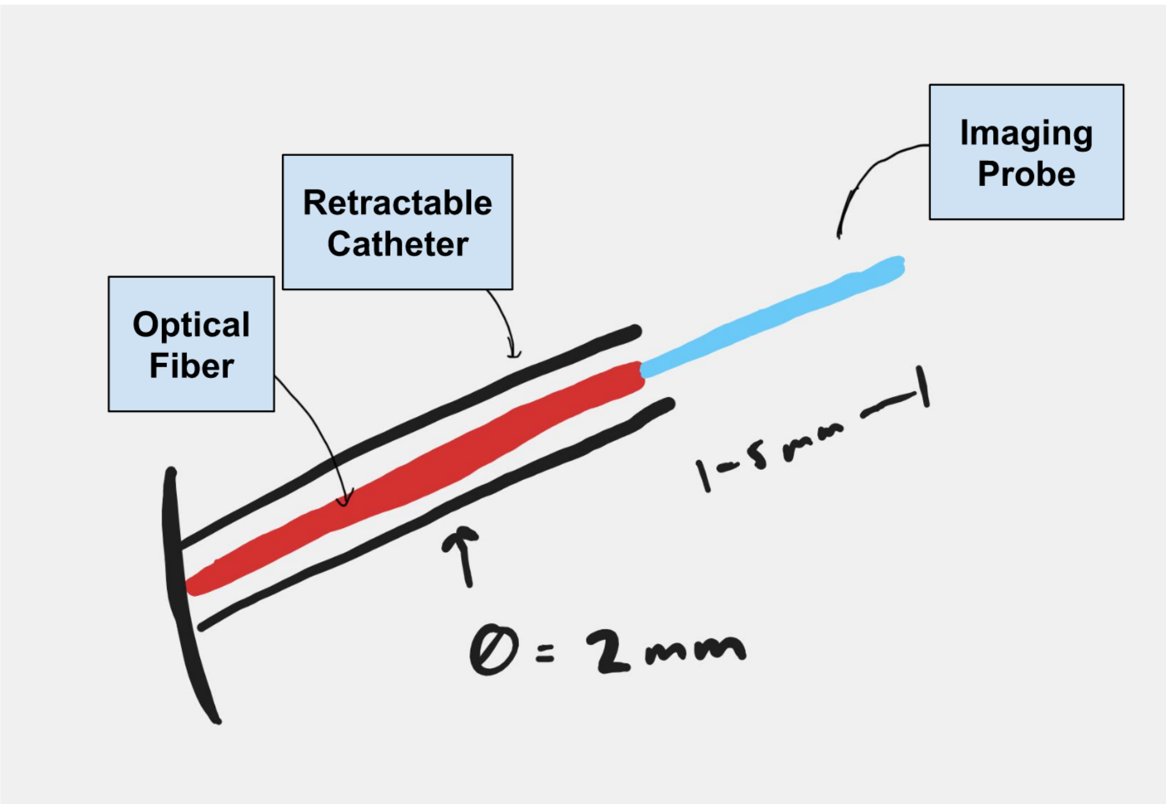
Goals: Talk about my design idea for the probe mechanism

Content:

Flexi-Catheter Withdrawal Design
-Based on Dragonfly Opstar Catheter
The idea of this design would be to use a similar design to the Dragonfly opstar catheter which has an outer layer that can be pushed through the airway to where we want to image and then the outer layer is retracted exposing the imaging device.



Videos:
https://www.youtube.com/watch?v=Kh8iCAMqWdk -Dragonfly Opstar in use
https://www.youtube.com/watch?v=z0UXrdVS39Y - Animation of C7 dragonfly deployment



Conclusions/action items:

The next steps are to share this design with the team and evaluate it compared to other designs.

9/15/22 Anatomy, Airway

JADE BERGET - Sep 22, 2022, 9:44 PM CDT

Title: "Anatomy, Airway"

Date: 9/15

Content by: Jade

Goals: Gain a basic understanding of the airway anatomy to get an idea of where the probe will need to image.

Content:

M. Ball, “Anatomy, Airway,” *Europe PMC*, 31-Oct-2017. [Online]. Available: https://europepmc.org/article/nbk/nbk459258?utm_medium=email&utm_source=transaction&client=bot#free-full-text. [Accessed: 15-Sep-2022].

- The airway aka respiratory tract are the organs that allow airflow during ventilation
- includes nares and buccal opening down to the end of alveolar sacs
- upper airway (the pharynx) is the mucous membrane-lined portion
- pharynx includes the nasopharynx, post-nasal space, posterior nasal cavity
- oro-pharynx connects the naso and hypopharynx
- the larynx is the portion between the pharynx and the trachea
  - contain the epiglottis and the vocal folds (vocal cords) which are the opening to the glottis
- the trachea is ciliated and pseudostratified, supported by c-shaped rings of cartilage
- the bronchi have complete cartilage rings
  - there are 2 main bronchi that supply ventilation to each lung
  - the right bronchus is larger in diameter and is aligned more vertically than the left
  - Bronchioles lack supporting cartilage skeletons and have a diameter of around 1 mm, they are ciliated and their lining does not contain mucous-producing cells
  - there are conduction, terminal, and respiratory bronchioles
  - Respiratory bronchioles contain occasional alveoli and have surface surfactant-producing
- The alveolar is the final portion of the airway, lined with a single-cell layer of pneumocytes
  - contain surfactant-producing type II pneumocytes and Clara cells
  - Alveolar ducts are tubular portions with respiratory surfaces where the alveolar sacs branch
  - Alveolar sacs are where the alveoli clusters are formed and connected. They are connected by pores which allow air pressure to equalize between them
- the mucous lining of the airway provides a barrier to prevent loss of excessive moisture during ventilation by increasing the humidity of the air in the upper airway

Conclusions/action items:

I gained a basic understanding of the anatomy of the airway. I now would like to transfer this and find an article specifically on the airway anatomy of a mouse to see how that differs and what affects the mucosa.

9/22/22 Mucosal IgE immune responses in respiratory diseases

JADE BERGET - Sep 22, 2022, 9:39 PM CDT

Title: "Mucosal IgE immune responses in respiratory diseases"

Date: 9/21/22

Content by: Jade

Goals: To understand the immune responses within the mucosa from respiratory diseases.

Content:

Eguiluz-Gracia, J. A. Layhadi, C. Rondon, and M. H. Shamji, "Mucosal ige immune responses in respiratory diseases," *Current Opinion in Pharmacology*, 17-Jun-2019. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1471489219300268#sec0005. [Accessed: 22-Sep-2022].

- IgE are the immunoglobulin antibodies.
- resident effector cells get rapidly sensitized, and free IgE can be found in mucosal secretions
- In allergic rhinitis and allergic asthma, the IgE-sensitization to environmental allergens triggers an eosinophilic inflammation of the airway mucosa of atopic patients
- Some biologicals antagonize IgE-mediated inflammation of the airway mucosa, but they have not shown a beneficial long-term effect after discontinuation.
- the respiratory and intestinal mucosae harbour the largest populations of IgE-producing plasma cells (PC) in the human body
- a significant proportion of circulating IgE is believed to originate in the mucosae with subsequent spill over through the lymphatic system
- IgE molecules in the human body are found attached to its receptors in mucosal effector cells, rather than free in serum
- In the absence of functional Tfh cells, the production of IgE in response to mucosal antigens is greatly impaired
- mucosal lymphoid aggregates were detected in patients with type 2-dominated nasal inflammation
- The natural exposure to the allergen is associated in AR patients with an expansion of mucosal IgE repertoires
- mucosal IgE changes are paralleled by a less prominent repertoire expansion in peripheral IgE antibodies

Conclusions/action items:

I learned about the effects that respiratory diseases had on the mucosa. I would like to find an article specifically on the dimensions of mucosa before and after immune responses.

