BME Design-Fall 2023 - SOPHIA SPEECE
Complete Notebook

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JACK STEVENS

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Dec 13, 2023 @10:20 PM CST

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Team contact Information

LUCY O'CULL - Sep 13, 2023, 8:51 PM CDT

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Project description

Bodey CARTIER - Sep 15, 2023, 1:14 PM CDT

Course Number: 200/300

Project Name: Computed Tomography (CT) circulation phantom to assess hyperdynamic contrast flow rates

Short Name:

Project description/problem statement:

About the client:

9/21/23 - First Client Meeting

Will Stephenson - Sep 21, 2023, 2:01 PM CDT

Title: First Client Meeting

Date: 9/21/23

Content by: Will

Present: Team

Goals: Meet with client, get a preliminary idea of what we are building, and get some of our questions answered

Content:

- CT scan
    - "big donut" that uses a radiowaves to image pieces and systems in a patient
    - Uses contrast to make systems easier to see
    - Dependent on weight, blood volume, flow rate, etc. for how much/can we use
    - There's an issue in being able to do make determination for ECMO patients
    - VV-ECMO is bypassing lungs
    - VA-ECMO is bypassing both lungs and heart, external lungs and heart
    - They aren't experts in it
    - Look for Josh
    - Issues:
        - Patients are sick, and not sure where
        - Have to get a whole CT Scan
    - VA-ECMO shoots blood in a different direction
    - If flow rate is too high, there could be issues with the different directions of blood and contrast, in the past it has been a guessing game
    - Doesn't have to be fancy
    - Ours is not a static object
    - Need to be able to look at contrast dynamically
    - Develop a prototype phantom to allow for CT and VA-ECMO groups to work together
    - Seeing more use on ECMO
    - Used to do it w/out contrast
    - Not much on VA-ECMO
    - VA-ECMO shoots blood very fast
    - It is not a natural system
    - Success can be dependent on catheter and other variables
    - No one has really developed a phantom for this
    - There are multiple scanners on multiple sites, very possible to get testing time
    - People with experience with contrast
    - VA-ECMO team can help with designing
        - May not have to make the whole thing, might just have to make the phantom to hook up to the ECMO
    - We should get the manuals/a dying ecmo
    - Could get help from a manufacturer who makes a flow rate phantom
    - Are we using an ECMO machine to pump, or are we using our own?
        - Ecmo is a pump. If there isn't one, then we can just use an off the shelf one. Prefer to get an older ECMO machine with a pump
    - Some patients have differing amounts of heart function, added variable.
    - Arterial Contrast is probably what we are working with
    - Timing would be possible
    - Could get a 3D printed heart
    - A lot of people working with imaging
        - Could connect with other people working on making simulated system
    - Oliver?
    - Alejo?
    - Kevin Johnson?
    - What do you mean by timing?
        - Don't need to conquer it
        - ECG is only half of it, EKG is unmeasurable
    - Could be reservoir or circuit based
    - Send progress reports to Giuseppe, Meg, and Timothy

Our Client Questions:

- What are the main goals/desired outcomes for the project? What are their expectations?
- Is there a certain design shape that the clients are looking for?
    - Mimicing circuit design rather than body, but no real shape is required.
    - There needs to be a more constant ECMO rate and a variable contrast injector, assuming cardiac function is zero
    - torso phantom, some venuos return to heart, ECMO return, contrast media injector
    - Get in the lab with MR
    - Connections for 3D printing
    - We have access to a clinical injector
    - If no ECMO, simulating pump at similar rate (~500ml/s)
    - Variable pump would be preferrable
- How often or how many times are they looking to use the device?
    - Continuous use, use cycles of about a minute
    - Dependent on contrast
    - Has to be robust
    - Have to have a good cleaning protocol
        - Could be just water, but TBD
    - PBS vs Water, if PBS is more expensive, just using water. PBS viscosity varies with temp
    - Heating component of ECMO machine?
- Do the clients want a user-friendly way to adjust flow rates?
- What measurements are needed to be gained from testing the device?
    - Houndsfield unit. Calibrated unit for CT. Higher = more contrast
    - Workhorse metric from imaging
    - Also times
    - All of the other variables, and flow rates
    - End goal is enhancement, from 10 Houndsfield to 600
    - Should be able to adjust input/output
- Do the clients have other phantoms that they can show us to better understand the design process?
- How similar must the phantom be to a real human/ ECMO machine?
- How similar does the phantom heart have to be to the actual heart? (For example, does it need all valves/chambers?)
- What is the budget?
    - Hundreds of dollars? Unsure of budget, but if there are costs just contact clients
    - Base Budget?
- Do you know of any similar products?
- How often will we be able to test the device? What would testing the device look like?
    - Can do it very frequently, on a daily basis, at least with in terms of hardware
    - We can schedule with technicians, do it within a

- Weight has to be within 500lbs
- Metal streaks exist if we use metal, blocking images

- Will the contrast be provided? (are we fabricating the contrast as well?)
- We are making one, correct?
  - Yes
- What work has been completed thus far on this product?
- What are the dimensions of the CT (ie how big of a space does the phantom/design have to work with?)
  - Largest is 78cm, but should be able to go and see it to see just general space
- How long would you typically run a test?
  - About a minute

Conclusions/action items:

Will Stephenson - Sep 21, 2023, 1:09 PM CDT

CARDIAC IMAGING

CT Angiography of Venoarterial Extracorporeal Membrane Oxygenation

SA-CME LEARNING OBJECTIVES

Online supplemental material is available for this article.

Introduction

An earlier incorrect version of this article appeared online and in print. This article was corrected on February 14, 2022.

[Download]

shen-et-al-2021-ct-angiography-of-venoarterial-extracorporeal-membrane-oxygenation.pdf (4.43 MB)

10.2.23 WIMR Meeting

EMMA FLEMMER - Oct 02, 2023, 6:07 PM CDT

Title: Meeting with James Rice from the Wisconsin Institutes for Medical Research

Date: 10/02/2023

Content by: Emma Flemmer

Present: Emma Flemmer, Lucy O'Cull, Sophie Speece, Jack Stevens

Goals: Learn more about the phantoms in the WIMR and get input on the team's potential design ideas

Content:

- James showed the team a retired negative space phantom of the left ventricle of the heart

- The WIMR creates these phantoms by 3D printing the parts of the heart in a dissolvable material, placing the parts in a container, pouring silicone or some material around it, and lastly dissolving the 3D printed parts leaving the imprint of the heart in the silicone

- He believed that the easiest design to fabricate would be a closed loop negative space phantom

- The team and James discussed different parts of the heart that needed to be present in the final design and brainstormed the best approach to model it in a simple way without compromising too much anatomical accuracy

- He thought it would be useful to have a water meter somewhere on the tubing to ensure that the flow rates trying to be produced by the pump are accurate to the flow rate actually running through the phantom

- He recommended that the injection site be the same or similar distance away from the heart that it is in the actual procedure in order to ensure similar diffusion of contrast

- James said the team will likely be able to borrow some tubing as well as an ECMO pump from the WIMR to use in the design. He also believes that he has a STL file of a heart that the team would be able to use and work off of

Conclusions/action items:

Apply this knowledge when deciding which design to move forward with.

10.23.23 James Rice Meeting

SOPHIA SPEECE - Oct 23, 2023, 6:20 PM CDT

Title: Meeting with James Rice in ME

Date: 10.23.23

Content by: Sophie

Present: Sophie, Lucy

Goals: Learn more about how to take a DICOM and turn it into a 3D model

Content:

- Softwares: Mimics and 3-digitize I think?
- Will provide tubing and pump
    - Can use ECMO but it can't leave the med school building
    - Want the roller pump to test/practice with
    - Should see the ECMO pump to see if it is easy to connect the tubes to both pumps, otherwise just stick to the roller pump.

Conclusions/action items:

Make the heart :)

12.6.23 Client Meeting - CT Testing

SOPHIA SPEECE - Dec 13, 2023, 8:33 PM CST

Title: Client Meeting - CT Testing

Date: 12.6.23

Content by: Sophie, Team

Present: Team

Goals: Test flow phantom with iodinated contrast and take CT images, get feedback from client regarding project progress

Content:

- CT Testing
  - Ran pump at dial 10 (about 3.5-3.75 L/min)
  - Luer-lock was too tight to fit their iodine injector, used an adaptor piece and tape to keep it in place
  - Took 24 series with 86 pictures per series for the scan
  - Ran the pump for half a second before beginning contrast administration
  - We got some data output, the attenuation in the same location at different times throughout the test
  - A bit of leakage, but nothing burst because of too much pressure
- Feedback
  - Great first start and proof of concept
  - In the future might want to see some "heart function" working against the flow of VA_ECMO
  - Hopefully can get a more powerful pump, even a real ECMO machine to use for testing

Conclusions/action items:

Present this information in the presentation and final report

9.8.23 Meeting - Initial Meeting

SOPHIA SPEECE - Sep 08, 2023, 1:58 PM CDT

Title: Initial Meeting with Prof. Williams

Date: 9.8.23

Content by: Sophia Speece

Present: Team, Advisor

Goals: Meet

Content:

- Decide on a time to meet as a team, both with and without advisor
  - ADVISOR MEETING: likely Friday 1:30-2:00, COMMUNICATOR send an email to advisor to request time and location (1153 ME?)
    - (any time from 12-2 works, but after 1pm is preferred because Sophie has a class 12-1)
  - TEAM MEETING: Mondays at 6:30 (locations to vary)
    - Sept 11th at College Library, room 3215
- COMMUNICATOR send an email to the client introducing the team and asking about meeting availability

Conclusions/action items:

- Begin preliminary research, look over Project Details on BME website. Be prepared for first meeting on Monday.

9.11.23 Team Meeting

Will Stephenson - Sep 18, 2023, 8:05 PM CDT

Title: First Team Meeting!

Date: 9.11.23

Content by: Sophie Speece

Present: Team

Goals: Choose a time to meet with our client, begin research and discussion on CT Circulation Phantom

Content:

- Introductions again (if we want)
- Announcements:
  - Upcoming assignments due:
    - Notebook check Thursday 9/14
    - Advisor meeting in 1153 ME on Friday, 9/15. Time TBD (sometime between 12 and 2pm)
    - PRODUCT DESIGN SPECIFICATIONS due Friday, 9/22 at MIDNIGHT
      - Must be uploaded by BWIG and BWIG only: one copy per group
      - A document has been started in PROJECT FILES (under Team Activities). Do not worry about it quite yet, but additional information about how to write a PDS and what the purpose is can be found here on the BME design website: https://bmedesign.engr.wisc.edu/course/resources
        - Do we want to create a shared doc of some sort?
      - Once completed, must be submitted to Canvas, uploaded to the website, and advisor and client emailed with file website link (BWIG and COMMUNICATOR)
    - TEAM LEADER, COMMUNICATOR, and BWIG: Compile progress report (TEAM LEAD), BWIG post to website, COMMUNICATOR email file website link to advisor and client, cc the team.
  - BSAC Meeting Friday, 9/15 at 11 am
- Client Meeting
  - Logistics
    - When? 9/21 Thursday, 1-2pm
    - Where? COMMUNICATOR (or someone) email client about where
    - Who can make it? Bodey, Will, Sophie, maybe: Emma, maybe: Lucy
  - Client questions. What do we want to ask the client to gain more insight about the project? It is useful to look at the PDS for guidance.
    - What are the main goals/desired outcomes for the project? What are their expectations?
    - Is there a certain design shape that the clients are looking for?
    - How often or how many times are they looking to use the device?
    - Do the clients want a user-friendly way to adjust flow rates?
    - What measurements are needed to be gained from testing the device?
    - Do the clients have other phantoms that they can show us to better understand the design process?
    - How similar must the phantom be to a real human/ ECMO machine?
    - How similar does the phantom heart have to be to the actual heart? (For example, does it need all valves/chambers?)

    - What is the budget?
    - Do you know of any similar products?
    - How often will we be able to test the device? What would testing the device look like?
    - Will the contrast be provided? (are we fabricating the contrast as well?)
    - We are making one, correct?
    - What work has been completed thus far on this product?
    - What are the dimensions of the CT (ie how big of a space does the phantom/design have to work with?)
    - How long would you typically run a test?
- Preliminary research. Has anyone found anything interesting or cool?

Conclusions/action items:

- When and where are we meeting next week?
- See also announcements

9.15.23 Advisor Meeting

Will Stephenson - Sep 15, 2023, 1:20 PM CDT

Title: Advisor Meeting

Date: 9.15.23

Content by: Sophie Speece, Will Stephenson

Present: Team, Prof. Justin Williams

Goals: Update advisor about our progress, receive feedback on current efforts. Divide PDS to begin

Content:

- Progress report
    - Looks good
- General Advisor meeting agenda
    - Past week events
    - Next week goals
    - Talk about deliverables details
- Past week events
    - Meeting
        - Talked about client meeting
        - Talked about client questions
        - Talked a bit about PDS timeline
    - Research
        - VA-ECMO
        - What we are specifically building
        - Computed Tomography
        - Existing CT Phantoms
- Upcoming goals
    - PDS
    - Three designs
- General Comments from Advisor
    - Figure out how often we can benchmark and test
    - Start working on the design process ASAP
        - Work out fine details
        - Figure out what works and what doesn't early
    - If there are common components, get them once you find them. Don't wait
        - If the client has some of the required materials, utilize them
    - Do research on Static CT Phantom (the ones described in the project desc)
        - There might be ideas/materials used in those devices that can help with the final designs
    - Do research on flow system Phantoms
        - Look at the pumps and other hardware pieces to help with design
    - Client thinking we are Seniors should be fine
        - If they have any questions about it, just direct questions to advisor
    - Notebooks
        - Good job, everyone has a lab entry
        - Generally, look at progress report and make sure there's also things in the notebook to match it
        - Anything you do should be in the notebook
        - Do labarchive entries once you complete something, or do it congruently

Conclusions/action items:

- Announcements:
    - Upcoming assignments due:
        - Notebook check Thursday 9/21
        - TEAM LEADER, COMMUNICATOR, and BWIG: Compile progress report (TEAM LEAD), BWIG post to website, COMMUNICATOR email file website link to advisor and client, cc the team 9/22
        - Advisor meeting in 1153 ME on Friday, 9/22 1-1:30pm
        - Client meeting 9/21 on Zoom 1-2pm
        - PRODUCT DESIGN SPECIFICATIONS due Friday, 9/22 at MIDNIGHT

    - Once completed, must be submitted to Canvas, uploaded to the website, and advisor and client emailed with file website link (BWIG and COMMUNICATOR)
    - A document has been started in PROJECT FILES (under Team Activities). Do not worry about it quite yet, but additional information about how to write a PDS and what the purpose is can be found here on the BME design website: https://bmedesign.engr.wisc.edu/course/resources
    - Must be uploaded by BWIG and BWIG only: one copy per group
- No BSAC meeting this week (9/22)

9.18.23 Team Meeting

SOPHIA SPEECE - Sep 18, 2023, 8:09 PM CDT

Title: Team Meeting

Date: 9.18.23

Content by: Sophie Speece

Present: Team

Goals: Updates on research, PDS, and maybe design ideas

Content:

- Announcements/upcoming
  - Thursday 9/21
    - Client meeting via Zoom at 1pm
      - COMMUNICATOR to write follow up email to confirm Zoom time and get link sent out
    - 2nd progress report due by 5pm (emailed to client, advisor, and posted to website)
  - Friday 9/22
    - Product Design Specifications (first draft) due by 1pm (technically midnight, but we should get feedback from our advisor as soon as we can)
    - Advisor meeting 1pm
  - Monday 9/25
    - Team meeting (6:30pm 3205 college lib)
    - Every come with one or two designs (sketches are great!) so that we can compile them
  - Thursday 9/28
    - Progress report 3 due by 5 pm
    - Design matrix criteria and 3 design ideas due (no due date/time given, but they must be included in this weeks progress report
  - Friday 9/29
    - BSAC Meeting at 11am in 2305 E-hall
    - BPAG Meeting 12:05-12:30pm (I am not seeing a location, perhaps it is online?)
- PDS
  - How is it coming along? Any questions or concerns?
  - Jack has made progress, good references
  - Discussed it's going to be challenging with due date close to client meeting but we plan to have a majority done prior to meeting.
- Research
  - Jack
    - Device with 2 **3D printed** components to develop quantification for CT imaging for dynamic flow rates
    - PAFC platforms with fast moving cells which does not work with static phantoms, need to simulate optical properties of blood cells and melanoma markers
  - Sophie
    - Circulation phantom to study different injection rates, 3D printed models of different cardiovascular systems. Pulsatile pump.
    - Another research study on delivery rates. Defined homeostatic physiological conditions.
- Design Ideas?

  - Anyone happen to have any preliminary designs? We can start discussing designs if we wish.
  - Not yet planning to
- Client questions. What do we want to ask the client to gain more insight about the project? It is useful to look at the PDS for guidance.
  - What are the main goals/desired outcomes for the project? What are their expectations?
  - Is there a certain design shape that the clients are looking for?
  - How often or how many times are they looking to use the device?
  - Do the clients want a user-friendly way to adjust flow rates?
  - What measurements are needed to be gained from testing the device?
  - Do the clients have other phantoms that they can show us to better understand the design process?
  - How similar must the phantom be to a real human/ ECMO machine?
  - How similar does the phantom heart have to be to the actual heart? (For example, does it need all valves/chambers?)
  - What is the budget?
  - Do you know of any similar products?
  - How often will we be able to test the device? What would testing the device look like?
  - Will the contrast be provided? (are we fabricating the contrast as well?)
  - We are making one, correct?
  - What work has been completed thus far on this product?
  - What are the dimensions of the CT (ie how big of a space does the phantom/design have to work with?)
  - What will actually be flowing through the device? Besides iodinated contrast, what will need to be included in the liquid? Are there certain things that the clients are looking for in their tests that need to be included?
  - Is there a method of a control for testing to base our testing values off of?

Conclusions/action items:

- See announcements for upcoming action items and events. Continue research, begin design brainstorm. Don't forget to put your ideas into your folder in the Labarchives!

9.22.23 Advisor Meeting

Bodey CARTIER - Sep 25, 2023, 4:16 PM CDT

Title: Advisor Meeting, post PDS first draft

Date: 2023/09/22

Content by: Bodey Cartier

Present: All

Goals: Speak with advisor and address concerns about PDS and project.

Content: Is consistency or accuracy more important?

We want to know the mean across trials and the variance between trials. Simple analysis of variance can give insight into consistency. It's not just if we are getting the same answer, but also how accurate that answer is.

There is no standard to use against a T-test.

Still have to decide which portion of the cardiovascular system for phantom.

4 components for the device.

Research into governing equations of fluid dynamics.

- What flow regime ‘these’ are in. 6 ml/s could be laminar but at 60 it could turn turbulent.
- Calculating Reynolds number for the flow regimes would give a good estimate.
- Different flows have different flow regimes which make interaction unpredictable and difficult to calculate.

If we can’t get the ecmo, we can find something to mimic its flow characters–if it comes to that.

Think about fluid components:

- Tubes embedded
- Phantom has voids in it to make the tubing.

Conclusions/action items:

- Research governing fluid dynamics equations.
- Follow up with the ECMO team to figure out if we need to use a pump instead.
- Learn what part of ECMO the client wants us to simulate if we do not get ECMO.
- Design Matrix is due next Friday 09/29.
- Get preliminary designs that are fundamentally different to be used in a design matrix. We may have to make multiple for various components.
- Think about preliminary design presentation.

Bodey CARTIER - Sep 25, 2023, 4:17 PM CDT

Title: Advisor Meeting, post PDS first draft

Date: 2023/09/22

Content by: Bodey Cartier

Present: All

Goals: Speak with advisor and address concerns about PDS and project.

Content: Is consistency or accuracy more important?

We want to know the mean across trials and the variance between trials. Simple analysis of variance can give insight into consistency. It's not just if we are getting the same answer, but also how accurate that answer is.

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Think about fluid components:

- Tubes embedded
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Conclusions/action items:

- Research governing fluid dynamics equations.
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- Think about preliminary design presentation.

Download

9.22.23_Advisor_Meeting.docx (17.8 kB)

9.25.23 Team Meeting

SOPHIA SPEECE - Sep 25, 2023, 7:47 PM CDT

Title: Team Meeting - Preliminary Designs

Date: 9.25.23

Content by: Sophie Speece

Present: Team

Goals: Come together with design ideas, decide on three and on design matrices

Content:

- Announcements/Upcoming
    - Thursday 9/28
        - Progress Report 3 by 5pm
        - Preliminary Designs and Design Matrices (to be included with the Progress Report)
    - Friday 9/29
        - BSAC Meeting11am in 2305 E-hall
        - BPAG Meeting 12:05-12:30 (no location listed, might be online)
        - Advisor Meeting 1pm in ME
    - Monday 10/2
        - Team Meeting (College Library 3205 at 6:30)
        - May also want a shorter meeting/zoom to practice giving the presentation before Friday)
    - Friday 10/6
        - Preliminary Presentation (presentation at 12pm, slides due in Canvas by 10am)
- Emails - do we want to email the people Dr. Toia connected us with to meet?
    - COMMUNICATOR will send emails to the person who initially reached out about having phantoms.
        - Can we come and see what you have? To borrow? At least an idea of fabrication?
        - Not worried about time, don't need to meet soon but good to get communication and plans rolling.
        - Not something everyone has to be there for
    - Talk with Josh about ECMO, see if he has one, otherwise a good point of contact for questions
        - Mostly need the flow rates, not how to oxygenate blood or the other fancy things
    - Reach out to Heart Phantom client as well, they did send heart phantom slides for us to use as well
        - They told us where they got the 3D print from
    - Maybe the MR people?
- Preliminary Designs
    - Lets see some designs
        - Lucy
            - HEART
            - Not able to model pulmonary system, "plug up" or make short tubes to shoot flow back into the main area
            - 3 main parts: pulmonary artery, aorta, main venous return
            - Encase heart in water in the phantom to model human tissue attenuation
        - Bodey
            - Box phantom, use negative space to let the water move through
            - Pump: centrifugal pump
            - Injector goes into vena cava, will mix with ECMO circuit
            - Use arduino and code to control and/or monitor injection rates and/or ECMO circuit
            - We know flow rate of 500ml/sec at the pump, but how does that translate to the flow rates inside the heart? Do we need to measure that? Or just the effect of the external flow rate ON the stuff in the heart.
        - Jack
            - Difference between VV and VA-ECMO, "come in" from below, both come in and enter the same spot
            - where should the contrast injector go? Diff than ECMO draw and return
            - Pump: they don't think they have one for us
                - ECMO actually uses the centrifugal pumps, newer and smaller
                - 3 types of centrifugal: radial flow, mixed flow and axial flow
                    - radial: displaces water outwards at 90 degrees to shaft
                    - mixed: in between, 35-80 rpm or 80-160
                    - axial: "specific speed is faster", (what is that) water is parallel to rotary

            - can have multiple impellers, 1 stage (large flow rate) 2 stage, or multistage (3+)
        - Phantoms
            - some are made of gelatin or silicone
        - Make your own flowmeter
            - can be purchased but are expensive
            - a section of tubing with a propeller, you know the diameter of the tube and can therefore calculate the flowrate with the diameter and speed of the propeller.
            - With water sensor DN80 and arduino (maybe even include a touch screen)
    - Will
        - Vena cava, fabricate plastic piece so injection can happen at several points within the vena cava, this is also something that can be studies
        - acrylic box
            - what size? will length of tubing effect flow rates?
            - do we want a closed or an open system? If in a closed system, the contrast might keep coming around, whereas an open system more accurately mimics the blood coming from and returning to the body
                - ALSO an open system will be much easier to clean
    - Emma
        - Pumps!
            - Centrifugal and roller pumps. The former has more complications but are more commonly used. Better for in vitro then in vivo
            - both expensive :/
    - Sophie
        - Presentation, divided into 4 parts, but only have matrices for the first two categories
            - combine the last category into the first section (Circulation Phantom)
  - Design criteria
    - Design Matrices for Circulation Phantom and ECMO Circuit, not for the injector nor the flow inlet/outlet
        - Do we include the the latter somehow?
  - Make the matrices
    - Design weight, descriptions and criteria descriptions due wednesday night so everyone has a chance to look them over before Thursday.
  - Split up the writing work
    - Everyone highlight/comment sections you are willing to work on, three each
    - Design Ideas: describe each idea in detail
    - Design criteria: describe each criteria, why it was chosen, why it has the weight it has, and why each design was given the rating it was.
- Maybe possibly start preliminary presentation if time allows
  - Time did not allow :(
- Other items
  -

Conclusions/action items:

Finish assigned sections in the Design Matrices, work on Progress Report 3

9.29.23 Advisor Meeting

SOPHIA SPEECE - Sep 29, 2023, 1:31 PM CDT

Title: Advisor Meeting - Preliminary Designs

Date: 9.29.23

Content by: Sophie, Team

Present: Team

Goals: Receive preliminary design feedback, receive PDS feedback

Content:

- Go through schedule
  - Dr. Puccinelli email - about presentation next Friday.
  - Includes presentation requirements and grading criteria
- Preliminary Designs
  - Color code/highlight the winner in each category
  - What was driving each score? How did it clearly differentiate?
  - Don't just read the numbers, hone in on the important ones
  - Look at numbers in the tables, make sure they are correct
  - compare pulsatile pump and centrifugal pump again
    - Adjustable flow rates
    - Cost
  - Pulsatile pumps and centrifugal pumps looked about the same to Prof. William's knowledge (not the same one as used in a ECMO)
    - Want to find a DC pump, control directly with an arduino, only about a couple hundred dollars.
    - SICCE makes some of the best DC fluid pumps, Prof. Williams has used these before, flow rate is proportional to the flow rate.
    - Also depends on what kind of flow rates are needed, the 100$ is probably plenty
    - Prof. Williams might also have a DC pump in his lab for a worst case scenario.
- No further feedback for the PDS at this time, make sure it aligns itself well with the criteria, check design matrix versus PDS. Criteria come directly from client requirements
- Prof. Williams is happy to answer questions via email
- How will injector mech with the flow system? Find a computer simulation, how are these fluids moving with each other?
  - Solidworks, you can simulate fluid flow
  - Probably overkill, but something to think about
  - Basic equations are just ohms law for fluid flow. Fluidic resistance, fluidic flow (current) and fluid flow (similar to voltage)
    - resistance is a function of tube diameter and length
  - Are the materials going to withstand the pressure?
  - Equations for when two fluid come together
    - overall flow rate (additive)

Conclusions/action items:

Preliminary presentation!

Revisit Design matrices (esp. for VA-ECMO Circuit)

10.2.23 Team Meeting

SOPHIA SPEECE - Oct 02, 2023, 7:09 PM CDT

Title: Team Meeting - Preliminary Presentation

Date: 10.2.23

Content by: Sophie, Team

Present: Team

Goals: Revise preliminary designs, begin and work on Preliminary Design Presentation

Content:

- Upcoming/Announcements
  - Thursday 10/5
    - Progress report due by 5 pm
    - Do we want a zoom meeting to practice the presentation? Or just run through a few minutes before class on Friday?
      - Yes, when? Wednesday at 9:15 via zoom (have assigned presentation sections complete by then preferably)
  - Friday 10/6
    - Preliminary Presentation slides due on Canvas and project website by 10 am (BWIG)
    - Everyone must attend the full class period on Friday 12:05-2:00 in 1153 ME
    - Our presentation is at 12:50 (we are 4th)
      - 10 minutes of presenting, 5 minutes for questions
    - Send a reminder email to client inviting them now that we have exact details
      - We can also email them the slides
    - **Presentation and report guidelines:** Review the documents for presentations and reports on the design course webpage: http://bmedesign.engr.wisc.edu/course/resources/

      Review documents on oral presentations

      Review documents on written reports

      Review documents on design notebooks
  - Monday 10/9
    - Team meeting (6:30, E-Hall somewhere)
  - Wednesday 10/11
    - **Preliminary Deliverables Due** (preliminary report, preliminary notebook, peer and self evaluation)
- Preliminary Designs Revision
  - Add colors
  - Look at VA-ECMO table again
  - Pull from information from WIMR meeting today
- Preliminary Presentation
  - Assign sections
  - work on sections
  - other
- Other

Conclusions/action items:

Preliminary report slides, meet virtually on Wednesday to practice

10.5.23 Team Meeting

SOPHIA SPEECE - Oct 05, 2023, 10:59 AM CDT

Title: Team Meeting - Practice

Date: 10.5.23

Content by: Sophie Speece

Present: Team

Goals: Practice presentation out loud

Content:

- Changed "image" to "figure"
- Updated Design Matrix
- Cited images
- Practiced the presentation outloud
    - Will we have a computer to look at? Otherwise memorize most of the slides
    - Was 12 minutes, goal is for 10. However, paused to ask questions

Conclusions/action items:

Present!

10.6.23 Class Meeting - Preliminary Presentations

SOPHIA SPEECE - Oct 06, 2023, 2:09 PM CDT

Title: Preliminary Presentations - Whole Class

Date: 10.6.23

Content by: Sophie

Present: Team

Goals: Present, listen to presentations, give and receive feedback

Content:

- Analysis of Insulating Properties of Skin Rodent
- Radiopharmaceutical Automation Setup
- Balloon Dilation Device
    - What is reverse sneezing?
- Us!
- Dual Handheld and Video Otoscope
    - How expensive are the really small cameras?
- Dynamic Balance Device
    - 25-80% of stroke survivors is a long range, do we know why?
    - Does the display require electronics?
- Intraoperative Patient Warming Device
- Phantom

Conclusions/action items:

10.9.23 Team Meeting

SOPHIA SPEECE - Oct 09, 2023, 6:52 PM CDT

Title: Team Meeting - Preliminary Report

Date: 10.9.23

Content by: Sophie, Team

Present: Team

Goals: Begin work on preliminary report

Content:

- Upcoming/Announcements
  - Nice job on the presentation everyone!
  - Wednesday 10/11
    - Preliminary Report due 11:59pm, BWIG upload to Canvas and website, COMMUNICATOR email link from website to client
    - Preliminary Notebook due 11:59pm, to be uploaded to canvas
    - Complete peer and self evaluation via Feedback Fruits
  - Friday 10/13 (spooky)
    - BSAC Meeting 11:00 am in 2305 E-hall
    - BME Advising day 12:05 am in 1003 ECB - not required but recommended (esp for 300)
    - Client meeting 1:00 pm either 1156 ME or zoom
  - Monday 10/16
    - Team meeting (College Library room 3215, 6:30)
- Discuss building a timeline for the project - we don't have any assignments officially sue until the final design deliverables in December, so keeping ourselves on track is important
- Discuss splitting into teams for research, obtaining materials, and fabrication
  - List of needed materials
- Preliminary report - split up the work
  - All figures must have captions
  - Number all the pages
  - Use SI units
  - PDS should be in the appendix
  - Format nicely with titles and subtitles
  - Use correct sig figs
  - Use a space between the number and the unit 40cm bad 40 cm good
  - Use Roman abbreviations

Conclusions/action items:

Sections are assigned, do them before wednesday!

10.13.23 Advisor Meeting

SOPHIA SPEECE - Oct 13, 2023, 1:18 PM CDT

Title: Advisor Meeting

Date: 10.13.23

Content by: Sophie, Team

Present: Team

Goals: Schedule for next 3 weeks, preliminary presentation feedback, plan woo

Content:

- Next Preliminary Deliverable is Show and Tell!
    - Want to have something ready for that
- Advisor out of town on October 27th, no meeting
- This week feedback fruits due tomorrow night (10/14)
- Preliminary Presentation
    - We did very well :) Congrats!
    - Nit picky comments
    - Look at Dr. Yasolkoi's comments more, has "fresh" outlook
    - PDS Design constraints: being more specific, putting numbers where able, will also help drive the problem
    - Maybe present something competing to show more of what is out there
    - Drawing were very nice :)
- Preliminary Report
    - Schedule a meeting with client to go over preliminary report
    - Receive heart model data and other supplies
    - Determine what else is needed
    - Will get feedback on report next week
- Fabrication
    - Heart Model - stl model, lots of prints online
    - Controlling the pump
        - Roller pump if provided
            - will need to determine how to control the flow
        - Retired ECMO pump we can try potentially?
        - Figure this out
    - Tubing can sometimes be a challenge, getting the right size and connectors
        - Also need a way to connect the heart to the tubing
- Start thinking about testing plan
    - Protocol, how to measure, etc.

Conclusions/action items:

10.16.23 Team Meeting

SOPHIA SPEECE - Oct 16, 2023, 8:17 PM CDT

Title: Team Meeting

Date: 10.16.23

Content by: Sophie, Team

Present: Team

Goals:

Content:

- Upcoming/Announcements
  - 10/16
    - Feedback fruits extended, due TONIGHT
  - 10/19
    - Progress report
  - 10/20
    - Feedback fruits review due
  - 10/23
    - Team Meeting (where and when?)
- Assign Teams
  - Lucy - heart
  - Emma - heart
  - Sophie - Pump (and heart)
  - Bodey - Heart
  - Jack - Pump
  - Will - Pump
  - Who does the injector site? Does it make sense to add on to heart piece?
- Update
  - Lucy has DICOM file, will reach out to James and talk about software
  - Rope in some of the pump/tubing people
  - Get as many materials as possible
- Materials List
  - Heart Model
    - PLA 3D print
  - Tubing
    - 1/4 or 3/8 diameter?
    - Connectors (at least 6)
  - Acrylic box
    - Epoxy
    - Caulk to seal edges
  - Flow meter (do the clients want one?)
    - Is it possible to fabricate one? If so, what materials do we need?
    - Not super expensive
  - Roller Pump
    - Or some form of connection to the ECMO machine in WIMR
  - Arduino (left over from 201?)
  - Some form of reservoir? Or just fill circuit and reconnect tubing each time? In that case, removable/replaceable connectors/tubing
  - (Contrast agent and injector - provided)
- Gantt Chart? Or some form of timeline?
  - Something by show and tell
  - Friday December 8th Final Poster Presentations
  - Wednesday Dec. 13th Final Deliverables
  - All fabrication and testing done by Friday Dec. 1
  - Preferably all preliminary fabrication Friday, November 17th (to begin testing, re-fabricating as needed)
  - Acquire materials by Monday or Wednesday next week

Conclusions/action items:

Speak with teams, acquire materials

10.20.23 Advisor Meeting

Will Stephenson - Oct 20, 2023, 1:20 PM CDT

Title: Advisor Meeting

Date: 10/20/23

Content by: Will

Present: All

Goals: Meet with advisor

Content:

- Prelim report
  - More engineering
    - Equations, design steps, etc.
    - Not bad for us
  - More clarity with figures
    - Make sure figures are labeled and referenced
  - Scores are based on the entirety of the report
- James Rice
  - Collegue of Giusseppe
  - Going to give us COMSOL files
    - We have access to COMSOL via engineering
    - COMSOL is great design software
    - Good tool for reports, presentations, etc
- Show and tell
  - Make sure to have something to show
    - Helps make presentation skills with product
    - There are a lot of people who might have a lot of good ideas
    - Try to have a rough phantom built
    - Currently printing the injector site, have a designed phantom
  - Heart Model
    - No real progress, couldn't meet with james
    - Looking for dicom file
    - Having an stl file for some heart would be good for modeling purposes
    - Most important to figure out connection point
  - Pump
    - Wanted to see if they had one for us
    - If needed, JW could provide one for us
    - Could bring one to the show and tell
    - Could even use a dc motor
    - Talk weekly about it

Conclusions/action items: Get ready for show and tell, and continue work on design.

10.23.23 Team Meeting

SOPHIA SPEECE - Oct 23, 2023, 6:45 PM CDT

Title: Team Meeting

Date: 10.23.23

Content by: Sophie, Team

Present: Team

Goals: Update team about James Rice meeting

Content:

- Announcements/Upcoming
    - Thursday 10/26
        - Progress Report due at 5
    - Friday 10/27
        - BSAC Meeting 11am 2305 E-hall
        - NO Advisor meeting
    - Monday 10/30
        - Team Meeting (where and when?) -> NO
- What would you guys like to do today?
    - From here on out (or at least for a couple weeks) no need to meet as a whole team, just with groups
- Updates from James Rice Meeting

Conclusions/action items:

Continue fabrication, maybe start thinking about testing protocols

10.30.23 Pump Team Meeting

JACK STEVENS - Oct 30, 2023, 6:00 PM CDT

Title: Pump Team Meeting

Date: 10/30/23

Content by: Jack Stevens

Present: Sophie Speece, Will Stephenson

Goals: Work with the newly acquired roller pump and tubing to work on creating a circuit with the correct flow to mimic the heart and VA-ECMO device.

Content: The three of us met at the Maker Space and tested the roller pump with tubing by flowing water through it and ensuring that water does indeed flow through at a correct rate. We discovered that the tubing needs to have water in it before starting the pump otherwise an air bubble will form and water will not flow through the roller part of the pump (which pushes water through the tube from one end to the other at a controllable rate). After working with the pump we went onto SolidWorks and obtained an STL file for a pump connector for our 3/8" tubing. We also designed a piece to be 3D printed that will represent the phantom for our upcoming show and tell on Friday.

Conclusions/action items: Start the print for the prototype "heart" and have the pump and tubing ready to show on Friday during Show and Tell.

11.3.23 Show and Tell Notes

Will Stephenson - Nov 03, 2023, 1:01 PM CDT

Title: Show and Tell notes

Date: 11.3.23

Content by: Will

Present: All

Goals: Gather notes and ideas from show and tell

Content:

- Dissolvable support printing (carbon printing?)
  - Could make thin wall printing possible
- Dr. Suarez for fluid dynamic stuff
- Ballistics gel for heart model?
  - Can make a mold for the heart and pour in the gel
- Use online model as opposed to the CT scan file or buy a model
- Crossbars in the injector site print
-

Conclusions/action items:

11.10.23 Advisor Meeting

Will Stephenson - Nov 10, 2023, 1:45 PM CST

Title: Advisor Meeting

Date: 11/10/23

Content by: Will

Present: All

Goals:

Content:

- 4 weeks left until poster project
- 2 more advisor meetings left
- Funding
  - Funding string from Tim's lab, not Giussepe
  - **We buy it, get reimbursed**, or department buys it, and they get reimbursed
- Flowmeter
  - Need to buy it (~$10-20)***
    - If we don't have one we could get quickly, we should brute force it
  - Does the client have one?
  - Could brute force it, but need to be careful depending on how fast the flow is
  - Could also do weight change testing
  - Could do both
- Heart model
  - Have a rough model, need to iterate
- Need to reprint injector site
  - Need to readjust the locking mechanism
- CT time
  - Going to rehash getting the CT time, making sure we can actually schedule it
  - Should be quick
  - Testing might be at odd hours
- Mimic softwore is a good tool, but not efficient for our purposes
  - Currently trying to use a trimmed out model from the CT data
  - Good heart STLs cost money, so doesn't really work for us.
- Client discussions
  - Need to discuss with client to help them understand what the project entails
  -

Conclusions/action items:

11/13/23 Pump/Flow Testing

JACK STEVENS - Nov 30, 2023, 5:11 PM CST

Title: Pump Testing

Date: 11/13/23

Content by: Jack Stevens

Present: Sophie Speece, Will Stephenson

Goals: Conduct testing with the pump and tubing to analyze flow rates.

Content:

Dial Number	Measured Volume (in 60 sec or per minute)	Measured Weight	Vol from Weight
1			
Trial 1	0.261 L	0.25965 kg	0.25965 L
Trial 2	0.200 L	0.20160 kg	0.20160 L
Trial 3	0.197 L	0.19249 kg	0.19249 L
Mean (STD)	Mean = 0.219 (0.0361)	Mean = 0.2179 (0.0364)	Mean = 0.2179 (.0364)
2			
Trial 1	.350 L	0.33978 kg	0.33978 L
Trial 2	.484 L	0.47868 kg	0.47868 L
Trial 3	0.468 L	0.46072 kg	0.46072 L
Mean (STD)	Mean =	Mean =	Mean =
3			
Trial 1	0.414 L	0.40752 kg	0.40752 L
Trial 2	0.506 L	0.42079 kg	0.42079 L
Trial 3	0.836 L	0.82696 kg	0.82696 L
Mean (STD)			
4			
Trial 1			
Trial 2			
Trial 3			
Mean (STD)			
5			
Trial 1	2.14 L	2.12264 kg	2.12264 L
Trial 2	2.112 L	2.079 kg	2.079 L
Trial 3	2.084 L	2.8111 kg	2.8111 L

Mean (STD)			
6			
Trial 1			
Trial 2			
Trial 3			
Mean (STD)			
7			
Trial 1	2.62 L	2.6428 kg	2.6428 L
Trial 2	2.724 L	2.74656 kg	2.74656 L
Trial 3	2.736 L	2.7606 kg	2.7606 L
Mean (STD)			
8			
Trial 1			
Trial 2			
Trial 3			
Mean (STD)			
9			
Trial 1	3.108 L	3.1316 kg	3.1316 L
Trial 2	3.148 L	3.15648 kg	3.15648 L
Trial 3	3.14 L	3.15004 kg	3.15004 L
Mean (STD)			
10			
Trial 1			
Trial 2			
Trial 3			
Mean (STD)			

Conclusions/action items: Analyze and share data regarding the pump and measured flow rates at the different pump dial speeds.