9/22/22 Measuring Lung Function

JADE BERGET - Sep 22, 2022, 10:20 PM CDT

Title: "Measuring the lung function in the mouse: the challenge of size" and "Mammalian tracheal development and reconstruction: insights from *in vivo* and *in vitro* studies"

Date: 9/22/22

Content by: Jade

Goals: Find the differences between a mouse's airway and humans.

Content:

C. G. Irvin and J. H. T. Bates, “Measuring the lung function in the mouse: The challenge of Size,” *Respiratory research*, 15-May-2003. [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC184039/. [Accessed: 22-Sep-2022].

K. Kishimoto and M. Morimoto, “Mammalian tracheal development and reconstruction: Insights from in vivo and in vitro studies,” *Development (Cambridge, England)*, 01-Jul-2021. [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8276987/#:~:text=The%20diameter%20of%20the%20mouse,different%20between%20mice%20and%20humans. [Accessed: 22-Sep-2022].

- total lung capacity (TLC) of the mouse is about 1 ml compared to 10 ml of the rat and 6,000 ml of a human.
- the mouse pleura is thin
- strong enough to be inflated to considerably higher pressures than the 30 cm H_2O normally associated with TLC
- The airways constitute a large percentage of the lung in mice (11%)
- Cartilage is present in the mouse trachea but is less well organized
- only the upper part of the trachea has the complete rings seen in other mammals and these rapidly change to plates as one proceeds distally.
- Mouse lungs have fewer respiratory bronchioles and airway generations (13–17 generations)
- the thinness of the respiratory epithelium and the relatively large airway lumen
- inflammatory processes that could compromise lung function in larger animals (e.g. humans) might have little effect in mice because of their relatively large airway size and/or lack of mucous glands.
- The diameter of the mouse trachea (−1.5 mm) is equivalent to that of the human bronchioles

Conclusions/action items:

I gained knowledge of the differences between a mouse's airway compared to other mammals including humans. I also got some exact size measurements. Now I need to include this information in my section of the PDS.

10/11/22 Respiratory Disease Statistics

JADE BERGET - Oct 11, 2022, 10:35 PM CDT

Title: "Prevalence and attributable health burden of chronic respiratory diseases, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017"

Date: 10/11/22

Content by: Jade

Goals: Find common airway diseases and their statistics

Content:

- Common airway diseases include asthma, chronic obstructive pulmonary disease (COPD), pulmonary fibrosis, pneumonia, bronchiectasis and lung cancer.
- Asthma affects about 14% of children 5
- COPD accounts for about 55% of respiratory diseases in both men and women
- 3 914 196 deaths due to chronic respiratory diseases in 2017
- accounted for 7·0% (6·8–7·2) of total all-cause deaths globally
- ranking chronic respiratory diseases as the third leading cause of death in 2017, just behind cardiovascular diseases (31·8%] of all deaths) and neoplasms 17·1%
- has overall increased over the years

Conclusions/action items:

Gained statistics about common respiratory diseases which will now be important in our preliminary report.

Clear Intubation Catheter

JADE BERGET - Oct 11, 2022, 9:51 PM CDT

Title: Clear Intubation Catheter Design

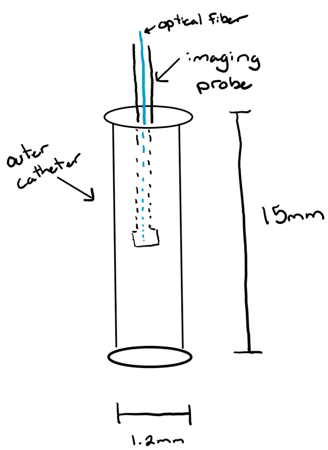
Date: 10/11/2022

Content by: Jade

Present: N/A

Goals: Create an optional probe design for our design matrix.

Content:



- The idea is based on an intubation tube.
- A clear outer catheter is inserted into the mouse's airway to keep it open and stable.
- It must be able to be imaged through.
- An imaging probe is then inserted into the catheter to take the image scan

Conclusions/action items:

I created a potential imaging probe design for our mouse airway. Now I need to present this option to my team and discuss alternative designs for our design matrix.

9/14/2022 Preliminary Research OFDI Concepts

Andy Slayton - Sep 14, 2022, 3:34 PM CDT

Title: Initial research into OFDI imaging

Date: 9/12/22

Content by: Andy Slayton

Present: Andy Slayton

Goals: To get an early understanding of how this imaging is executed and understand the benefits compared to other methods.

Sources:

1]

S. Yun, G. Tearney, J. de Boer, N. Iftimia, and B. Bouma, "High-speed optical frequency-domain imaging," *Optics express*, 03-Nov-2003. [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2758565/. [Accessed: 14-Sep-2022].

2]

Y. S. H. B. C. T. G. J. B. BE; "High-speed wavelength-swept semiconductor laser with a polygon-scanner-based wavelength filter," *Optics letters*. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/14587796/. [Accessed: 14-Sep-2022].

3]

L. P. Hariri, M. B. Applegate, M. Mino-Kenudson, E. J. Mark, B. D. Medoff, A. D. Luster, B. E. Bouma, G. J. Tearney, and M. J. Suter, "Volumetric optical frequency domain imaging of pulmonary pathology with precise correlation to histopathology," *Chest*, Jan-2013. [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3537541/. [Accessed: 14-Sep-2022].

Content:

BACKGROUND/nomenclature🈴

- RIN is "relative intensity noise"; inherent noise associated with source at differing freqs.
  - Other forms of noise are 1) thermal noise 2) shot/poisson noise(static charge interaction with photosensors)
- SNR is "signal-to-noise"; important in imaging, higher the better,

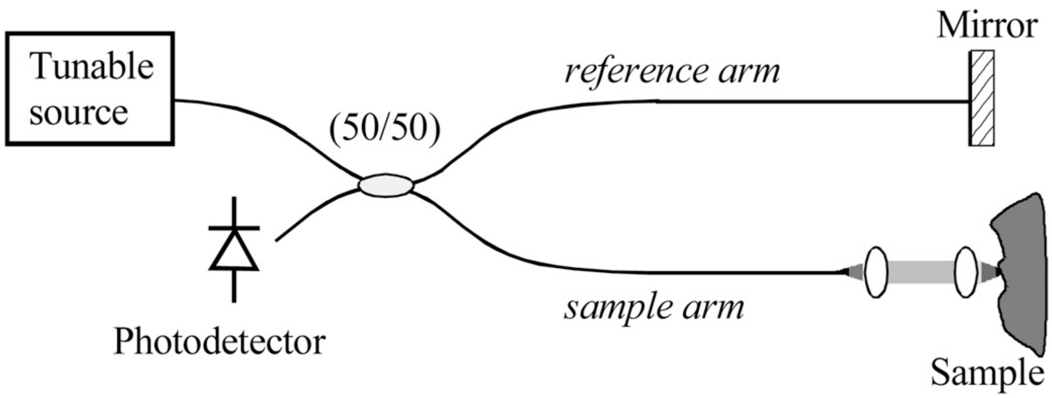
- A wavelength-swept laser produces a variable frequency of light on a triangular wave. Basically giving all frequencies evenly, linear increase/decrease in frequency(triangle).
- It seems like OFDR and OFDI are somewhat interchangeable, OFDR is the basis for OFDI as a whole.
- Frequency vs Time domain imaging

Time domain	Frequency domain
Analysis done on an oscilloscope. Higher freq = more peaks in given time.	Uses a signal analyzer or oscilloscope with FFT. (Oscope has higher noise floor so worse). Peak gives an inpulse.
	Better at managing multiple inputs. Can use to identify and filter sources of noise.