11.17.23 Advisor Meeting

SOPHIA SPEECE - Nov 17, 2023, 1:19 PM CST

Title: Advisor Meeting - Testing Protocols

Date: 11.17.23

Content by: Sophie

Present: Team

Goals: Get feedback on final prototype and testing protocols, as well as an outline for the rest of the semester

Content:

- Logistics
  - Poster session is 3 weeks from today
    - Schedule is posted on the design website so we know when we are presenting
    - We are at 12:50, #33, along the wall by the rockwell automation lab. We will need power, would be outlets, might need an extension cord. Either get there early or request to reserve one
      - I can bring one from home, I a=can grab it over thanksgiving if needed
  - Next week, no progress report due, can still reach out with questions (still good to get some work done if we can)
  - Where will we print the poster? Print early or make reservations (E-hall, College, Steinbok)
  - Prof. would be happy to look over the poster Wednesday or before before the poster session
- Progress
  - Push for CT scan time, most important test and get feedback from client, need to show that what we have is meeting the client's needs.
  - Backup plan for iodine injector
  - Heart is printing, will take a bit
  - Injector site also printing

Conclusions/action items:

- start working on poster if time allows, can have Prof. look it over
- Next meeting is in two weeks, Friday at the same time, and hopefully in ME

11.30.23 Team Meeting

SOPHIA SPEECE - Nov 30, 2023, 2:44 PM CST

Title: Team Meeting

Date: 11.30.23

Content by: Sophie, Team

Present: Team

Goals: Assemble final prototype, begin testing if time allows

Content:

- Upcoming/Announcements:
  - Thursday, 11/30
    - Progress report due before 5
  - Friday 12/1
    - BSAC Meeting 11:00am in 2305 E-hall
    - Advisor Meeting 1:00pm
  - Wed 12/6
    - CT Testing at 1pm, location TBD
    - Final Client Meeting at 4pm?
  - Fri 11/8
    - Poster due on website and canvas by 10:00am according to course schedule
    - Poster Presentations 12:05-2:00
  - Wed 11/13
    - Final Paper due by midnight
    - Final Notebook due by midnight
    - BWIG upload to website and canvas
    - Final peer and self evaluation
- Assembly
- Testing
  - Make sure there is no backflow from the

Conclusions/action items:

12.1.23 Team Meeting

Will Stephenson - Dec 01, 2023, 1:16 PM CST

Title: Advisor Meeting

Date: 12/1/23

Content by: Will Stephenson

Present: Team

Goals: Final meeting with Advisor!

Content:

- Schedule
    - One week and a half left
    - We have a plan for printing poster
        - Crunch work Wednesday night
        - Print thursday
    - Friday morning, copy of poster needs to be uploaded
    - Might need extension cord for power supply
    - Following wednesday is when all final deliverables are due*
    - Any time after friday we can do one final team meeting w/ advisor
- Testing
    - Everything is fabricated
    - We know the acrylic box doesn't leak
    - Have CT time
    - Need to make sure we can run stuff through the system
    - Need to compare to norms
        - Want to show the relation of performance of our prototype to the initial guidelines
    - Could do a paired t-test to work with the statistics we need
    - Want to figure out what we want to adjust in testing
    - Need to make sure injector piece fits
        - Could use parafilm tape for easy sealant
    - Want to test different injection flow rates
-

Conclusions/action items:

12.4.23 Team Meeting

SOPHIA SPEECE - Dec 04, 2023, 7:07 PM CST

Title: Team Meeting

Date: 12.4.23

Content by: Sophie, Team

Present: Team

Goals: Work on testing and statistics

Content:

- Upcoming/Announcements
  - Wed 12/6
    - CT Testing at 1pm, do we know the location? I'm assuming somewhere in WIMR
    - Possibly a client meeting at 4pm, but I think it will just be lumped in to the CT testing that we do.
  - Thurs 12/7
    - Final progress report, due at 5pm
  - Fri 12/8
    - Poster Session 12:05-2pm
      - Please plan on being there the whole time if you can
      - Business casual, but on the business-ier side
      - We present at 12:50 and are group 33. We are located kind of behind the stairwell in front of room 1060. Dr. Puccinelli sent out an email with the map.
      - Set up (and pizza) will begin at 11 am. This isn't required for everyone, but we do need at least a couple people there. I can make it.
      - Take down will occur at 2:15-2:30. I can also stay for take down, and it would be cool to have a couple others, but I understand that you may have prior commitments.
      - Does anyone have an extension cord to bring? We can discuss whether or not we run our pump or simply take a video of it running and show that, but it would be good just in case.
  - Wed 12/13
    - Final Paper due
    - Final Notebook due
    - Don't forget the peer and self evaluation! It counts for a kinda large part of your grade.
    - I think it would be a good idea to have a team paper session where we all work on it together, maybe next weekend? I think working together we can get a lot done. I want to hear what you guys think about this, however, and I totally understand that there are other finals and projects you will be working on. I was thinking sometime Sunday?
- Action Items
  - If we haven't already, ask for a flow meter for verification testing.
  - Invite clients to the poster session!
  - Jack, are you still good to print the poster at some time on Thursday?
    - This also means we should have the testing part done by Wednesday night
    - Plan to have everything except the testing done for the poster by Tuesday night so we can send our poster to Prof. Williams for feedback.
  - I would like to meet with Prof. Williams a final time, but I think that would be an if you want to join thing and not required for everyone. If you want to be a part of that meeting, please let me know so we can find a time that works for all of us. If you don't care about meeting, do not worry :)
  - Submit receipts for reimbursement.
  - I think I will do some work with Matlab and stats today for the initial flow testing, probably around either 3pm or 7pm. Let me know if you would like to join that.

Conclusions/action items:

Preliminary Designs

SOPHIA SPEECE - Sep 29, 2023, 12:47 PM CDT

Title: Preliminary Designs

Date: 9.29.23

Content by: Team

Present: Team

Goals: Brainstorm preliminary designs and use a design matrix to help decide which is best to move forward with

Content:

Preliminary Designs and Matrices

Circulatory Phantom Designs:

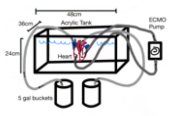
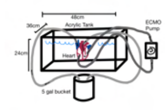
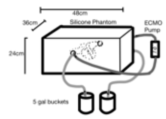
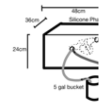
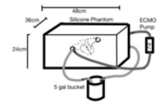
Acrylic Box with 3D Printed Heart with an Open Circuit: The acrylic box phantom design is similar to designs used in other circulation phantom studies [1]–[3]. It consists of a water-tight acrylic rectangular prism 48cm long, 36cm wide, and 24cm tall, which roughly reflects the dimensions of an average human body [4]. While there is significant variation in the size of the human torso, these dimensions reflect both male and female anatomy and provide ample space for the 3D printed heart and tubing that will be placed within. The walls will be made from ¼ inch, or 6.35mm, acrylic sheeting of any color, although clear is preferable. The walls will be fused with epoxy and reinforced for water retention with caulk. Before each test on the CT machine, the acrylic box will be filled with water. The anatomically accurate heart will be printed from flexible filament, or acquired. A tube will run from the water reservoir (a 5 gallon bucket) into the superior vena cava of the 3D printed heart to mimic how deoxygenated blood would enter the heart from the body. A tube will run from the aorta to the waste bucket (also a 5 gallon bucket) to mimic how oxygenated blood returns to the body. A custom 3D printed piece will also attach in the vena cava to provide an insertion site for the iodine contrast injector which will allow for injection but prevent fluid from leaking. The VA-ECMO circuit will originate somewhere in the right atrium and return in the left ventricle [5]. The pulmonary veins and arteries will be connected with tubing rather than running through a pulmonary model. The heart will be submerged in water in the acrylic box phantom.

Acrylic Box with 3D Printed Heart with a Closed Circuit: The acrylic box, 3D printed heart, and VA-ECMO circuit in this design will be the same as in the acrylic box with an open circuit. This design varies, however, in that instead of a fluid reservoir and dump vessel, the tubing will be one continuous loop. The inflow and outflow will originate from and deposit into the same vessel (a 5 gallon bucket) and be recycled over time. This intends to model how blood is constantly reused in the human body.

Negative Space Phantom with an Open Circuit: This design for the physical phantom includes a solid silicone base that is molded to mimic the circulatory system in and around the heart. The outside dimensions will be the same as in the acrylic box phantom. In addition, this design includes an input and output reservoir for blood mimicking solution, which connects to the silicone mold via PVC tubing. The contrast injector would have a stationary entry point onto the vena cava to allow for injection of iodinated contrast into the bloodstream.

Negative Space Phantom with a Closed Circuit: This design for the physical phantom includes a solid silicone base that is molded to mimic the circulatory system in and around the heart. In addition, this design includes a circular design for the blood circulation, including PVC tubing that connects to blood coming out of the vena cava and running it back to the pump to go back into the heart. The contrast injector would have a stationary entry point onto the vena cava to allow for injection of iodinated contrast into the bloodstream.

Phantom	Acrylic Box with 3D Printed Heart with an Open Circuit	Acrylic Box with 3D Printed Heart with a Closed Circuit	Negative Space Phantom with an Open Circuit	Negative Space Phantom with a Closed Circuit

Pictures									
Criteria	**Weight**	**Score (max 5)**	**Weighted Score**	**Score (max 5)**	**Weighted Score**	**Score (max 5)**	**Weighted Score**	**Score (max 5)**	**Weighted Score**
Anatomical Accuracy	30	3	18	4	24	2	12	3	18
Ease of Fabrication	25	5	25	4	20	2	10	1	5
Maintenance	20	5	20	3	12	4	16	2	8
CT Compatibility	15	5	15	5	15	5	15	5	15
Cost	10	4	8	4	8	2	4	2	4
Sum	**100**		86		79		57		50

Design Criteria:

Anatomical Accuracy: Anatomical accuracy describes how closely the phantom mimics actual circulatory function. This category was the highest rated criteria because that criteria is crucial to our design being able to solve our client's problem. They need a device that simulates conditions well enough that it can be used to calibrate CT settings and other variables for clinical use. Without achieving anatomical accuracy, our design does not accomplish its main function. Each design loses a point from the maximum due to none of the designs replicating the size and shape of an entire human torso. Between the Acrylic Box with 3D Printed Heart designs and the Negative Space Phantom designs, the former scored higher due to the water being more physiologically accurate than the foam to be used in the negative space phantom. In comparing the open circuit designs with the closed circuit designs, the closed circuit designs were deemed more anatomically accurate due to the closed circuit better representing the human circulatory system.

Ease of Fabrication: Ease of Fabrication refers to how difficult it would be for us to make a functioning phantom with the tools and skills we have. This criteria includes a consideration of time of fabrication and prototyping, cost of fabrication and prototyping, and how easy it would be to work with the materials. It is the second highest weighted criteria because if we can't feasibly produce a functional phantom, then that design doesn't really work for the design process. In general, both Acrylic box designs score a lot higher than the negative space designs for this criteria. Creating an Acrylic box is generally speaking pretty easy, and it wouldn't take many iterations to produce, and adjusting the internal circuitry wouldn't be difficult. The most complicated piece would be the heart, but that is also a piece that can be 3D printed. Between the open and closed variations of this design, the open design would be easier to fabricate because there would be more considerations to make the closed circuit anatomically accurate. The negative space design would be very difficult to fabricate for two main reasons. One, designing a heart in negative space that is both sturdy and moves our solution correctly would be very difficult to design. Two, if anything isn't correct with our design, the entire design of the mold would have to change and be produced, a both time and cost intensive process. For these reasons our Acrylic box design with an open design scored the best for ease of fabrication.

Maintenance: Maintenance of the design describes the capability of the design to be cleaned after each trial. The contrast agents that we will use tend to dry and get sticky if not thoroughly cleaned after use. We determined this to be of middle importance in the weighting process because the quality of the design after multiple uses will be better with a design that is easier to clean. However, this aspect of the design is not absolutely crucial to its function. Between the open and closed circuit designs, the closed circuit designs automatically scored lower. In the closed circuit, it would be very difficult to flush new water through the tubing while having a way for the old water with the contrast agent moved out. In comparison of the Acrylic Box designs versus the Negative Phantom designs, the negative phantom scored worse due to the material around the "heart" being harder to clean. In the Acrylic Box design, the water around the heart can just be removed and replaced in the case of a leak or other mishap. In the case of the negative phantom, if the solution were to leak, it could get trapped in the silicone and cause issues with future scans.

CT Compatibility: CT compatibility is how well the design is believed to perform with the Computed Tomography scanner. This is determined based on the materials and overall design. CT compatibility is important because the design will be tested inside a CT scanner. All four designs were ranked the same, receiving the maximum score, across the board. All materials used in the designs are safe to put through a CT scanner and are regularly used in CT phantoms so there should not be any complications.

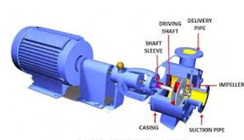
Cost: The cost refers to how much money each design would require for all of its components. This includes both the market value of a new item and takes into consideration the portions that can be fabricated from already obtained parts. While it is important to be cognizant of the client's resources, this criterion was rated lowest because each of the phantom designs are similar in cost and because a client funding prioritizes a functioning prototype. The two acrylic box designs were rated well because acrylic sheets are cheap and accessible, as well as water. The components for the open and closed circuit are also expected to be the same cost. The negative space phantom was rated lower because the price and volume of silicone needed is more expensive than the acrylic box phantom.

VA-ECMO Circuit Designs:

ECMO Machine: this design utilizes ECMO pumping to pass fluid through the circuit to the phantom. It will have exact flow rates while also being adjustable. But, ECMO machines are expensive, complex, and difficult to attain.

Centrifugal Pump: this design utilizes a centrifugal pump to pass fluid through the circuit to the phantom. ECMO devices contain centrifugal pumps so this design will closely mimic the flow rates of the ECMO design while minimizing cost.

Pulsatile Pump: this design utilizes a pulsatile pump to pass fluid through the circuit to the phantom. Pulsatile pumps are easily acquired, are less complex than other designs, and are generally cheaper than centrifugal pumps and ECMO machines.

VA - ECMO Circuit		**ECMO Machine**		**Centrifugal Pump**		**Pulsatile Pump**	
Pictures							
Criteria	**Weight**	**Score (max 5)**	**Weighted Score**	**Score (max 5)**	**Weighted Score**	**Score (max 5)**	**Weighted Score**
Adjustable Flow Rates	25	5	25	4	20	3	15
Compatibility	20	3	12	4	16	4	16
Usability	20	2	8	5	20	5	20
Maintenance	15	2	10	4	12	4	12

Safety	10	5	10	3	6	3	6
Cost	10	1	2	3	6	5	6
Sum	**100**	**Sum**	67	**Sum**	80	**Sum**	75

Design Criteria:

Adjustable Flow Rates: The adjustable flow rates category describes the ability of a design to adjust the flow rate of the iodinated contrast through the ECMO/phantom circuit. This category was ranked as the most important for the VA-ECMO design because the main goal of the design/project is to address the current lack of knowledge on CT scanning phantoms with dynamic flow rates. The ECMO machine scored a perfect five out of five because it has complex components, such as a pump and a flowmeter, already built into it which allow the operator to easily monitor and measure the flow rate as well as adjust it in real time. The second device, the centrifugal pump, had the second highest score of four out of five compared to the pulsatile pump which scored the lowest with a three out of five. The centrifugal pump scored higher than the pulsatile pump in this category because the centrifugal design has a constant flow rate that can be more easily adjusted versus the more difficult to adjust, pulsing flow of a pulsatile pump.

Compatibility: The compatibility category describes how easily the VA-ECMO design/substitute can be incorporated into the entire design/circuit as a whole. The circuit consists of various parts such as the phantom which need to be connected to mimic the anatomy of a patient on a VA-ECMO machine. The compatibility category was tied for the second most important category because it is vital to our design that the VA-ECMO design works with the phantom and the rest of the circuit. In order for the flow of the iodinated contrast to properly mimic blood flow of a patient in a CT scanner the device needs to connect properly without leaks and provide a means to correctly measure the flow rate. Both the centrifugal and pulsatile pumps scored the best with a four out of five while the ECMO machine scored last with a three. This is because the two pumps are independent components and can more easily be connected to the circuit via tubing. The ECMO machine is more complicated than the two pumps and would therefore be less compatible with the design of the circuit which requires just one input and one output for the pump. While the ECMO has more functionality than the two pumps, the requirements of the project are better suited by either the centrifugal pump or the pulsatile pump.

Usability: The usability category describes how easily and how effectively the device can be used by the person operating it. It was tied for the second most important category because a key aspect of the design is that it can be used by the clients to effectively address any clinical or research questions they may have in regards to ECMO and CT scans. The centrifugal and pulsatile pumps both scored the highest with five out of five because they are straightforward, independent devices that can take little training to use. The ECMO machine, on the other hand, is far more complicated as it has more uses. This caused it to score the lowest with a two out of five because it takes more knowledge and training to operate properly. In order to optimize the efficiency and effectiveness of the device, the circuit needs to be, technically speaking, as straightforward as possible to remove any operating difficulties.

Maintenance: Maintenance was ranked fourth at a weight of 15 because in an ideal this device would be able to be used for years to further knowledge and understanding of the blood flow rates and patterns of patients on VA-ECMO machines. In order to guarantee the longest possible lifespan for this device, it may need occasional maintenance upkeep. It is likely that this device would be used in an environment with professionals who have experience working with ECMO devices. Due to this experience they would likely have an understanding on the protocols for upkeep of the device. Because of this, the ECMO machine was ranked the highest. Centrifugal pumps were ranked the next highest as they are often utilized in ECMO circuits. Therefore, the operator would likely have an understanding of the pump and its components. A pulsatile pump was also ranked at a 4 as they are not as often seen in ECMO machines so the operator may not have as much experience working with them than the other two pump options. However they are known to be simple machines and are used to mimic cardiac flows in other medical settings.

Safety: The safety category depicts the risk of injury for the technician that performs a scan on the phantom. This was rated relatively low in our weighting of the matrix because the project itself does not pose a very big risk of injury. The phantom does not directly impact patient care, which makes it less of an important factor in our design. The ECMO machine received a perfect rating because there are numerous federal regulations and other medical standards that ensure that the ECMO is safe to use in a clinical setting. Another reason why the ECMO scored higher than the other two pumps is that the ECMO is designed specifically to pump fluid through the human circulatory system, which our design aims to mimic. The other two pumps lost a point in their respective scores due to the fact that they were not designed to pump through the human circulatory system. However, the two other designs still score highly due to the risk of injury would not be high in the case of some type of mechanical failure in the design.

Cost: Cost is determined based on either the market value for the pre-existing devices or the estimated cost to fabricate the pump. The client did not provide an explicit budget and believed that they would be able to source components for the team to borrow for the duration of the project. Because of this, cost was weighted as least important. The ECMO machine was ranked at a 1 for cost. An ECMO machine can cost upwards of $100,000 and therefore is not a realistic option for the design. Centrifugal pump was ranked the next highest at a 3. ECMO circuits on the market that utilize centrifugal pumps cost around $10,000 which is still out of the budget range. The pulsatile pump was given a 5 as they can be purchased online for just a few hundred dollars.

References

[1] B. Driscoll, H. Keller, and C. Coolens, “Development of a dynamic flow imaging phantom for dynamic contrast-enhanced CT,” *Med. Phys.*, vol. 38, no. 8, pp. 4866–4880, Aug. 2011, doi: 10.1118/1.3615058.

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Conclusions/action items:

Confirm final design, begin fabrication protocol

Preliminary Designs - Revised

SOPHIA SPEECE - Oct 05, 2023, 11:05 AM CDT

Title: Preliminary Designs - Revised

Date: 10.5.23

Content by: Sophie, Team

Present: Team

Goals: Update the Preliminary designs and design matrices based upon feedback from advisor

Content:

Circulatory Phantom Designs:

Acrylic Box with 3D Printed Heart with an Open Circuit: The acrylic box phantom design is similar to designs used in other circulation phantom studies [1]–[3]. It consists of a water-tight acrylic rectangular prism 48cm long, 36cm wide, and 24cm tall, which roughly reflects the dimensions of an average human body [4]. While there is significant variation in the size of the human torso, these dimensions reflect both male and female anatomy and provide ample space for the 3D printed heart and tubing that will be placed within. The walls will be made from ¼ inch, or 6.35mm, acrylic sheeting of any color, although clear is preferable. The walls will be fused with epoxy and reinforced for water retention with caulk. Before each test on the CT machine, the acrylic box will be filled with water. The anatomically accurate heart will be printed from flexible filament, or acquired. A tube will run from the water reservoir (a 5 gallon bucket) into the superior vena cava of the 3D printed heart to mimic how deoxygenated blood would enter the heart from the body. A tube will run from the aorta to the waste bucket (also a 5 gallon bucket) to mimic how oxygenated blood returns to the body. A custom 3D printed piece will also attach in the vena cava to provide an insertion site for the iodine contrast injector which will allow for injection but prevent fluid from leaking. The VA-ECMO circuit will originate somewhere in the right atrium and return in the left ventricle [5]. The pulmonary veins and arteries will be connected with tubing rather than running through a pulmonary model. The heart will be submerged in water in the acrylic box phantom.

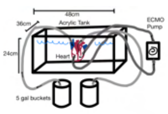
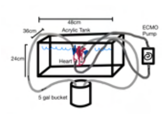
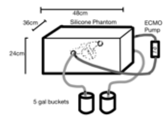
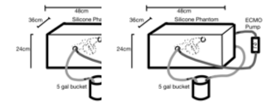
Acrylic Box with 3D Printed Heart with a Closed Circuit: The acrylic box, 3D printed heart, and VA-ECMO circuit in this design will be the same as in the acrylic box with an open circuit. This design varies, however, in that instead of a fluid reservoir and dump vessel, the tubing will be one continuous loop. The inflow and outflow will originate from and deposit into the same vessel (a 5 gallon bucket) and be recycled over time. This intends to model how blood is constantly reused in the human body.

Negative Space Phantom with an Open Circuit: This design for the physical phantom includes a solid silicone base that is molded to mimic the circulatory system in and around the heart. The outside dimensions will be the same as in the acrylic box phantom. In addition, this design includes an input and output reservoir for blood mimicking solution, which connects to the silicone mold via PVC tubing. The contrast injector would have a stationary entry point onto the vena cava to allow for injection of iodinated contrast into the bloodstream.

Negative Space Phantom with a Closed Circuit: This design for the physical phantom includes a solid silicone base that is molded to mimic the circulatory system in and around the heart. In addition, this design includes a circular design for the blood circulation, including PVC tubing that connects to blood coming out of the vena cava and running it back to the pump to go back into the heart. The contrast injector would have a stationary entry point onto the vena cava to allow for injection of iodinated contrast into the bloodstream.

Design Criteria:

Phantom	**Acrylic Box with 3D Printed Heart with an Open Circuit**	**Acrylic Box with 3D Printed Heart with a Closed Circuit**	**Negative Space Phantom with an Open Circuit**	**Negative Space Phantom with a Closed Circuit**

Pictures									
Criteria	**Weight**	**Score (max 5)**	**Weighted Score**	**Score (max 5)**	**Weighted Score**	**Score (max 5)**	**Weighted Score**	**Score (max 5)**	**Weighted Score**
Anatomical Accuracy	30	3	18	4	24	2	12	3	18
Ease of Fabrication	25	5	25	5	25	2	10	1	5
Maintenance	20	5	20	4	16	4	16	3	12
Duration of single use	15	3	9	5	15	3	9	5	15
Cost	10	4	8	4	8	2	4	2	4
Sum	**100**		80		88		51		54

Anatomical Accuracy: Anatomical accuracy describes how closely the phantom mimics actual circulatory function. This category was the highest rated criteria because that criteria is crucial to our design being able to solve our client's problem. They need a device that simulates conditions well enough that it can be used to calibrate CT settings and other variables for clinical use. Without achieving anatomical accuracy, our design does not accomplish its main function. Each design loses a point from the maximum due to none of the designs replicating the size and shape of an entire human torso. Between the Acrylic Box with 3D Printed Heart designs and the Negative Space Phantom designs, the former scored higher due to the water being more physiologically accurate than the foam to be used in the negative space phantom. In comparing the open circuit designs with the closed circuit designs, the closed circuit designs were deemed more anatomically accurate due to the closed circuit better representing the human circulatory system.

Ease of Fabrication: Ease of Fabrication refers to how difficult it would be for us to make a functioning phantom with the tools and skills we have. This criteria includes a consideration of time of fabrication and prototyping, cost of fabrication and prototyping, and how easy it would be to work with the materials. It is the second highest weighted criteria because if we can't feasibly produce a functional phantom, then that design doesn't really work for the design process. In general, both Acrylic box designs score a lot higher than the negative space designs for this criteria. Creating an Acrylic box is generally speaking pretty easy, and it wouldn't take many iterations to produce, and adjusting the internal circuitry wouldn't be difficult. The most complicated piece would be the heart, but that is also a piece that can be 3D printed. Between the open and closed variations of this design, the open design would be easier to fabricate because there would be more considerations to make the closed circuit anatomically accurate. The negative space design would be very difficult to fabricate for two main reasons. One, designing a heart in negative space that is both sturdy and moves our solution correctly would be very difficult to design. Two, if anything isn't correct with our design, the entire design of the mold would have to change and be produced, a both time and cost intensive process. For these reasons our Acrylic box design with an open design scored the best for ease of fabrication.

Maintenance: Maintenance of the design describes the capability of the design to be cleaned after each trial. The contrast agents that we will use tend to dry and get sticky if not thoroughly cleaned after use. We determined this to be of middle importance in the weighting process because the quality of the design after multiple uses will be better with a design that is easier to clean. However, this aspect of the design is not absolutely crucial to its function. Between the open and closed circuit designs, the closed circuit designs automatically scored lower. In the closed circuit, it would be very difficult to flush new water through the tubing while having a way for the old water with the contrast agent moved out. In comparison of the Acrylic Box designs versus the Negative Phantom designs, the negative phantom scored worse due to the material around the "heart" being harder to clean. In the Acrylic Box design, the water around the heart can just be removed and replaced in the case of a leak or other mishap. In the case of the negative phantom, if the solution were to leak, it could get trapped in the silicone and cause issues with future scans.

Duration of Single Use: This design criteria specifies how long the product can be used continuously. It is important that the product be able to last through at least one CT scan. However, because CT scans are very quick (less than a minute), this criterion was given less weight than the other criteria (save for cost).

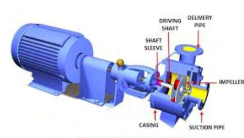
Cost: The cost refers to how much money each design would require for all of its components. This includes both the market value of a new item and takes into consideration the portions that can be fabricated from already obtained parts. While it is important to be cognizant of the client's resources, this criterion was rated lowest because each of the phantom designs are similar in cost and because a client funding prioritizes a functioning prototype. The two acrylic box designs were rated well because acrylic sheets are cheap and accessible, as well as water. The components for the open and closed circuit are also expected to be the same cost. The negative space phantom was rated lower because the price and volume of silicone needed is more expensive than the acrylic box phantom.

VA-ECMO Circuit Designs:

ECMO Machine: this design utilizes ECMO pumping to pass fluid through the circuit to the phantom. It will have exact flow rates while also being adjustable. But, ECMO machines are expensive, complex, and difficult to attain.

Centrifugal Pump: this design utilizes a centrifugal pump to pass fluid through the circuit to the phantom. ECMO devices contain centrifugal pumps so this design will closely mimic the flow rates of the ECMO design while minimizing cost.

Pulsatile Pump: this design utilizes a pulsatile pump to pass fluid through the circuit to the phantom. Pulsatile pumps are easily acquired, are less complex than other designs, and are generally cheaper than centrifugal pumps and ECMO machines.

VA - ECMO Circuit		**ECMO Machine**		**Centrifugal Pump**		**Pulsatile Pump**
Pictures						
Criteria	**Weight**	**Score (max 5)**	**Weighted Score**	**Score (max 5)**	**Weighted Score**	**Score (max 5)**	**Weighted Score**
Adjustable Flow Rates	25	5	25	4	20	3	15
Compatibility	20	3	12	4	16	4	16
Usability	20	2	8	5	20	5	20
Maintenance	15	2	10	4	12	4	12
Safety	10	5	10	3	6	3	6
Cost	10	1	2	3	6	5	10
Sum	**100**	**Sum**	67	**Sum**	80	**Sum**	79

Design Criteria:

Adjustable Flow Rates: The adjustable flow rates category describes the ability of a design to adjust the flow rate of the iodinated contrast through the ECMO/phantom circuit. This category was ranked as the most important for the VA-ECMO design because the main goal of the design/project is to address the current lack of knowledge on CT scanning phantoms with dynamic flow rates. The ECMO machine scored a perfect five out of five because it has complex components, such as a pump and a flowmeter, already built into it which allow the operator to easily monitor and measure the flow rate as well as adjust it in real time. The second device, the centrifugal pump, had the second highest score of four out of five compared to the pulsatile pump which scored the lowest with a three out of five. The centrifugal pump scored higher than the pulsatile pump in this category because the centrifugal design has a constant flow rate that can be more easily adjusted versus the more difficult to adjust, pulsing flow of a pulsatile pump.

Compatibility: The compatibility category describes how easily the VA-ECMO design/substitute can be incorporated into the entire design/circuit as a whole. The circuit consists of various parts such as the phantom which need to be connected to mimic the anatomy of a patient on a VA-ECMO machine. The compatibility category was tied for the second most important category because it is vital to our design that the VA-ECMO design works with the phantom and the rest of the circuit. In order for the flow of the iodinated contrast to properly mimic blood flow of a patient in a CT scanner the device needs to connect properly without leaks and provide a means to correctly measure the flow rate. Both the centrifugal and pulsatile pumps scored the best with a four out of five while the ECMO machine scored last with a three. This is because the two pumps are independent components and can more easily be connected to the circuit via tubing. The ECMO machine is more complicated than the two pumps and would therefore be less compatible with the design of the circuit which requires just one input and one output for the pump. While the ECMO has more functionality than the two pumps, the requirements of the project are better suited by either the centrifugal pump or the pulsatile pump.

Usability: The usability category describes how easily and how effectively the device can be used by the person operating it. It was tied for the second most important category because a key aspect of the design is that it can be used by the clients to effectively address any clinical or research questions they may have in regards to ECMO and CT scans. The centrifugal and pulsatile pumps both scored the highest with five out of five because they are straightforward, independent devices that can take little training to use. The ECMO machine, on the other hand, is far more complicated as it has more uses. This caused it to score the lowest with a two out of five because it takes more knowledge and training to operate properly. In order to optimize the efficiency and effectiveness of the device, the circuit needs to be, technically speaking, as straightforward as possible to remove any operating difficulties.

Maintenance: Maintenance was ranked fourth at a weight of 15 because in an ideal this device would be able to be used for years to further knowledge and understanding of the blood flow rates and patterns of patients on VA-ECMO machines. In order to guarantee the longest possible lifespan for this device, it may need occasional maintenance upkeep. It is likely that this device would be used in an environment with professionals who have experience working with ECMO devices. Due to this experience they would likely have an understanding on the protocols for upkeep of the device. Because of this, the ECMO machine was ranked the highest. Centrifugal pumps were ranked the next highest as they are often utilized in ECMO circuits. Therefore, the operator would likely have an understanding of the pump and its components. A pulsatile pump was also ranked at a 4 as they are not as often seen in ECMO machines so the operator may not have as much experience working with them than the other two pump options. However they are known to be simple machines and are used to mimic cardiac flows in other medical settings.

Safety: The safety category depicts the risk of injury for the technician that performs a scan on the phantom. This was rated relatively low in our weighting of the matrix because the project itself does not pose a very big risk of injury. The phantom does not directly impact patient care, which makes it less of an important factor in our design. The ECMO machine received a perfect rating because there are numerous federal regulations and other medical standards that ensure that the ECMO is safe to use in a clinical setting. Another reason why the ECMO scored higher than the other two pumps is that the ECMO is designed specifically to pump fluid through the human circulatory system, which our design aims to mimic. The other two pumps lost a point in their respective scores due to the fact that they were not designed to pump through the human circulatory system. However, the two other designs still score highly due to the risk of injury would not be high in the case of some type of mechanical failure in the design.

Cost: Cost is determined based on either the market value for the pre-existing devices or the estimated cost to fabricate the pump. The client did not provide an explicit budget and believed that they would be able to source components for the team to borrow for the duration of the project. Because of this, cost was weighted as least important. The ECMO machine was ranked at a 1 for cost. An ECMO machine can cost upwards of $100,000 and therefore is not a realistic option for the design. Centrifugal pump was ranked the next highest at a 3. ECMO circuits on the market that utilize centrifugal pumps cost around $10,000 which is still out of the budget range. The pulsatile pump was given a 5 as they can be purchased online for just a few hundred dollars.

References

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Conclusions/action items:

Use this information to choose final design

Final Design (Sketch and Images)

SOPHIA SPEECE - Dec 13, 2023, 8:41 PM CST

Title: Final Design Images

Date: N/A

Content by: Team

Present: Team

Goals: Record images of final product

Content:

See below attachments

Conclusions/action items:

Use these images in final poster and reports

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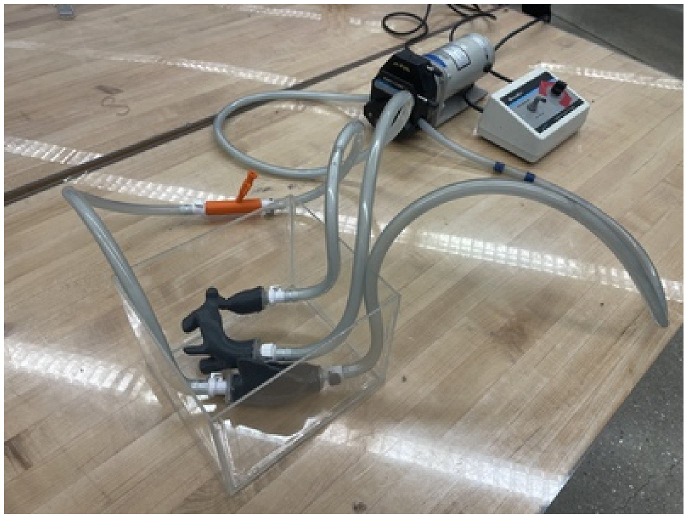

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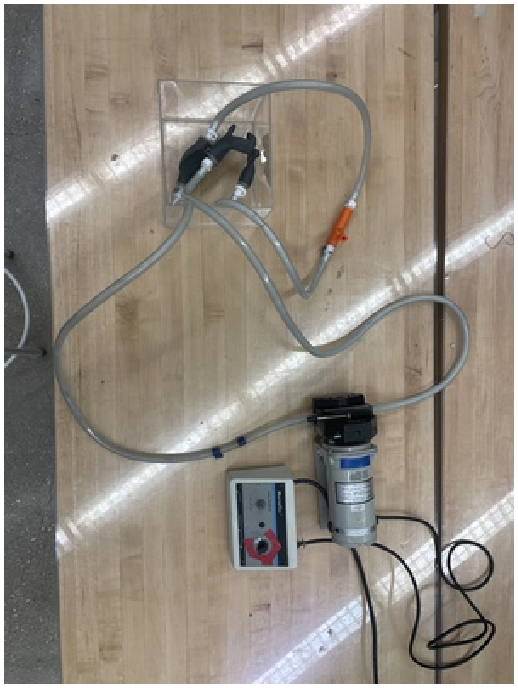
SOPHIA SPEECE - Dec 13, 2023, 8:37 PM CST



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82416C2D-B7FD-4B06-91F7-913AA3B51AAF.jpeg (3.72 MB)

SOPHIA SPEECE - Dec 13, 2023, 8:37 PM CST

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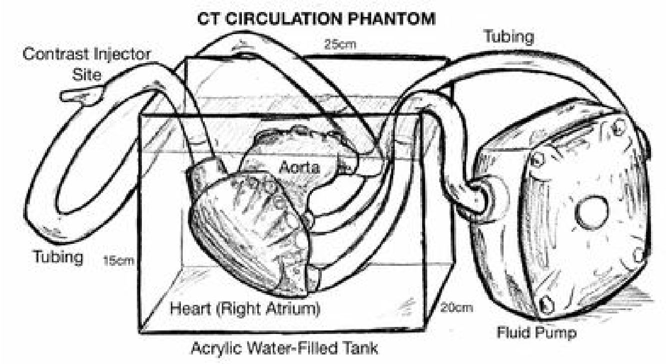
5267A8A0-DB08-4E4D-8F10-0E5A9D5D51CB.jpeg (3.59 MB)

SOPHIA SPEECE - Dec 13, 2023, 8:41 PM CST



Download

final_prototype_sketch.JPG (204 kB)

Phantom Study Using a Dynamic Circulation Model

SOPHIA SPEECE - Sep 17, 2023, 11:11 AM CDT

Title: Reduced Iodinated Contrast Media Administration in Coronary CT Angiography on a Clinical Photon-COunting Detector CT System: A Phantom Study Using a Dynamic Circulation Model

Date: 9.17.23

Content by: Sophie Speece

Search Term: "CT Circulation Phantom" Search Engine: UW Library System > Ovid

Citation: Emrich, T. , O'Doherty, J. , Schoepf, U. , Suranyi, P. , Aquino, G. , Kloeckner, R. , Halfmann, M. , Allmendinger, T. , Schmidt, B. , Flohr, T. & Varga-Szemes, A. (2023). Reduced Iodinated Contrast Media Administration in Coronary CT Angiography on a Clinical Photon-Counting Detector CT System. *Investigative Radiology, 58* (2), 148-155. doi: 10.1097/RLI.0000000000000911.

Content:

Abstract

- Study purpose: the evaluate strategies to reduce contrast media volumes for coronary computed tomography (CT) using a dynamic circulation phantom
- Materials and Methods:
  - Coronary CT angiograph: method for assessment of coronary artery disease, works by administering iodinated contrast media. The goal is to use the least amount of contrast necessary to still have good image quality.
  - Used a dynamic circulation phantom with a 3D printed model of the thoracic aorta and coronary arteries
  - Used clinical contrast injection protocol with stepwise reduces agent concentrations
    - 100%, 75%, 50%, 40%, 30%, 20% contrast media content with the same 50 mL bolus, resulting in delivery rates of 1.5, 1.1, 0.7, 0.6, 0.4
    - Used on a first gen, dual source PCD-CT

Body

- What is CCTA? Coronary computed tomography angiography, a test for coronary artery disease. Requires an iodinated contrast media to attenuate vessel structures to a sufficient level.
- Phantom design
  - this study custom built a dynamic circulation phantom.
  - built with low and high pressure compartments connected by plastic tubing with a silicone vessel model including thoracic aorta and the coronary arteries which simulate human anatomy.
  - A water-filled acrylic container encases the thoracic aorta to mimic the mediactinal CT attentuation characteristics.
  - The system is driven by a pulsatile pump connected to an ECG simulator.
  - Two tanks used to fill and drain the phantom.
  - The whole vessel can hold 4000 mL of water. This test used heated water (to human bosy temperature), pumped through the "body" with a pulsatile pump (Bs4, Harvard Apparatus, Holliston, MA)
  - ECG signal simulated according to pump movement. Reflects normal heart rate of 68 beats/min, stroke volume of 90mL (cardiac output of 6.1 L/min), and blood pressure of 120/80 mm Hg.
  - Contrast media injected at dedicated injection point.

Conclusions/action items:

This is a good source to look at when coming up with preliminary designs

Intravascular Enhancement Using Circulation Phantom

SOPHIA SPEECE - Sep 17, 2023, 12:36 PM CDT

Title: Intravascular Enhancement with Identical Iodine Delivery Rate Using Different Iodine Contrast Media in a Circulation Phantom

Date: 9.17.23

Content by: Sophie Speece

Search Term: N/A, obtained reference from CCTA article

Citation: Mihl, C. , Wildberger, J. E. , Jurencak, T. , Yanniello, M. J. , Nijssen, E. C. , Kalafut, J. F. , Nalbantov, G. , Mühlenbruch, G. , Behrendt, F. F. & Das, M. (2013). Intravascular Enhancement With Identical Iodine Delivery Rate Using Different Iodine Contrast Media in a Circulation Phantom. *Investigative Radiology, 48* (11), 813-818. doi: 10.1097/RLI.0b013e31829979e8.

Content:

- Purpose: Iodine delivery rate (IDR) and iodine concentration are factors for vascular enhancement in CCTA. If IDR is kept the same, is high iodine concentration better than low iodine concentration? This study looks at the effects of different iodine concentrations on a circulation phantom while maintaining constant IDR
- Circulation Phantom
    - With physiological circulation parameters
    - low pressure and high pressure body circulation systems
    - Accurate replicas of entire aorta and coronary arteries
    - connecting tubes, water filled acrylic container, 2 pressure meters, pressure relief valve for modulation of arterial and venous pressure.
    - Filled with body temperaute (37 degrees celsius) water
    - circulation driven by pulsatile Harvard medical heart pump (BS4; Harvard Apparatus, Holliston, MA).
    - 60 bpm, 60mL stroke volume, 60:40 dioastole/systole ratio, blood pressure of 120/80 mm Hg
    - Aortic and coronary elements in the water chamber
- See article for imagaes of the set up (LabArchives will not let me post them in)

Conclusions/action items:

Useful for coming up with design ideas

Contrast Media Protocol Optimization Using Circulation Phantom

SOPHIA SPEECE - Sep 17, 2023, 1:05 PM CDT

Title: Contrast media injection protocol optimization for dual-energy coronary CT angiography: results from a circulation phantom

Date: 9.17.23

Content by: Sophia Speece

Search Term: N/A, obtained reference from "Phantom Study Using..."

Citation: https://web-s-ebscohost-com.ezproxy.library.wisc.edu/ehost/pdfviewer/pdfviewer?vid=0&sid=7dbe53dc-1761-4e15-a340-c86f15c14566%40redis (need to get citation, surrently working on a computer without my citation program)

Content:

- Objective: to investigate the minimum iodine delivery rate (IDR) required to acheive diagnostic coronary attenuation (300 HU (hounsfield units)) with dual-energy coronary CTA
- Circulation Phantom
    - Low and high pressure compartments connected by plastic tubing with life sized replicas of aortic arch, coronary arteries, and descneding aorta. Used silicone coronary tree model (Elastrat, Model T-S-N-002, Shelley Medical Inc., Londaon, Ontario, Canada) mimics the human vasculature
    - Thoracic aorta is made up of a tube corresponding to the pulmonary trunk.
    - The aorta is in a water filled acrylic case, which mimics CT attenuation characteristics (5900 mL)
    - 37 degrees celsuis driven through Harvard pulsatile heart pump
    - Cardiovascular system flow system uses systolic and diastolic pressure model to simulate normal haemodynamic parameters
    - Injection port allowing for CM injection also present
    - 60 bpm, 90 mL stroke volume, blood pressure of 120/80 mm Hg
- Injection protocols
    - CM (Iopromide, 370 mgI/mL) was injected consistently over a time of 12 seconds.
    - Used a dual syringe CT injection system with an injection port simulating an 18-gauge IV access.

Conclusions/action items:

- Look up the silicone tree model
- What are systolic, diastolic, and haemodynamic?
- What does an injection port look like?

Expense Chart

EMMA FLEMMER - Dec 13, 2023, 9:09 AM CST

Title: Expense Chart

Date: 12/11/2023

Content by: Emma Flemmer

Present: Emma Flemmer

Goals: Lay out the expenses for the fabrication and testing of the product

Content:

Component	Cost
Ultimaker Tough PLA for Injector Piece	$5.26
Roller Pump	$0 (borrowed)
Plastic Tubing	$0 (borrowed)
Acrylic Sheets	$0 (already owned)
Epoxy	$15.00
Stratasys ABS M30 / Stratasys QSR Support for Phantom	$25.15
Total	$45.41

Conclusions/action items:

Get reimbursement from the client.

Acrylic Box Protocol

SOPHIA SPEECE - Dec 13, 2023, 8:45 PM CST

Title: Acrylic Box Protocol

Date: 12.13.23

Content by: Sophie

Present: Sophie

Goals: Record the step by step process to creating the acrylic box so that others in the future can replicate it if needed

Content:

Materials

- ⅛” clear acrylic
- Two Part Epoxy
- Bandsaw
- Sandpaper or Sanding Belt
- Deburring tool

Methods

1. Measure and mark one 25cm x 20 cm, two 25 cm x 15 cm, and two 20 cm x 15 cm pieces of acrylic
2. Using the bandsaw, carefully cut out the clear acrylic pieces
3. Using sandpaper or the sanding belt, smooth down the sides to a flat edge
4. Use a deburring tool to scrape off excess shrapnel
5. Assemble pieces to form a rectangular prism with open top
6. Glue and seal with epoxy

Conclusions/action items:

N/A

Heart Model Protocol

SOPHIA SPEECE - Dec 13, 2023, 8:46 PM CST

Title: Heart Model Protocol

Date: 12.13.23

Content by: Sophie

Present: Team

Goals: Record the step by step process of making the heart phantom so that others in the future can follow the steps and replicate them

Content:

Materials

- PLA
- Acrylic
- Epoxy
- Standard Connectors
- Modeling Software:
  - Meshlab
  - Meshmixer
  - Blender

Methods

1. Acquire stl files either from online sources or from a DICOM
2. Import the file into either Meshlab or Meshmixer
3. If in Meshlab (works well for cutting irregular shapes)
   1. Select the “Select faces in a rectangular region” in the options menu at the top
   2. Holding down the control key, select the faces that need to be cut. They should be highlighted in red
   3. Press delete
   4. Repeat steps a-c until left with the needed parts
   5. Re-mesh and smooth using the drop-down menus at the top
   6. Once the part is complete, export as an STL file.
4. If in Meshmixer (works well for plane cuts)
   1. Select the “Edit” option on the left side of the screen
   2. In the dropdown, select “Plane Cut”
   3. Use the sliders that appear on screen to adjust where the model is cut
   4. If needed, use the “Make Solid” and/or “Close Cracks” options (also under “Edit”) to smooth the model and close holes.
   5. Once the part is complete, export as an STL file
5. Import both pieces into Blender. Ensure the program is in “Object Mode”
6. Using the toolbar on the right side, scale, translate, and rotate the two models into the correct position
7. Holding down the shift key, select both objects

8. Select the “Object” dropdown at the top of the screen
9. Select “Join” to make the objects into one. Make sure there is ample overlap between the two parts so that it can print correctly.
10. Export the final 3D object as an STL file
11. Upload the STL file to the Stratasys 3D printer (or another 3D printer) and print
12. Once printed, dissolve supports
13. Attach 4 tubing connectors (two female and two male, one each for the atrium and aorta) to the heart phantom. Use clear acrylic and epoxy to fill any gaps and secure the attachments.
14. Test to ensure the device is water tight. Fill holes with Epoxy as needed

Conclusions/action items:

N/A

Injection Site Protocol

SOPHIA SPEECE - Dec 13, 2023, 8:48 PM CST

Title: Injection Site Protocol

Date: 12.13.23

Content by: Sophie, Lucy, Jack, Emma

Present: Team

Goals: Record the process by which the injection site was modelled and fabricated for future researchers' reference

Content:

Materials

- Ultimaker tough PLA
- Standard connectors
- Modeling Software:
  - Meshlab
  - Meshmixer
  - Blender

Methods

1. Open Solidworks
   1. Extrude a circular region into a cylinder at least 3 in tall and with a diameter of at least 2 in
   2. Make an extruded cylindrical cut through the cylinder of ⅜”, which is the same dimension as the outside of the tubing connectors
   3. Extrude another cylinder, this time at an angle of 45° to the center of the object, and only extrude halfway through the object
   4. Export as an STL
2. Open Blender
   1. Import the Solidworks tube and a luer-lock file acquired from online into Blender
   2. Using the same methods as the Heart Model, combine the two into one and export the combined object
3. Print the injection site on an Ultimaker printer out of Tough PLA
4. Once supports are removed, insert the connectors into each end (one female and one male). If the connectors do not fit, use a file to widen the injector site opening
5. Tap connectors into place with a mallet if need be

Conclusions/action items:

N/A

2023/11/30 Phantom Workday

EMMA FLEMMER - Dec 01, 2023, 12:30 PM CST

Title: Phantom Workday

Date: 11/30/2023

Content by: Emma Flemmer

Present: Bodey, Emma, Lucy, Sophie, Will

Goals: Finish fabrication, work on poster, and begin testing

Content:

- Bodey, Emma, Lucy, and Sophie fabricated acrylic caps for the phantom. The caps will be used to securely attach the connectors to the phantom

- Will worked on the poster

Figure 1: Bodey using the saw to cut the acrylic down

Figure 2: Lucy securing the cap to prepare for drilling

Figure 3: Lucy and Emma filing down the caps

- Sophie and Lucy attached the caps to the phantom using epoxy and added the connectors

Conclusions/action items:

Finish testing and begin statistical analysis. Work on the poster and final report.

2023/11/16-Modelling Work Day- Final Assembly

Bodey CARTIER - Dec 12, 2023, 9:51 PM CST

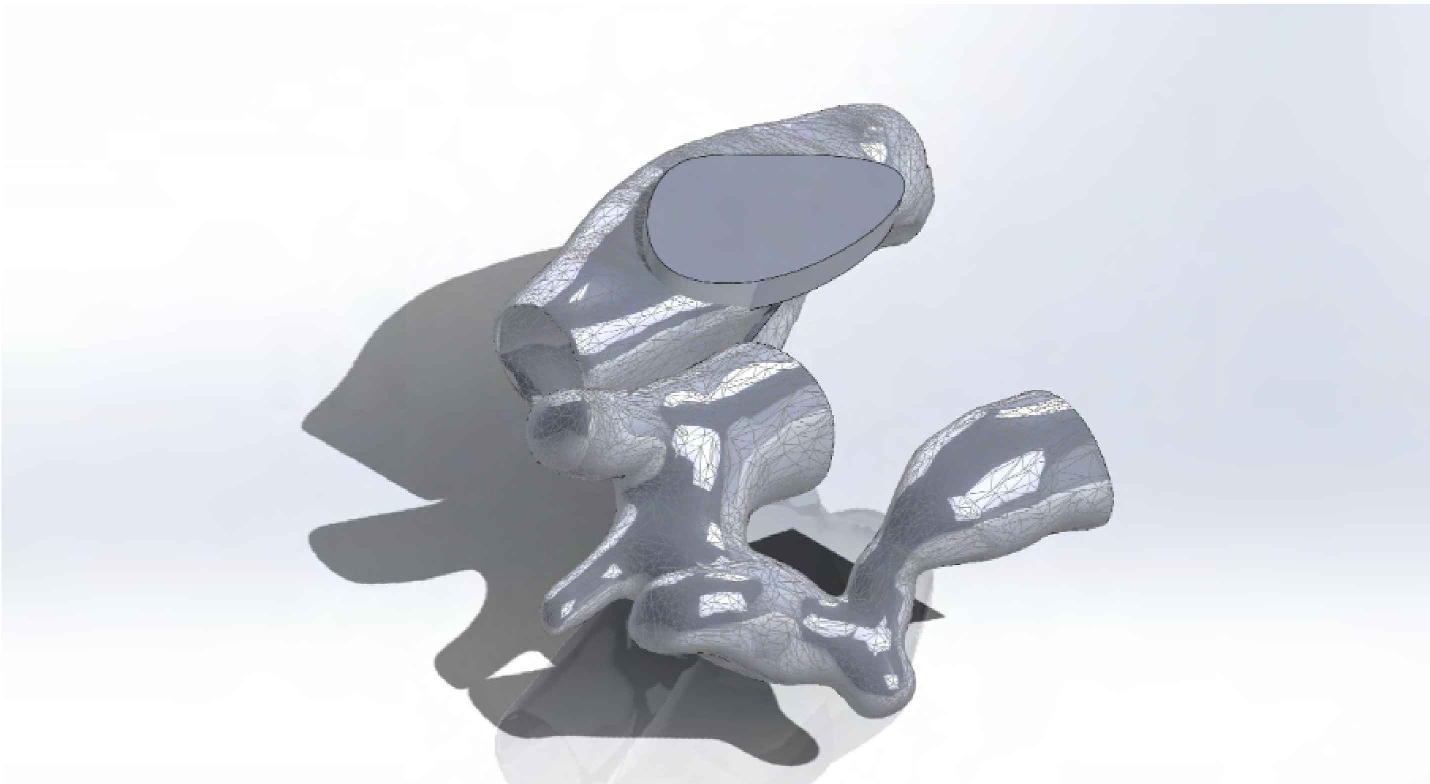
Title: Modelling Work day

Date: November 16th 2023

Content by: Bodey Cartier

Goals: Finalize a model to print

Content:



Conclusions/action items: Print model, finalize testing protocols, and test flow under CT setting.

2023/11/07 Phantom Modeling Workday

EMMA FLEMMER - Nov 07, 2023, 3:41 PM CST

Title: Phantom Modeling

Date: 11/07/2023

Content by: Emma Flemmer

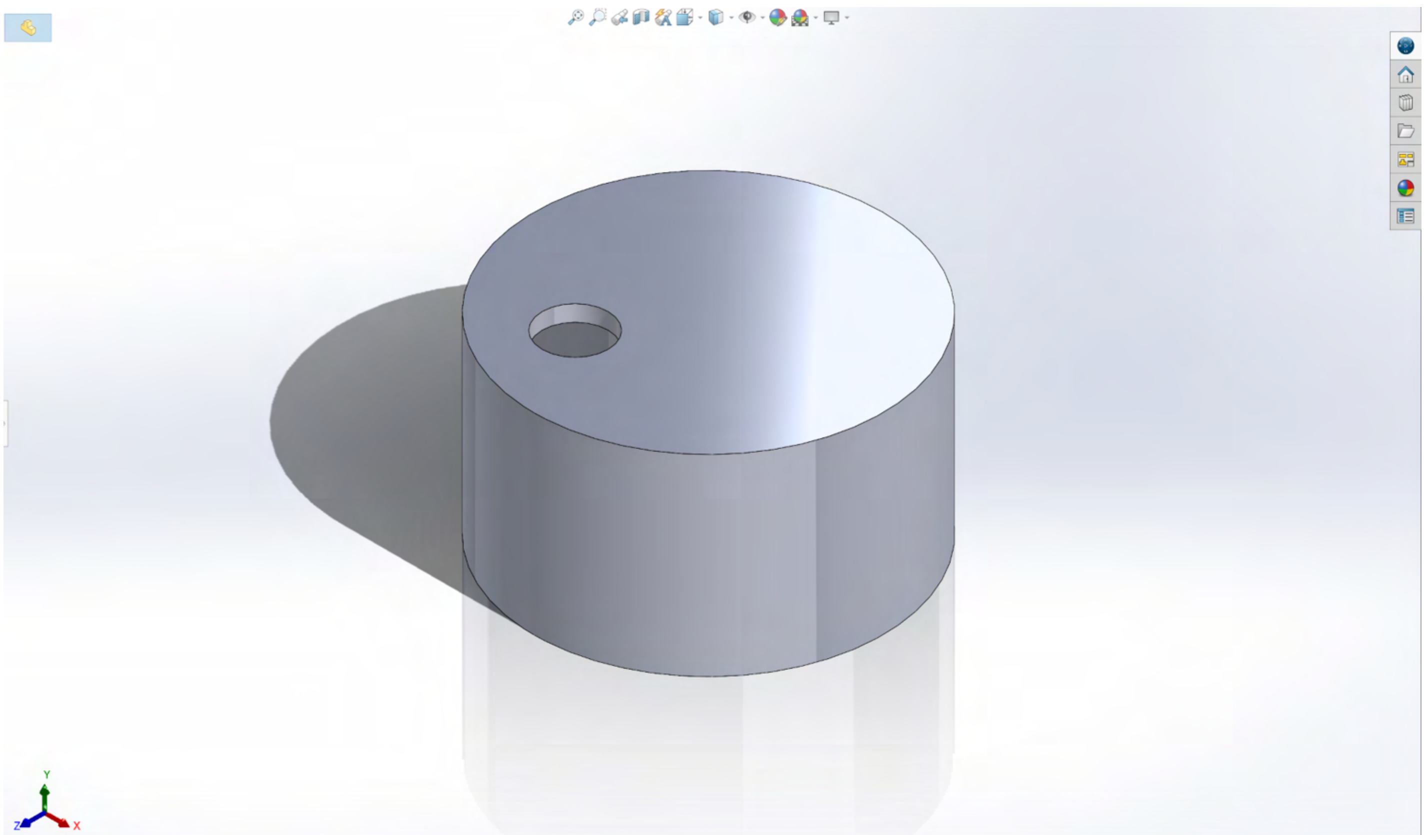
Present: Bodey Cartier

Goals: Model a simplified phantom as a backup

Content:

- Modeled the phantom using dimensions of a average male heart according to the National Library

- Modeled the right atrium as a cylinder with the same volume as the average male right atrium



Conclusions/action items:

Continue to work on the other phantom design.

EMMA FLEMMER - Nov 07, 2023, 3:39 PM CST

Link: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7849841/

Naseem, M., & Samir, S. (2021, January 8). *Right atrial volume index as a predictor of persistent right ventricular dysfunction in patients with acute inferior myocardial infarction and proximal right coronary artery occlusion treated with primary percutaneous coronary intervention*. Journal of the Saudi Heart Association. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7849841/

2023/11/02 Modeling Workday 2

EMMA FLEMMER - Nov 03, 2023, 2:15 PM CDT

Title: Modeling Workday 2

Date: 11/02/2023

Content by: Emma Flemmer

Present: Lucy O'Cull

Goals: Finish cleaning up the model and begin hollowing it out

Content:

- Had struggles getting the Mimics software to work

- We finished cleaning up the extra data points but had some issues filling all the small holes and completely smoothing the model over

- Also experienced issues with hollowing out and cutting into the Aorta (back yellow segment)

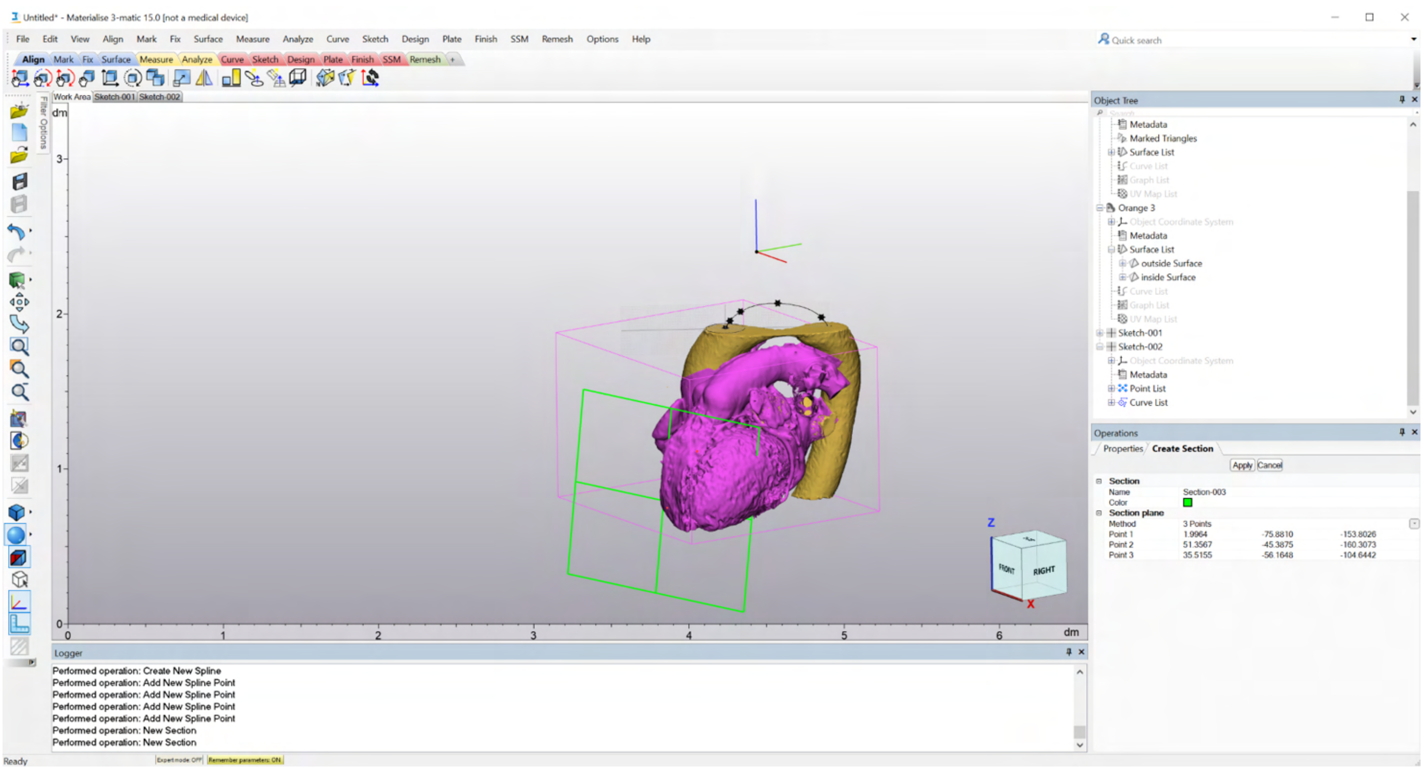


Figure 1: Screenshot of where we got with the modeling

- As you can see in the image above the model could be cleaner and there is a lot of unwanted texture and small holes that need to be smoothed over/filled

Conclusions/action items:

Going forward we are going to continue to work to clear up the model. However, we also will make a simplified version of the phantom using SolidWorks in case we are unable to get the model to a final printable state.

2023/10/26 Modeling Workday

EMMA FLEMMER - Nov 02, 2023, 2:38 PM CDT

Title: Modeling Workday

Date: 10/26/2023

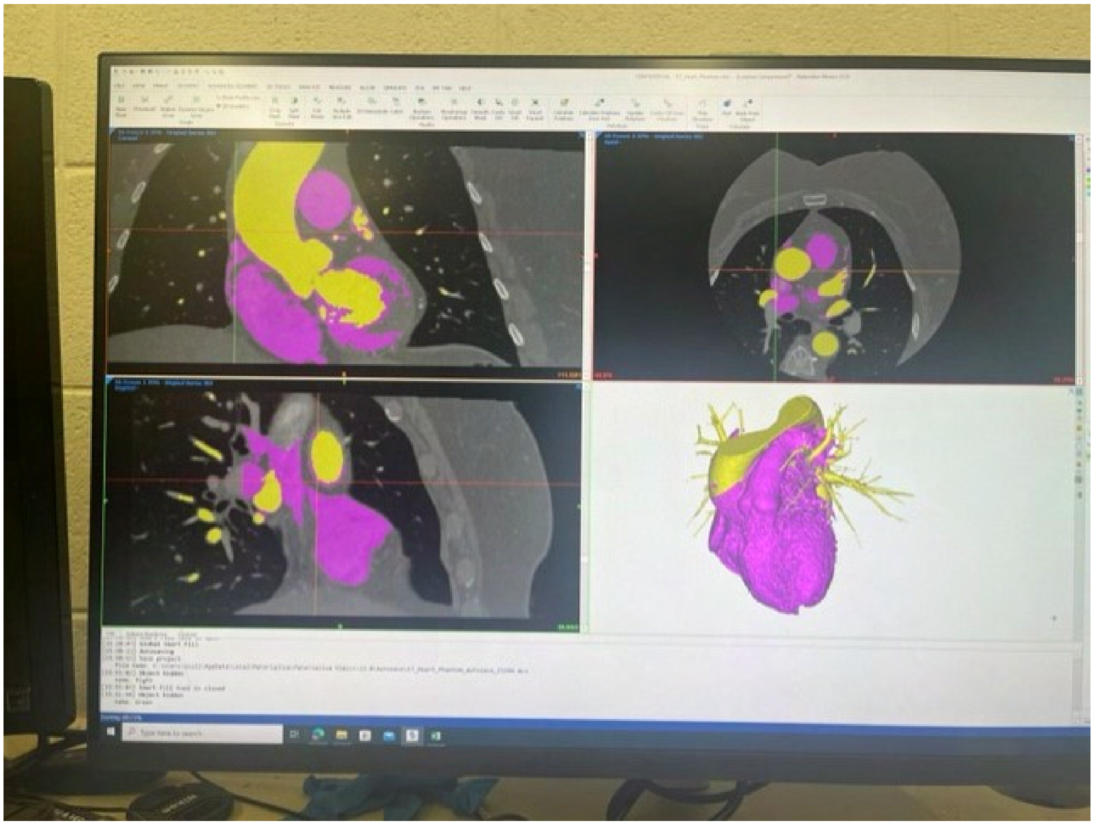
Content by: Lucy O'Cull

Present: Emma Flemmer, Bodey Cartier

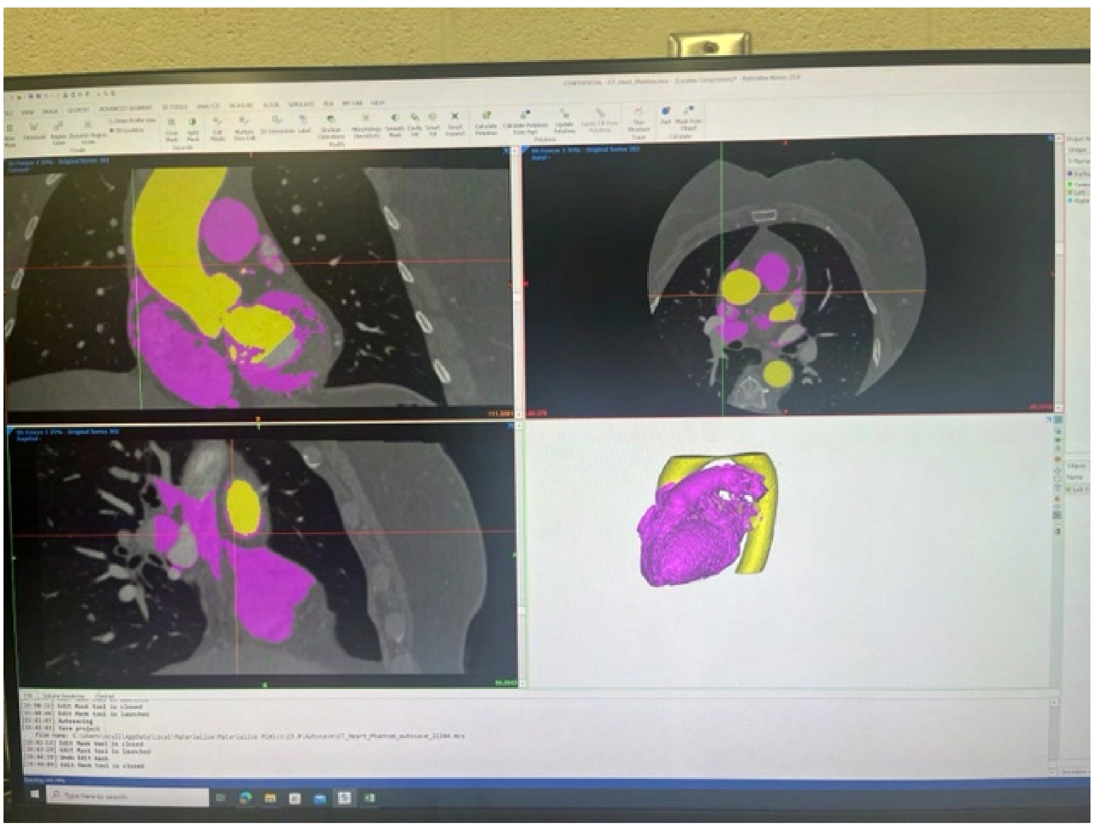
Goals: Work on Making a model from the CT scans and a backup.

Content:

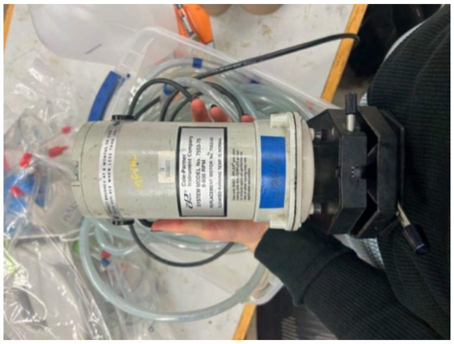
This is the backup aortic arch that was modeled by Lucy and Bodey, and can be considered for use in the phantom.

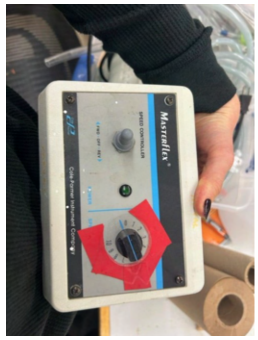


This is the 3D model after about 45 minutes of manipulating. In yellow is the left side of the heart, which was in really good condition. In magenta is the right side of the heart, which was in poor condition. It previously included much of the rib cage, sternum, and spine along with other noise that was indistinguishable. We were able to pair it down to what is seen above. It still needs work smoothing and hollowing.



Shown above is the model we achieved after some more manipulation. We were able to remove the unwanted coronary arteries that were seen in the previous image.





The above images show the pump that we acquired from the UW CVFD lab. Along with this pump we were given tubing and I believe a flowmeter.

Conclusions/action items:

We made pretty good progress into completing segmenting and filling in holes. Next steps include hollowing the model and sending it into other software to prepare for printing. Finish a backup for the show and tell

Acrylic Box Phantom

SOPHIA SPEECE - Oct 20, 2023, 2:47 PM CDT

Title: Acrylic Box Fabrication Phantom

Date: 10.20.23

Content by: Sophie

Present: Sophie

Goals: Fabrication Acrylic Box Phantom

Content:

See images attached below

Conclusions/action items:

Test to see if it is waterproof, if not, caulk the edges

SOPHIA SPEECE - Oct 20, 2023, 2:48 PM CDT

Download

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SOPHIA SPEECE - Oct 20, 2023, 2:48 PM CDT

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IMG_3597.HEIC (2.24 MB)

SOPHIA SPEECE - Oct 20, 2023, 2:48 PM CDT

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IMG_3598.HEIC (2.1 MB)

SOPHIA SPEECE - Oct 20, 2023, 2:48 PM CDT

Download

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11/13/23 Pump/Flow Testing Protocols

JACK STEVENS - Nov 13, 2023, 5:50 PM CST

Title: Pump/Flow Testing Protocols

Date: 11/13/23

Content by: Jack Stevens

Present: Sophie Speece and Will Stephenson

Goals: State the testing protocols for the pump and flow testing

Content:

Materials

- Roller Pump
- 3 ft. ⅜ in tubing
- Graduated cylinder
- Weigh scale
- Water collecting vessel
- Reservoir

Methods

1. First ensure that the roller pump and tubing are connected properly. See Figure 1 below for an image of the correct set up.
2. Using either gravity, or running the pump, fill the entirety of the tube with water.
3. Set a timer for 1 minute. Position the pump and tubing so that water is drawn from a reservoir and deposits into a dry, empty vessel.
4. Turn the speed dial to 1. See Figure 2 below. Start the timer
5. Once the timer ends, stop collecting water. Turn off the pump.
6. Measure the resulting volume of water using a graduated cylinder for the volume and the scale for the weight. Make sure to zero the scale with the weight of the empty collecting vessel beforehand
7. Repeat steps 3-6 twice more, report the average and standard deviation of each trial for each method of measurement
8. Repeat steps 3-7 for each speed on the pump
9. Analyzing the data, determine which speeds correspond to the different rates of volume output, and therefore which ones most accurately mimic the flow rates of an ECMO circuit (4-6 L/min).

Equations

Converting weight of water to volume of water: 1 kg of water is equal to 1 L of water

Conclusions/action items: Conduct testing of the pump and analyze the results to improve prototype

2023/12/05 Flow Rate Verification Protocol

LUCY O'CULL - Dec 12, 2023, 5:00 PM CST

Title: Flow Rate Verification Protocol

Date: 12/05/2023

Content by: Lucy O'Cull

Present: Lucy, Sophie, and James Rice at the UW Cardiovascular Fluid Dynamics Laboratory

Goals: Establish the protocol for the verification of the linear regression model created with the data from the original flow rate testing

Materials:

1. Full Circulation Phantom
2. 1/4" vinyl tubing
3. 3/8" to 1/4" tubing connectors
4. flowmeter
5. water

Methods:

1. In between the connection at the output of the aorta and it's respective tube, place the appropriate connectors and 1/4" tubing. (The flowmeter can only clamp onto and get measurements for this size tubing).
2. At the connection point on either side of the site of the injection, fill the circuit completely. There must be no air bubbles or the flowmeter will fail to get a reading.
3. Connect the flowmeter to the section with the 1/4" tubing. Turn on the flowmeter and calibrate.
4. Run the pump at the desired dial number setting. Record the flowmeter reading.
5. Repeat for each dial number setting.

CT Scanner Testing Protocol

SOPHIA SPEECE - Dec 13, 2023, 8:50 PM CST

Title: CT Scanner Testing Protocol

Date: 12.6.23

Content by: Lucy

Present: Team

Goals: Document CT Testing protocol so that future researchers could follow and replicate if needed

Content:

Materials

- Flow Phantom
    - Roller pump
    - Tubing circuitry
    - Heart model
    - Acrylic box
    - Iodinated contrast injector site
- Water source
- Sink
- Iodinated contrast injector
- Spill protection pads
- CT Scanner

Pre-Work

1. Connect together all of the tubing.
    1. Right atrium and aorta should be connected via short tubing with the injector site in the middle.
    2. Long tubing should connect the other ends of the right atrium and aorta.
2. Place the middle of the long tubing into the pump.
3. Disconnect the tubing from the injector piece.
4. Place one or both ends of the free tubing into a water source.
5. Turn on the pump at medium setting (4-5) and turn up to ten once the direction is determined.
6. Run the pump until water is present through the tubing without air bubbles.
    1. Inversion of the heart model is necessary to get air bubbles out of the heart.
    2. When the pump is turned off, make sure all holes are covered to prevent leakage.
7. Re-connect the injector site, attempting to keep all water in the system.
8. Make sure the injector site remains pointing upwards.
9. Cover the CT Scanner and bench with spill-protection padding.
10. Place the Acrylic box onto a bench on spill protection padding.

Calibration

1. Once the acrylic box is set, remove everyone from the room and make sure only the acrylic box will be scanned.
2. Scan the acrylic box to calibrate the scanner to that specific location.
3. Make sure that the acrylic box stays in that location throughout the scanning process.

Testing

1. Place the heart model inside the acrylic box.
2. Put the iodinated contrast injector into the injector site.
    1. To ensure a secure connection, an extra connector piece and tape will be required to reduce backflow.
3. Wrap the injector and injector site in towels in case of a spill.
4. Perform a final check to make sure everything is connected.
5. Turn on the pump at setting 10.
6. Make sure the room is cleared.
7. Scan phantom.
    1. 70+ seconds at cycles just over 2 seconds
8. Turn off the pump.

Post Work

1. Dispose of liquid left in the phantom.
    1. Go to sink (or other disposal location)
    2. Disconnect tubing around the injector site
    3. Place one end into the water source, and the other into the sink
    4. Run pump at medium setting (4-5) until pure water has cycled through the system
    5. Take water source end out of water
    6. Run the pump until water is no longer in the circuitry
2. Clean up spillages and spill pads.

Conclusions/action items:

N/A

2023/12/1 Water tight testing

EMMA FLEMMER - Dec 01, 2023, 4:30 PM CST

Title: Water tight testing

Date: 12/1/2023

Content by: Emma Flemmer

Present: Emma, Sophie, and Will

Goals: Test to ensure that the phantom and circuit are waterproof

Content:

- The team connected the tubing to the phantom and put the tubing through the pump. Two ends of the tube were placed in a reservoir of water

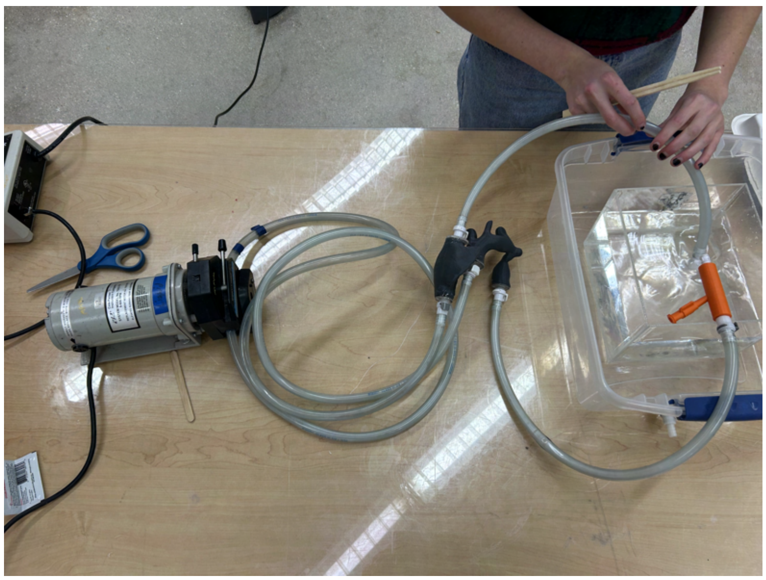


Figure 1. Testing setup

- The first test was ran. The tubes and connections were tight and no leakage occurred there. However, the phantom seemed to be leaking slightly at the top where the layers weren't completely covered

- A thin layer of epoxy was applied to attempt to seal any gaps between the layers of PLA

- A second test was ran and the phantom appeared to be water tight

Conclusions/action items:

Run the circuit through a CT scanner

11/30 Calculated Flow Data Spreadsheet

JACK STEVENS - Nov 30, 2023, 5:19 PM CST

Title: Brute Flow Data Spreadsheet

Date: 11/30/23

Content by: Jack Stevens

Present: No one

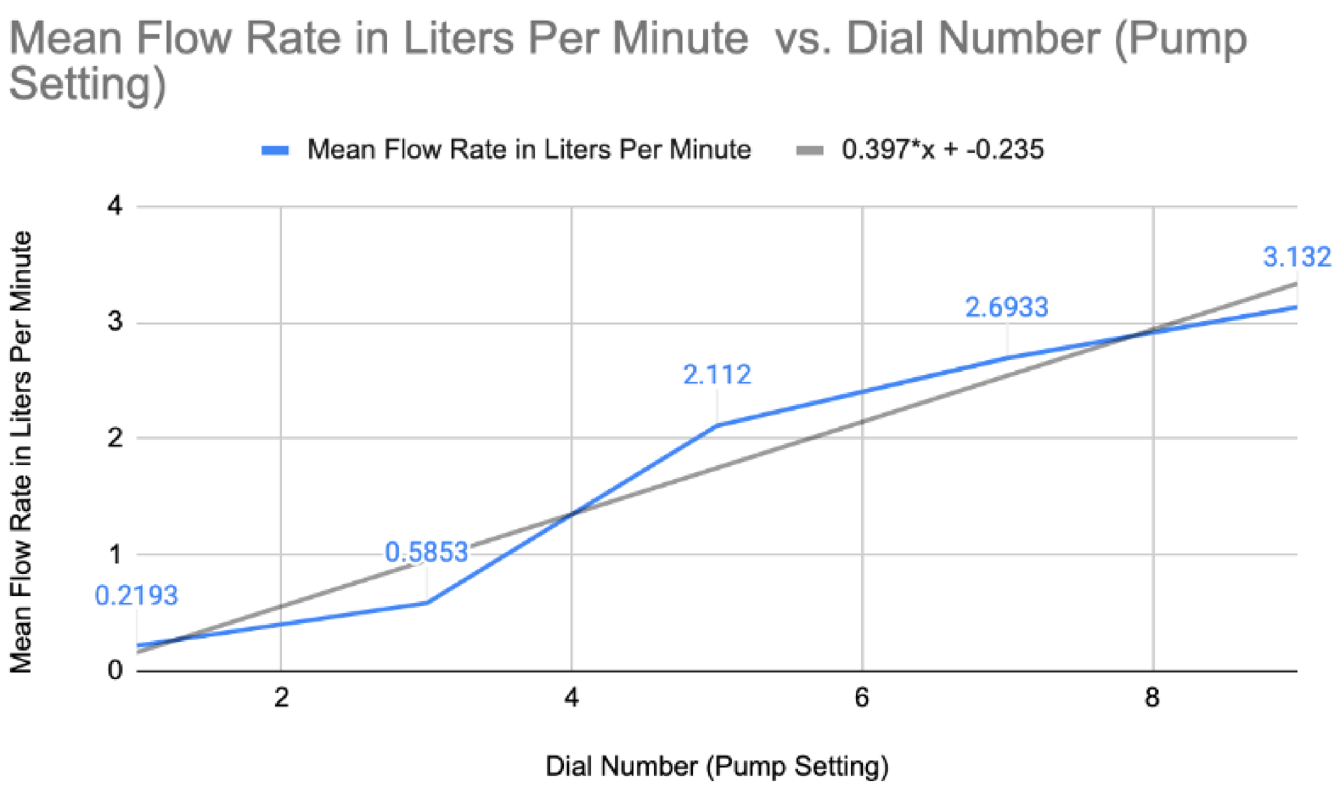
Goals: Analyze the brute flow data and make a graph to use on the final poster.

Content:

Link to spreadsheet:

https://docs.google.com/spreadsheets/d/1OJI2BD9YhiGNbvBXwXTxJ383OVZf2umSAaaEunI5ZNY/edit#gid=0

Graph of average flow rate for each pump setting



Conclusions/action items: Share data analysis with team and edit the graph to add to final poster and add figure caption or number on the poster.

12/4/23 Further Data Analysis on Testing

LUCY O'CULL - Dec 12, 2023, 5:17 PM CST

Title: Further Data Analysis on Testing

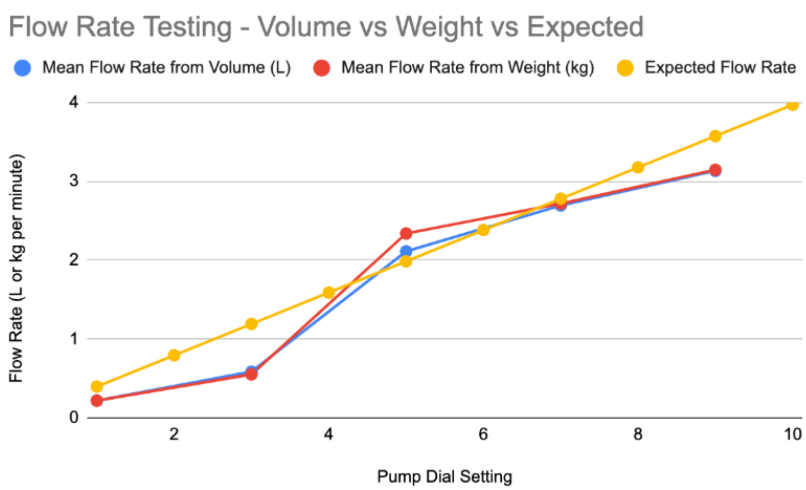
Date: 12/4/23

Content by: Jack Stevens

Present: Lucy, Sophie, Bodey, Emma

Goals: Keep working on making graphs and analyzing the data for the pump testing and any other testing.