High-Speed optical frequency-domain imaging
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2758565/

- Allow cross-sectional imaging of biological samples.
- OFDI/OFDR is a response to the slow imaging time of optical coherence tomography (OCT) imaging. OFDI allows imaging of much larger samples.
- The experimental setup uses a wavelength-swept laser and common photodetectors which are tuned to specs in the following article.

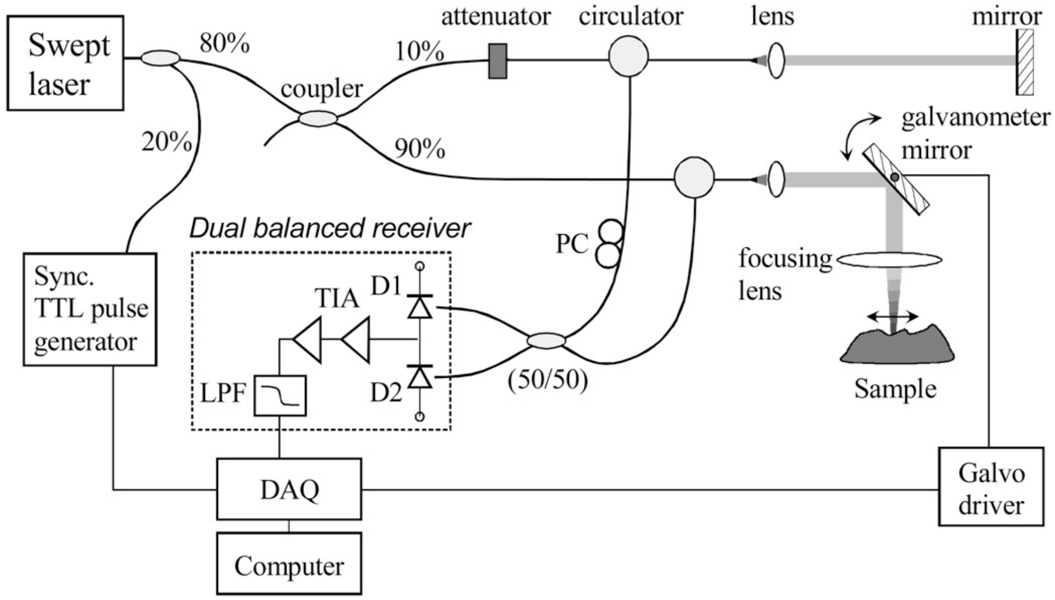
Basic Setup for OFDR



1. Light input from the laser is split evenly to each branch
2. Reflected light from each branch interferes due to different reflective surfaces.
3. A photodetector measures the interference and can generate 2D image

Really hard to do from scratch, math is in the link

Actual experimental setup for OFDI imaging



Laser tuning procedure/configuration for above setup:
Complicated, seems expensive too
https://pubmed.ncbi.nlm.nih.gov/14587796/
https://opg.optica.org/ol/fulltext.cfm?uri=ol-28-20-1981&id=74886

Article Provided
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3537541/

- Image processing done using ImageJ 1.38w and Osirix 2.75

OFDI and OCT setup information for given article:

1. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2709216/ (OFDI-really good source for processing info)
2. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2713046/ (spectral-domain OCT)

Conclusions/action items:

1. Need to know the budget
2. After getting an understanding of OFDI, begin working on reducing the size of the probe
3. Hopefully someone is versed in MatLab or other language for image formation
4. **prepare questions for Yesilkoy on OFDI**
5. ODFR might be a better path to a working prototype but still code-heavy.
6. Anyone learn about fourier transformations (filtering process)

10/05/2022 Rotating Probe Design

Andy Slayton - Oct 12, 2022, 1:28 PM CDT

Title: Rotating Probe design

Date: 9/12/22

Content by: Andy Slayton

Present: Andy Slayton

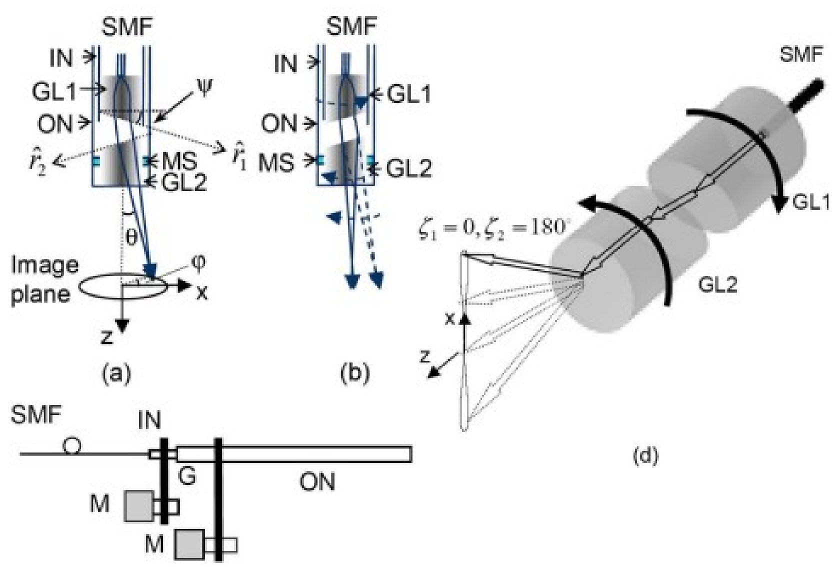
Goals: to start research into understanding the principals behind rating oct imaging probs and the type of manufacturing process that allowed them to fabricate the probe.

Sources:

1]

“Paired-angle-rotation scanning optical coherence tomography forward-imaging probe,” *Optica Publishing Group*. [Online]. Available: https://opg.optica.org/ol/viewmedia.cfm?uri=ol-31-9-1265&seq=0. [Accessed: 12-Oct-2022].

Content:



- The probe uses two rotating lenses with offset faces to direct light to the optic fiber
- The lenses allow for a large degree of throughput between different samples by adjusting the orientation of the the lenses.
- This reduces the amount of material moving in the probe, but it does add some intricacy we might be able to achieve.

Conclusions

- I will bring this design up at the next advisor meeting, if Dr. Yesilkoy things its a good idea it would be good to talk to Jeremy rogers again to see what he thinks about the idea.
- I will continue research into this type of probe design, Tsi article was short but cited more procedure articles.
- I think this would be a good way of directing light rather than moving the entire receptor.

11/25/2022 Circuit Research

Andy Slayton - Dec 14, 2022, 9:34 AM CST

Title: Circuit research

Date: 11/25/2022

Content by: Andy Slayton

Present: Andy Slayton

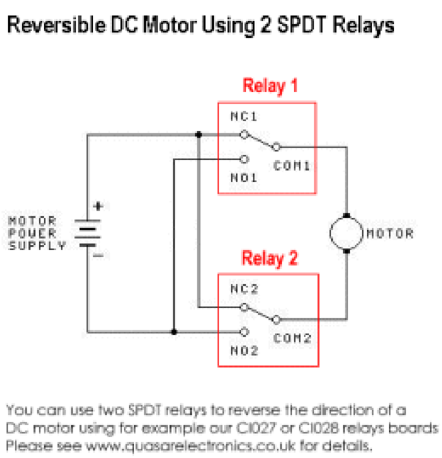
Goals: To understand how to wire the DC motor to be controlled by a re

Source:

https://quasarelectronics.co.uk/dc-motor-reversing-circuits-automatic-remote-control

Content:

Possible to use two SPDT relays to reverse the polarity of the DC motor's input. Using a relay also allows for the electricity to the motor to be controlled by the arduino microcontroller.



Conclusions/action items:

Add the Arduino relay shield to the list of materials to be ordered.

9/15/2022 - Preliminary Project Research

LILLIAN ZAHN - Oct 11, 2022, 2:18 PM CDT

Title: Preliminary Project Research

Date: 9/15/2022

Content by: Lillian Zahn

Present: N/A

Goals: Conduct preliminary research on OFDI imaging and begin brainstorming questions to ask client.

Content:

The following articles were used to research OFDI imaging and its applications on our project.

Title: High-speed optical frequency-domain imaging

This study was conducted in order to test the efficacy of a particular OFDI system and explain the concepts which allow it to work. In the study are links to two other studies that explain the setup used to conduct OFDI imaging.

Reference: S. Yun, G. Tearney, J. de Boer, N. Iftimia, and B. Bouma, "High-speed optical frequency-domain imaging," *Optics express*, 03-Nov-2003. [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2758565/. [Accessed: 14-Sep-2022].

Title: Optical Coherence Tomography (OCT): Principle and Technical Realization

This review describes the methods, theories and technicalities of OCT imaging.

Reference: S. Aumann, S. Donner, J. Fischer, και F. Müller, 'Optical Coherence Tomography (OCT): Principle and Technical Realization', στο High Resolution Imaging in Microscopy and Ophthalmology: New Frontiers in Biomedical Optics, J. F. Bille, Επιμ. Cham: Springer International Publishing, 2019, σσ. 59–85.

Conclusions/action items: The above articles provided a good background of OCT imaging and how it has been applied in other studies. The next steps will be to create questions to ask client to promote further project organization and research.

10/11/2022 Optical Frequency Domain Imaging

LILLIAN ZAHN - Oct 12, 2022, 3:03 PM CDT

Title: Optical Frequency Domain Imaging Research

Date: 10/11/2022

Content by: Lillian Zahn

Present: (Individual Work)

Goals: Research OFDI mechanisms and specifics, specifically for a concise explanation in the Preliminary Report.

Content:

Optical frequency domain imaging, or OFDI, uses infrared light to generate cross-sectional images of tissue with a resolution between 10 and 20 micrometers. The theory behind OFDI imaging is to direct light waves at tissue and measure the delays of the back-reflected light to estimate the thickness of the tissue. To produce accurate imaging, the device must be stable and able to collect and transmit data to an external imaging device.

Reference:

S. Aumann, S. Donner, J. Fischer, και F. Müller, 'Optical Coherence Tomography (OCT): Principle and Technical Realization', στο High Resolution Imaging in Microscopy and Ophthalmology: New Frontiers in Biomedical Optics, J. F. Bille, Επιμ. Cham: Springer International Publishing, 2019, σσ. 59–85.

Conclusions/action items: Compile research to create a concise explanation of OFDI mechanisms for the preliminary report.

9/20/2022 Competing Design Research

LILLIAN ZAHN - Oct 12, 2022, 3:10 PM CDT

Title: Competing Design Research

Date: 9/20/2022

Content by: Lillian Zahn

Present: (Individual Work)

Goals: Research competing designs and other teams that have successfully used OFDI probes.

Content: (Research document included below)

Conclusions/action items: There are relatively few researchers that have successfully used OFDI probes on a small scale. However, labs that have used OFDI on human lungs and the esophagus of swine provide useful information and potential techniques.

LILLIAN ZAHN - Oct 12, 2022, 3:11 PM CDT

OFDI Imaging on Human Lungs with Custom Bronchoscope

Hariri et. al. published a study in 2012 recording the use of OFDI on human lung imaging. The study described two methods, one of bronchoscopy airway-centered imaging and one of parenchymal imaging. A custom-built bronchoscope was used with a diameter of 0.8 - 1.7 mm. The OFDI methods were only performed on human lungs.

Reference:

> L. P. Hariri, M. B. Applegate, M. Mino-Kenudson, E. J. Mark, B. D. Medoff, A. D. Luster, B. E. Bouma, G. J. Tearney, and M. J. Suter, “Volumetric optical frequency domain imaging of pulmonary pathology with precise correlation to histopathology,” Chest, Jan-2013. [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3537541/. [Accessed: 20-Sep-2022].

OFDI Imaging for Stent Healing in Pigs with Catheter Stabilization

Templin et. al. published a study in 2010 that successfully used OFDI for stent healing evaluation in vivo on pigs. The study described using a Terumo-OFDI catheter on a 0.014-inch guidewire. The study successfully used OFDI on the animals 1, 3, 10, 14, and 28 days after the stents were implanted.

Reference:

> C. Templin, M. Meyer, M. F. Müller, V. Djonov, R. Hlushchuk, I. Dimova, S. Flueckiger, P. Kronen, M. Sidler, K. Klein, F. Nicholls, J.-R. Ghadri, K. Weber, D. Paunovic, R. Corti, S. P. Hoerstrup, T. F. Lüscher, and U. Landmesser, “Coronary optical frequency domain imaging (OFDI) for in vivo evaluation of Stent Healing: Comparison with light and electron microscopy,” European heart journal, Jul-2010. [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2903715/. [Accessed: 20-Sep-2022].

OFDI Imaging of Distal Esophagus of Swine with Balloon Stabilization

Vakoc et. al. published a study in 2006 where OFDI was successfully performed on the distal esophagus of two swine using a 4.5 cm long inflatable balloon. The study successfully acquired cross sectional imaging of the mucosal vascular network within two living swine.

Reference:

> B. J. Vakoc, M. Shishko, S. H. Yun, W.-Y. Oh, M. J. Suter, A. E. Desjardins, J. A. Evans, N. S. Nishioka, G. J. Tearney, and B. E. Bouma, “Comprehensive esophageal microscopy by using optical frequency–domain imaging (with video),” Gastrointestinal Endoscopy, 26-Mar-2007. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0016510706026691. [Accessed: 20-Sep-2022].

No patents were found for a product that could successfully
use OFDI in the airways of any animals smaller than pigs

use OFDI in the airways of any animals smaller than pigs.