Content:



This graph compares the flow rates that we calculated from various means (either from the volume of water output by the pump or by the weight of the water output by the pump). There is also an expected flow rate that came from the equation for the line of best fit which shows any errors in testing that resulted in significantly different calculated flow rates.

Bodey and I also worked with the completed circuit to make sure that the 3D printed heart does not leak water.

Equations for Flow Rate and Pressure:

Hagen-Poiseuille Equation

$$\Delta p = \frac{8\mu L Q}{\pi R^4}$$

Δp = pressure difference between the two ends
μ = dynamic viscosity
L = length of pipe
Q = volumetric flow rate
π = pi
R = pipe radius

Viscosity of water = 0.01 poise

Reynolds number equation to predict fluid flow patterns:

$$Re = \frac{\rho u L}{\mu}$$

Conclusions/action items: Add to poster, share with team, present poster on Friday

2023/12/05 Flow Rate Verification Results

LUCY O'CULL - Dec 12, 2023, 5:14 PM CST

Title: Flow Rate Verification Results

Date: 12/05/2023

Content by: Lucy O'Cull

Present: Lucy, Sophie, James Rice from UW Cardiovascular Fluid Dynamics Laboratory

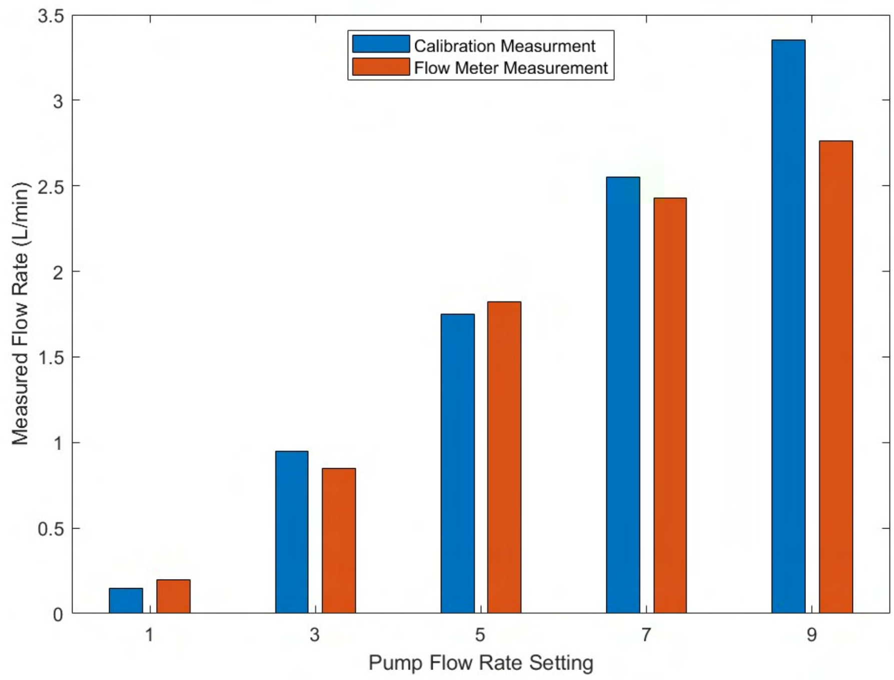
Goals: Complete the verification testing as outlined in the protocol section and analyze the data in relation to the original flow rate testing on MATLAB

Content:

1. Worked with James to complete the testing as outlined in the protocol section
2. We discovered that if the pump runs for a long time (over 3 min) it begins to melt the tubing
3. Data was recorded for all of the dial settings that corresponded with the results of the original test.

MATLAB code:

```
setting = [1,3,5,7,9]'
FlowMeter = [0.2,0.85,1.82,2.43,2.76]';
calibration = (setting .* 0.40) - 0.25;
data = [calibration,FlowMeter];
figure(1);
bar(setting,data,'BarWidth', 0.7)
xlabel("Pump Flow Rate Setting")
ylabel("Measured Flow Rate (L/min)")
legend("Calibration Measurment","Flow Meter Measurement","location","north")
[h, p, ci, stats] = ttest2(FlowMeter,calibration)
if h
   fprintf('Reject the null hypothesis. There is a significant difference between the groups.\n');
else
   fprintf('Fail to reject the null hypothesis. There is no significant difference between the groups.\n');
end
```



Conclusions/action items:

It was determined that the flow rates obtained by the flowmeter were not statistically significantly different than the flow rates predicted using the linear regression model from the first test. This conclusion means that we can say that with some statistical accuracy, we can control the flow rates that are outputted by the pump.

2023/12/06 CT Testing at WIMR

LUCY O'CULL - Dec 12, 2023, 5:42 PM CST

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

Date: 9/5/2016

Content by: Lucy O'Cull

Present: Lucy, Sophie, Bodey, Jack, Will, Dr. Toia, Dr. Sticks, CT technicians

Goals: Complete a few scans of the phantom to investigate its performance

Content:

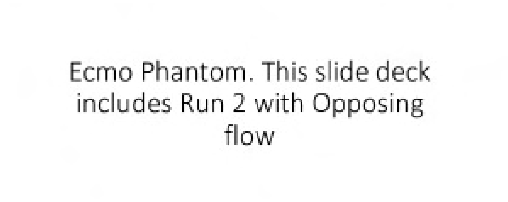
1. Met up with Dr. Toia and Dr. Sticks along with 2 CT technicians to scan the phantom
2. Showed the client how the phantom is put together and how to fill it up
3. Worked with the client and technicians to secure a modification into the connector piece so that it would fit perfectly with the injection machine
4. Dr. Sticks calibrated the machine via X-Ray
5. Dr. Sticks and the technicians talked through what settings they wanted to conduct the scan with (24 series 86 pictures per series, 9mL/s for the injector)
6. First scan was ran with pump moving fluid in the direction for a normal human being.
7. Looked through the pictures to make sure they were good quality scans
8. Flushed the phantom and prepared for next scan
9. Second scan was ran with pump moving fluid in the direction for a human on VA-ECMO
10. Looked through the pictures to make sure they were good quality scans
11. The radiologists and technicians talked us through the data of interest and made a plan for getting us that data because we do not have access to PACs
12. Talked with Client about future work
    1. design circuit that has capabilities for new fresh water to be introduced to the system
    2. Make injector piece out of rubber to reduce pressure build up in the connection
    3. if we want the phantom to be suspended in solution, need to come up with a way that the suspension does not "slosh"
    4. Design more anatomically accurate circuit

LUCY O'CULL - Dec 12, 2023, 5:37 PM CST

Download

ECMO_phantom_test_RUN_1.pdf (1.84 MB) Trial 1

LUCY O'CULL - Dec 12, 2023, 5:37 PM CST



Download

researchECMO.pdf (2.63 MB) Trial 2

LUCY O'CULL - Dec 12, 2023, 5:41 PM CST

Conclusions/action items:

Overall very successful testing. We were able to find some clear images without much artifact. The most important thing that we got out of todays testing was the temporal variation of HU in the region of interest plots featured at the end of the trial slide decks attached above. The client said that those plots are exaclty what they are looking to study and as the phantom is improved upon, those plots will be valuable for created a standard to CT scans on patients on ECMO.

Matlab Code - Flow Testing

SOPHIA SPEECE - Dec 13, 2023, 8:52 PM CST

Title: Matlab Code from Flow Rate Testing to Generate Graphs

Date: 12.6.23

Content by: Sophie, Lucy, Jack

Present: Sophie, Lucy, Emma, Jack

Goals: Document Matlab code used for graphing and analyzing CT flow rate data

Content:

Flow Rate Testing

```
flow_data = table2array(FlowTestingData);

test_1_vol = flow_data(:,1);

test_1_w = flow_data(:,2);

test_2_vol = flow_data(:,3);

test_2_w = flow_data(:,4);

test_3_vol = flow_data(:,5);

test_3_w = flow_data(:,6);

dial_number = flow_data(:,7);

mean_tests = mean(flow_data(:,1:6)');

std_tests = std(flow_data(:,1:6)')

x = [1,3,5,7,9];

meanies = [0.2186, 0.5685, 2.0754, 2.7050, 3.1390];

[p, S] = polyfit(x, meanies, 1)

err = [0.0325, 0.2068, 0.5035, 0.0587, 0.0175]

hold("on")

scatter(dial_number, [test_1_vol test_2_vol test_3_vol], "r", "filled")

scatter(dial_number, [test_1_w test_2_w test_3_w], "b", "filled")

%scatter(dial_number, test_2_vol, "r")

%scatter(dial_number, test_2_w, "b")

%scatter(dial_number, test_3_vol, "r")

%scatter(dial_number, test_3_w, "b")

plot(x, 0.3989.*x-0.2530, "black")

plot(x, mean_tests, "blue")

title("Flow Rate in L/min for the Roller Pump according to Dial Number")

xlabel("Dial Number")

ylabel("Flow Rate in L/min")

hold("off")\
```

Flow Rate Verification Testing

```
setting = [1,3,5,7,9]'

FlowMeter = [0.2,0.85,1.82,2.43,2.76]';

calibration = (setting .* 0.40) - 0.25;

data = [calibration,FlowMeter];

figure(1);

bar(setting,data,'BarWidth', 0.7)

xlabel("Pump Flow Rate Setting")

ylabel("Measured Flow Rate (L/min)")

legend("Calibration Measurment","Flow Meter Measurement","location","north")

[h, p, ci, stats] = ttest2(FlowMeter,calibration)

if h

  fprintf('Reject the null hypothesis. There is a significant difference between the groups.\n');

else

  fprintf('Fail to reject the null hypothesis. There is no significant difference between the groups.\n');

end
```

Conclusions/action items:

N/A

Product Design Specifications - First Draft

SOPHIA SPEECE - Sep 22, 2023, 12:46 AM CDT

CT Circulation Phantom - BME 200/300

Product Design Specifications

BME 200/300 Design
September 22, 2023

Client: Dr. Giuseppe Toia

Advisor: Professor Justin Williams
University of Wisconsin-Madison
Department of Biomedical Engineering

Team:
Leader: Sophia Speece
Communicator: Lucy O'Cull
BSAC: Will Stephenson
BWIG: Emma Flemmer
BWIG: Jack Stevens
BPAG: Bodey Cartier

Function:

A CT phantom is a device used to calibrate Computed Tomography machines by acting as a "stand in" for human tissues [1]. Most phantoms currently in use are static; they do not allow for dynamic flow. Some patients obtaining a CT scan may need a circulatory support device, such as a VA-ECMO (veno-arterial extracorporeal membrane oxygenation) device [2]. There is a clinical need for a CT phantom with dynamic flow capabilities to study the correct ways to conduct CT vascular imaging for patients on ECMO devices. This phantom should model the inflow and outflow of an ECMO patient and have capabilities to simulate the addition of contrast media into the vascular system. Ultimately, this device will help medical personnel to better understand the flow of CT contrast through a patient on an ECMO machine, as the circulation pathways of an ECMO patient differs from a patient not on ECMO.

Client requirements:

- A CT Phantom with the main components of the heart and circulatory system accessed during VA-ECMO, capable of dynamic flow. The inflow and outflow cannulas are typically placed in the right atrium and ascending aorta, respectively [3]
- A ECMO pump and tubing with adjustable flow rates, and connectability to the phantom
- An iodine contrast injector capable of multiple injection rates, as well as an access point in the phantom for this injector
- A reservoir to draw fluid from and a disposal chamber
- Easily cleaned

- Ability to be used continuously

Design requirements:

1. Physical and Operational Characteristics

a. *Performance requirements*: The CT Circulation Phantom will be tested and used in a CT machine. CT, or computed tomography, scans take less than a minute to complete. The phantom would be used up to thirty times a day, for up to many years. The phantom must therefore be constructed in a durable manner to withstand loading and unloading from the CT gantry, as well as in a way that can withstand the effective dose, which is the energy deposited by ionizing radiation x-rays. This dose can range between 7 mSv (millisievert) and 20 mSv for a torso scan, depending on the use of a contrast agent [4]. Because this device will not be used to calibrate a CT machine, the phantom does not have to adhere to FDA CT phantom dimension and material regulations [5]. See *Standards and Regulations* for more information regarding FDA requirements for CT equipment.

b. *Safety*: There are no explicit safety standards regarding static CT phantoms. There are, however, extensive criteria for ECLS (Extracorporeal Life Support) machines. These measures primarily refer to patient safety and are not required for our client and user safety, but they are important parameters for the machine to achieve. The circuit should support fluid flow of 3 L/m^2/min. The inlet and outlet pressure should not exceed -300 mmHG and 400mmHg respectively [6]. The Circulation Phantom does not need to be sterilized, but should be cleaned thoroughly after each use to prevent staining and mold/bacteria growth. All components should be water tight to prevent leakage and therefore damage. In general, all materials should be non-toxic, secure, and non-sharp.

c. *Accuracy and Reliability*: The design is intended to create a better understanding of the injection rates and volume of contrast needed to properly conduct CT scans on VA-ECMO patients. It is important to maintain maximum possible accuracy so the data produced from testing is useful.

d. *Life in Service*: The device is designed to be used to test and assess dynamic flow rates through a fabricated phantom. The consumer, likely a medical team, would buy the product to calibrate a CT machine with dynamic flow rates for patients that have dynamic blood flow rates.

e. *Shelf Life*: Because the product's purpose is the specialized usage of phantoms, the device will remain out of use during many periods of its life cycle. Due to this fact, the device is designed to resist normal shelf life conditions for many years. Pre-existing, medical-grade static phantoms are typically in use for many years if not decades. Our design utilizes inexpensive off-the-shelf materials which will lower its shelf life when compared to manufactured products. Due to all of the moving components, the shelf life of the dynamic phantom is believed to be several years, or until one of the components loses accuracy or functionality.

f. *Operating Environment*: The device will operate in a standard CT scanning room. A CT scanning room is very close to 22°C, never to exceed 24°C or fall below 18°C [7]. The standard humidity for operating rooms is between 30% and 70% which the device will be subject to. The procedure is done meticulously, ensuring cleanliness of the area for maximum accuracy of the scan.

g. *Ergonomics*: The phantom should not be excessively difficult to move around. The efficiency of testing procedures should not be affected by a device that is physically demanding to handle. Technicians should not experience ergonomic strain and discomfort when performing testing with the phantom. Research shows that technician fatigue can be a source of excessive radiation administration [8]. Fatigue should not be a byproduct of operating with the phantom.

h. *Size*: The final design will be run through a Computed Tomography scanner for testing. Therefore the size limitation will be determined by the size of the gantry aperture. Typical CT scanner openings range in diameter from 75-85 cm, with some older models being as small as 70 cm [9]. The design should be kept under 70 cm to ensure that testing will be able to take place.

i. *Weight*: The design will have to adhere to the weight limitations of the CT scanner. These limitations state that the device that is put onto the couch that will go into the scanner must be less than 500 pounds, or 228 kg. This is a very obtainable limitation. The device should probably be easy to carry and maneuver, so less than 100 pounds, or 45 kg would be preferable for the purposes of testing and fabrication.

j. *Materials*: The CT Scanner doesn't have a limitation for the materials that we can or can't use while scanning, however, for imaging purposes the prototype should be built without any metals or plexiglass. This primarily rules out using metals and avoiding plexiglass. In addition, the prototype is going to go through many many tests, which means that the construction needs to be robust. Strong plastics, such as PVC [10], should be used for tubing, and other pieces of the construction should be strong enough to hold the key components of the mock-ECMO circuitry. The addition of an off the shelf pump is dependent on the availability of an unused ECMO machine/pump to be used with the prototype. If there is not an ECMO pump available, the pump must be able to pump fluid up to the levels of an ECMO pump (500ml/s) [3]. A contrast pump will be provided in the form of a clinical injector.

k. *Aesthetics, Appearance, and Finish*: The preferred shaping of this phantom would be that of something reminiscent of a torso on the exterior, with a tubing circuitry system within to simulate the body of a patient on a VA-ECMO machine. This device should also be adjustable in terms of catheter placement on the body. However, this doesn't need to be a perfect replica as the main goal of the phantom is to show the effects of the varying flow rates within the circuitry. Therefore there is room for appearance adjustments in favor of functionality. Aesthetics and Finish are both non-priority as the point of the device is to be scanned, and neither of those two pieces change the functionality of the device.

2. Production Characteristics

a. *Quantity*: For the duration of this project the goal is to produce one final working product. However, the design will be made and documented in detail so that the product could be duplicated in the future.

b. *Target Product Cost*: As of (9/21/2023) the team is intending to borrow phantom components from various departments of UW Health. For anything that cannot be procured from our contacts, the intention is to keep products costs under 200 dollars.

3. Miscellaneous

a. *Standards and Specifications*: Standards and specifications have been established to optimize performance of CT equipment. These guidelines help to ensure that our design will assist in providing accurate diagnoses while minimizing unnecessary radiation exposure to patients and technicians. The FDA's CFR title 21, subchapter J, section 1020.33 establishes standards that feature the importance of employing phantoms to test CT equipment. It requires specific data to be reported from phantom calibration that can be used as evidence of compliance with regulations: contrast scale, noise, nominal tomographic section thickness, and spatial resolution capability of the system for low and high contrast objects [5]. ASTM E1695-20e1 is a standard test method for CT system performance measurement. Section 5 outlines physical specifications for the phantom testing apparatus including shape, size, material, and finish [11]. Other relevant standards include IEC 61223-3-5, AAPM Report No. 111, NEMA XR 21, and IPEM Report 87. The FDA classifies our device as a Class I medical device with general controls. The FDA recognizes that this device is exempt from premarket notification 510(k) procedures, and exempt from current good manufacturing practice requirements of the quality system regulation except for general requirements concerning records and complaint files [12].

b. *Customer*: Our customers/clients in the department of Medical Physics at UW Madison are in need of a phantom to be used for the testing and calibrating of a Computed Tomography machine. The phantom must be able to mimic the dynamic blood and contrast flow that occurs in a patient when they are using a VA-ECMO machine. By using an off the shelf pump, the phantom must be built with a structure similar to a VA-ECMO machine as well as the heart and major systemic arteries. Current phantoms with static flow rates are well understood and allow for proper imaging to take place on real patients. Meanwhile, vascular imaging with dynamic flow rates is not as well understood which is why the clients need the phantom device to allow for alterable flow rates.

c. *Patient-related concerns*: While the device is important for the care of many patients, it will not be in contact with any as its main purpose is to calibrate and be used for testing in CT machines. That being said, the device must still follow strict guidelines in its creation in order to eliminate any risk when running tests on it.

d. *Competition:* There are currently phantoms designed with dynamic flow rates for CT testing. One such device is a two-compartment, 3D printed phantom which allows for testing on various CT, MRI, and PET machines. Testing on the device allows for the creation of TACs (Typical Clinical Time-Attenuation Curves) which can be analyzed for DCE-CT (Dynamic Contrast Enhanced Computed Tomography) validation and to create more realistic imaging models of patients [13]. Another device was created because photoacoustic (PA) spectroscopy, while useful, was found to be too slow. Dynamic PA flow cytometry (PAFC) platforms have fast-moving cells that can have velocities from 20-50 cm/s which does not work with most blood phantoms that involve static flow. The team created a device that resembles the properties of whole flowing blood and CTCs (circulating tumor cells). Their device used silicone and "Layer-by-Layer" assembled capsules that had hemoglobin and "natural melanin micro- and nanoparticles." They found it challenging to make these objects seem similar to the real things and to "simulate their optical properties". Finally, their device represented different cell types and used "scattering-absorbing medium" and plastic tubing. It was successfully used to test "high speed signal processing in PAFC." Hollow polymer and silica capsules correctly simulated blood cells and melanoma markers which allowed the device to resemble blood in its optical and dynamic properties [14].

References

[1] "What Are Imaging Phantoms?," *NIST*, Apr. 2018, Accessed: Sep. 13, 2023. [Online]. Available: https://www.nist.gov/physics/what-are-imaging-phantoms

[2] M. S. Choi, K. Sung, and Y. H. Cho, "Clinical Pearls of Venoarterial Extracorporeal Membrane Oxygenation for Cardiogenic Shock," *Korean Circ. J.*, vol. 49, no. 8, pp. 657–677, Jul. 2019, doi: 10.4070/kcj.2019.0188.

[3] J. Shen, MD, J. Ruey Tse, MD, F. Chan, MD, PhD, and D. Fleischmann, MD, "CT Angiography of Venoarterial Extracorporeal Membrane Oxygenation," *Stanford Univ. Sch. Med. Dep. Radiol.*, p. 16, Feb. 2022.

[4] S. Seed, "How Much Radiation Do You Get From CT Scans?," *WebMD*. https://www.webmd.com/cancer/radiation-doses-ct-scans (accessed Sep. 22, 2023).

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[6] "ELSO Guidelines | Extracorporeal Membrane Oxygenation (ECMO)." https://www.elso.org/ecmo-resources/elso-ecmo-guidelines.aspx (accessed Sep. 22, 2023).

[7] "The Best CT Scan Room Temperature and Humidity for Maximum Uptime." https://info.blockimaging.com/bid/99019/the-best-ct-scan-room-temperature-and-humidity-for-maximum-uptime (accessed Sep. 22, 2023).

[8] "Failure to Adjust CT Scanners to Pediatric Settings is a Major Cause of Unnecessary Radiation Exposure to Children," Aug. 24, 2023. https://www.researchsquare.com (accessed Sep. 22, 2023).

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[11] "Standard Test Method for Measurement of Computed Tomography (CT) System Performance." https://www.astm.org/e1695-20e01.html (accessed Sep. 22, 2023).

[12] "CFR - Code of Federal Regulations Title 21." https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfCFR/CFRsearch.cfm?FR=892.1940 (accessed Sep. 22, 2023).

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[14] A. Kozlova *et al.*, "Dynamic blood flow phantom for in vivo liquid biopsy standardization," *Sci. Rep.*, vol. 11, no. 1, Art. no. 1, Jan. 2021, doi: 10.1038/s41598-020-80487-8.

SOPHIA SPEECE - Sep 22, 2023, 12:46 AM CDT

CT Circulation Phantom - BME 200/300

Product Design Specifications

BME 200/300 Design
September 22, 2023

Client: Dr. Giuseppe Toia

Advisor: Professor Justin Williams
University of Wisconsin-Madison
Department of Biomedical Engineering

Team:
Leader: Sophia Speece
Communicator: Lucy O'Cull
BSAC: Will Stephenson
BWIG: Emma Flemmer
BWIG: Jack Stevens
BPAG: Bodey Cartier

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Product_Design_Specifications_-_First_Draft.pdf (246 kB)

Preliminary Design Presentation Slides

SOPHIA SPEECE - Oct 06, 2023, 12:02 PM CDT

Title: Preliminary Design Presentation Slides

Date: 10.6.23

Content by: Team

Present: Team

Goals: Present and receive feedback to move forward with

Content:

See attached

Conclusions/action items:

Begin preliminary report, fabrication!

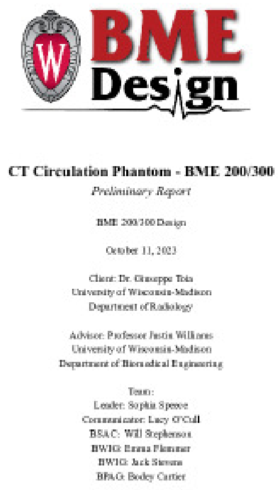
SOPHIA SPEECE - Oct 06, 2023, 12:02 PM CDT

Download

Preliminary_Presentation.pdf (1.47 MB)

Preliminary Report

EMMA FLEMMER - Dec 13, 2023, 9:20 AM CST


BME Design

CT Circulation Phantom - BME 200/300

Preliminary Report

BME 200/300 Design

October 11, 2023

Client: Dr. Giuseppe Toia
University of Wisconsin-Madison
Department of Radiology

Advisor: Professor Justin Williams
University of Wisconsin-Madison
Department of Biomedical Engineering

Team:
Leader: Sophia Speece
Communicator: Lucy O'Cull
BSAC: Will Stephenson
BWIG: Emma Flemmer
BWIG: Jack Stevens
BPAG: Bodey Cartier

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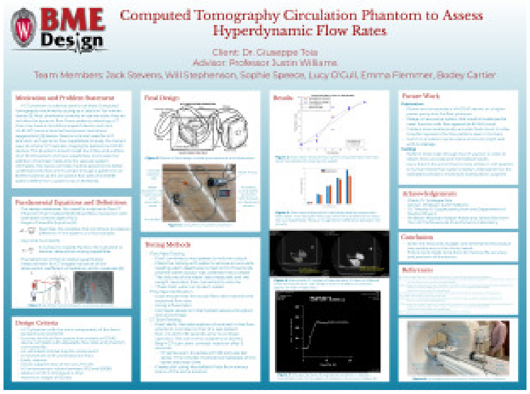
Preliminary_Report_-_BME_Design_.pdf (2.44 MB)

Final Poster Presentation

EMMA FLEMMER - Dec 13, 2023, 9:19 AM CST



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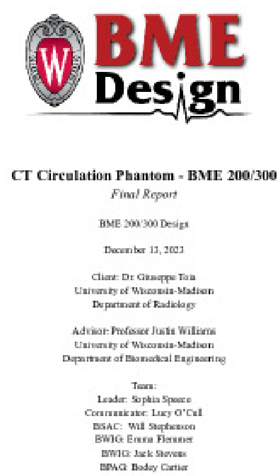
FINAL_POSTER.pptx.pdf (1.95 MB)

Final Report

SOPHIA SPEECE - Dec 13, 2023, 10:07 PM CST



CT Circulation Phantom - BME 200/300

Final Report

BME 200/300 Design

December 13, 2023

Client: Dr. Giuseppe Toia
University of Wisconsin-Madison
Department of Radiology

Advisor: Professor Justin Williams
University of Wisconsin-Madison
Department of Biomedical Engineering

Team:
Leader: Sophia Speece
Communicator: Lucy O'Cull
BSAC: Will Stephenson
BWIG: Emma Flemmer
BWIG: Jack Stevens
BPAG: Bodey Cartier

Download

Final_Report_-_BME_200_300.pdf (6.44 MB)

What is a CT Phantom?

SOPHIA SPEECE - Sep 14, 2023, 8:20 PM CDT

Title: What are Imaging Phantoms?

Date: 9.14.23

Content by: Sophie

Search Term: "What is a CT Phantom?" in regular Google

Citation: “What Are Imaging Phantoms?,” *NIST*, Apr. 2018, Accessed: Sep. 13, 2023. [Online]. Available: https://www.nist.gov/physics/what-are-imaging-phantoms

Content:

- What is an Imaging Phantom?
  - Used as a stand in for human tissues to calibrate imaging machines. Used to make sure these imaging devices are operating correctly
- How do they work?
  - Each phantom is different depending on what kind of imaging technique will be used on it
  - Often mimic the response of human tissues under said imaging technique
  - Some materials include: NaCl solutions, silicone, epoxy, polyurethane, carbon powder, water

What is VA-ECMO?

SOPHIA SPEECE - Sep 14, 2023, 8:48 PM CDT

Title: What is VA-ECMO?

Date: 9.14.23

Content by: Sophie

Search Term: "What is VA-ECMO?" in regular Google

Citation: M. S. Choi, K. Sung, and Y. H. Cho, "Clinical Pearls of Venoarterial Extracorporeal Membrane Oxygenation for Cardiogenic Shock," *Korean Circ. J.*, vol. 49, no. 8, pp. 657–677, Jul. 2019, doi: 10.4070/kcj.2019.0188.
Accessed: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6675698/

Content:

- ECMO stands for Extracorporeal membrane oxygenation
  - This uses a pump to drain blood from a body, circulate blood through a membrane lung, and return oxygenated blood to the body.
- VA means Venoarterial.
  - VA-ECMO is a simplified version of the heart-lung machine that assists native pulmonary and/or cardiac function
  - Composed of a drain from the venous system and return flow to the arteries.
  - Used to treat cardiogenic shock or cardiac arrest.
- The first uses of something similar to an ECMO was in 1953
  - In 1957, only 6 years later, Kammermeryer found silicone to be strong enough for hydrostatic pressure, but was permeable by gas.
  - A silicone membrane oxygenator was created
- Basic components of an ECMO circuit
  - A cannula for drainage, a cannula for return, tubing, a pump, and a membrane lung.
  - VA-ECMO draws deoxygenated blood from the venous system through a drainage cannula, pumps blood through a membrane lung, and returns the blood to the arteries through the return cannula.
  - VA-ECMO bypasses the cardiopulmonary system (doesn't go through the heart or the lungs)
- Oxygenator
  - also known as a membrane lung
  - comprised of hollow fiber bundles, gas inside these fibers exchange with the blood circulating outside the fibers
  - This maximizes the blood-gas contact surface area.
  - Some materials include Microporous polypropylene, compressed surface polymers (such as polymethylpentene (PMP))
- Pumps
  - Roller pumps used to be used, now centrifugal pumps are typically used. These are the standard now for ECMO.
  - Centrifugal pumps generate flow by spinning a rotor that produces centrifugal force.
  - The centrifugal pumps for ECMO use either pivot-bearing or a bearing-free magnetic levitation design (see footnote here for more on these types of pumps)
- VA-ECMO goal is the restore organ blood flow and adequate tissue oxygenation while the patient recovers, without damaging the lungs nor circulation
- Interaction between ECMO and the cardiovascular system
  -

CT Angiography of VA-ECMO

SOPHIA SPEECE - Sep 22, 2023, 10:50 AM CDT

Title: CT Angiography of Venoarterial Extracorporeal Membrane Oxygenation

Date: 9.21.23-9.22.23

Content by: Sophia Speece

Search Term: N/A, given to team by client at client meeting

Citation:

Shen, MD, Jody, Justin Ruey Tse, MD, Frandics Chan, MD, PhD, and Dominik Fleischmann, MD. “CT Angiography of Venoarterial Extracorporeal Membrane Oxygenation.” *Standford University School of Medicine, Department of Radiology*, Cardiac Imaging, February 12, 2022, 16.

Content:

- Abstract
    - Imaging is important for patients with bleeding or cardiac/pulmonary complications on VA-ECMO. Radiologists should be familiar with flow related artifacts associated with the VA-ECMO system.
    - VA-ECMO is a form of temporary mechanical circulatory support for critically ill patients with acute, refractory cardiac or pulmonary failure
    - VA-ECMO use is increasing (client has said especially since COVID)
    - These patients are at high risk for thromboembolic events and bleeding complications: therefore they often require AT angiography.
    - VA-ECMO can be implemented by central or peripheral cannulation
    - VA-ECMO circuit alters the flow and direction of contrast medium enhancement, and these flow related artifacts can obscure or mimic diseases or complications.
    - Misinterpretation of CTA artifacts can lead to inappropriate surgical or medical intervention
    - There is no universal protocol for CTA on patients on VA-ECMO
- Introduction
    -

Conclusions/action items:

Pumps and Flow Rates

SOPHIA SPEECE - Oct 09, 2023, 1:15 AM CDT

Title: Control the Flow of a Pump

Date: 10.9.23

Content by: Sophie Speece

Search Term: "How to change a pump's flow rate" in Google

Citation:

Equilibar. “Control the Flow of a Pump.” Accessed October 9, 2023. https://www.equilibar.com/application/control-the-flow-of-a-pump/.

Content:

- Methods of controlling pump flow
  - meet minimum flow requirements by setting up a recirculation loop from the reservoir (this is also known as a bypass line) equipped with a pressure bypass valve
  - Use a pump with variable speed drive
  - Throttle the discharge by opening and closing a valve at the exit of the pump.
- Simple Pump Flow control for Non Positive Displacement Pumps (what is a non positive displacement pump?)
  - Often, people use a PID loop to electronically control the loop based on flow meter output.
  - The control element is usually a rising stem flow control valve or a variable frequency drive on the pump's electric motor
  - A centrifugal pump is also called a non positive displacement pump or a rotary impeller pump
    - these are defined where the output flow is inversely proportional to the pressure of the pump. When the pressure of the pump is low, the output flow of the pump is high
    - For every pressure, the pump will deliver one specific flow rate. Therefore, you need to change the output pressure in order to get the desired flow rate
      - How do we change the pressure? I believe is has to do with changing the speed, which is what we want to do anyway
      - The output pressure can also be set using a back pressure regulator

Conclusions/action items:

Use this information to develop an ECMO like flow circuit with adjustable flow rates

Some Heart 3D Files

SOPHIA SPEECE - Oct 09, 2023, 1:30 AM CDT

Title: Some Heart 3D Files

Date: 10.9.23

Content by: Sophie Speece

Present: N/A

Goals: To use if we are unable to obtain 3D files or a 3D print from client

Content:

- Human textured heart 3D model - https://free3d.com/3d-model/heart-human-textured-5197.html
  - 2 dollars
  - I believe from the images that these are accurate inside as well
- Human Heart 3D Model - Dugong Models - https://free3d.com/3d-model/human-heart-8680.html
  - Has accuracy inside but it is $200
- Heart Circulator (1) 3D Model - https://free3d.com/3d-model/heart-circulatory-1-7307.html
  - Also includes some of the circulatory system
  - $39 dollars
- Realistic Human Heart - https://sketchfab.com/3d-models/realistic-human-heart-3f8072336ce94d18b3d0d055a1ece089
  - Free download, but I don't think the inside of the 3D model is hollow
- NIH (National Institute of Allergy and Infectious Diseases) 3D - Heart Library - https://3d.nih.gov/collections/heart-library
  - A collection of digital reproductions of human anatomic hearts
  - Most of them focus on disease abnormalities

Conclusions/action items:

Use these models if client models/files do not work out

FDA Title 21 Ch1 Subchapter J - Radiological Health

SOPHIA SPEECE - Sep 21, 2023, 11:52 AM CDT

Title: Title 21 - Food and Drugs, Chapter 1 - Food and Drug Administration Department of Health and Human Services, Subchapter J - Radiological Health, Part 1020 - Performance Standard for Ionizing Radiation Emitting Products

Date: 9.21.23

Content by: Sophia Speece

Search Term: "CT Phantom Safety Standards" in Google

Citation:

"CFR - Code of Federal Regulations Title 21." Accessed September 21, 2023. https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/CFRSearch.cfm?FR=1020.33.

Content:

Section 1020.33:

- Applicability: These standards are applicable to CT systems manufactured after 1984
- Definitions
  - CT dosimetry phantom: the phantom used for the determination of dose delivered be a CT x-ray system
  - The phantom shall be a right circular cylinder of polymethl-methacrylate of density 1.19 grams per cubic centimeter.
  - The phantom shall be at least 14 cm in length and have a diameter of 32cm for whole body testing and 16cm for head testing.
  - Has to withstand rate and duration of x-ray exposure
  - Indicates contrast scale, noise, nominal tomographic section thickness, the spatial resolution capability of the system for low and high contrast objects, and measuring the mean CT number of water or a reference material
  - The radiation emitted (by the scanner, not the phantom haha) can not exceed 0.88 milligray (vice 100 milliroentgen exposure) in 1 hour at any point 5cm outside the external surface of the housing of the scanning mechanism when the shutter is closed.

Section 1020.30:

-

Conclusions/action items:

Use this information to determine performance and safety requirements of the CT phantom

ELSO ECLS General Guidelines

SOPHIA SPEECE - Sep 22, 2023, 10:37 AM CDT

Title: Extracorporeal Life Support Organization (ELSO) General Guidelines for all ECLS (Extracorporeal Life Support) Cases

Date: 9.21.23 - 9.22.23

Content by: Sophia Speece

Search Term: "ECMO Safety Standards" in Google

Citation:

"ELSO Guidelines | Extracorporeal Membrane Oxygenation (ECMO)." Accessed September 22, 2023. https://www.elso.org/ecmo-resources/elso-ecmo-guidelines.aspx.

Content:

- These guidelines apply to prolonged ECLS and ECMO usage on patients of ang age with cardiac or respiratory failure
    - This document is not so much the safety standards for the ECMO device, but rather the settings and how it is used in a patient setting. While we will be using a phantom rather than a person, the values are still useful because the team is looking to replicate said values.
- Access is always venoarterial. Circuit components must support flow of 3 l/m^2/min
    - this is determined by vascular access, drainage and tubing resistance, and pump properties
- Basic circuit components include a pump, membrane lung (we don't need an oxygenator), and tubing. Sometimes a heat exchanger, monitors, and an alarm are included.
- Pump must provide full blood flow for patient
    - Centrifugal or axial rotary pump, peristaltic pump)
- inlet suction pressure should not exceed -300 mmHg. Outlet pressure should not exceed 400 mmHg
- No reverse flow
- The blood flow through 1 meter of tubing at 100 mmHg pressure gradient for common internal diameter in inches is:
    - 3/16 for 1.2 L/min
    - 1/4 for 2.5 L/min
    - 3/8 for 5 L/min
    - 1/2 for 10 L/min
- Vascular access usually by cannulation of large vessels in neck or groin.

Conclusions/action items:

Use information for PDS and preliminary designs.

Preliminary Preliminary Design Ideas

SOPHIA SPEECE - Sep 24, 2023, 10:42 PM CDT

Title: Brainstorm Preliminary Design Ideas

Date: 9.24.23

Content by: Sophie Speece

Present: Sophie Speece

Goals: Compile some design ideas to share with my team at our meeting

Content:

Please see attached PDF

Conclusions/action items:

Present ideas and brainstorm with team tomorrow!