2022/9/29 Probe Geometry Research

YASH SHAH - Sep 29, 2022, 10:22 PM CDT

Title: Probe Geometry

Date: 9/29/2022

Content by: Yash Shah

Present: Yash Shah

Goals: To research the most optimal geometry for a probe that can enter the airway of a mouse

Content:

Sources:

[1] L. P. Hariri, M. B. Applegate, M. Mino-Kenudson, E. J. Mark, B. D. Medoff, A. D. Luster, B. E. Bouma, G. J. Tearney, and M. J. Suter, "Volumetric optical frequency domain imaging of pulmonary pathology with precise correlation to histopathology," *Chest*, Jan-2013. [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3537541/. [Accessed: 29-Sep-2022].

[2] Lee, Anthony MD et al. "Wide-field in vivo oral OCT imaging". *Biomedical optics express* vol. 6,7 2664-74. 24 Jun. 2015. [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4505717/. [Accessed: 29-Sep-2022].

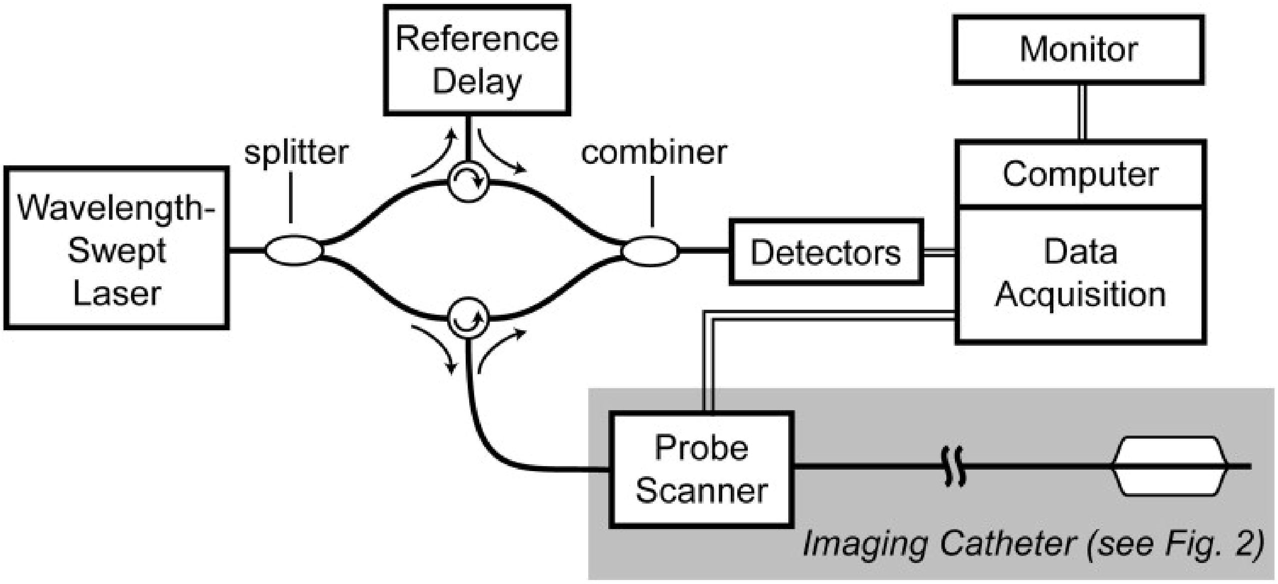
[3] B. J. Vakoc, M. Shishko, S. H. Yun, W.-Y. Oh, M. J. Suter, A. E. Desjardins, J. A. Evans, N. S. Nishioka, G. J. Tearney, and B. E. Bouma, "Comprehensive esophageal microscopy by using optical frequency–domain imaging (with video)," *Gastrointestinal Endoscopy*, 26-Mar-2007. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0016510706026691. [Accessed: 29-Sep-2022].

[1]

- "The technical details of OFDI have been described previously.5,6 Images were obtained at 10 to 50 frames/s with either custom-built bronchoscopic 2.4F to 5.1F (0.8-1.7 mm diameter) helical scanning catheters or a dual-axis benchtop scanner. The axial resolution of the OFDI system was 6 μm in tissue."
- Helical Catheter for probe geometry used on humans.
- Relatively simple to manufacture based on research for materials used
- Can be made cheap because not complicated in design
- safe design if soft and dull material used
- Fine tip makes it accurate
- reusable if covering used that is discardable

[2]

- "A prototype OFDI system was developed for endoscopic imaging. The system was used in combination with a balloon-centering catheter to comprehensively image the distal esophagus in swine."



- "A schematic of the OFDI system used in this study is shown in Figure 1. Light from a wavelength-swept laser was divided by a fiber-optic splitter into a reference arm and a sample arm. The sample-arm light was directed to a fiber-optic catheter (Fig 2), which was connected to the system by a scanner that allowed rotation and axial pullback of the catheter. The catheter delivered the source light to the area to be imaged, collected the reflected light, and returned this light to the OFDI system, where it was combined with light from the reference arm. The resulting interference signal was detected by a set of photo receivers and was recorded by a data acquisition unit. Data were passed to a control computer, which performed the processing required to generate and display images. The data-acquisition unit, in addition, controlled the catheter scanner and recorded the actual scanner position for each depth scan. This allowed for the correction of nonlinear catheter-scanner motion."
- Balloon on catheter for OFDI Imaging
- May be difficult in manufacturing due to the balloon being fragile and needs to be small enough for a mouse mucosa
- can be made cheap
- reusable if balloon is replaceable that is used as a covering
- safe if material is okay for mice
- does not really contribute to accuracy

[3]

An external file that holds a picture, illustration, etc. Object name is boe-6-7-2664-g001.jpg

Schematic diagram of endoscopic PSOCT system. SS = swept-source laser, PC = polarization controller, CIRC = circulator, C = collimator, POL = polarizer, RM = reference mirror, AIM = aiming laser, WDM = wavelength division multiplexer, FORJ = fiber optic rotary joint, RPC = rotary pullback catheter, PMFC = polarization maintaining fiber coupler, PBS = polarization beamsplitter, BD = balanced detector. Dashed (red) lines indicate PM fiber; all others are SM fiber. The SM and PM patch cables indicated within the dotted box can be removed to yield a standard (polarization-independent) OCT imaging system.

Conclusions/action items:

1) Discuss geometric ideas for probe with team

- Helical scanning catheter
- scanning catheter with balloon

2) Update Design Matrix based off of team criteria for geometry

2022/10/12 Helical Balloon Catheter

YASH SHAH - Oct 12, 2022, 2:55 PM CDT

Title: Helical Balloon Catheter

Date: 10/12/2022

Content by: Yash Shah

Present: Yash Shah

Goals: Have a viable probe design idea that can be used to optically image the airway of a mouse

Content:

Helical Balloon Catheter:

The helical balloon catheter design contains a small deflated balloon covering on the outside of a helical shaped catheter during insertion. Once the helical catheter has been inserted into the mucosa, the balloon is then inflated in order to stabilize the airway for accurate and safe imaging. The balloon would only cover the body of the catheter, leaving the tip exposed for the imaging probe. With nothing covering the imaging probe, there will be higher resolution with no extra artifacts. The dimensions of this catheter with an inflated balloon would be 1.0mm in diameter and 5.0mm in length. Figure 1 shows an image of the overall design of the catheter during insertion, where the balloon surrounds the body of the catheter waiting to be inflated for imaging. Figure 2 shows how the catheter will look during imaging with the balloon inflated to stabilize the airway.

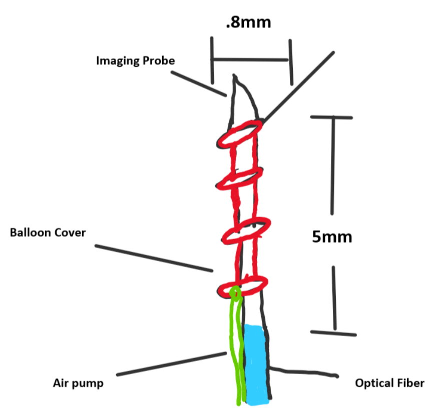


Figure 1: Helical Balloon Catheter with balloon deflated for insertion.

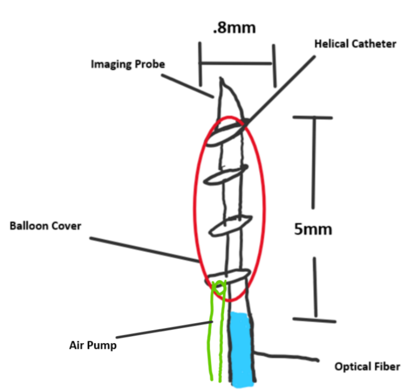


Figure 2: Helical Balloon Catheter with balloon inflated for stabilization during imaging.

Conclusions/action items:

Collaborate with team about all design ideas and decide which design idea will be implemented for our project.

Plan ways of fabrication of our design using the necessary materials and resources

2022/9/15 Tissue engineering airway mucosa: A systematic review

SOFIA CASTAGNOZZI - Sep 15, 2022, 11:01 AM CDT

Title: Tissue engineering airway mucosa: A systematic review

Date: 9/14/2022

Content by: Notes taken by Sofia Castagnozzi

Article written by: Nicholas Hamilton BSc, MBChB,Anthony J. Bullock BSc, PhD,Sheila MacNeil BSc, PhD,Sam M. Janes BSc, MBBS, MSc, PhD,Martin Birchall MA, MB, BChir, MD

Present: Sofia Castagnozzi

Goals: To conduct research on the functions of the Airway Mucosa

Content:

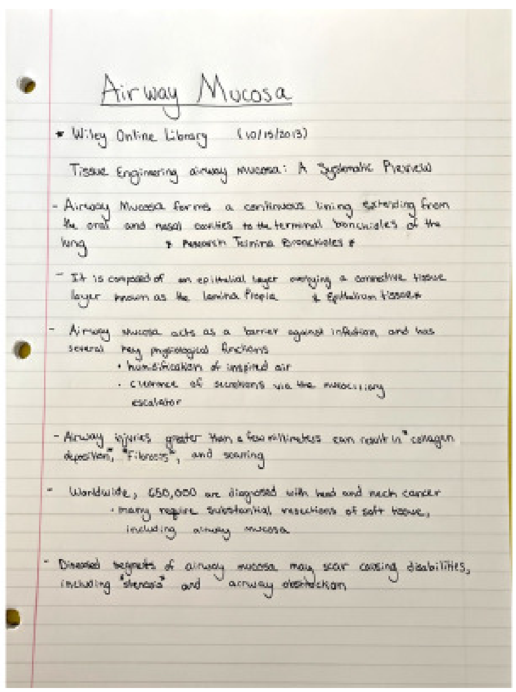
Research Notes attached below

Conclusions/action items: The Airway Mucosa serves an important function to overall bronchial health as it can act as a barrier to infections and clear out secretions from the airway. When damage is done to the Airway Mucosa many complications can arise such as scarring and Laryngotracheal Stenosis.

Sources: Hamilton, N., Bullock, A.J., MacNeil, S., Janes, S.M. and Birchall, M. (2014), Tissue engineering airway mucosa: A systematic review. The Laryngoscope, 124: 961-968. https://doi-org.ezproxy.library.wisc.edu/10.1002/lary.24469

https://onlinelibrary-wiley-com.ezproxy.library.wisc.edu/doi/full/10.1002/lary.24469

SOFIA CASTAGNOZZI - Sep 15, 2022, 10:50 AM CDT



[Download](#)

Airway_Mucosa_Reasearch_1.pdf (484 kB)

2022/9/15 High-speed optical frequency-domain imaging

SOFIA CASTAGNOZZI - Sep 15, 2022, 11:43 AM CDT

Title: High-speed optical frequency-domain imaging

Date: 9/15/2022

Content by: Notes by Sofia Castagnozzi

Article by: S. H. Yun, G. J. Tearney, J. F. de Boer, N. Iftimia, and B. E. Bouma

Present: Sofia Castagnozzi

Goals: To research and better understand the concept of OFDI

Content:

Notes attached below

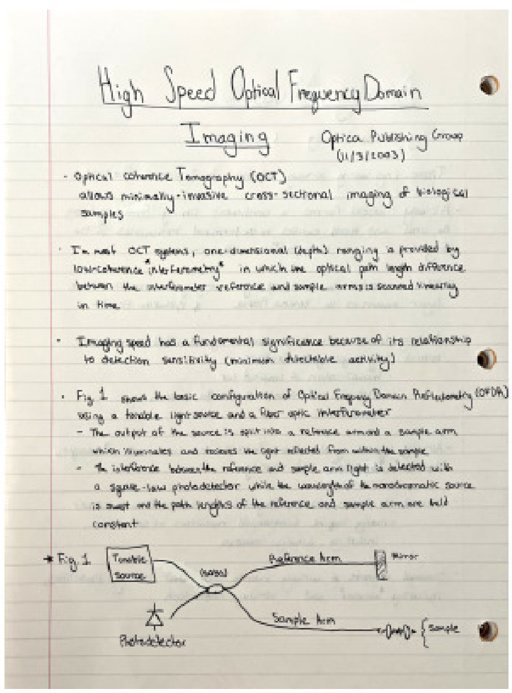
Conclusions/action items: The speed of imaging has a direct relationship with detection sensitivity, maximum sensitivity is optimal, however there are limitations on speed and exposure levels. The device itself is split into different components: the Reference Arm, Sample Arm, Mirror, Photodetector, and Tunable Source, and a detection current is used.

Sources:

S. H. Yun, G. J. Tearney, J. F. de Boer, N. Iftimia, and B. E. Bouma, "High-speed optical frequency-domain imaging," Opt. Express 11, 2953-2963 (2003)

https://opg-optica-org.ezproxy.library.wisc.edu/oe/fulltext.cfm?uri=oe-11-22-2953&id=77825

SOFIA CASTAGNOZZI - Sep 15, 2022, 11:49 AM CDT


High Speed Optical Frequency Domain Imaging

Optica Publishing Group (11/3/2003)

- Optical coherence Tomography (OCT) allows minimally-invasive cross-sectional imaging of biological samples
- In most OCT systems, one-dimensional (depth) ranging is provided by low-coherence "interferometry" in which the optical path length difference between the interferometer reference and sample arms is scanned linearly in time
- Imaging speed has a fundamental significance because of its relationship to detection sensitivity (minimum detectable activity)
- Fig. 1 shows the basic configuration of Optical Frequency Domain Reflectometry (OFDR) using a tunable light source and a fiber optic interferometer
  - The output of the source is split into a reference arm and a sample arm, which illuminates and receives the light reflected from within the sample
  - The interference between the reference and sample arm light is detected with a square-law photodetector while the wavelength of the monochromatic source is swept and the path lengths of the reference and sample arm are held constant