SOPHIA SPEECE - Sep 24, 2023, 10:43 PM CDT

Download

Preliminary_Design_Ideas.pdf (331 kB)

Final Design - Sketch

SOPHIA SPEECE - Oct 05, 2023, 11:09 AM CDT

Title: Final Design Sketch

Date: 10.5.23

Content by: Sophie

Present: Sophie

Goals: Sketch and dimension proposed final design

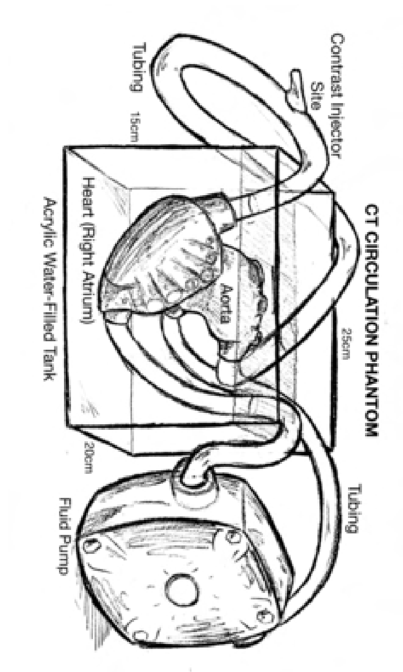
Content:

See attachment

Conclusions/action items:

Get to planning and fabricating

SOPHIA SPEECE - Oct 05, 2023, 11:09 AM CDT



Download

File_000.png (833 kB)

Top Half of Heart

SOPHIA SPEECE - Nov 13, 2023, 5:17 PM CST

Title: Top Half of Heart 3D Model

Date: 11.13.23

Content by: Sophie

Present: Sophie

Goals: Extract and append the heart areas of interest (right atrium, aorta)

Content:

See attachments below

Conclusions/action items:

Add connectors and print

SOPHIA SPEECE - Nov 13, 2023, 5:17 PM CST

Download

right_atrium_2.stl (880 kB)

SOPHIA SPEECE - Nov 13, 2023, 5:17 PM CST

Download

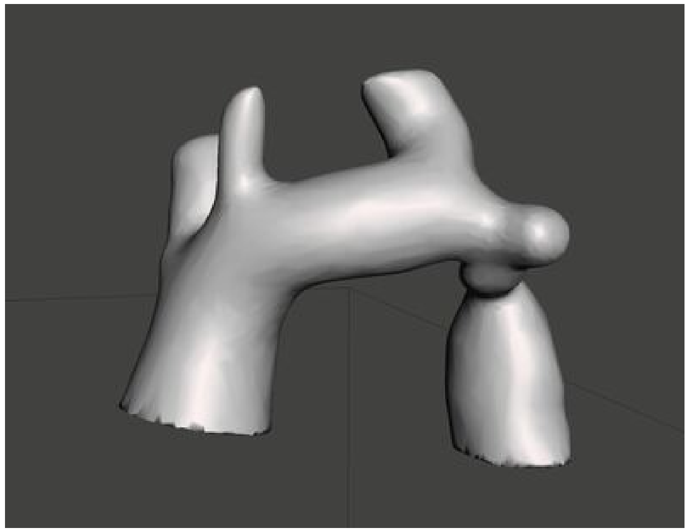
top_half_heart.stl (1.84 MB)

SOPHIA SPEECE - Nov 13, 2023, 5:17 PM CST

Download

aorta_cut.stl (5.12 MB)

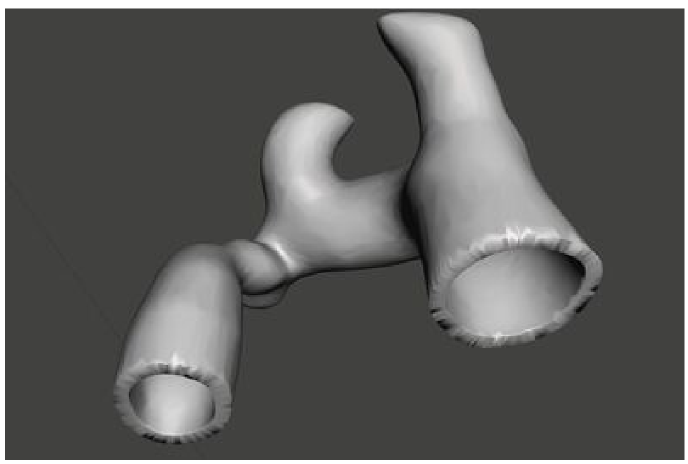
SOPHIA SPEECE - Nov 13, 2023, 5:28 PM CST



Download

aorta_pic_back.JPG (73.8 kB)

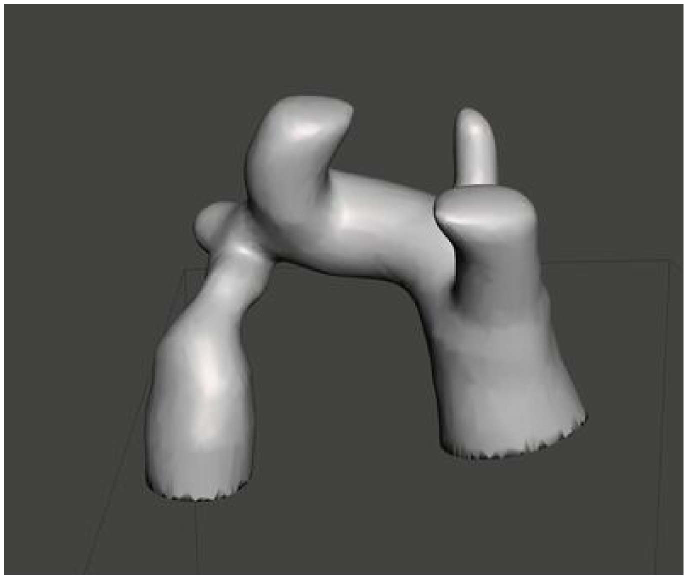
SOPHIA SPEECE - Nov 13, 2023, 5:28 PM CST



Download

aorta_pic_bottom.JPG (132 kB)

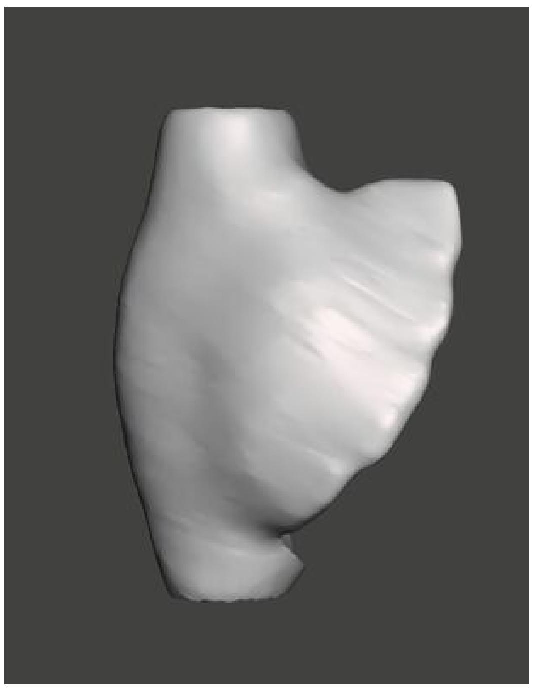
SOPHIA SPEECE - Nov 13, 2023, 5:28 PM CST



Download

aorta_pic_front.JPG (83.2 kB)

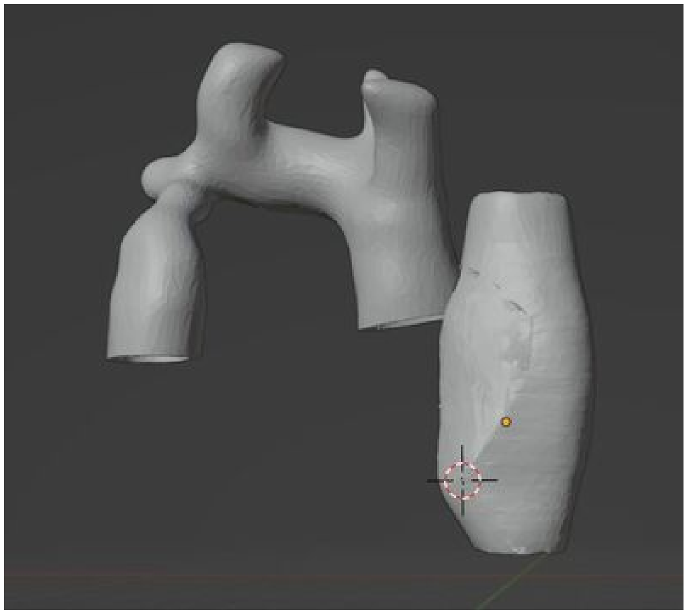
SOPHIA SPEECE - Nov 13, 2023, 5:28 PM CST



Download

right_atrium_pic_front.JPG (48.1 kB)

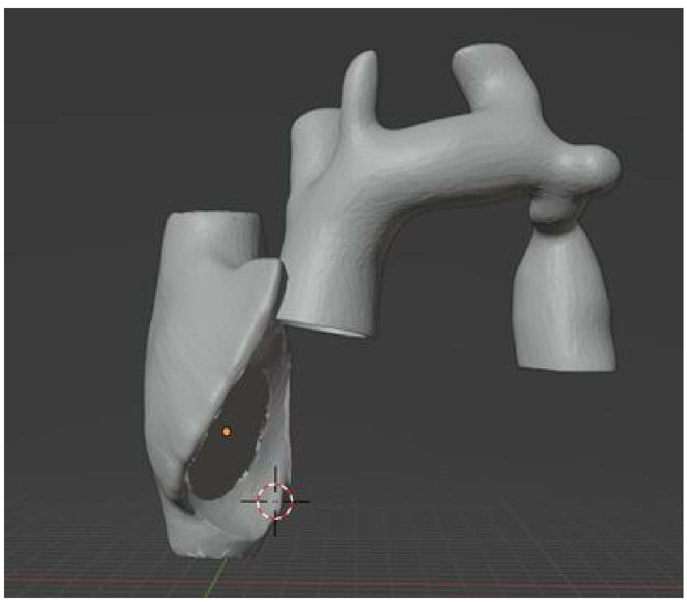
SOPHIA SPEECE - Nov 13, 2023, 5:28 PM CST



Download

top_half_pic_back.JPG (36.2 kB)

SOPHIA SPEECE - Nov 13, 2023, 5:28 PM CST



Download

top_half_pic_front.JPG (43.7 kB)

Tong Lecture

SOPHIA SPEECE - Nov 10, 2023, 12:56 PM CST

Title: Tong Lecture

Date: 11.10.23

Content by: Sophie

Present: Everyone in the entire BME program

Goals:

Content:

- Travelle Ellis - Exact Sciences
    - Want to help people through science
    - Initially wanted to be a surgeon, but got to Exact Sciences and develop cancer treatments
- Tips
    - Find your people, use them to network
    - Do things that scare you (just a little bit)
    - Laugh until you cry and cry until you laugh
        - failure is ok, use it as a teaching moment
    - EVERYONE IS COUNTING ON YOU
    - but you can do this :)

Conclusions/action items:

Speaker encouraged us to take some time and "write your story"

2023/09/10 "Veno-arterial-ECMO in the intensive care unit: From technical aspects to clinical practice"

LUCY O'CULL - Sep 10, 2023, 7:36 PM CDT

Title: "Veno-arterial-ECMO in the intensive care unit: From technical aspects to clinical practice"

Date: 09/10/2023

Content by: Lucy O'Cull

Goals: To gain a better understanding of ECMO

Search Terms: This article was suggested by the initial project selection page.

URL: [Veno-arterial-ECMO in the intensive care unit: From technical aspects to clinical practice - ScienceDirect]

Citation:

[1] A. Le Gall, A. Follin, B. Cholley, J. Mantz, N. Aissaoui, and R. Pirracchio, "Veno-arterial-ECMO in the intensive care unit: From technical aspects to clinical practice," *Anaesthesia Critical Care & Pain Medicine*, vol. 37, no. 3, pp. 259–268, Jun. 2018, doi: 10.1016/j.accpm.2017.08.007.

Content:

1. VA-ECMO also referred to as ECLS, are devices that replace the function of the heart and lungs.
2. This device was initially used exclusively for cardiac surgery, improvements to the device have allowed the use of it in the ICU.
3. It is important to identify reasonable patients for this treatment due to inconsistent success rates, significant complications and high cost.
4. How it works:
    1. A centrifugal pump suctions deoxygenated blood through a venous cannula in a large central vein.
    2. It is oxygenated and warmed
    3. It is returned to systemic circulation through an arterial cannula
5. ECMO circuits can be inserted **central**ly (vein and artery insertion closer to the heart) or **peripheral**ly (insertion further from the heart)
6. Peripheral ECMO complications
    1. obstruction of femoral artery
    2. competition between the retrograde flow via ECMO and native anterograde flow
    3. Worsen Left ventricle overload
    4. Worsen Harlequin syndrome
7. Central ECMO complications
    1. Can only be inserted via a surgical team thus higher risk of bleeding
8. Gas Exchange determinants
    1. PaO_2 and $PaCO_2$ depend upon extracorporeal circulation settings and patient's characteristics
    2. cardiac output
    3. pump flow rates
    4. inspired oxygen fraction
    5. sweep gas flow
9. Indications for EMCO
    1. acute myocardial infarction
    2. fulminant myocarditis
    3. severe chronic heart failure,
    4. drug intoxication
    5. hypothermia

    6. intractable arrhythmia
10. Because EMCO has possible complications its important to remove as soon as possible
11. removal should not be attempted within the first 48 hours since renal/hepatic function should normalize first
12. to be eligible for removal, patients should be determined to be hemodynamically stable

Conclusions/action items:

This article helped me to gain fundamental knowledge about ECMO and how it is used in various clinical settings. I hope to apply this knowledge towards my research now into phantoms used for circulation CT scans.

2023/09/13 "Piston-Based vs Peristaltic Pump-Based CT Injector Systems"

LUCY O'CULL - Sep 14, 2023, 2:23 PM CDT

Title: "Piston-Based vs Peristaltic Pump-Based CT Injector Systems"

Date: 09/13/2023

Content by: Lucy

Goals: To learn about the different pump systems that we could be choosing between.

Search Terms: Provided by the project selection description page

URL: Piston-Based vs Peristaltic Pump-Based CT Injector Systems - PubMed (nih.gov)

Citation:

[1] A. Chaya, G. Jost, and J. Endrikat, “Piston-Based vs Peristaltic Pump-Based CT Injector Systems,” *Radiol Technol*, vol. 90, no. 4, pp. 344–352, Mar. 2019.

Content:

1. This study examined two types of pumps to be used as iodinated contrast media delivery systems for CT scans
    1. (one) piston-based system (Stellant MP, MEDRAD)
    2. (two) peristalic pump-based systems (CT motion, Ulrich Medical; CT Expres, Bracco)
2. Variables:
    1. media: iopromide and iopamidol
    2. concentrations: 300mg/mL and 370mg/mL
    3. catheter sizes: 18, 20, 22G
3. Results:
    1. Stellant MP injector achieve significantly higher flow rates compared to the other models across all catheter sizes
    2. Stellant MP injector has steady flow, where as the two pulsatile injector systems had a significantly greater variance
4. It was concluded that the piston-based injector system was achieved higher max flow rates and was more consistant than the other systems tested.

Conclusions/action items:

It is worth noting these findings about the various systems on the market. I am thinking that our client will want us to make a decision on which type of pump to work with. Unfortunately, I did not have full access to this article, so I might ask our clients if they have a subscription, and if it is possible that they send a pdf or something. I think it will be interesting to read more about the performance of these pump systems, because even though this article presented the piston based as the clear winner, there might be aspects of it that make it not as beneficial for our design. I can also search for maybe more studies done like this one, however the author mentions that they think that this study is the first of its kind.

2023/09/27 Basic Fluid Dynamics

LUCY O'CULL - Sep 27, 2023, 10:12 PM CDT

Title: Basic Fluid Dynamics

Date: 09/27/2023

Content by: Lucy O'Cull

Goals: Gain an understanding of some fluid dynamics principles that may help us to develop a mathematical model to describe our problem to others.

Search Terms: Google Scholar: "fluid dynamics for liquid moving at two flow rates initially"

Content:

Reynolds Number

$R = (ul\rho)/(\mu)$

u: characteristic velocity

l: a characteristic length

ρ: mass density

μ: viscosity

or

$R = (VD\rho)/(\mu)$

V = average velocity

D = diameter of tube

ρ: mass density

μ: viscosity

Reynolds number determines that flow will change from laminar to turbulent in the range of Reynolds numbers from 2000 to 4000

If both liquids are considered laminar, minimal mixing is expected

If both liquids are considered transitional, mixing behavior will be dependent on specific flow conditions

if both liquids are considered turbulent, efficient mixing behavior is expected

Citation: V. Streeter, *Fluid Mechanics*, 3rd ed. McGraw-Hill, 1962.

I prompted ChatGPT by open AI for various injection methods in the context of mixing two liquids. I summarized into the following:

1. **coaxial injection:** one liquid is injected through a central nozzel into another liquid flowing through the tube. Mixing depends on flow rates, nozzle design, and relative velocities

2. **T-junction injection**: joining a side stream of one liquid into a primary flow of another liquid. Mixing depends on the geometry of the junction, flow rates, and velocity profiles. Used for mixing of small volumes
3. **Jet injection:** introducing one liquid as a high-velocity jet into another liquid. Jet's kinetic energy helps to disperse and mix the two fluids. Used in industrial processes where rapid mixing is required
4. **Static mixer:** device that consists of stationary blades or elements placed within a pipe or channel. As fluids flow through the mixer they are subjected to shearing and folding.
5. **Ejector Mixing:** Ejectors use a high-pressure jet to mix a secondary fluid into a primary flow.

Conclusions/action items:

I think that the Reynolds number could be a good way of describing the problem broadly, especially if after solving for both the liquids. I keep trying to find an established formula for the mixing behavior but I think it might just be too complicated so I would like to find a simulation or something of that sort that I can run. I also think that those injection methods might help me to find an established formula. I would like to decide with method is most similar to the current CA injection method clinically because that is what we aim to replicate. I think after I decide that it will help me to find either a simulation or equation that replicates the problem that I am trying to more clearly define.

2023/09/10 "Performance evaluation of a C-Arm CT perfusion phantom"

LUCY O'CULL - Sep 13, 2023, 8:00 PM CDT

Title: "Performance evaluation of a C-Arm CT perfusion phantom"

Date: 09/13/2023

Content by: Lucy O'Cull

Goals: To gain more insight about the specifications/performance expectations of CT phantoms.

Search Terms: This article was provided in the project selection page

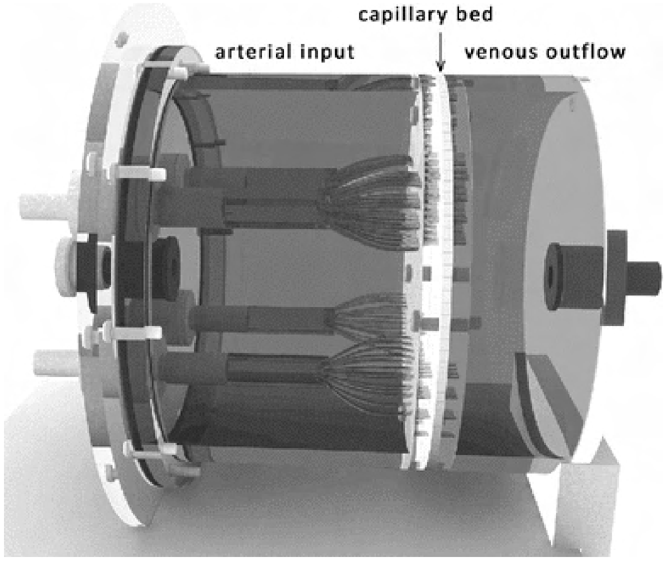
URL: [Performance evaluation of a C-Arm CT perfusion phantom | SpringerLink]

Citation:

[1] A. Boese *et al.*, “Performance evaluation of a C-Arm CT perfusion phantom,” *Int J CARS*, vol. 8, no. 5, pp. 799–807, Sep. 2013, doi: 10.1007/s11548-012-0804-4.

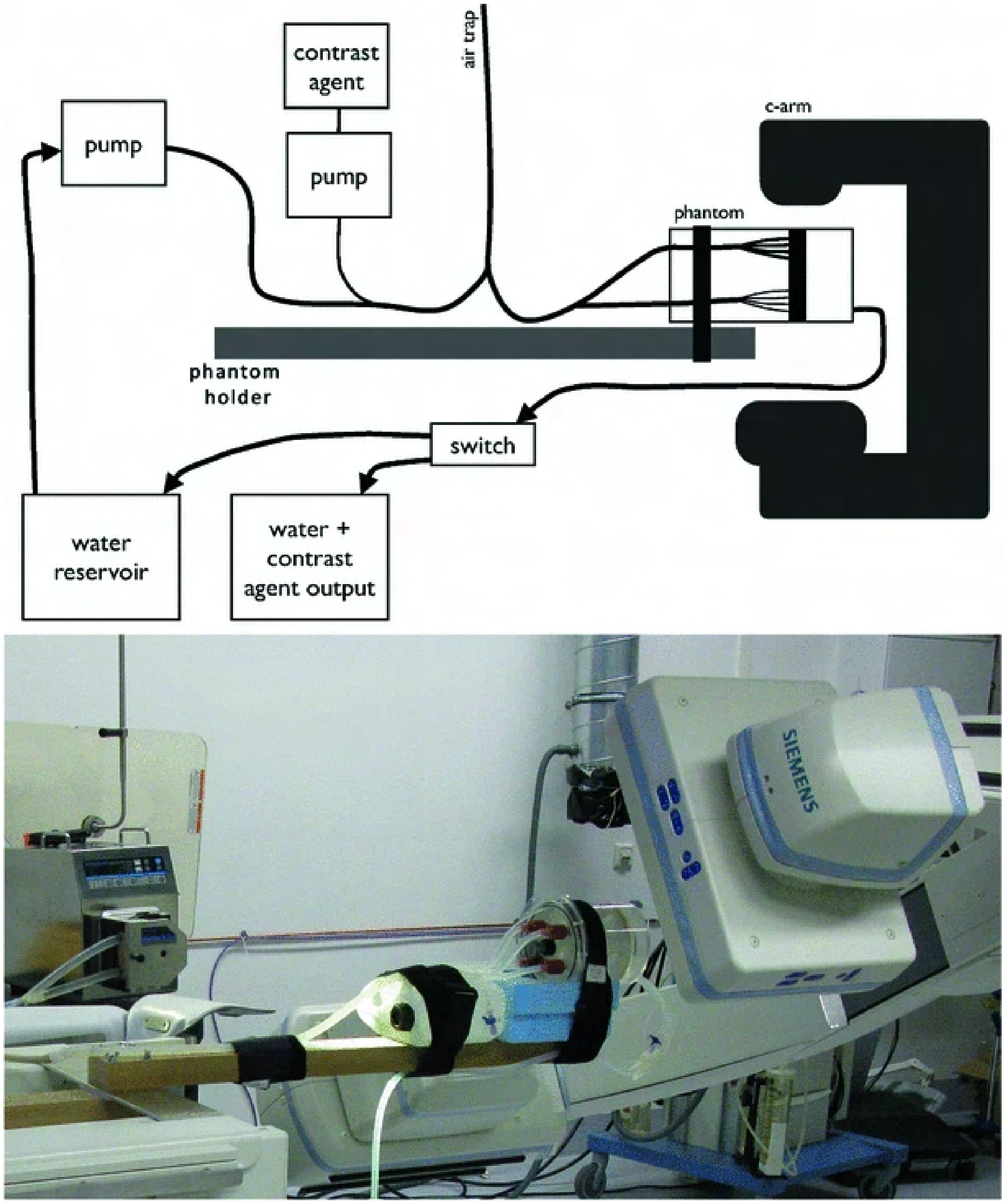
Content:

1. In this study they are looking at improving treatment via CT scan for stroke patients. The phantom that they are testing is therefore resemblant of a human head. The study is gauging the performance of the perfusion properties of the phantom with the hopes that in the future the phantom can be used as a first trial or another way to compute perfusion parameters in future studies.
2. Phantoms can be made of two different types of materials
    1. Widespread capillary bed:
        1. Perfusion of larger vessels and micro vascular tissue.
        2. series of tubes splitting up multiple times and with each split the inner diameter of the tubes is reduced.
        3. The simulation can only show one particular perfusion situation.
    2. Compressed capillary beds:
        1. mostly used compressed polymers which offers greater amount of channels
        2. this simulation is highly customizable and can display different types of perfusion.
3. This phantom construction:
    1. 150mm diameter cylindrical housing (Perspex)
    2. 3 mm think sinter board (HDPE) in the middle. The board had average porosities of size 10 micrometers with is comparable to brain capillaries (5-15 micrometers)
    3. for feeding arteries, start with main tube that splits into four tubes leading into the phantom which splits into sixteen tubes feeding the tissue board. Of the sixteen, half go to the top part of the phantom (1.7mm) half go to the bottom part of the phantom (1.0mm)
    4. for outflow, all of the input flows into a collection reservoir at the bottom and

5. 

6. The phantom was filled with water and to remove air two valved were fixed on the top and bottom.
7. no metal was included in the design so to not interfere with the CT scans and to make the phantom also compatible with MRI

4. The experiment
    1. They used a peristaltic pump: Masterflex I/P set on pulsatile flow
    2. flow rate was matched to physiological typical conditions (avg flow of 800 ml/min) *measured on the output tube of the phantom)
    3. 1.8 mm cannula placed into main input tube for the administration of the contrast agent (Imeron 400)
    4. An **air trapping (???)** was placed before the split into the four to reduce air bubbles
    5. a valve separated the contaminated water to avoid recirculation
    6. the sinter board was adjusted in plane to the central slices of the scanner



7.

5. Functionality of the phantom was tested with two different CT scanners.
6. It was determined that the developed phantom is suitable for perfusion studies.
7. It was concluded that the phantom can be used to analyze the suitability of the C-Arm-based CT perfusion measurements.

Conclusions/action items:

This study had a lot of solid information about the design of the phantom. It seems like what we are aiming to do is in a lot of ways similar to what this study was aiming to do. This article left me with a lot of fabrication questions, but I want to wait to look more into that until we have a better idea of our clients vision.

2023/09/10 "Reduced Iodinated Contrast Media Administration in Coronary CT Angiography on a Clinical Photon-Counting Detector CT System"

LUCY O'CULL - Sep 10, 2023, 8:05 PM CDT

Title: "Reduced Iodinated Contrast Media Administration in Coronary CT Angiography on a Clinical Photon-Counting Detector CT System"

Date: 09/10/2023

Content by: Lucy O'Cull

Goals: To develop a better understanding of what studies look like regarding dynamic circulation phantoms.

Search Terms: This study was provided in the project selection site

URL: Reduced Iodinated Contrast Media Administration in Coronary... : Investigative Radiology (lww.com)

Citation:

[1] T. Emrich *et al.*, “Reduced Iodinated Contrast Media Administration in Coronary CT Angiography on a Clinical Photon-Counting Detector CT System: A Phantom Study Using a Dynamic Circulation Model,” *Investigative Radiology*, vol. 58, no. 2, p. 148, Feb. 2023, doi: 10.1097/RLI.0000000000000911.

Content:

1. The purpose of this particular study was to look into various strategies to **reduce contrast media volumes** for coronary CT angiography in a PCD-CT system using a circulation phantom.
2. This study the phantom was a 3d Printed model of the thoracic aorta and coronary arteries was evaluated using contrast fluid of stepwise reducing concentrations.
3. The attenuation and noise were measured to produce the contrast to noise ratio.
4. It was determined that it was possible to reduce contrast media concentration by 50% while still obtaining diagnostic attenuation and objective image quality for coronary CT angiography.
5. It should be noted that these results have not been validated in clinical studies.

Conclusions/action items:

It seems like this determination from this study is similar to what we are going to be determining from our own device and subsequent testing. As we have yet to meet with our client, it will be important to ask about the type of CT scan we should be expecting to use. That way I can do more initial research on that type of scan and maybe even find a more applicable study. It will also be interesting to see if our client would like us to 3D print a phantom because that would be another good point of research: 3D printing methods for phantoms.

2023/09/20 "Contrast media injection protocol optimization for dual-energy coronary CT angiography: results from a circulation phantom"

LUCY O'CULL - Sep 20, 2023, 8:09 PM CDT

Title: "Contrast media injection protocol optimization for dual-energy coronary CT angiography: results from a circulation phantom"

Date: 09/20/2023

Content by: Lucy O'Cull

Goals: Get a better idea of the specific components of circulation phantoms specifically and one step further: try to imagine where the ECMO component would fit in.

Search term: "CT circulation phantom"

Content:

Components:

1. high and low pressure compartments connected by plastic tubing
2. life sized replicas of the aortic arch, coronary arteries and descending aorta (silicone coronary tree model)
3. Thoracic aorta has a tube which corresponds to the pulmonary trunk for a single slice that monitors contrast enhancement dynamics
4. water (37 degrees Celsius) filled acrylic container encapsulates the thoracic aorta which mimics the CT attenuation characteristics (5900 mL)
5. water driven through the system by Harvard pulsatile heart pump
6. ECG simulator connected directly with the pump system and the scanner which creates a **simulated ECG signal based on the motion of the pump and transmits the signal to the CT scanner for ECG synchronization** *(I am curious about applying this to having this kind of thing synced with the "ECMO" that we make. I think it would be cool to have this component if we can figure it out)*
7. systolic and diastolic pressure model to simulate the normal hemodynamic parameters
8. injection port for contrast agent injection
9. physiological circulation parameters were variable (60 bpm, 5.4L/min CO, 90mL stroke volume, BP 120/80 mmHg
10.

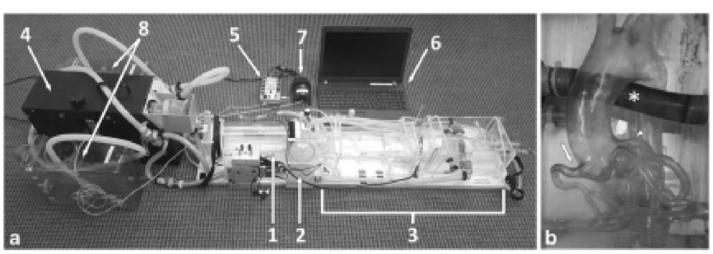


Fig. 1 A comprehensive overview of the circulation phantom (**A**) and close-up view of the mediastinal compartment (**B**). The phantom is equipped with high- and low-pressure compartments (1 and 2) operated at different blood pressures to simulate the body and lung compartments, respectively. The aorta, coronary arteries and aortic arch are encased in water-filled units (3) to simulate the body's attenuation properties. The system is driven by a pulsatile pump (4) connected to an ECG-simulator (5) as well as the CT scanner, and is monitored in real-time by means of a laptop equipped with a data acquisition system (6). An air pump (7) is connected to the phantom and drains the residual air within the vessels. Two tanks (8) are used to fill and drain the phantom, respectively. The close-up view of the mediastinal compartment (**B**) shows the tube simulating the pulmonary trunk (asterisk) and thoracic aorta with the right (arrow) and left main (arrowhead) coronary arteries

Springer

URL: https://pubmed.ncbi.nlm.nih.gov/29488083/

Citation:

[1] D. De Santis *et al.*, "Contrast media injection protocol optimization for dual-energy coronary CT angiography: results from a circulation phantom," *Eur Radiol*, vol. 28, no. 8, pp. 3473–3481, Aug. 2018, doi: 10.1007/s00330-018-5308-3.

Conclusions/action items:

I think this design has some really good attainable ideas. I think we should look into a tubing system like the one here with the silicone heart like they did. I also really liked the whole ECG simulation aspect. This article referenced the following:
https://journals.lww.com/investigativeradiology/fulltext/2008/10000/introduction_of_a_dedicated_circulation_phantom.7.aspx
I am focusing my current research on fabrication/design ideas, so I am interested in looking into this article for even more fabrication details. I am still pretty unsure about how ECMO will fit into this. We still haven't met with the client but I plan to get more clear direction about how they imagine that to be implemented.

2023/09/20 "Introduction of a Dedicated Circulation Phantom for Comprehensive In Vitro Analysis of Intravascular Contrast Material Application"

LUCY O'CULL - Sep 20, 2023, 8:28 PM CDT

Title: "Introduction of a Dedicated Circulation Phantom for Comprehensive In Vitro Analysis of Intravascular Contrast Material Application"

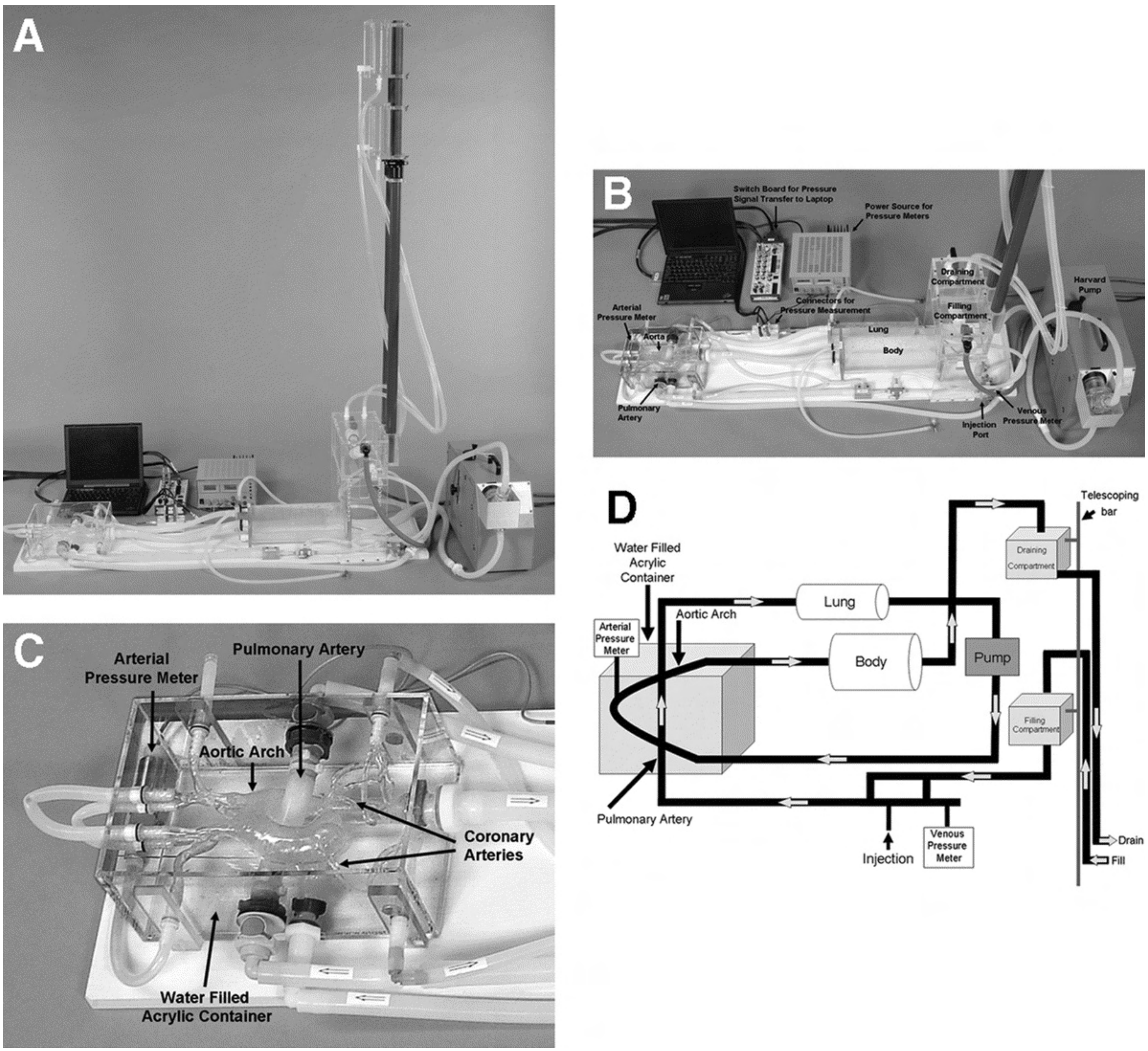
Date: 09/20/2023

Content by: Lucy O'Cull

Goals: See another example of circulation phantom components

Search Terms: Referenced from article featured in this notebook: Lucy O'Cull >> Research Notes >> Competing Designs >> 2023/09/20 "Contrast media injection protocol optimization for dual-energy coronary CT angiography: results from a circulation phantom"

Content:



URL: https://journals.lww.com/investigativeradiology/fulltext/2008/10000/introduction_of_a_dedicated_circulation_phantom.7.aspx

Citation:

[1] F. F. Behrendt *et al.*, “Introduction of a Dedicated Circulation Phantom for Comprehensive In Vitro Analysis of Intravascular Contrast Material Application,” *Investigative Radiology*, vol. 43, no. 10, p. 729, Oct. 2008, doi: 10.1097/RLI.0b013e318182267e.

Conclusions/action items:

Need to compile what I have found so far in terms of designs and see what I can create myself for a design idea. Will be more beneficial and save time to do this after we meet with the clients tomorrow.

2023/09/20 Code of Federal Regulation

LUCY O'CULL - Sep 20, 2023, 1:16 PM CDT

Title: CT Equipment CFR

Date: 09/20/2023

Content by: Lucy

Goals: Learn about the Code of Federal Regulations pertaining to CT equipment (particularly phantoms)

Content:

US FDA CFR:

TITLE 21--FOOD AND DRUGS

CHAPTER I--FOOD AND DRUG ADMINISTRATION

DEPARTMENT OF HEALTH AND HUMAN SERVICES

SUBCHAPTER J - RADIOLOGICAL HEALTH

PART 1020 -- PERFORMANCE STANDARDS FOR IONIZING RADIATION EMITTING PRODUCTS

Sec. 1020.33 Computed tomography (CT) equipment.

Electronic Product Radiation Control Program - FDA

The purpose of this regulation is to establish standards to ensure safe and efficient operation of CT equipment.

It outlines:

1. quality assurance for diagnostic accuracy
2. radiation dose limits
3. continued compliance with established performance standards
4. notification of noncompliance
5. production of record of compliance(performance ,maintenance, testing)
6. labeling
7. user instructions
8. reporting of accidents

Regulation's application to the use of phantoms:

1. Quality assurance: General testing with a phantom to ensure that the function of CT equipment is within parameters, safety guidelines, or standards that have otherwise been set.
2. Dose measurement: Phantoms mimic human tissue for a targeted region and should be used to make determinations about appropriate doses for clinical use. Crucial to employ dosages that are within acceptable limits defined by this regulation.
3. Image quality assessment: Phantoms should have certain structures and materials of which known qualities can be used to assess the clarity, contrast, and resolution of the images produced.

4. Dose Optimization: optimize CT protocols to achieve maximum image quality while minimizing radiation dose
5. Documentation and record keeping: The regulation requires documentation of performance and testing of CT equipment. These records can be produced from phantom testing and used for evidence of compliance with this regulation.

Regulations requirement of phantoms:

1. description of phantom and test protocol
2. capability to provide indication of contrast scale, noise, nominal tomographic section thickness, spatial resolution capability of the system for low and high contrast objects, and measuring the mean CT number of water or a reference material
3. instructions on the use of the phantom

URL: https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/CFRSearch.cfm?FR=1020.33

or

https://www.ecfr.gov/current/title-21/chapter-I/subchapter-J/part-1020/section-1020.33

Reference:

[1] "CFR - Code of Federal Regulations Title 21." [Online]. Available: https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/CFRSearch.cfm?FR=1020.33. [Accessed: Sep. 20, 2023]

or

[1] "21 CFR 1020.33 -- Computed tomography (CT) equipment." [Online]. Available: https://www.ecfr.gov/current/title-21/part-1020/section-1020.33. [Accessed: Sep. 20, 2023]

Conclusions/action items:

As made clear by this regulation, phantoms are a necessary tool for ensuring compliance of CT equipment with FDA regulations. These regulations will help us to come up with specifications on top of client requirements for our product design specifications.

2023/09/20 Medical Device Classification

LUCY O'CULL - Sep 20, 2023, 1:39 PM CDT

Title: Medical Device Classification

Date: 09/20/2023

Content by: Lucy

Goals: Determine an FDA Medical Classification for our device.

Content:

Code of Federal Regulations

Title 21, Volume 8

CITE: 21CFR892.1940

TITLE 21--FOOD AND DRUGS

CHAPTER I--FOOD AND DRUG ADMINISTRATION

DEPARTMENT OF HEALTH AND HUMAN SERVICES

SUBCHAPTER H - MEDICAL DEVICES

PART 892 -- RADIOLOGY DEVICES

Subpart B - Diagnostic Devices

Sec. 892.1940 Radiologic quality assurance instrument.

1. Defines a radiologic quality assurance instrument as a device intended for medical purposes to measure a physical characteristic associated with another radiologic device
2. FDA classifies this as a Class I medical device (general controls).
3. exempt from the premarket notification 510(k) procedures.
4. exempt from current good manufacturing practice requirements of the quality system regulation except for general requirements concerning records and complaint files

URL: https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfCFR/CFRsearch.cfm?FR=892.1940

Citation:

[1] “CFR - Code of Federal Regulations Title 21.” [Online]. Available: https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfCFR/CFRsearch.cfm?FR=892.1940. [Accessed: Sep. 20, 2023]

Conclusions/action items:

Through records with the FDA I determined that our device would be be a Class I medical device. This information is important to note for PDS and other deliverables, as it helps others to get a little bit oriented with the parameters that our design will be dealing with.

2023/09/20 ASTM standards for CT testing

LUCY O'CULL - Sep 20, 2023, 2:06 PM CDT

Title: ASTM standards for CT testing

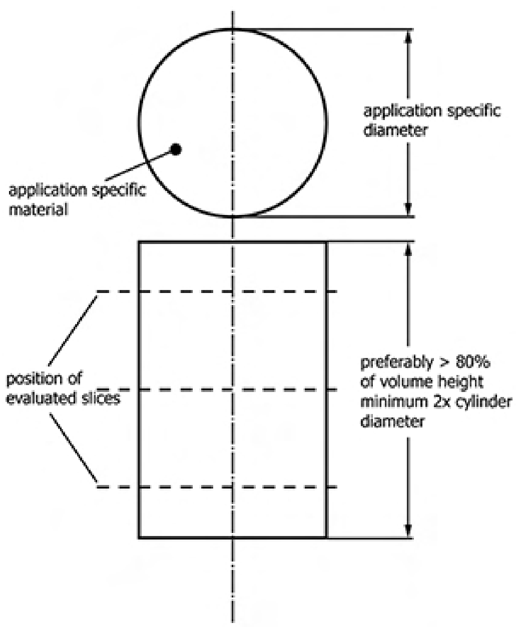
Date: 09/20/2023

Content by: Lucy

Goals: Find standards from other organizations that pertain to CT phantoms.

Content:

ASTM E1695-20e1: Standard Test Method for Measurement of Computed Tomography (CT) System Performance

1. Section 5 of this standard explains the standard apparatus of the test method which is a phantom.
    1. phantom is to be in the shape of a right cylinder
    2. material:
        1. such that the phantom approximates the attenuation range of the examination object
    3. Diameter:
        1. such that the phantom approximates the attenuation range of the examination object
        2. occupies at least 250 voxels in diameter of the resulting image
    4. Height
        1. height of cylinder should cover 80% the detector height
        2. may be shorter if there are means to move it across the field of view
    5. shape
        1. the axis of revolution with respect to the surface used to mount the phantom on the CT system shall not compromise the measurement of geometrical unsharpness
    6. Finish
        1. the surface texture roughness of the curved surface shall not affect the measurement of geometrical unsharpness
2. Rough visualization of the cylinder phantom
    1. 

URL: https://compass.astm.org/document/?contentcode=ASTM%7CE1695-20E01%7Cen-US

Citation:

[1] "compass." [Online]. Available: https://compass.astm.org/document/?contentcode=ASTM%7CE1695-20E01%7Cen-US. [Accessed: Sep. 20, 2023]

Conclusions/action items:

This was the ASTM standard that most closely related to the project. There were other ASTM standards that relate to verification of CT equipment, but they did not really reflect the goal of our CT phantom. This standard was more specific in size and shape requirements relative to the standard set forth by the FDA. It will be interesting to talk to the client about this standard and see if they agree with how it applies to our project.

2023/09/25 Pre Design meeting design ideas

LUCY O'CULL - Sep 25, 2023, 5:26 PM CDT

Title: Pre Design Meeting Design Ideas

Date: 09/25/2023

Content by: Lucy O'Cull

Goals: Get some ideas sketched out for guiding discussion with group tonight.

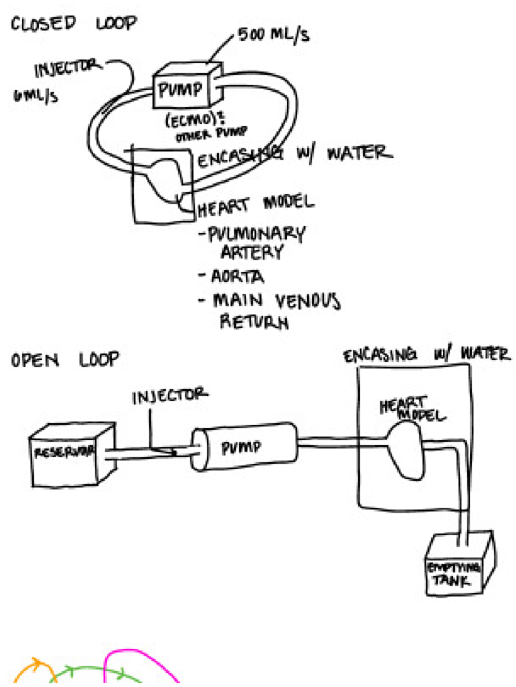
Content:

See attatchment.

Conclusions/action items:

Meet with the rest of the team tonight to share what we have come up with so far.

LUCY O'CULL - Sep 25, 2023, 5:27 PM CDT



Download

Pre_meeting_Design_Ideas.pdf (1.8 MB)

2023/10/19 Injector Connector

LUCY O'CULL - Oct 19, 2023, 10:33 AM CDT

Title: Injector Connector

Date: 10/29/2023

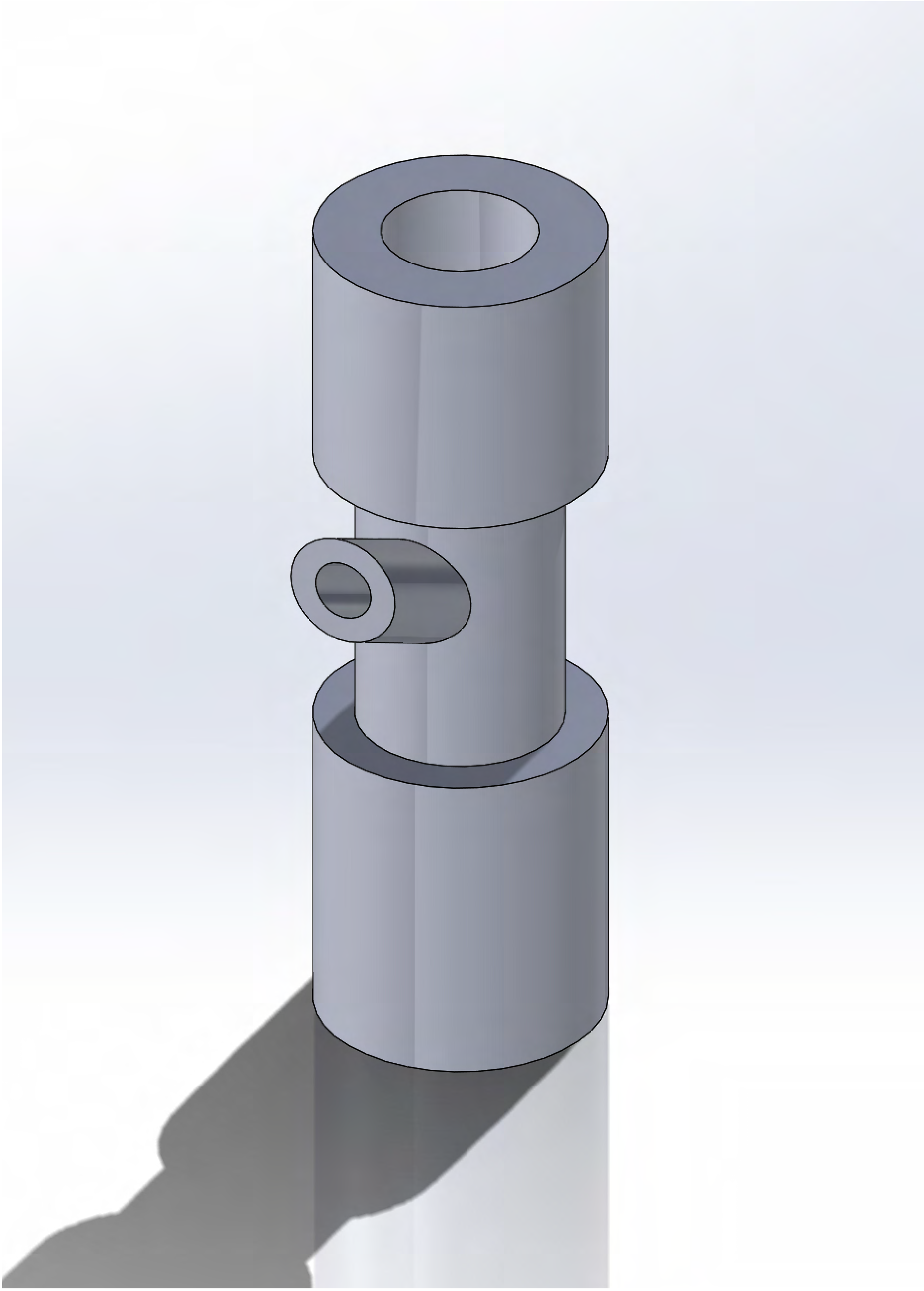
Content by: Lucy O'Cull

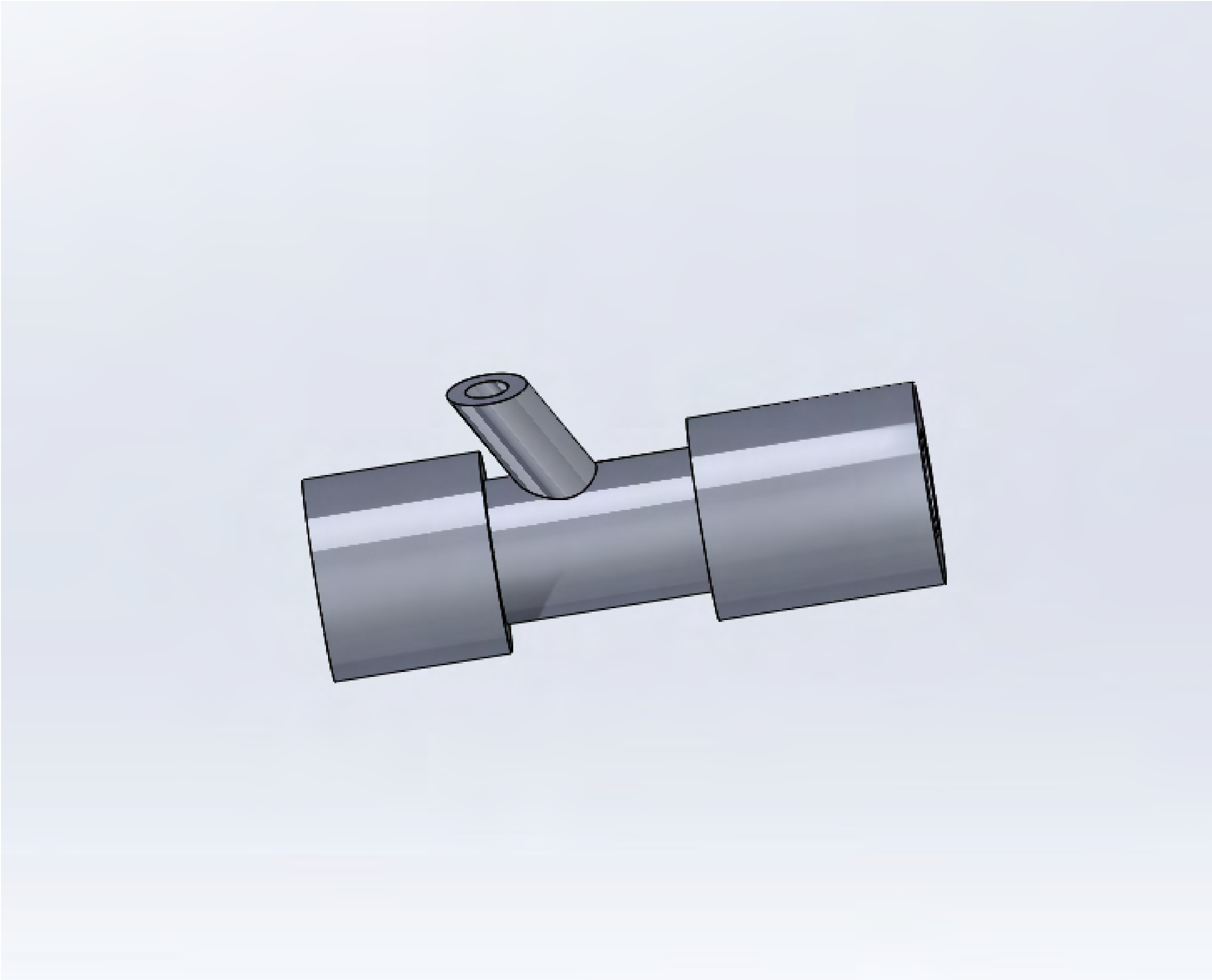
Present: Bodey Cartier

Goals: Research and Model a connection piece for the injector system.

Content:

1. Intended on meeting with UW cardiovascular lab to work on heart model, but the licensing for the software was not up to date and we needed to postpone.
2. Decided to pivot into looking into the injector component and how we will incorporate it into the circuit.
3. Researched how injector systems work clinically using the video in the references section.
4. We decided to create a connector that we can print. It has an off shoot that we will fill with some type of elastic polymer that a needle can be placed into to sort of like the catheter in the skin. This will also prevent the CA from backflowing out of the system.
5. We modeled our idea in solidworks see pictures below.





References:

[1] *[Listen to Authors] High-Rate CT Contrast Injection with Two Small Catheters*. Accessed: Oct. 19, 2023. [Online Video]. Available: https://www.youtube.com/watch?v=g8RfTsqqKEM

Conclusions/action items:

Bodey is taking the model to the makerspace to get printed. Hopefully we will meet with the cardiovascular lab ASAP to work through modeling the heart.

2023/10/26 Modeling Workday

LUCY O'CULL - Oct 26, 2023, 5:00 PM CDT

Title: Modeling Workday

Date: 10/26/2023

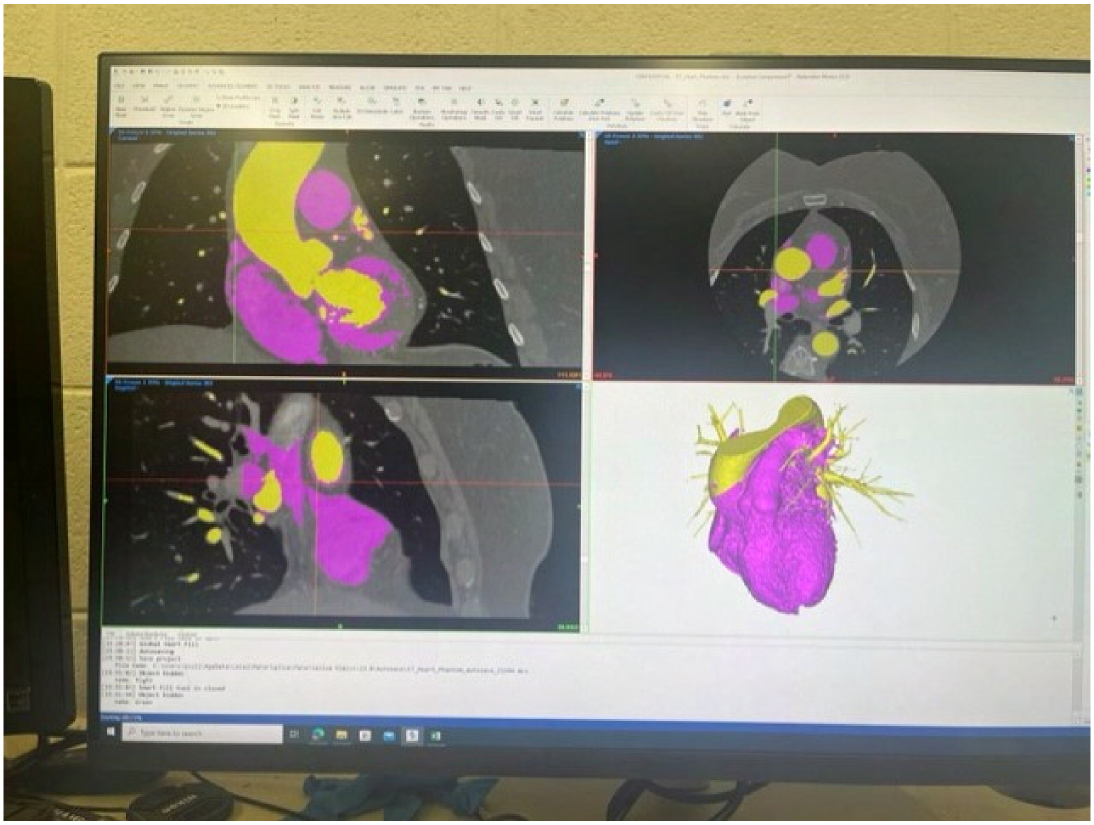
Content by: Lucy O'Cull

Present: Emma Flemmer, Bodey Cartier

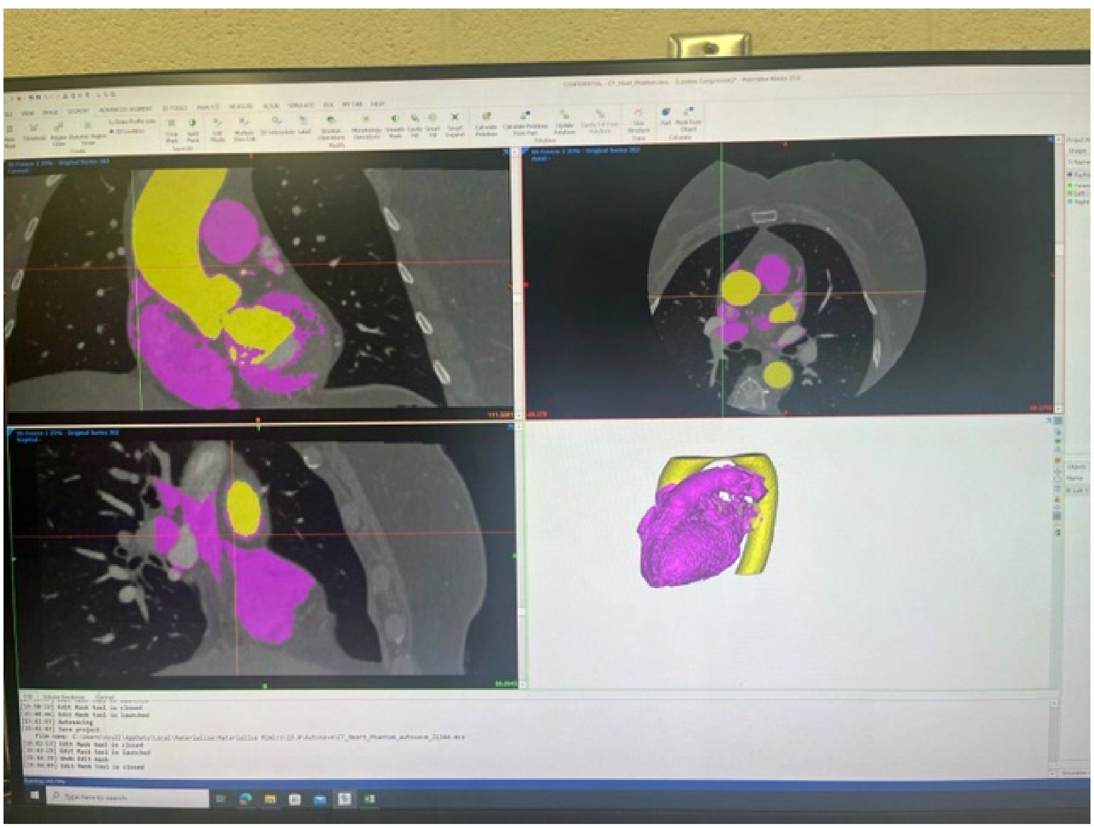
Goals: Work on Making a model from the CT scans and a backup.

Content:

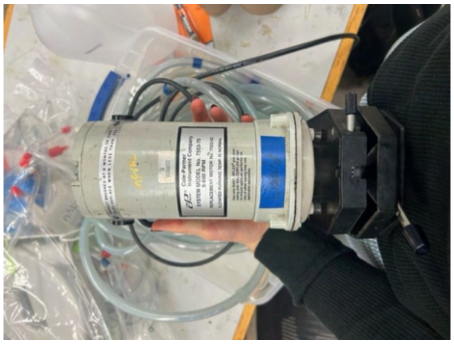
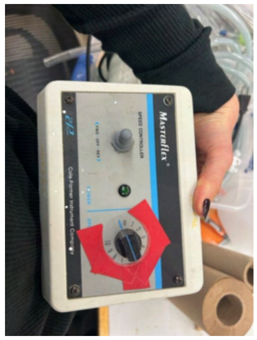
This is the backup aortic arch that was modeled by Lucy and Bodey, and can be considered for use in the phantom.



This is the 3D model after about 45 minutes of manipulating. In yellow is the left side of the heart, which was in really good condition. In magenta is the right side of the heart, which was in poor condition. It previously included much of the rib cage, sternum, and spine along with other noise that was indistinguishable. We were able to pair it down to what is seen above. It still needs work smoothing and hollowing.



Shown above is the model we achieved after some more manipulation. We were able to remove the unwanted coronary arteries that were seen in the previous image.


The above images show the pump that we acquired from the UW CVFD lab. Along with this pump we were given tubing and I believe a flowmeter.

Conclusions/action items:

We made pretty good progress into completing segmenting and filling in holes. Next steps include hollowing the model and sending it into other software to prepare for printing. Finish a backup for the show and tell

2023/10/26 Generic Tubing Attachment For Models

LUCY O'CULL - Oct 26, 2023, 5:41 PM CDT

Title: Generic Tubing Attachment For Models

Date: 10/26/2023

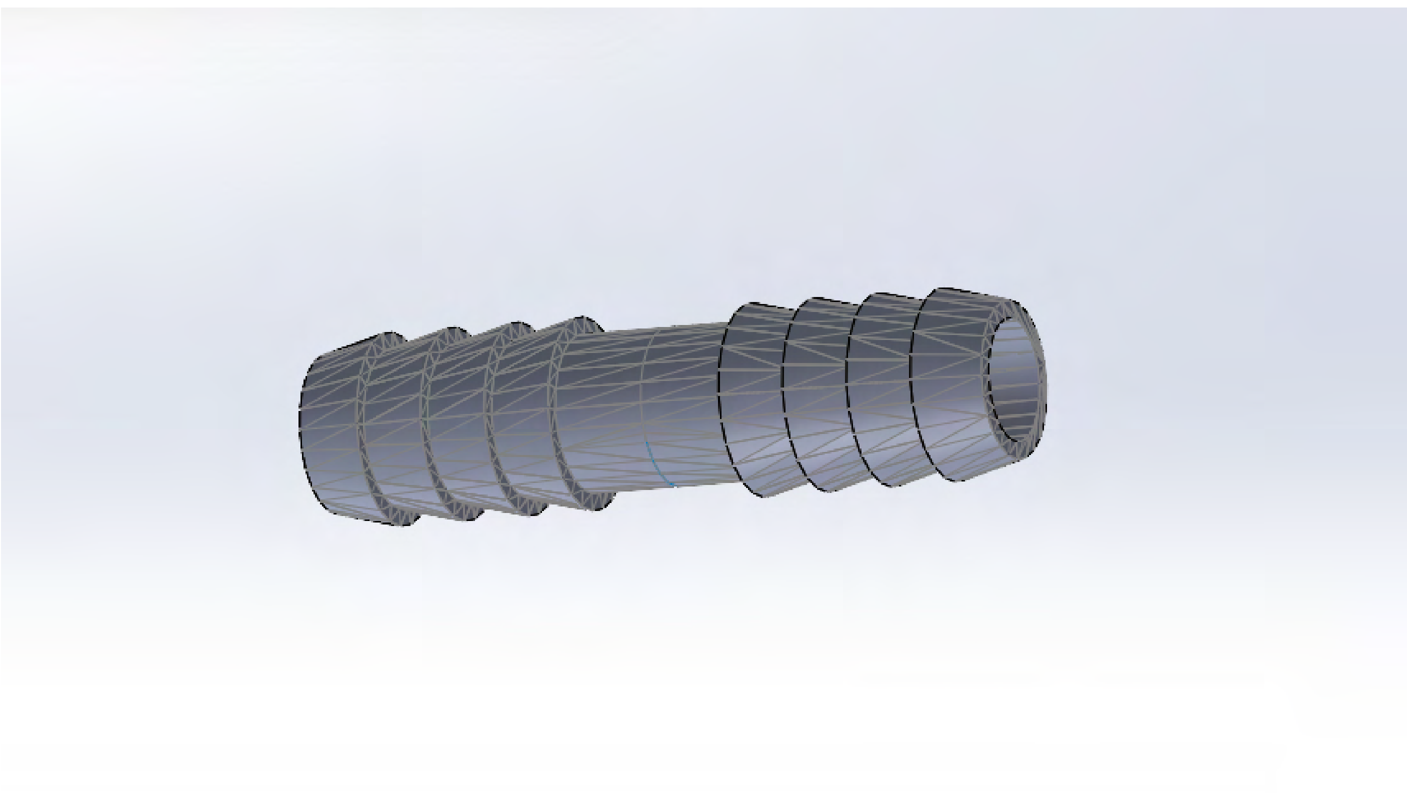
Content by: Lucy O'Cull

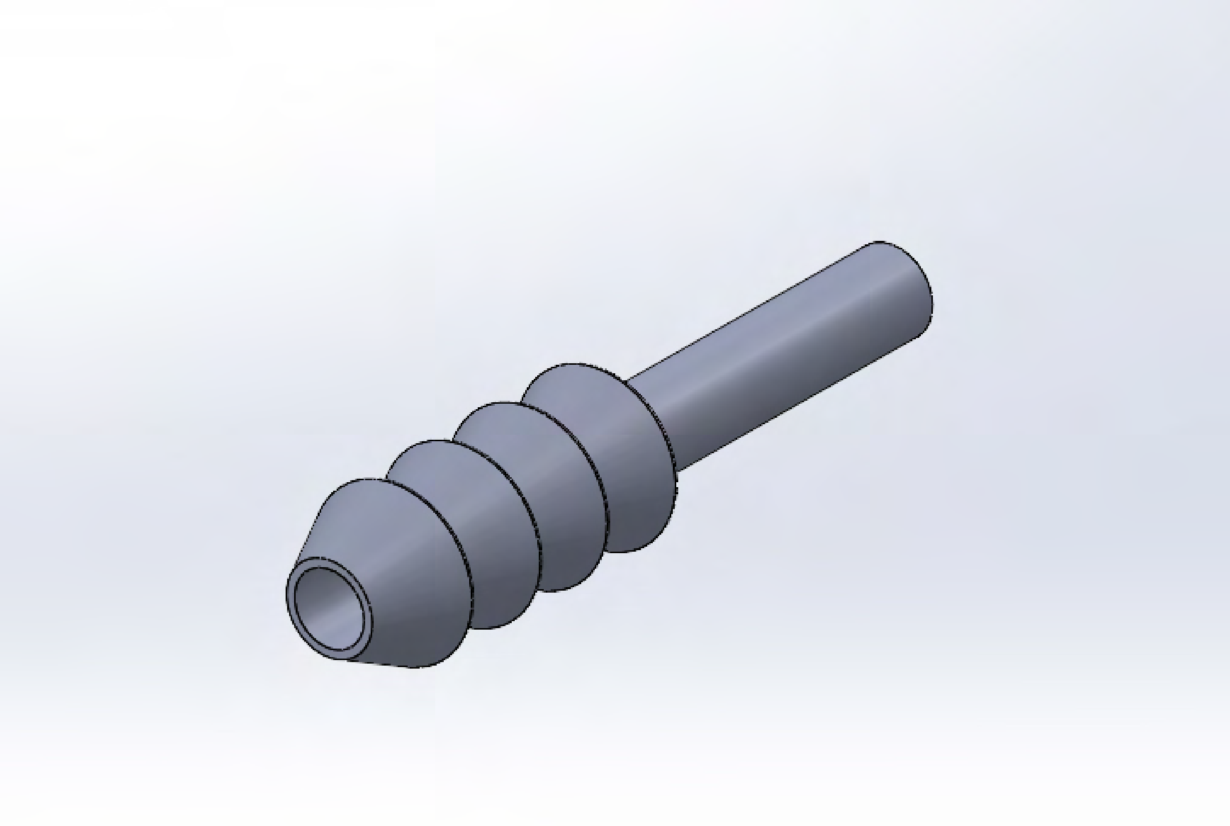
Goals: Create an attachment to incorporate into our models to make connections to tubing more successful

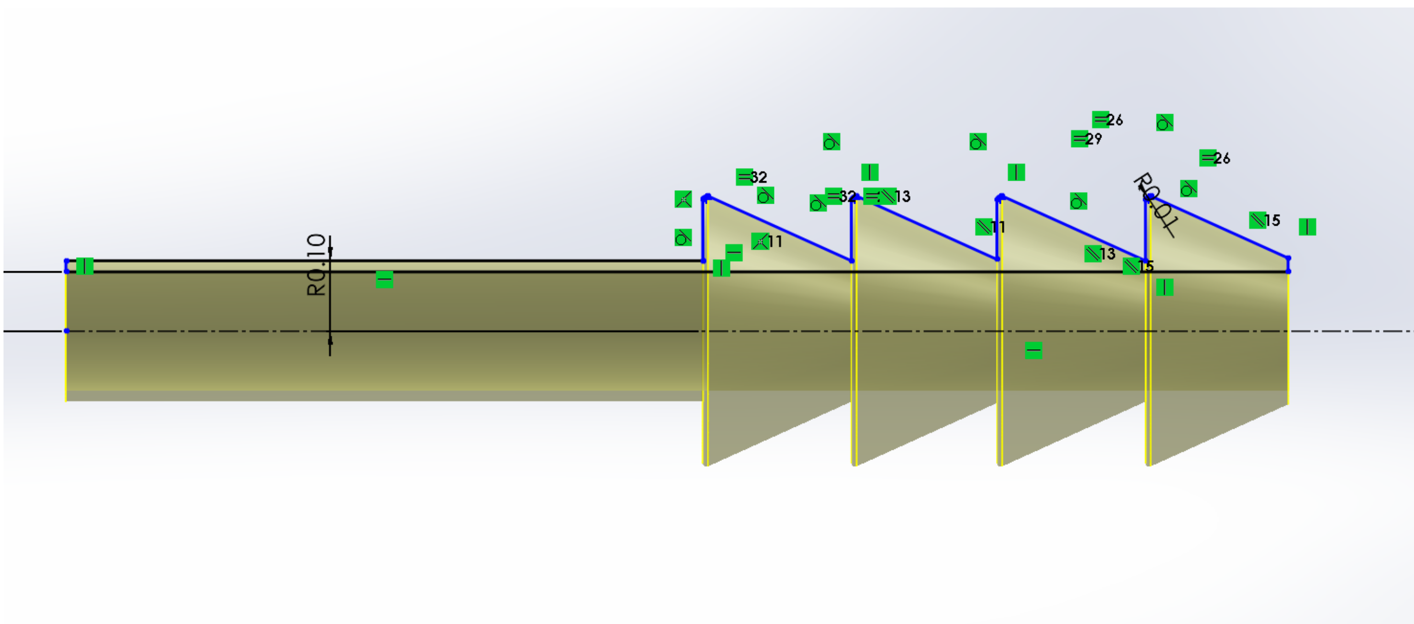
Content:

https://www.thingiverse.com/thing:11255

I tried to work with this connector from thingiverse, however the model was unsecure and was not easily modifiable is solidworks. I decided that it would be easier to build it from scratch and made my own connector shown below.







I created the above model using a revolution of the sketch shown in the second image.

Conclusions/action items:

Next steps for this aspect of the project would be to incorporate these connectors where necessary in our models of the heart. We will need to work out the best way to go from the thin diameter of the tubing to the relatively thicker tubing of the heart components. Studying real anatomy (diameter change from systemic veins/arteries to major veins/arteries) will help with this goal.

2023/11/15 Modeling Workday (2)

LUCY O'CULL - Nov 16, 2023, 10:48 AM CST

Title: Modeling Workday (2)

Date: 11/15/2023

Content by: Lucy O'Cull

Present: Bodey, Emma

Goals: To evaluate Sophie's heart model for print and to redo the injector connector.

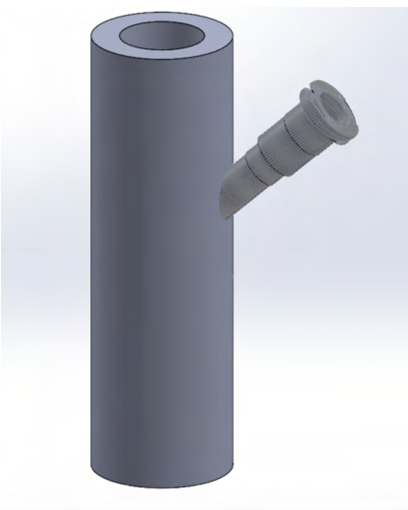
Content:

Found an stl of the female end of luer lock to incorporate into the connection (https://grabcad.com/library/fitting-luer-lock).

The problem with the file is that it did not specify the size of the luer lock. I just had to make an approximation for the time being.

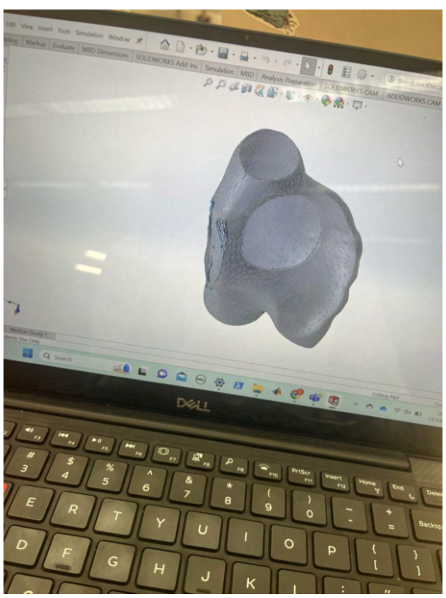
I found from a source that the a venous catheter is typically inserted at a 45 degree angle, so I designed our injection point to insert into the connector at a 45 degree angle.

I combined the files into one assembly.



When we printed the model, the luer lock sizing seemed to be off and the actual lock mechanism of it did not print cleanly.

The heart model by sophie is not a clean model and was not ready to print. We tried some methods of cleaning it up but it did pan out.



The most obvious large whole in the center has been patched. The hole on the left side of the image (more pronounced edges in black outline) is a very broken portion of the model. We need to patch this up in order to make a print.

References:

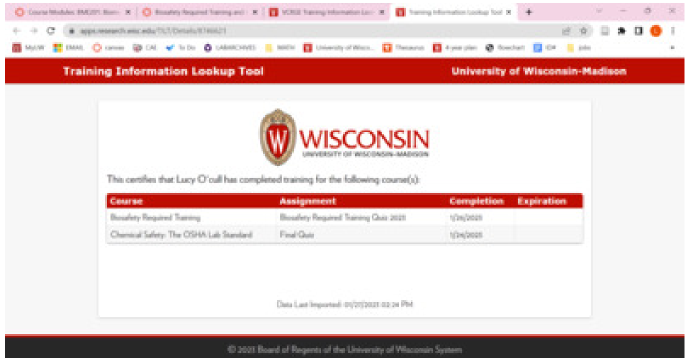
[1] J. Kolikof, K. Peterson, and A. M. Baker, “Central Venous Catheter,” in *StatPearls*, Treasure Island (FL): StatPearls Publishing, 2023. Accessed: Nov. 16, 2023. [Online]. Available: http://www.ncbi.nlm.nih.gov/books/NBK557798/

Conclusions/action items:

We need to get a known size for the luer lock that will be compatible with the injection system that we will be using. That should be a pretty simple fix and reprint. Next we need to finish fixing up the heart model and get that out to print as well.

Biosafety and chemical safety training

LUCY O'CULL - Jan 27, 2023, 2:51 PM CST

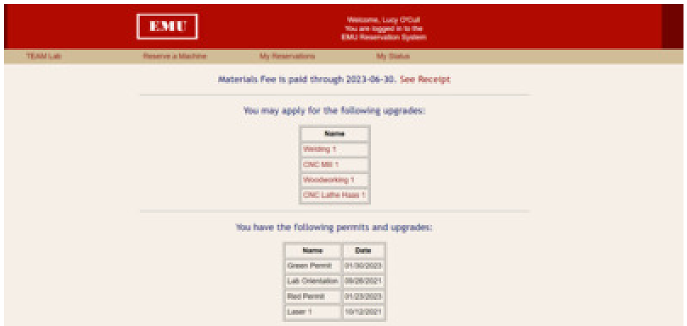


[Download](#)

Screenshot_20230127_024515.png (166 kB)

Green Pass Documentation

LUCY O'CULL - Jan 30, 2023, 6:36 PM CST



Download

Screenshot_20230130_063428.png (71.4 kB)

Extracorporeal Membrane Oxygenation 09/07/2023

EMMA FLEMMER - Sep 18, 2023, 9:06 PM CDT

Title: Extracorporeal Membrane Oxygenation

Date: 09/18/2023

Content by: Emma Flemmer

Present: Emma Flemmer

Goals: Learn more about ECMO machines

Content:

- An ECMO unit consists of the vascular access (cannulas), tubing, a driving force (pump), and a gas exchange unit (oxygenator)

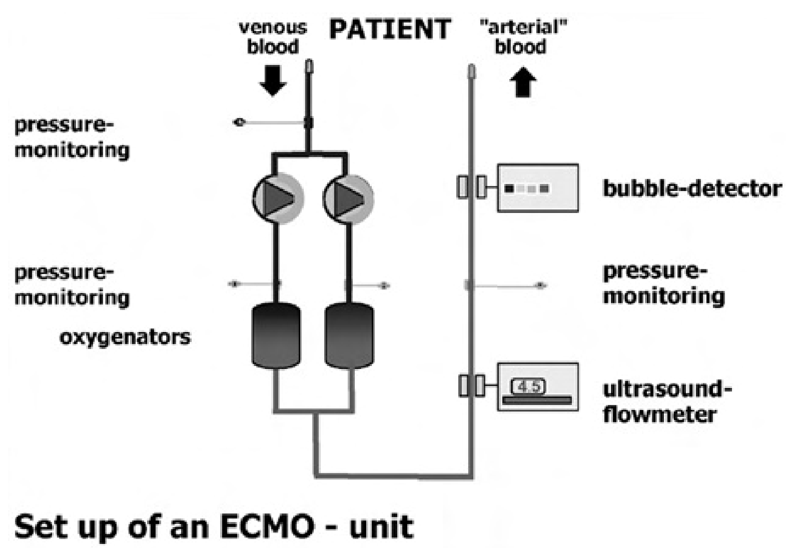


Figure 1. ECMO Circuit

- Roller or centrifugal pumps are the driving force in ECMO circuits

- Some centers use two pumps in the case that one pump fails

- High end pumps can pump blood at rates between 0 and 10 L/min. These pumps are controlled externally by remotes

Conclusions/action items:

ECMO circuits have four crucial components. Circuits can look very different from each other while still serving the same general purpose.

EMMA FLEMMER - Sep 09, 2023, 7:46 PM CDT

Mielck, Frank; Quintel, Michael. Extracorporeal membrane oxygenation. Current Opinion in Critical Care 11(1):p 87-93, February 2005.

https://journals.lww.com/co-criticalcare

CT Scans in ECMO Patients 09/18/2023

EMMA FLEMMER - Sep 18, 2023, 8:52 PM CDT

Title: Multislice CT Scans in Patients on Extracorporeal Membrane Oxygenation: Emphasis on Hemodynamic Changes and Imaging Pitfalls

Date: 09/18/2023

Content by: Emma Flemmer

Present: Emma Flemmer

Goals: Learn about what CT scans look like for patients on ECMO machines

Content:

- ECMO is a modified pulmonary bypass to support life in recovery after a patient experiences a severe cardiac failure

- Computed Tomography (CT) is used to assess a variety of conditions

- CT scans for ECMO patients are tricky due to the different blood flow rates as a result of the ECMO machines

- These different flow rates cause the contrast to be distributed differently than it would be in a patient not on an ECMO machine. The machine causes an inconsistent mixing of the blood and the contrast

- To address this issue a full bypass is required with an empty left ventricle and closed aortic valve. In these circumstances the left heart can not be opacified by the contrast medium

- "To prevent dilution of contrast medium in the ECMO system, Lidegran proposed administering the contrast agent into the arterial ECMO tubing after the membrane oxygenator, or into the venous line distal to the membrane oxygenator. "

Conclusions/action items:

Patients on ECMO machines have different flow rates than patients without. It is important to keep these differences in mind when injecting contrast for CT scans as the regular techniques would result in a defective scan.

EMMA FLEMMER - Oct 11, 2023, 10:08 PM CDT

Liu, K.-L., Wang, Y.-F., Chang, Y.-C., Huang, S.-C., Chen, S.-J., Tsang, Y.-M., & Chang, C.-C. (2014, April 29). *Multislice CT scans in patients on extracorporeal membrane oxygenation: Emphasis on hemodynamic changes and imaging pitfalls*. Korean Journal of Radiology. https://synapse.koreamed.org/articles/1026943

https://synapse.koreamed.org/articles/1026943">https://synapse.koreamed.org/articles/1026943

Dynamic Flow Phantom 09/15/2023

EMMA FLEMMER - Sep 20, 2023, 10:06 AM CDT

Title: Development of a dynamic flow imaging phantom for dynamic contrast-enhanced CT

Date: 09/15/2023

Content by: Emma Flemmer

Present: Emma Flemmer

Goals: Learn about similar products currently on the market.

Content:

- This dynamic flow phantom features two compartments

- It was 3D printed

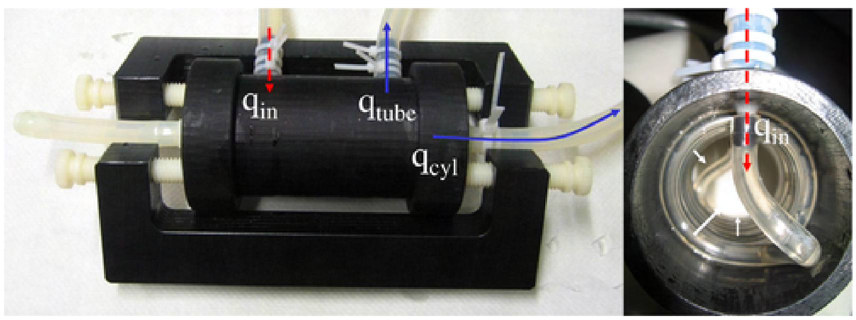


Figure 1. Dynamic flow prototype

- The tubes were made out of vinyl tubing

- The 3D printing material was polymer PC-ABS

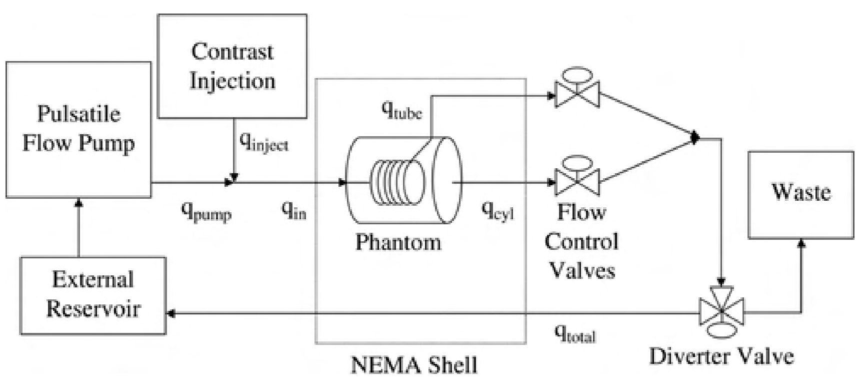


Figure 2. Components of the circuit

- The pump used allowed for flow rates between 0.1 to 35 mL/s

Conclusions/action items:

Keep this product in mind when creating design ideas and beginning the fabrication process.

EMMA FLEMMER - Oct 11, 2023, 10:13 PM CDT

Driscoll, B., Keller, H., & Coolens, C. (n.d.). *Development of a dynamic flow imaging phantom for dynamic contrast ...*American Association of Physicists in Medicine. https://aapm.onlinelibrary.wiley.com/doi/abs/10.1118/1.3615058

https://aapm.onlinelibrary.wiley.com/doi/full/10.1118/1.3615058">https://aapm.onlinelibrary.wiley.com/doi/full/10.1118/1.3615058

CT Scanner Dimensions 09/20/2023

EMMA FLEMMER - Sep 20, 2023, 10:16 AM CDT

Title: Computed Tomography Scanner Dimensions

Date: 09/20/2023

Content by: Emma Flemmer

Present: Emma Flemmer

Goals: Understand the physical limitations of a CT scanner

Content:

- Modern CT Scanners are typically 75-85 cm in diameter

- Some can be as small as 50 cm

- Sizes vary but the information should be available from the radiology staff in charge of operating the scanner

Conclusions/action items:

Understand that the design must fit inside a CT scanner and therefore should ideally not be larger than 75 cm.

EMMA FLEMMER - Oct 11, 2023, 10:16 PM CDT

Fursevich, D., LiMarzi, G., O'Dell, M., & Hernandez, M. (2016, May 27). *Bariatric CT Imaging: Challenges and solutions | radiographics*. Radiology Society of North America. https://pubs.rsna.org/doi/10.1148/rg.2016150198

https://pubs.rsna.org/doi/10.1148/rg.2016150198">https://pubs.rsna.org/doi/10.1148/rg.2016150198

Pumps 09/25/2023

EMMA FLEMMER - Sep 25, 2023, 3:57 PM CDT

Title: Centrifugal pumps and hemolysis in pediatric extracorporeal membrane oxygenation (ECMO) patients: An analysis of Extracorporeal Life Support Organization (ELSO) registry data

Date: 09/25/2023

Content by: Emma Flemmer

Present: Emma Flemmer

Goals: Learn more about possible pump options

Content:

- Historically occlusive roller pumps were utilized in ECMO circuits but centrifugal pumps are more common in modern designs

- Centrifugal pumps are becoming more common because they allow for smaller circuits and decreased air emboli

- Centrifugal pumps have less complications with hemolysis in vitro than in vivo

- In this sample size it was found that 60.4% of ECMO circuits utilized a centrifugal pump

- Another pump option that was in the experiment was a roller pump

- Hemolysis (rupture or destruction of blood cells) was found to be a complication in 20% of centrifugal pumps and 5% of roller pumps

- It was found that kidney injury was observed in 20% of centrifugal pumps and 14% of roller pumps

Conclusions/action items:

Consider this information when determining which pump to use in the team's design.

EMMA FLEMMER - Oct 11, 2023, 10:17 PM CDT

Ciaran O'Brien, Julie Monteagudo, Christine Schad, Eva Cheung, William Middlesworth, Centrifugal pumps and hemolysis in pediatric extracorporeal membrane oxygenation (ECMO) patients: An analysis of Extracorporeal Life Support Organization (ELSO) registry data, Journal of Pediatric Surgery, Volume 52, Issue 6, 2017, Pages 975-978 https://doi.org/10.1016/j.jpedsurg.2017.03.022.

https://www.sciencedirect.com/science/article/pii/S0022346817301719">https://www.sciencedirect.com/science/article/pii/S0022346817301719

Roller Pump 09/25/2023

EMMA FLEMMER - Sep 25, 2023, 4:04 PM CDT

Title: Development of the Roller Pump for Use in the Cardiopulmonary Bypass Circuit

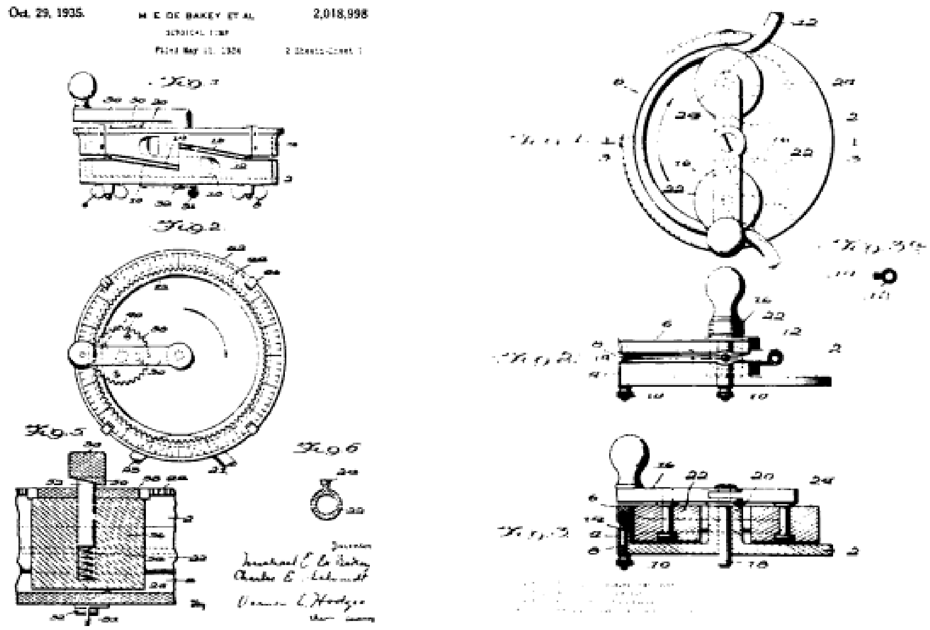
Date: 09/25/2023

Content by: Emma Flemmer

Present: Emma Flemmer

Goals: Visualize roller pumps.

Content:



Figs. 4a and **4b** Patent drawings showing the modification of DeBakey and Schmidt to the rotary pump. "The tube 22 is provided with a flange 24 which is cut with its sides converging toward the point where it is affixed to the tube 22" (Patent application 2,018,998).

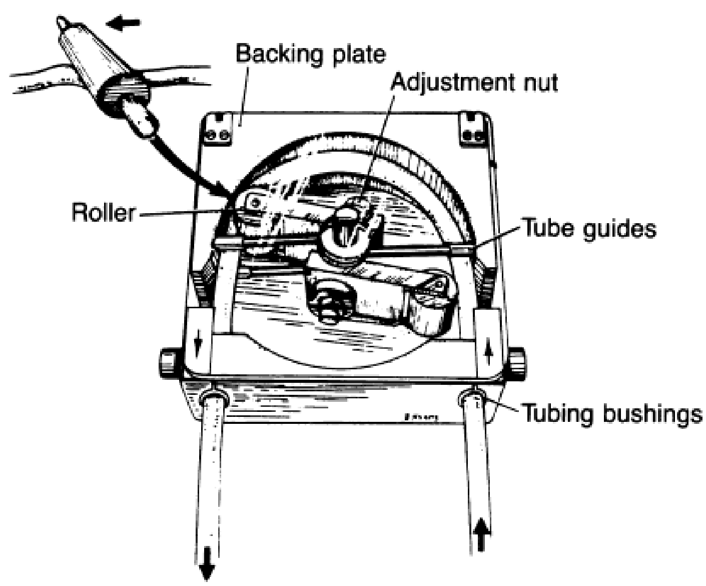


Fig. 5 The roller pump used in the cardiopulmonary bypass circuit today—essentially the same as that patented by Porter and Bradley in 1855.

Figure 1. Roller pump patent drawing

Sheet 2-2 Sheets

Porter & Bradley,

Rotary Pump,

No. 12,753. Patented Apr. 17, 1855.

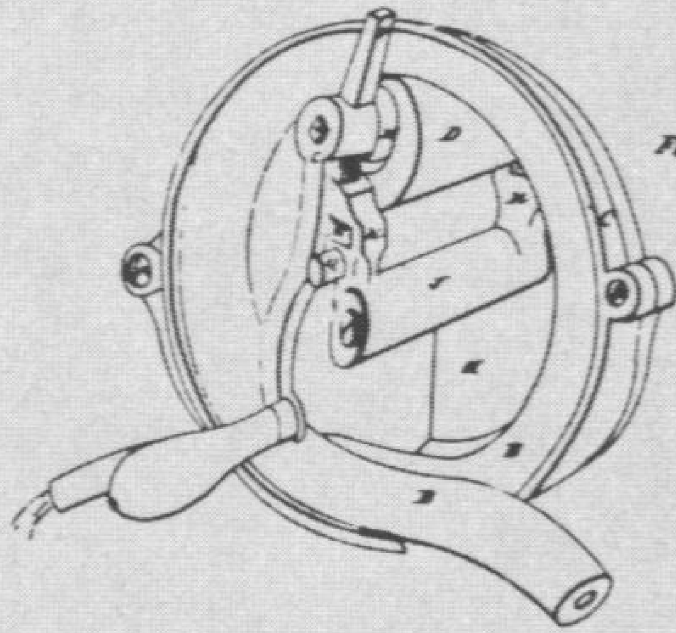


Fig. 6

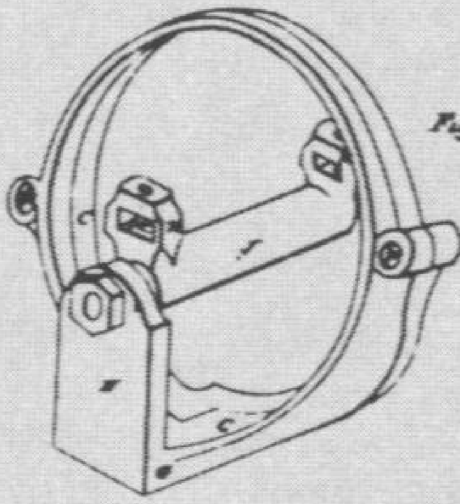


Fig. 7

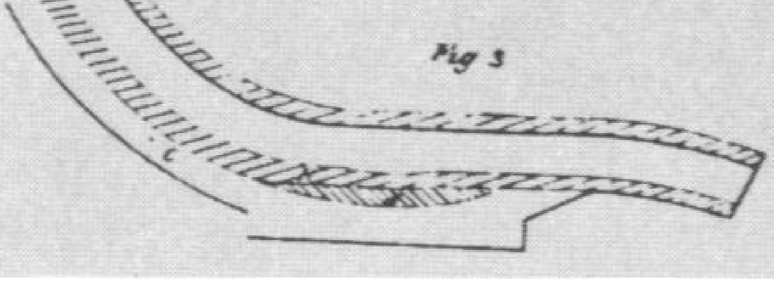


Fig. 3

Figure 2. Roller pump patent drawing two

Conclusions/action items:

Consider a roller pump as a possible component in the team's design.

Centrifugal Pump 09/25/2023

EMMA FLEMMER - Sep 25, 2023, 4:10 PM CDT

Title: Hemolytic characteristics of three commercially available centrifugal blood pumps

Date: 09/25/2023

Content by: Emma Flemmer

Present: Emma Flemmer

Goals: Learn more about centrifugal pumps

Content:

- This article recognized the unacceptable rates of hemolysis seen with centrifugal pumps and believes that it is a problem that can be addressed

- Centrifugal pumps, unlike roller pumps, avoid the risk of tubing rupture due to high pressures

- Centrifugal pumps would be helpful for neonatal situations as they allow for a smaller circuit

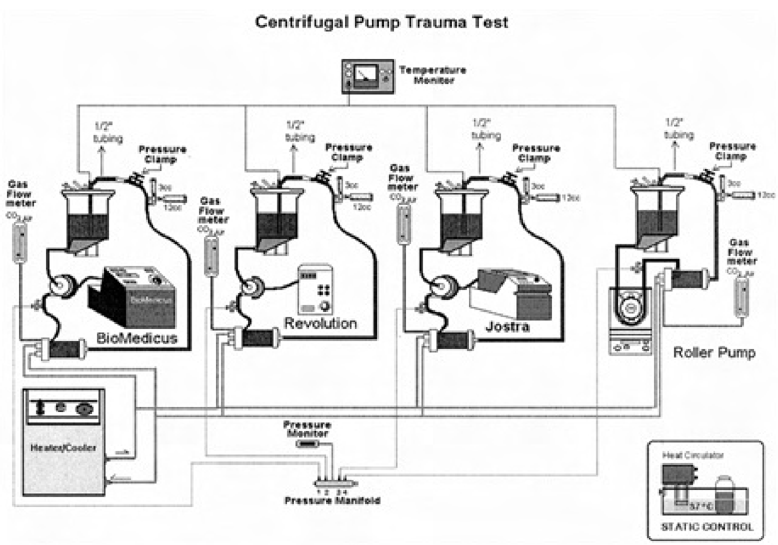


Figure 1. Testing circuit

Conclusions/action items:

Consider using a centrifugal pump in the design.

EMMA FLEMMER - Oct 11, 2023, 10:18 PM CDT

Lawson, D Scott BS, CCP; Ing, Richard MB, BCh, FCA(SA); Cheifetz, Ira M. MD; Walczak, Rich BS, CCP; Craig, Damian MS; Schulman, Scott MD; Kern, Frank MD; Shearer, Ian R. BS, CCP; Lodge, Andrew MD; Jaggers, James MD. Hemolytic characteristics of three commercially available centrifugal blood pumps. Pediatric Critical Care Medicine 6(5):p 573-577, September 2005. | DOI: 10.1097/01.PCC.0000163282.63992.13

https://journals.lww.com/pccmjournal/fulltext/2005/09000/Hemolytic_characteristics_of_three_commercially.13.aspx">https://journals.lww.com/pccmjournal/fulltext/2005/09000/Hemolytic_characteristics_of_three_commercially.13.aspx

Closed Circuit Phantom 10/3/2023

EMMA FLEMMER - Oct 03, 2023, 9:03 PM CDT

Title: Closed Circuit Phantom

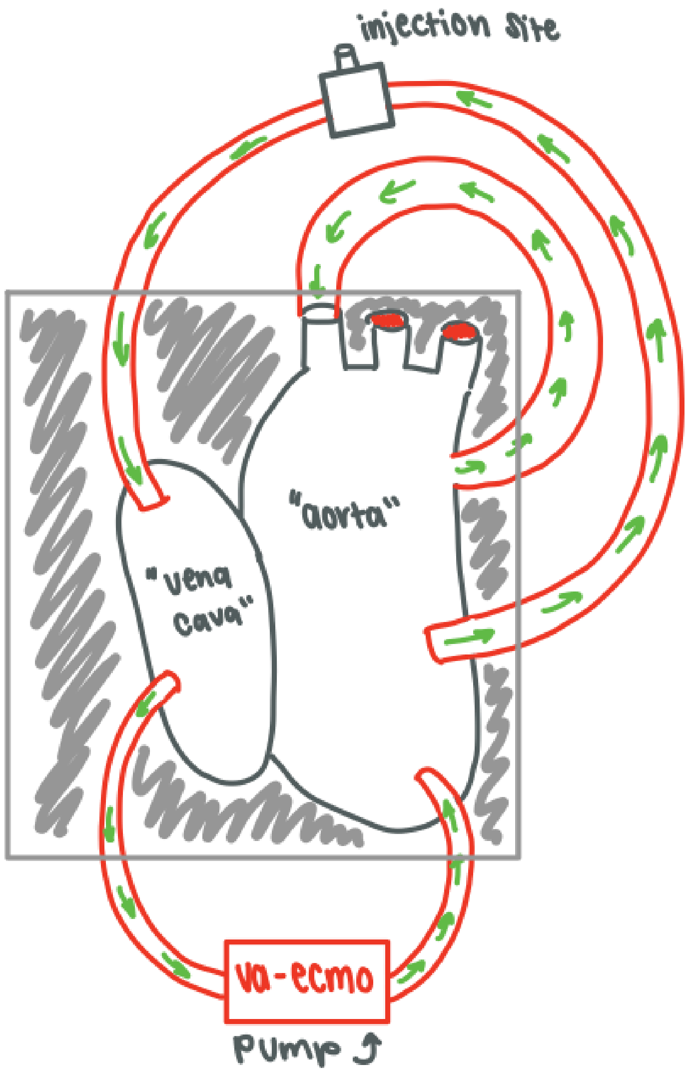
Date: 10/3/2023

Content by: Emma Flemmer

Present: Emma Flemmer

Goals: Layout a possible circuit for the phantom component of the design

Content:



Conclusions/action items:

Present this design to the team at the next team meeting

9/15/23 - VA-ECMO Overview

Will Stephenson - Sep 22, 2023, 3:08 PM CDT

Title: VA - ECMO Research

Date: 9/15/23

Content by: Will Stephenson

Present: N/A

Goals: Research what VA-ECMO is and why/when it is used

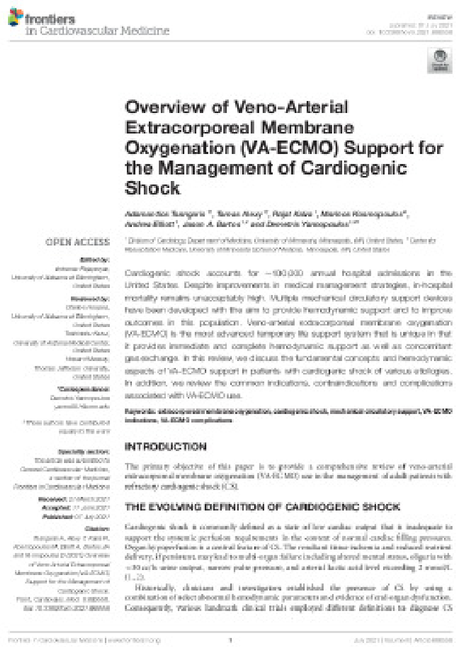
Content:

- [1] Source 1
  - VA-ECMO machines offer temporary life support with a system that replaces heart function and gas exchange
  - Used for people who go into cardiac shock
  - Heart function mechanism is done by a centrifugal pump (up to 8L/min)
  - Gas exchange is done by a hollow fiber membrane oxygenator
  - Can also be used in a surgical setting
  - Some complications:
    - People over the age of 75
    - Heart issues, namely aortic regurgitation, ventricular distension, vascular disease, anitcoagulation, and others
    - Infection
    - Recovery
- [2] Source 2
  - There are multiple methods of using VA-ECMO, in this case conservative and immediate
  - Using immediate VA-ECMO treatment did not necessarily improve deteriorating or severe cardiogenic shock, however the involvement of VA-ECMO is an important piece of treatment
- [3] Source 3
  - Roller Pumps
    - Generate direct suction on the venuous catheter
    - Bladder is attatched to an electrical switch that slows or stops pump when threshold suction is reached
    - Suction is created by distance between patient and the floor.
    - Bladder and electrical switch provides servo-regulation and safety for long periods of ECMO usage
    - Pump is adjusted to provide flow for different gas exchange or cardiac support rates
  - Centrifugal pump
    - Spinning rotor which generates flow and pressure.
    - Replacing roller pumps due to durability
    -

[1] A. Tsangaris *et al.*, "Overview of Veno-Arterial Extracorporeal Membrane Oxygenation (VA-ECMO) Support for the Management of Cardiogenic Shock," *Front Cardiovasc Med*, vol. 8, p. 686558, Jul. 2021, doi: 10.3389/fcvm.2021.686558.
[2] P. Ostadal *et al.*, "Extracorporeal Membrane Oxygenation in the Therapy of Cardiogenic Shock: Results of the ECMO-CS Randomized Clinical Trial," *Circulation*, vol. 147, no. 6, pp. 454–464, Feb. 2023, doi: 10.1161/CIRCULATIONAHA.122.062949.
[3] L. Lequier, S. B. Horton, D. M. McMullan, and R. H. Bartlett, "Extracorporeal Membrane Oxygenation Circuitry," *Pediatr Crit Care Med*, vol. 14, no. 5 0 1, pp. S7-12, Jun. 2013, doi: 10.1097/PCC.0b013e318292dd10.

Conclusions/action items:

Will Stephenson - Sep 15, 2023, 12:42 PM CDT


frontiers in Cardiovascular Medicine

Overview of Veno-Arterial Extracorporeal Membrane Oxygenation (VA-ECMO) Support for the Management of Cardiogenic Shock

OPEN ACCESS

Cardiogenic shock accounts for ~100,000 annual hospital admissions in the United States. Despite improvements in medical management strategies, in-hospital mortality remains unacceptably high. Multiple mechanical circulatory support devices have been developed with the aim to provide hemodynamic support and to improve outcomes in this population. Veno-arterial extracorporeal membrane oxygenation (VA-ECMO) is the most advanced temporary life support system that is unique in that it provides immediate and complete hemodynamic support as well as concomitant gas exchange. In this review, we discuss the fundamental concepts and hemodynamic aspects of VA-ECMO support in patients with cardiogenic shock of various etiologies. In addition, we review the common indications, contraindications and complications associated with VA-ECMO use.

INTRODUCTION

THE EVOLVING DEFINITION OF CARDIOGENIC SHOCK

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Tsangaris_et_al._-_2021_-_Overview_of_Veno-Arterial_Extracorporeal_Membrane_.pdf (566 kB)

Will Stephenson - Sep 15, 2023, 2:39 PM CDT


Circulation

ORIGINAL RESEARCH ARTICLE

Extracorporeal Membrane Oxygenation in the Therapy of Cardiogenic Shock: Results of the ECMO-CS Randomized Clinical Trial

Editorial, see p 465

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CIRCULATIONAHA.122.062949.pdf (429 kB)

9/15/23 - Computed Tomography/Phantom Overview

Will Stephenson - Sep 18, 2023, 11:48 AM CDT

Title: CT and CT Phantom Research

Date: 9/15/23

Content by: Will Stephenson

Present: N/A

Goals: Research Computed Tomography and CT Phantoms

Content:

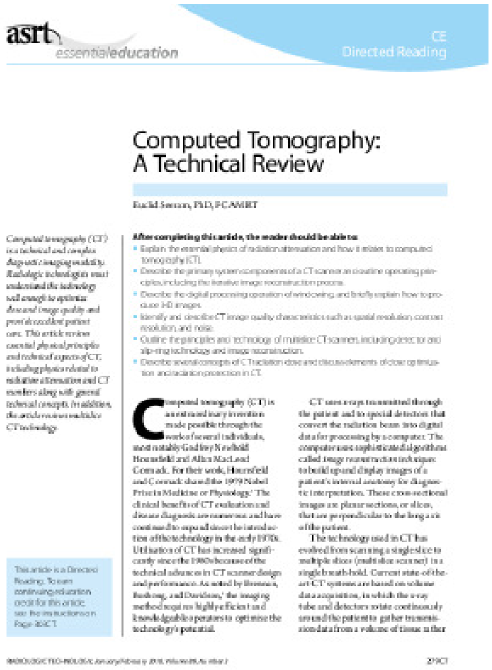
- [1] Source 1
  - Uses x-rays transmitted through patient which convert radiation to digital data, builds display images of patient internal anatomy
  - They have progressed to be able to display a beating heart, etc.
  - CT Scans operate in slices
  - Multiple different ways to compile renderings dependent on what is being imaged
  - Image fusion is the combination of CT images and radiation imaging
- [2] Source 2
  - CT phantoms are used for many things in radiology including quality assurance and imaging calibration
  - Metal can be used, and CT phantoms can be made inexpensively
    - Good information for things like fillers to be used in our design.

[1] E. Seeram, “Computed Tomography: A Technical Review,” *RADIOL TECHNOL*, vol. 89, no. 3, pp. 279CT-305CT, Feb. 2018, Accessed: Sep. 15, 2023. [Online]. Available: https://ezproxy.library.wisc.edu/login?url=https://search.ebscohost.com/login.aspx?direct=true&AuthType=ip,uid&db=rzh&AN=127014197&site=ehost-live&scope=site

[2] B. Tins and J. H. Kuiper, “Building an orthopaedic CT phantom for under £50,” *Br J Radiol*, vol. 92, no. 1094, p. 20180279, Feb. 2019, doi: 10.1259/bjr.20180279.

Conclusions/action items:

Will Stephenson - Sep 15, 2023, 3:05 PM CDT



asrt essentialeducation

CE Directed Reading

Computed Tomography: A Technical Review

Euclid Seeram, PhD, FCAMRT

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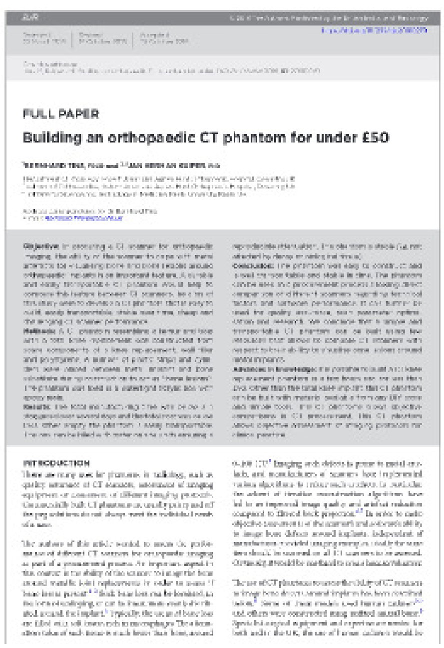
Will Stephenson - Sep 18, 2023, 11:48 AM CDT



FULL PAPER

Building an orthopaedic CT phantom for under £50

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phantom.pdf (6.67 MB)

10/26/23 - Roller Pump Research

Will Stephenson - Oct 26, 2023, 2:01 PM CDT

Title: Roller Pump research

Date: 10/26

Content by: Will Stephenson

Present: N/A

Goals: Research Roller Pumps

Content:

- Nature of roller pumps makes it so we have to be deliberate about the fluid we use
  - Assuming we end up using a roller pump
  - Roller pumps effictively "roll" out the fluid through tubing
  - If the fluid is too thick or thin, the expulsion of fluid from the roller pump will be different than what human blood would be
  - Must be very precise in our fluid choice
- More susceptible to overpressurization or kinking in the tubing
  - Could be a point of consideration for longevity
-

https://www.sciencedirect.com/topics/engineering/roller-pump#:~:text=It%20has%20the%20disadvantage%20that,backflows%20with%20very%20high%20velocities.

Conclusions/action items:

10/11/23 - Updated Phantom Research

Will Stephenson - Oct 11, 2023, 9:00 PM CDT

Title: Updated Phantom Research

Date: 10/11/2023

Content by: Will

Present: N/A

Goals: Look at CT phantoms, static and dynamic, for competing designs

Content:

- Materials like fill powder and some metals could be used for a phantom
    - Metals should only be used to simulate metal streaking
- Lasers could be used to track flow rates
- Mechanical pumps are common place for flow phantoms
- 3D printing is also a viable tool for flow systems
- Control Valves might be a consideration

[1] B. Tins and J. H. Kuiper, “Building an orthopaedic CT phantom for under £50,” *Br J Radiol*, vol. 92, no. 1094, p. 20180279, Feb. 2019, doi: 10.1259/bjr.20180279

[1] A. Kozlova *et al.*, “Dynamic blood flow phantom for in vivo liquid biopsy standardization,” *Sci Rep*, vol. 11, no. 1, Art. no. 1, Jan. 2021, doi: 10.1038/s41598-020-80487-8.
.

[1] B. Driscoll, H. Keller, and C. Coolens, “Development of a dynamic flow imaging phantom for dynamic contrast-enhanced CT: Development of a dynamic flow phantom for DCE-CT,” *Med. Phys.*, vol. 38, no. 8, pp. 4866–4880, Aug. 2011, doi: 10.1118/1.3615058.

Conclusions/action items:

9/25/23 - Preliminary Design Ideas

Will Stephenson - Sep 28, 2023, 11:30 AM CDT

Title: Preliminary Design Ideas

Date: 9/25/23

Content by: Will

Present: N/A

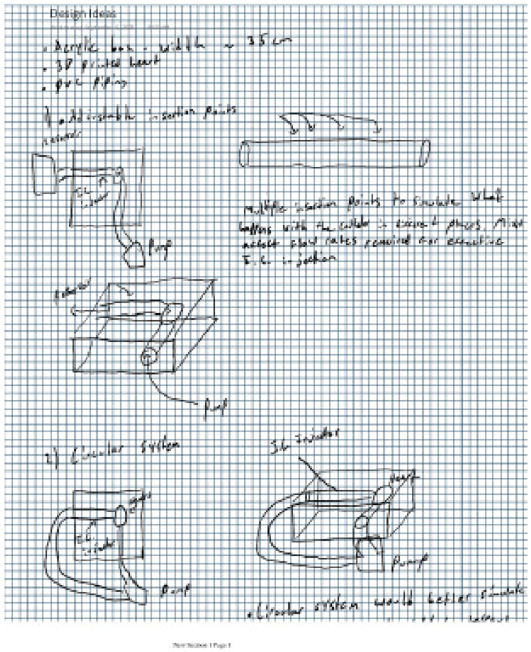
Goals: Make some ideas for the preliminary design

Content:

- Should be a clear acrylic box filled with water, about 35 cm width
- Clear PVC tubing for observations and durability
- 3D printed heart to simulated blood flow
- Vena Cava insertion
    - I.C. inserts into the Vena Cava
    - This should be done with a fabricated plastic piece connecting the heart with the PVC tubing to allow for repeatable insertion.
    - Can also be made with multiple insertion points to allow for simulated flow with different I.C. injection points
- Closed vs. Open circuit
    - Closed ciruit would circulate blood, allowing for the I.C. to build up over time, increasing the HU over time
        - This would happen pretty rapidly
        - Might not simulate human bloodstream well, dependent on circuit size
    - Open circuit would pump blood into a reservoir, not allowing I.C. build up
        - Only would get to measure the interaction between the I.C. and the blood flow
        - Might not be the interaction we are going for

Conclusions/action items: Meet with group, decide on key points of interest in design.

Will Stephenson - Sep 25, 2023, 6:08 PM CDT



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Design_Ideas.pdf (1.06 MB)

9/27/23 - Negative Space/Fabrication ideas

Will Stephenson - Sep 28, 2023, 11:43 AM CDT

Title: Negative Space/Fabrication Ideas

Date: 9/27

Content by: Will

Present: N/A

Goals: Think through how the negative space designs and fabrication

Content:

- Negative space designs
    - Silicone mold
    - Would mold the insides to resemble a venous system with a heart
    - Heart would be difficult to design and design sturdily
    - Any screw ups would mean going back to the drawingh board
    - Open
        - Fluid is pumped through phantom into a reservoir
        - A little external tubing required
    - Closed
        - Fluid is pumped around and back through the phantom
        - A lot of external tubing required
        - A key point of potential failure might be the connection from the tubing to the phantom
- Fabrication
    - Acrylic box
        - Utilizes acrylic pieces which are easy to work with
        - Internally uses 3D printed heart, PVC tubing, and water, all three of which are easy to use/fabricate
    - Negative Space
        - Utilizes silicon molding which requires a lot of time and money
        - Mistakes could also cause more time and money to be wasted

Conclusions/action items:

10/27/23 - Testing Ideas

Will Stephenson - Nov 30, 2023, 2:43 PM CST

Title: Ideal Testing Ideas

Date: 10/27

Content by: Will Stephenson

Present: N/A

Goals: Create some Ideal testing Ideas

Content:

Pump:

- Measure flow with flow meter at the source
- Measure flow before going into the heart
- Measure flow after going into the heart

Tubing connection:

- Pump at target flow for over the target time (2 min?)
- If it hits target time, slowly turn the pump up to a higher setting
    - Edit: Target flow rate is at max pump setting, (and it isn't even quite rate we need it at), so can't throttle up the flow rate

Conclusions/action items:

12.13.23 Testing/Operational Protocols

Will Stephenson - Dec 13, 2023, 2:30 PM CST

Title: Testing/Operational Protocols

Date: 12/13

Content by: Will

Present: N/A

Goals: Create Testing and Operational Protocols for the phantom device

Content:

Flow Rate Verification Testing

Materials

- Flow Phantom
  - Roller pump
  - Tubing circuitry
  - Heart model
  - Acrylic box
- Flow Meter
- Water collecting vessel
- Water source

Methods

1. Ensure all tubing circuitry is able to connect properly
2. Take two open ends and place both in the water source. Run pump at medium setting (4-5) and run until water is fully through the circuitry with no air bubbles.
   1. May require inverting heart model to let air escape from the heart
   2. Once pump is turned off, make sure all holes are closed to avoid leakages
3. Reconnect open circuitry. Attach flow meter along the circuitry
4. Set the timer for 15 seconds
5. Set pump dial to 1, and allow for it to run for the 15 seconds
6. Record the average flow rate captured by the flow meter
7. Repeat steps 4-6 two more times to ensure good data
8. Repeat steps 4-7 with every odd setting on the dial
9. Compare data with brute force testing data, and determine appropriate dial setting for usage.

CT Scan Testing Protocol

Materials

- Flow Phantom
  - Roller pump

    - Tubing circuitry
    - Heart model
    - Acrylic box
    - Iodinated contrast injector site
- Water source
- Sink
- Iodinated contrast injector
- Spill protection pads
- CT Scanner

Pre-Work

1. Connect together all of the tubing
    1. Right atrium and aorta should be connected via short tubing with injector site in the middle
    2. Long tubing should connect other ends of right atrium and aorta
2. Place middle of long tubing into pump
3. Disconnect tubing from injector piece
4. Place one or both ends of free tubing into a water source
5. Turn on pump at medium setting (4-5) and turn up to ten once direction is determined
6. Run pump until water is present through tubing without air bubbles
    1. Inversion of heart model is necessary to get air bubbles out of heart
    2. When pump is turned off, make sure all holes are covered to prevent leakage
7. Re-connect injector site, attempting to keep all water in the system
8. Make sure injector site remains pointing upwards
9. Cover CT Scanner and bench with spill protection padding
10. Place Acrylic box onto bench on spill protection padding

Calibration

1. Once Acrylic box is set, remove everyone from the room, and make sure only the acrylic box will be scanned
2. Scan acrylic box to calibrate scanner to that specific location
3. Make sure that acrylic box stays in that location throughout scanning process

Testing

1. Place heart model inside acrylic box
2. Put iodinated contrast injector into injector site
    1. To ensure secure connection, an extra connector piece and tape will be required to reduce backflow
3. Wrap injector and injector site in towels in case of spill
4. Do last check to make sure everything is connected
5. Turn on pump at setting 10
6. Make sure room is cleared

7. Scan phantom
    1. 70+ seconds at cycles just over 2 seconds
8. Turn off pump

Post Work

1. Dispose of liquid in the phantom
    1. Go to sink (or other disposal location)
    2. Disconnect tubing around the injector site
    3. Place one end into water source, and other into sink
    4. Run pump at medium setting (4-5) until pure water has cycled through the system
    5. Take water source end out of water
    6. Run pump until water is no longer in circuitry
2. Clean up spillages and spill pads

Operational Protocol

Pre-Running Checklist

- Make sure reservoir is filled with water
    -
- Make sure all connections are secure between tubing, heart, and reservoir
- Make sure acrylic box is filled with water, with heart and connections submerged

Running Directions

1. Connect pump controller into the pump
2. Connect pump controller into power supply
3. Set pump to low running setting
    1. Rec. at ~4-5
4. Turn pump on
5. Allow to run until water is throughout the system
    1. Make sure there are no air bubbles around the pump
    2. Turn off once done
6. Set pump to max setting
7. Turn pump on
8. Run without contrast injection for 1 minute
9. Start contrast injection
10. Run with contrast injection for 1 minute

11. Turn off contrast injection
12. Turn off pump
13. Drain system
    1. Find a draining site, like a sink
    2. Disconnect input tube into reservoir
    3. Run pump at low setting (3-4) until fluid is drained through system

Conclusions/action items: The two testing protocols were used for the final report. The operational protocol is a guide to running just to test the system (Could be with or without CT scanner).

(2023/10/11) Cannulation Techniques for extracorporeal life support

Bodey CARTIER - Nov 15, 2023, 11:04 AM CST

Title: Cannulation Techniques for extracorporeal life support.

Date: 2023/20/11

Content by: Bodey Cartier

Goals: Gain insight into the different output flow rates for VA-ECMO, determine the size of the catheters used for cannulation, and determine their pressure gradients.

Content:

The tubes for VA-ECMO devices are typically around 15-25 centimeters in length. Their pressure gradient for 20 Fr at 4 L/min in mmHg varies. It can be as low as 13 or as high as 60. Our device should support both. Additionally, the tubing of ECMO circuits has an external diameter of 9.525 mm.

Conclusions/action items:

We should design the device to be compatible with typical VA-ECMO tubing and connections. It should also be able to handle typical flow rates and pressure gradients induced by a VA-ECMO.

(2023/09/14) Optimization of the composition of phantom materials for computed tomography

Bodey CARTIER - Nov 15, 2023, 11:00 AM CST

Title: Optimization of the composition of phantom materials for computed tomography

Date: 09/14

Content by: Bodey Cartier

Goals: Research different materials for to-be-fabricated phantom device

Content: Phantom materials have been designed for many different applications in radiotherapy. This means that many different materials have been tested out and different ones are used depending on which type of phantom is being designed. Many of the phantoms that are created use materials that mimic the attenuation of water and body tissues. The article mentioned that most phantoms are made out of polyethylene or epoxy resins.

Conclusions/action items:

[1] P. Homolka, A. Gahleitner, M. Prokop, and R. Nowotny, "Optimization of the composition of phantom materials for computed tomography," *Phys. Med. Biol.*, vol. 47, no. 16, p. 2907, Aug. 2002, doi: 10.1088/0031-9155/47/16/306.

While the article mentions the use of polyethylene and epoxy resins, I am not too sure how practical that would be for our project. It will be interesting to learn about the materials and fabrication desired by our client when we first meet with them. The next thing to research would be if 3d printers can produce a phantom that can mimic the attenuation of a heart or if that aspect of the device is irrelevant to the project.

(2023/09/20) Development of Dynamic Phantom

Bodey CARTIER - Nov 16, 2023, 2:17 PM CST

Title: Development of a dynamic flow imaging phantom for dynamic contrast-enhanced CT

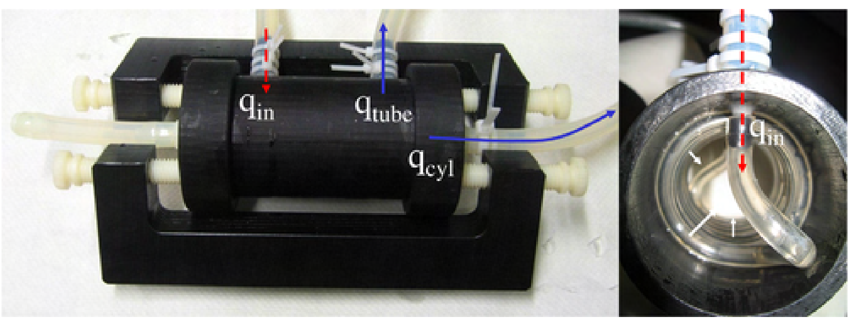
Date: 2023/09/20

Content by: Bodey Cartier

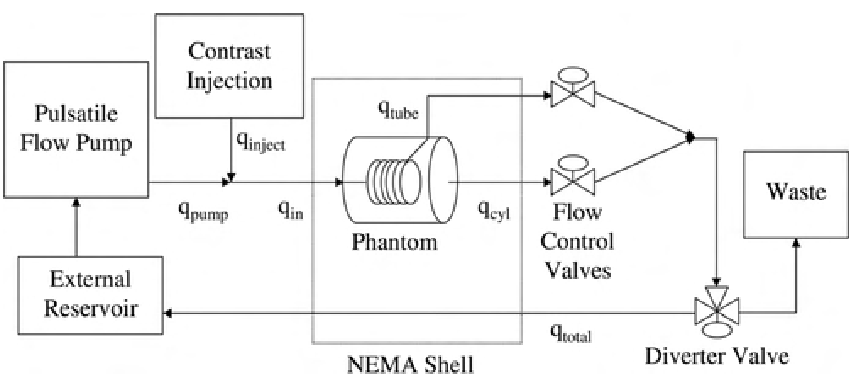
Goals: Research dynamic flow CT phantoms to gain insight for design.

Content: In this article, the researchers 3D printed a two-compartment model phantom. They first measured standard flows. This was used to generate typical attenuation curves for dynamic contrast-enhanced CTs. A phantom prediction model was then applied to compute the input and output typical attenuation curves (TACs) based on five different experimental parameters that included pump flow rate, injection pump flow rate, injection contrast concentration, and both control valve positions. This was then inversely applied to gain the control parameters necessary to generate a set of desired input and output TACs. This was then applied to learn about image noise, partial volume effects, and CT number accuracy under realistic flow conditions. The article also mentions that it is currently assumed that the CT machine behaves similarly in static and dynamic settings, but this fact has never been validated.

In their design, the researchers created a two-compartment dynamic flow phantom to generate a wide range of adjustable sets of input and output TACs. They also mentioned that the overall design of the phantom resembled a shell and tube heat exchanger, but mass is exchanged rather than heat through a series of small holes. The shell was 10 cm long and 5 cm in diameter.



This image shows the input and output of the phantom as well as the internal exchange mechanism, which consists of a contrast distribution tube with small pores. The holes are 1.2mm in diameter, and the contrast-distributing tube was created out of vinyl tubing (1/8 in ID) that can be removed for variation.



This depiction shows the major components of the flow system designed around dynamic flow. In this research experiment, the team used Compuflow 1000MR pulsatile flow, a positive displacement pump which was capable of flows between .1 and 35 ml/s

To insert contrast, a remote-controlled syringe infusion pump was utilized, which had flow rates as low as 2 microliters per minute and as high as 90 ml per minute. The syringe was inserted into the vinyl tubing described above.

Conclusions/action items:

The design shown in this text is very similar to the project that our BME 200/300 team was tasked with. They used 3D-printed parts to create a two-chamber phantom coupled with a variable pump to exhibit dynamic flow rates. Their design also had vinyl tubing that allowed for variable contrast injection via remote-controlled syringe infusion.

Source:

B. Driscoll, H. Keller, and C. Coolens, “Development of a dynamic flow imaging phantom for dynamic contrast-enhanced CT: Development of a dynamic flow phantom for DCE-CT,” Med. Phys., vol. 38, no. 8, pp. 4866–4880, Aug. 2011, doi: 10.1118/1.3615058.

(2023/09/25) Multislice CT Scans in Patients on Extracorporeal Membrane Oxygenation

Bodey CARTIER - Sep 25, 2023, 4:40 PM CDT

Title: Multislice CT Scans in Patients on Extracorporeal Membrane Oxygenation:

Date: 2023/09/25

Content by: Bodey Cartier

Goals: Learn about implications of VA-ECMO CT image implications for designs.

Content: To prevent contrast dilution in the ECMO system, the researchers proposed administering the contrast agent into the arterial ECMO tubing after the membrane oxygenator; or into the venous line distal to the membrane oxygenator.

Conclusions/action items: The reversal of blood flow by VA-ECMO can cause the CT scan to show a poorly pacified aorta or a crescent-filling defect within the aorta. This can be a cause for aortic dissection.

The article did not provide a solution to the problem but warned that radiologists should be familiar with hemodynamic changes associated with ECMO machines. It also mentioned the location of the contrast input within the ECMO system.

K.-L. Liu et al., “Multislice CT Scans in Patients on Extracorporeal Membrane Oxygenation: Emphasis on Hemodynamic Changes and Imaging Pitfalls,” Korean J Radiol, vol. 15, no. 3, pp. 322–329, 2014, doi: 10.3348/kjr.2014.15.3.322.

(2023/09/18) PDS Research

Bodey CARTIER - Nov 15, 2023, 11:03 AM CST

Title: PDS

Date: 2023/09/18

Content by: Bodey Cartier

Goals: Determine shelf life, life in service, and operating environment for soon-to-be fabricated device.

Content:

Life in Service: The device is designed to be used to test and assess dynamic flow rates through a fabricated phantom. The consumer, likely a medical team, would buy the product to calibrate a CT machine with dynamic flow rates for patients that have dynamic blood flow rates.