Download

OFDI_research_1.pdf (620 kB)

2022/9/22 OFDI and OCT Research

SOFIA CASTAGNOZZI - Sep 23, 2022, 1:08 PM CDT

Title: OFDI and OCT Technology on Esophagus

Date: 9/21/2022

Content by: Notes by Sofia Castagnozzi

Present: Sofia Castagnozzi

Goals: To research average length of OFDI and OCT imaging on esophagus

Content:

Attached Below

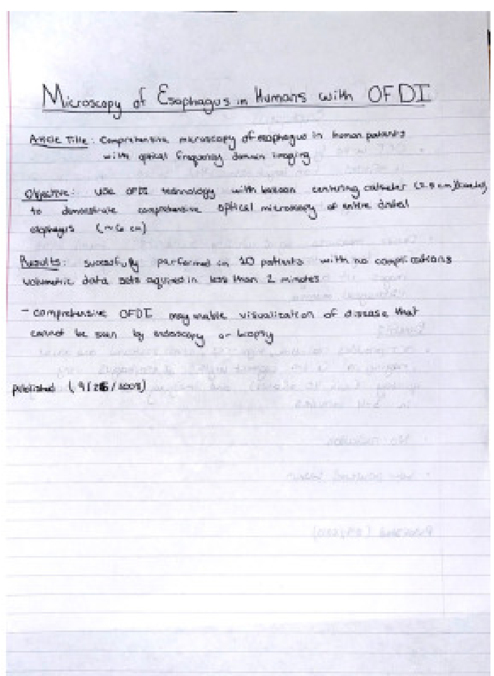
Conclusions/action items: Average length of imaging using OFDI is 2 minutes, OCT is 3-4 minutes

Sources:

M. J. Suter, B. J. Vakoc, P. S. Yachimski, M. Shishkov, G. Y. Lauwers, M. Mino-Kenudson, B. E. Bouma, N. S. Nishioka, and G. J. Tearney, "Comprehensive microscopy of the esophagus in human patients with optical frequency domain imaging," *Gastrointestinal Endoscopy*, 26-Sep-2008. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0016510708018361. [Accessed: 22-Sep-2022].

V. Kaul, "Optical coherence tomography for Barrett esophagus," *Gastroenterology & hepatology*, Apr-2018. [Online]. Available:https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6009188/. [Accessed: 22-Sep-2022].

SOFIA CASTAGNOZZI - Sep 23, 2022, 1:05 PM CDT



Microscopy of Esophagus in Humans with OFDI

Article Title: Comprehensive microscopy of esophagus in human patients with optical frequency domain imaging

Objective: use OFDI technology with balloon centering catheter (2.5 cm) [illegible] to demonstrate comprehensive optical microscopy of entire distal esophagus (~6 cm)

Results: successfully performed in 10 patients with no complications; volumetric data sets acquired in less than 2 minutes

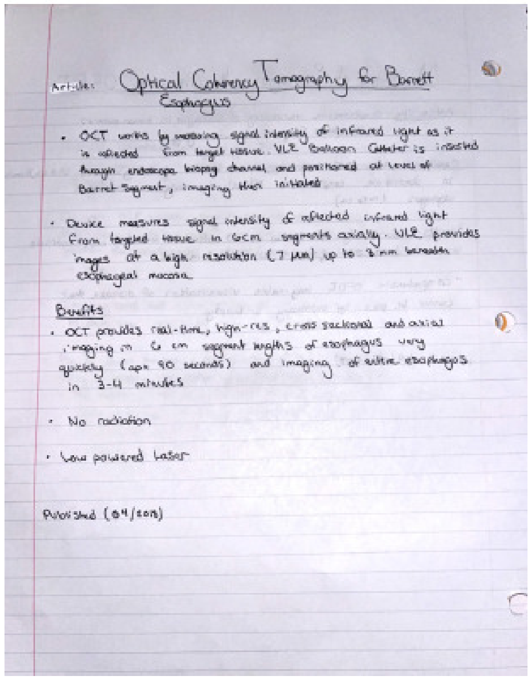
- comprehensive OFDI may enable visualization of disease that cannot be seen by endoscopy or biopsy

Published (9/26/2008)

Download

Microscopy_of_Esophagus_in_Humans_with_OFDI_1.pdf (545 kB)

SOFIA CASTAGNOZZI - Sep 23, 2022, 1:06 PM CDT


Article: Optical Coherency Tomography for Barrett Esophagus

- OCT works by measuring signal intensity of infrared light as it is reflected from target tissue. VLE Balloon Catheter is inserted through endoscope biopsy channel and positioned at level of Barrett Segment, imaging then initiated
- Device measures signal intensity of reflected infrared light from targeted tissue in 6cm segments axially. VLE provides images at a high resolution (7 µm) up to 3 mm beneath esophageal mucosa

Benefits

- OCT provides real-time, high-res, cross sectional and axial imaging in 6 cm segment lengths of esophagus very quickly (apx 90 seconds) and imaging of entire esophagus in 3-4 minutes
- No radiation
- Low powered laser

Published (04/2018)

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Optical_Coherency_Tomography_for_Barrett_Esophagus_1.pdf (735 kB)

2022/9/29 Miniaturized Single-Fiber-Based needle probe for Combined imaging and sensing in deep tissue

SOFIA CASTAGNOZZI - Sep 29, 2022, 12:45 PM CDT

Title: Research on Miniaturized OCT Probes

Date: 9/29/2022

Content by: Sofia Castagnozzi

Present: Sofia Castagnozzi

Goals: Conduct research on miniaturized OCT probes and the material used.

Content:

Attached Below

Conclusions/action items:

- The outer design of the probe is made from a biocompatible polycarbonate tube

- "Silicon is one of the best known materials for not exhibiting hysteresis and this study observed repeatable scanning along a straight line, crucial to consider the micromirror device for an OCT optical probe"

- This design used a probe 5mm in diameter

Action Item- Continue research on probe materials

Sources:

Xu, Y et al. “Design and Development of a 3D Scanning MEMS Oct Probe Using a Novel ...” *Design and Development of a 3D Scanning MEMS OCT Probe Using a Novel SiOB Package Assembly*, Journal of Micromechanics and Microengineering , 30 Oct. 2008, https://iopscience.iop.org/article/10.1088/0960-1317/18/12/125005.

SOFIA CASTAGNOZZI - Sep 29, 2022, 12:46 PM CDT

Journal of Micromechanics and Microengineering

In this article, it discussed the research and experimentation done with a MEMS optical coherence tomography probe prototype developed using a unique assembly based on silicon optical bench methodology.