Shelf Life: Because the product's purpose is the specialized usage of phantoms, the device will remain out of use during many periods of its life cycle. Due to this fact, the device is designed to resist normal shelf life conditions for many years. Pre-existing, medical-grade static phantoms are typically in use for many years if not decades. Our design utilizes inexpensive off-the-shelf materials, which will lower its shelf life when compared to manufactured products. Due to all of the moving components, the shelf life of the dynamic phantom is believed to be several years, or until one of the components loses accuracy or functionality.

Operating Environment: The device will operate in a standard CT scanning room. A CT scanning room is very close to 72°F, never to exceed 75°F or fall below 64°F. The standard humidity for operating rooms is between 30 and 70%, which the device will be subject to. The procedure is done meticulously, ensuring the cleanliness of the area for maximum accuracy of the scan.

Link to CT Room standards: https://info.blockimaging.com/bid/99019/the-best-ct-scan-room-temperature-and-humidity-for-maximum-uptime

Conclusions/action items: Determine the client's needs to ensure the proper designs are made for the device. This will include figuring out how long the client will use the device, if the device should be compact or if there will be separate components that exist in different locations while in use, and the budget for the device. Finding out the budget will allow us to research materials.

2023/10/19 Injector Connection

Bodey CARTIER - Nov 15, 2023, 10:59 AM CST

Title: Injector Connector

Date: 10/29/2023

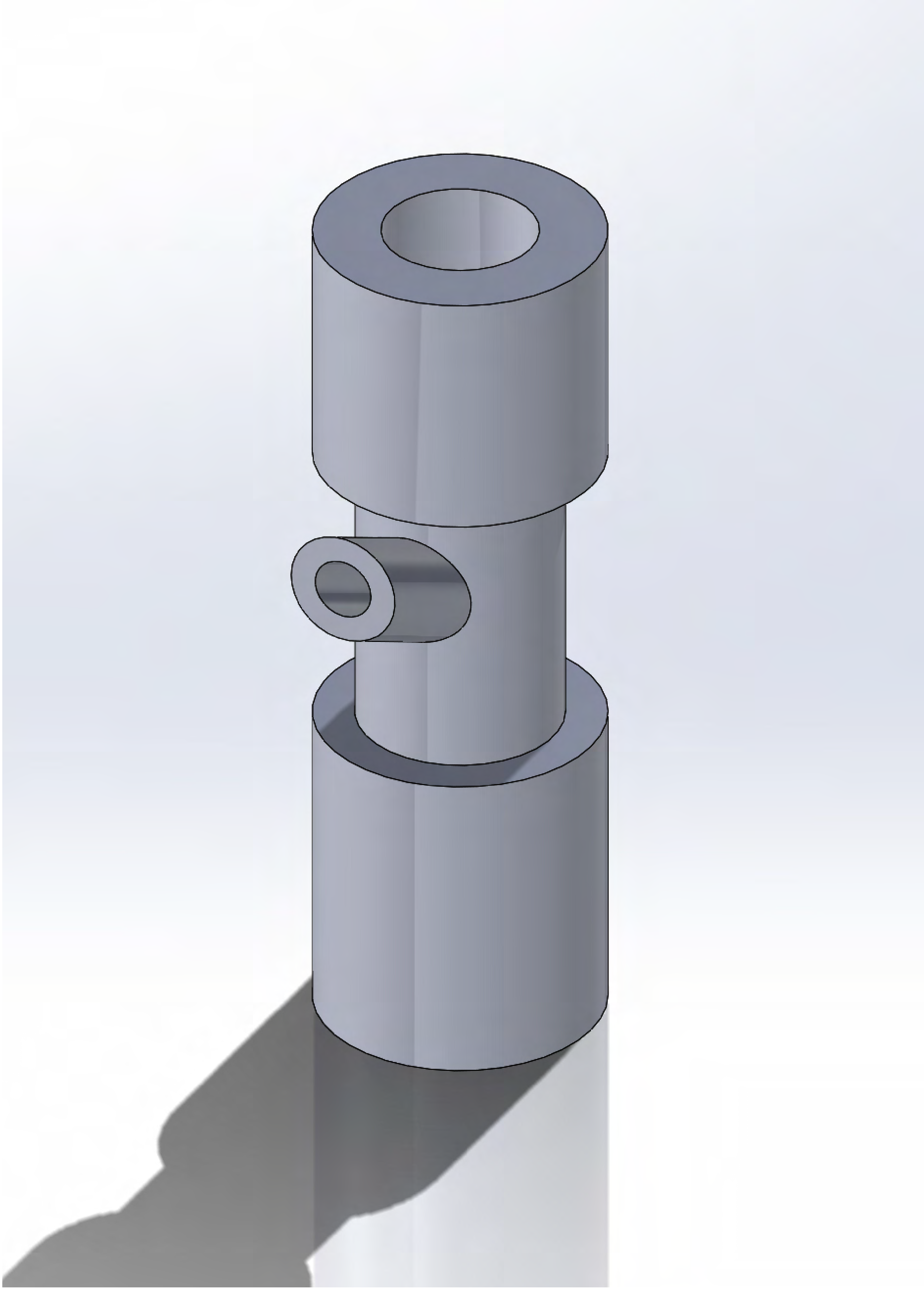
Content by: Lucy O'Cull

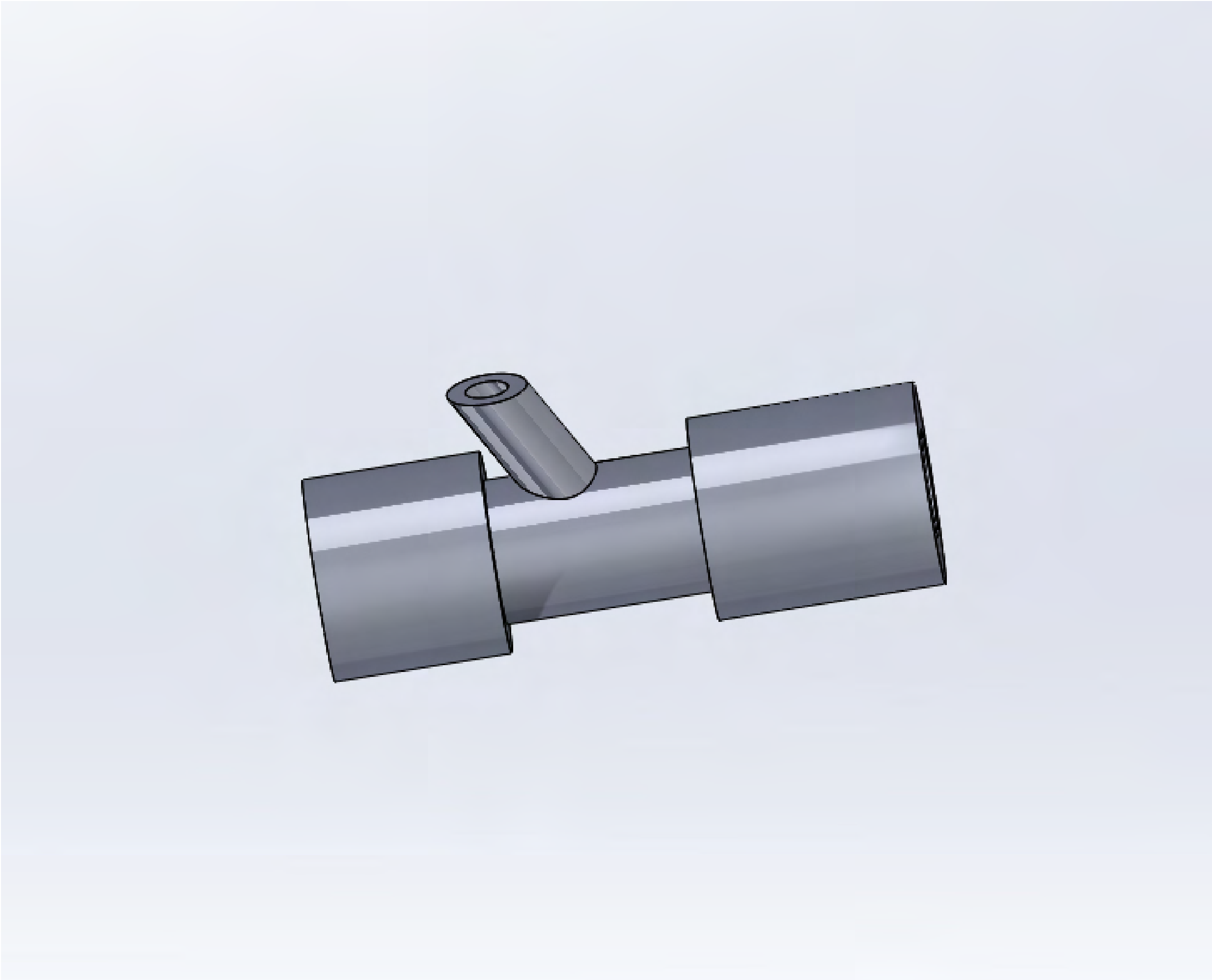
Present: Bodey Cartier

Goals: Research and Model a connection piece for the injector system.

Content:

1. Intended on meeting with UW cardiovascular lab to work on heart model, but the licensing for the software was not up to date and we needed to postpone.
2. Decided to pivot into looking into the injector component and how we will incorporate it into the circuit.
3. Researched how injector systems work clinically using the video in the references section.
4. We decided to create a connector that we can print. It has an off shoot that we will fill with some type of elastic polymer that a needle can be placed into to sort of like the catheter in the skin. This will also prevent the CA from backflowing out of the system.
5. We modeled our idea in solidworks see pictures below.





References:

[1] *[Listen to Authors] High-Rate CT Contrast Injection with Two Small Catheters*. Accessed: Oct. 19, 2023. [Online Video]. Available: https://www.youtube.com/watch?v=g8RfTsqqKEM

Conclusions/action items:

Took the heart to the MakerSpace to get it printed but ran into issues running Solidworks. Will hopefully get printed by Sophie later today.

2023/10/26 Modeling Workday

Bodey CARTIER - Nov 15, 2023, 11:08 AM CST

Title: Modeling Workday

Date: 10/26/2023

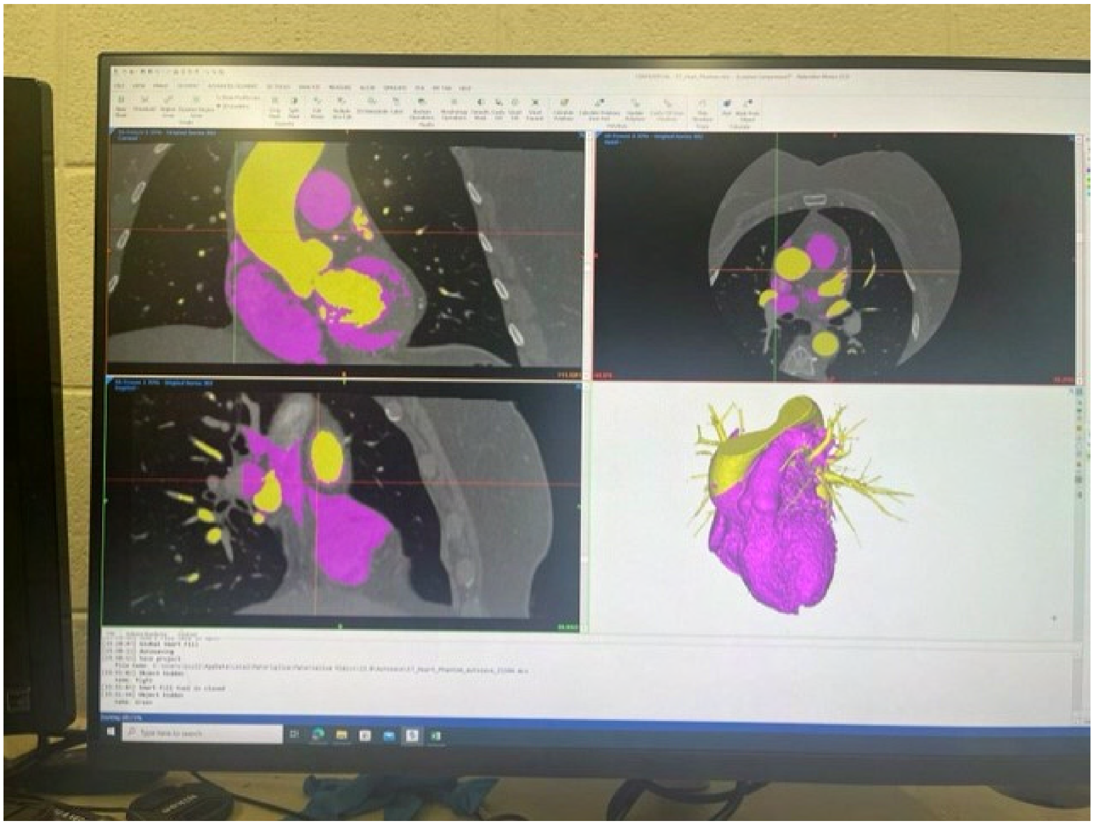
Content by: Lucy O'Cull

Present: Emma Flemmer, Bodey Cartier

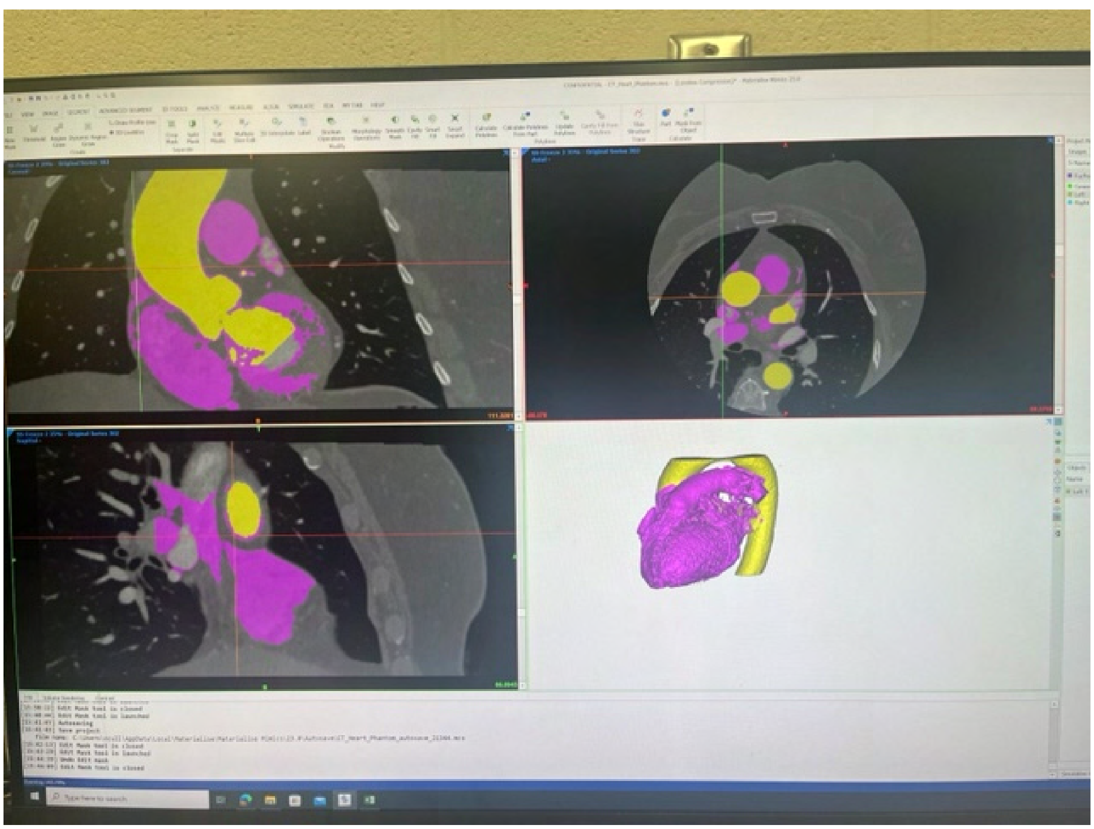
Goals: Work on Making a model from the CT scans and a backup.

Content:

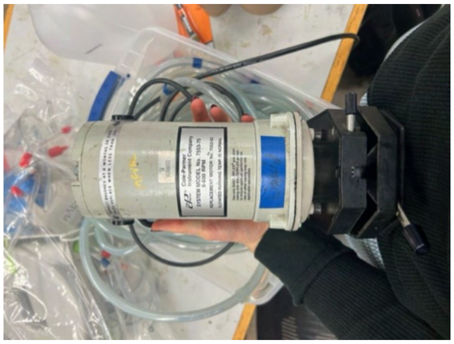
This is the backup aortic arch that was modeled by Lucy and Bodey, and can be considered for use in the phantom.

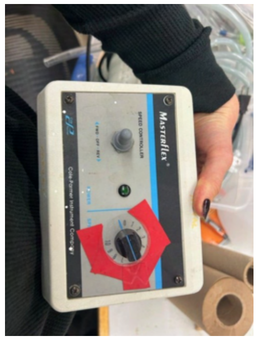


This is the 3D model after about 45 minutes of manipulating. In yellow is the left side of the heart, which was in really good condition. In magenta is the right side of the heart, which was in poor condition. It previously included much of the rib cage, sternum, and spine along with other noise that was indistinguishable. We were able to pair it down to what is seen above. It still needs work smoothing and hollowing.



Shown above is the model we achieved after some more manipulation. We were able to remove the unwanted coronary arteries that were seen in the previous image.





The above images show the pump that we acquired from the UW CVFD lab. Along with this pump we were given tubing and I believe a flowmeter.

Conclusions/action items:

We made pretty good progress into completing segmenting and filling in holes. Next steps include hollowing the model and sending it into other software to prepare for printing. Finish a backup for the show and tell

2023/11/07 Phantom Modeling Workday

Bodey CARTIER - Nov 15, 2023, 11:07 AM CST

Title: Phantom Modeling

Date: 11/07/2023

Content by: Emma Flemmer

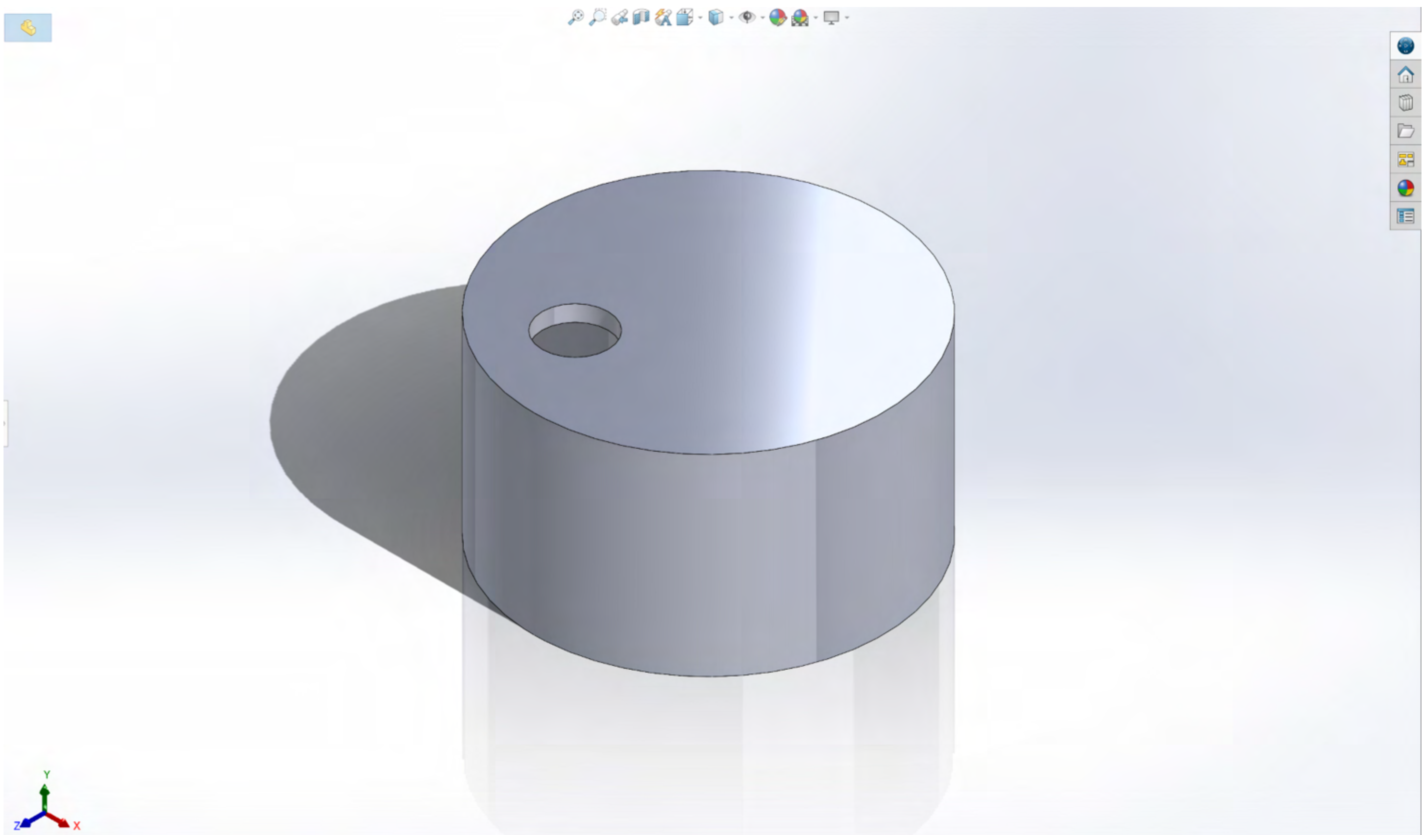
Present: Bodey Cartier

Goals: Model a simplified phantom as a backup

Content:

- Modeled the phantom using dimensions of a average male heart according to the National Library

- Modeled the right atrium as a cylinder with the same volume as the average male right atrium



Conclusions/action items:

Continue to work on the other phantom design.

Bodey CARTIER - Nov 15, 2023, 11:07 AM CST

Link: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7849841/

Naseem, M., & Samir, S. (2021, January 8). *Right atrial volume index as a predictor of persistent right ventricular dysfunction in patients with acute inferior myocardial infarction and proximal right coronary artery occlusion treated with primary percutaneous coronary intervention*. Journal of the Saudi Heart Association. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7849841/

2023/11/16-Modelling Work Day- Final Assembly

Bodey CARTIER - Nov 16, 2023, 2:15 PM CST

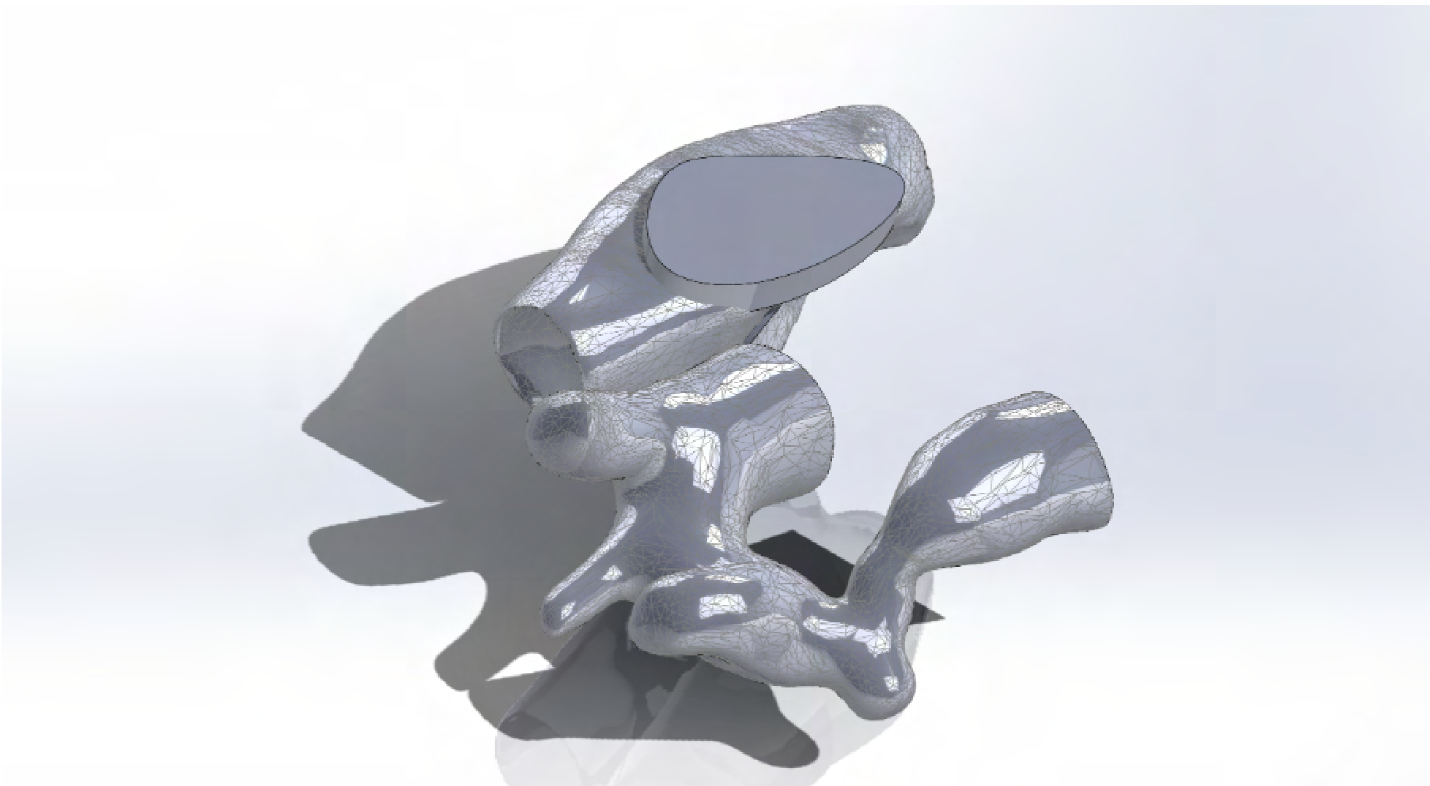
Title: Modelling Work day

Date: November 16th 2023

Content by: Bodey Cartier

Goals: Finalize a model to print

Content:



Conclusions/action items: Print model, finalize testing protocols, and test flow under CT setting.

2023/11/30 Fabrication Work Day

Bodey CARTIER - Dec 12, 2023, 9:48 PM CST

Title: Fabrication work day

Date: November 30th, 2023

Content by: Bodey Cartier

Present: Sophie, Lucy, Emma, Will

Goals: Create end caps for the heart that can modified to include fittings for vinyl tubing.

Content: End caps were created by measuring the circumference of outlet holes in the phantom. They were then machined out of an acrylic sheet. Tube connectors were then added to create compatibility with existing tubing.

Conclusions/action items: Test to see if the circuit is watertight, and test for backflow from various sources. Where there is backflow, add epoxy to seal the system.

2023/12/04 Fabrication Work Day

Bodey CARTIER - Dec 04, 2023, 8:00 PM CST

Title: Fabrication Work day

Date: December 04, 2023

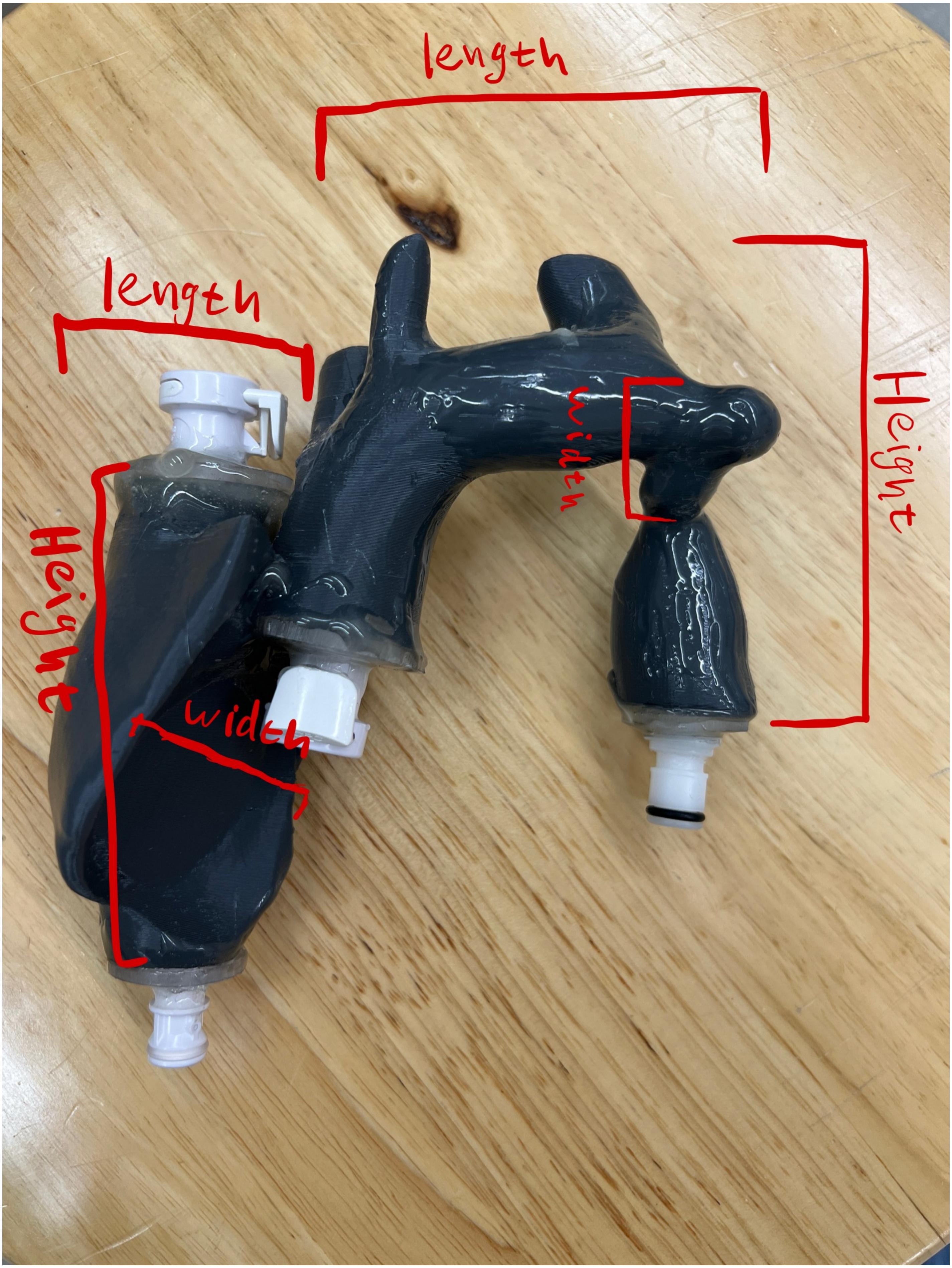
Content by: Bodey

Present: Sophie, Lucy, Jack, Emma

Goals: Test to see if the circuit is airtight, and do initial backflow testing.

Content: Aorta: Height: 84.86 mm, length: 89.50 mm, width/depth: 53.65 mm

Atrium: Height: 84.72 mm, length: 37.34 mm, 69.00 mm


length
length
Height
width
Height
width

Conclusions/action items:

9/11/23 Initial Project Research

JACK STEVENS - Sep 11, 2023, 2:04 PM CDT

Title: Initial Project Research

Date: 9/11/23

Content by: Jack Stevens

Present: None

Goals: Conduct initial research to gather information about our selected project in order to meet with the clients and come prepared with background knowledge as well as questions to ask in order to begin the project process.

Content:

Main project task: Create a phantom to use dynamic contrast flow rates in order to solve how to perform CT (Computed Tomography) scans on patients that are on an ECMO (extracorporeal membrane oxygenation) machine. ECMO patients need a CT scan to assess possible causes of cardiogenic shock (when the heart cannot pump enough blood to the brain and vital organs). Our phantom must model the inflow and outflow parameters of an ECMO patient and simulate the injection of a contrast bolus (dose) to study the effect of vessel contrast quality as a function of adjustable flow rates. Due to a concern with the contrast and injection rate, CT image quality is "significantly compromised".

We want to build a closed set of tubing to mimic ECMO, heart, and major systemic arteries. We will select a pump to pump fluid through the tubing and then find a means to add CT IV contrast to the system.

Outcome of the project: Derive an algorithm for determining the IV contrast and injection rate that is needed in ECMO patients for improved vascular CT imaging.

ECMO:

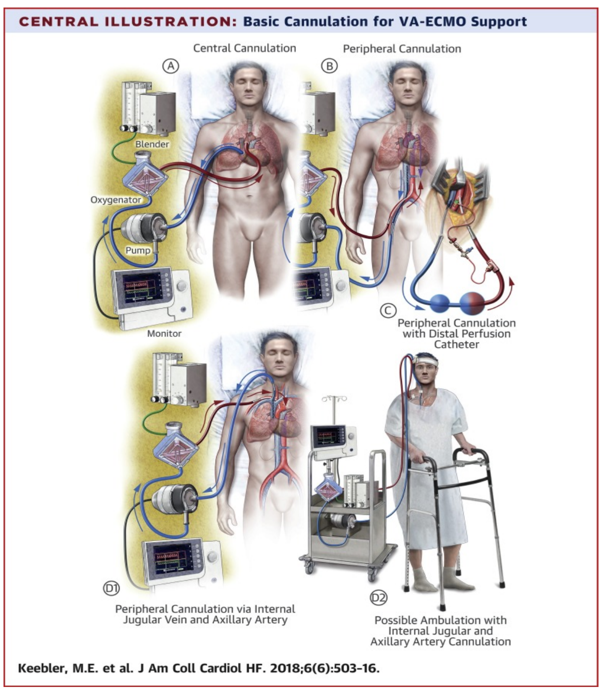


Image Source: https://www.sciencedirect.com/science/article/pii/S2213177918301288

ECMO Information:

This machine pumps blood to a heart-lung machine that removes CO2 and sends oxygenated blood into and throughout the patient's body. Blood from the right side of the patient's heart flows into the membrane oxygenator which warms the blood before sending it back into the body. By using an ECMO machine, the patient's organs undergo less stress than if they had to pump blood on their own.

Can be used in heart conditions such as heart attack, heart muscle disease, heart muscle inflammation, sepsis, severe hypothermia, and cardiogenic shock. Possible lung conditions include: ARDS, blockage in a pulmonary artery, COVID-19, flu, pneumonia, respiratory failure, and more.

Risks with using ECMO include bleeding, blood clot, infection, seizures, loss of blood, or stroke.

Using an ECMO: A thin tube called a cannula is inserted into a vein to draw out blood and a second tube is inserted into a vein or artery in order to insert warmed, oxygenated blood back into the body

Source: "Extracorporeal membrane oxygenation (ECMO)," Mayo Clinic, https://www.mayoclinic.org/tests-procedures/ecmo/about/pac-20484615 (accessed Sep. 11, 2023).

Imaging Phantoms:

Used as stand-ins for human tissues to make sure that imaging systems can image real human tissue properly. Phantoms are usually used to calibrate imaging systems. Phantoms use a variety of hard, soft, and digital materials to mimic possible responses of human tissues. Materials include plastics, salt solutions, silicones, epoxy, foams, water, etc.

Source: "What are imaging phantoms?," NIST, https://www.nist.gov/physics/what-are-imaging-phantoms (accessed Sep. 11, 2023).

Anatomy and Physiology of the Heart:

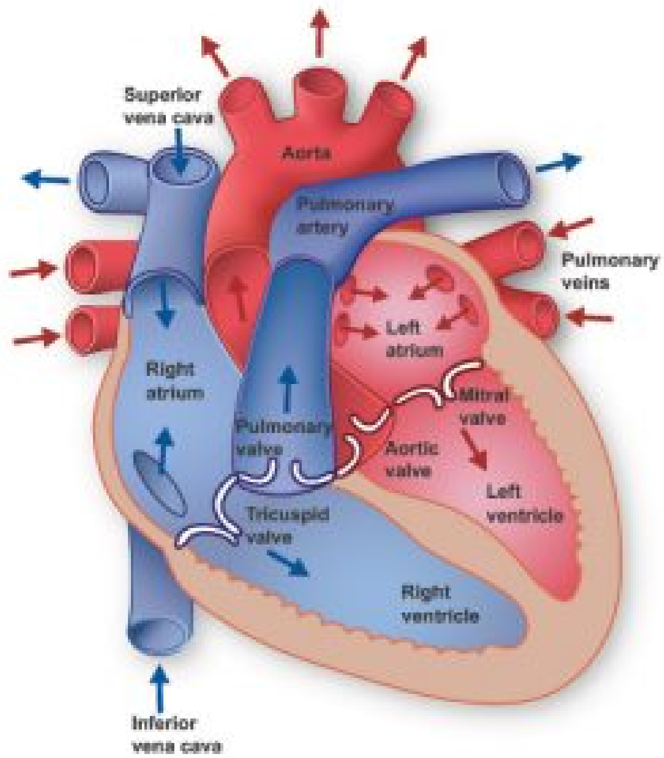


Image Source: https://www.texasheart.org/wp-content/uploads/2018/01/thi-anatomy-heart.jpg

Notes:

- The pericardium is a two layer membrane surrounding the heart that secures and protects it. A fluid in between the two layers allows the heart to move while it beats
- 4 chambers: Left and right atrium, left and right ventricle, wall of muscle divides left and right
- Valves: tricuspid is between right atrium and ventricle, pulmonary valve regulates flow from right ventricle into pulmonary arteries which carry blood to lungs to be oxygenated, pulmonary veins carry oxygenated blood into left atrium where the mitral valve regulates flow into the left ventricle where the aortic valve regulates flow into the aorta which sends oxygenated blood throughout the rest of the body
- Tubing will have to represent the chambers, direction of flow, as well as regulation valves, could color them as picture shows to easily differentiate the "two sides" of the heart
- Heart beats from an electrical signal caused by the myocardium (heart muscle), the signal begins at the sinoatrial node at the top of the right atrium, signal travels along path of blood flow and causes each part of the heart to contract causing flow of blood from high to low dense areas, rate of contractions increases with stress, activity, etc.

Source: "Heart anatomy," The Texas Heart Institute, https://www.texasheart.org/heart-health/heart-information-center/topics/heart-anatomy/ (accessed Sep. 11, 2023).

Possible, CT-safe Materials for the Phantom:

- Goal is to simulate tissues and other parts of the body
- polystyrene resin
- Possible IV Contrast: Omnipaque, not entirely sure how to purchase
- Plastic tubing for ECMO and veins/arteries

Source: K. D. Allert, S. Vangala, and F. A. Dibianca, “Novel materials for low-contrast Phantoms for Computed Tomography,” Journal of X-ray science and technology, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1945223/ (accessed Sep. 11, 2023).

Conclusions/action items: I have a basic understanding of the systems and parts of the body involved in the process. I still need to learn more about how to address the problem and what the clients specifically want done about the dynamic flow in the phantom. By meeting with the clients we will be able to gain a better understanding on what we need to incorporate into our initial design ideas.

9/11/23 Competing Designs Initial Research

JACK STEVENS - Sep 11, 2023, 2:06 PM CDT

Title: Competing Designs Initial Research

Date: 9/11/23

Content by: Jack Stevens

Present: None

Goals: Conduct initial research on phantoms and learn how their structure relates to their function.

Content:

One example of a CT phantom:

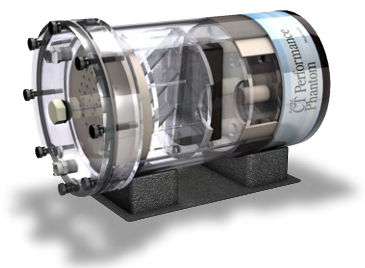


Image Source: https://www.cirsinc.com/wp-content/uploads/2018/12/M610_092813.png

- Various tubes inside the phantom are filled with different liquids to conduct testing in one try
- A contrast test object is placed at the bottom of the device with cavities that are filled with different substances for contrast evaluation
- Can measure noise, sensitivity, radiation dose, spatial uniformity, etc

Source: "AAPM CT Performance Phantom," CIRS, https://www.cirsinc.com/products/diagnostic-ct/aapm-ct-performance-phantom/ (accessed Sep. 11, 2023).

Conclusions/action items: I need to conduct further research on how phantoms work and how we can mimic the ECMO machine and internal organs involved. By looking into other phantoms and designs I will be able to narrow down what kinds of materials we can use in our design in order to be accurate to the human body as well as work well with a CT scanner. Seeing a phantom in person and learning from someone that works with them would provide the knowledge we need to begin creating our own preliminary designs.

9/17/23 Research on Customer Needs, Patient Concerns, and Competing Designs

JACK STEVENS - Sep 18, 2023, 7:54 PM CDT

Title: Research on Customer Needs, Patient Concerns, and Competing Designs

Date: 9/17/23

Content by: Jack Stevens

Present: No one

Goals: Conduct research on my sections of my group's PDS including customer needs, relevant patient concerns, and existing competing or similar designs.

Content:

Information for the customer needs was found on the project page with more to come following the client meeting on 9/21/23. The link to the project page is here: https://bmedesign.engr.wisc.edu/selection/projects/ba566363-b75d-4c72-9b87-acd7d8f7328a

As far as relevant patient concerns, there are not really any as the device is used for testing and calibrating a CT machine and does not come into contact with patients. If there are any concerns that the clients voice at the meeting, they will be added to the PDS.

Research on Competing Designs:

One such device was created in 2011 which involved two compartments that were 3D printed. The goal of the device was to develop a "framework for the quantification and validation of DCE-CT measurements and kinetic modeling under realistic