- The probe is formed by integrating a 3D scanning micromirror, gradient refractive index (GRIN) lens and optical fiber on SiOB substrates having prefabricated self aligned slots.
- **The optical prove was enclosed within a biocompatible transparent and waterproof polycarbonate tube with a view of in vivo diagnostic applications**
- The general design of side-view scanning probes consists of a dynamic reflection and scanning mechanism (such as a mirror or a microprism) mounted at the tip of the probe to manipulate the focused beam from SMF or OCT imaging
- There is a trade off between the size of the probe and the quality of the OCT images
- In the case of miniature optics. The diameter of the probe restrict the overall dimensions of the micromirror/microprism and hence in a way constrains the overall efficiency of managing the light beam incident on the sample and scattered light from the sample
- A 3D scanning MEMS micromirror which was developed using a novel single substrate silicon on insulator (SOI) fabrication process, is a key component of the probe
- **The assembled optical probe was packaged within a biocompatible transparent and waterproof polycarbonate tube with a view of in vivo diagnostic applications**
- **As a result, the diameter of the miniaturized probe was designed to be less than 4mm and the length of its rigid part was about 25 mm**
- Electrothermal actuators require a very low drive voltage, which is an advantage in *in vivo* biomedical applications
- The mirror consists of a high reflective gold-chromium mirror plate, four flexural springs and four electrothermal bimorph actuators
- Silicon is one of the best known materials for not exhibiting hysteresis and in the study observed repeatable scanning along a straight line, crucial to consider the micromirror device for an OCT optical probe
- **In an earlier reported work, an OCT probe with less than 5 mm diameter was realized using acrylic sheath package assembly for housing and wire binding for electrical connection**
- **Another used a machined aluminum package with tiny screw sets for housing and optical alignment**
- **Those assembly solutions require precision mechanical machining and also labor intensive precision optical alignment, tedious and difficult for a manual process**

Download

Design_and_Development_of_a_3D_Scanning_MEMS_OCT_Probe_Using_a_Novel_SiOB_Package_Assembly.pdf (48 kB)

2022/9/30 Polycarbonate: High Performance Resin

SOFIA CASTAGNOZZI - Sep 30, 2022, 11:17 AM CDT

Title: Research on Polycarbonate

Date: 9/30/2022

Content by: Sofia Castagnozzi

Present: Sofia Castagnozzi

Goals: To conduct research on properties of polycarbonate resin and its use in medical devices

Content:

Attached Below

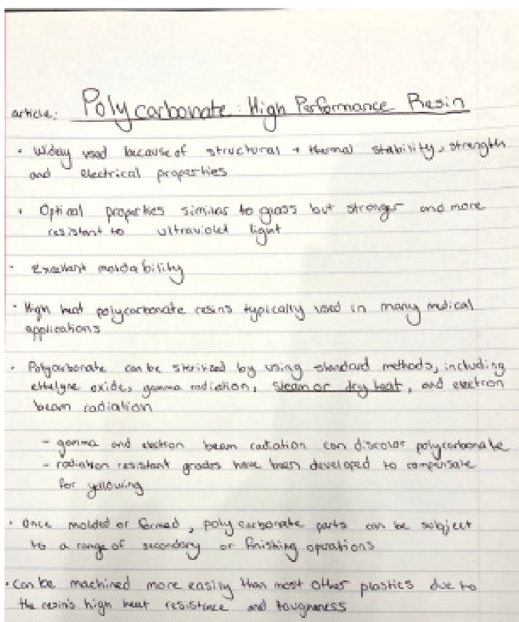
Conclusions/action items:

- Polycarbonate is easily moldable, has a high heat resistance, and is easily sterilized

Sources:

Lazear, N.R. "Polycarbonate: high-performance resin." Advanced Materials & Processes, vol. 147, no. 2, Feb. 1995, pp. 43+. Gale Academic OneFile, link.gale.com/apps/doc/A16639940/AONE?u=greenbay&sid=googleScholar&xid=bf2cc526. Accessed 30 Sept. 2022.

SOFIA CASTAGNOZZI - Sep 30, 2022, 11:20 AM CDT



article: Polycarbonate: High Performance Resin

- Widely used because of structural + thermal stability, strength and electrical properties
- Optical properties similar to glass but stronger and more resistant to ultraviolet light
- Excellent moldability
- High heat polycarbonate resins typically used in many medical applications
- Polycarbonate can be sterilized by using standard methods, including ethylene oxide, gamma radiation, steam or dry heat, and electron beam radiation
  - gamma and electron beam radiation can discolor polycarbonate
  - radiation resistant grades have been developed to compensate for yellowing
- Once molded or formed, polycarbonate parts can be subject to a range of secondary or finishing operations
- Can be machined more easily than most other plastics due to the resin's high heat resistance and toughness

Download

polycarbonate_high_performance_resin_1.pdf (461 kB)

2022/10/11 Silicone Rubber Properties

SOFIA CASTAGNOZZI - Oct 11, 2022, 7:03 PM CDT

Title: Research on Silicone Rubber

Date: 10/11/2022

Content by: Sofia Castagnozzi

Present: Sofia Castagnozzi

Goals: To research the properties of silicone material and its usage in biomedical technology

Content:

Attached below

Conclusions/action items: Silicone is a widely used material and is highly compatible with biomaterials. It is often used in catheter tubing, a similar structure to our probe design, making it an efficient material for our project.

SOFIA CASTAGNOZZI - Oct 11, 2022, 7:01 PM CDT

10/11/2022
Sofia Castagnozzi

Properties of Silicone

Silicone-based biomaterials for biomedical applications: Antimicrobial strategies and 3D printing technologies: Journal of Applied Polymer Science (2021)

- Silicone elastomers are available in a wide range of hardness, have good UV resistance, excellent thermal and chemical resistance
- It possesses good electrical properties, flame resistant, and allows sterilization using steam, autoclave, or gamma radiation.
- Silicone is highly permeable to gases, optically transparent, and easy to manufacture
- Silicone is highly biocompatible and bio-durable when interacting with host tissues
- Silicone is also generally unaffected by host tissue attack and repeated sterilization due to its widely recognized chemical and thermal stability
- Silicone elastomer is used as tubing for catheters or drains that requires it to be transparent, flexible, inert, lubricant, and biocompatible; insulation for electronic implants (pacemaker leads)
- Some key functional properties of silicone are
    1. Silicone elastomers are relatively firm and flexible
    2. Form stability under a wide range of temperature and chemical conditions.
    3. Hemocompatibility due to its hydrophobicity, thus retaining blood properties.
    4. Silicone has a high permeability to gases, including oxygen, carbon dioxide and moisture.
    5. It is inert, nontoxic, and nonbiodegradable.

Zare, Mina, et al. "Silicone-Based Biomaterials for Biomedical Applications: Antimicrobial Strategies and 3D Printing Technologies." Wiley Online Library, Journal of Applied Polymer Science, 1 July 2021, https://onlinelibrary.wiley.com/doi/full/10.1002/app.50969.

Download

Properties_of_Silicone_1_.pdf (34.6 kB)

2014/11/03-Entry guidelines

John Puccinelli - Sep 05, 2016, 1:18 PM CDT

Use this as a guide for every entry

- Every text entry of your notebook should have the **bold titles** below.
- Every page/entry should be **named starting with the date** of the entry's first creation/activity, subsequent material from future dates can be added later.

You can create a copy of the blank template by first opening the desired folder, clicking on "New", selecting "Copy Existing Page...", and then select "2014/11/03-Template")

Title: Descriptive title (i.e. Client Meeting)

Date: 9/5/2016

Content by: The one person who wrote the content

Present: Names of those present if more than just you (not necessary for individual work)

Goals: Establish clear goals for all text entries (meetings, individual work, etc.).

Content:

Contains clear and organized notes (also includes any references used)

Conclusions/action items:

Recap only the most significant findings and/or action items resulting from the entry.

2014/11/03-Template

John Puccinelli - Nov 03, 2014, 3:20 PM CST

Title:

Date:

Content by:

Present:

Goals:

Content:

Conclusions/action items: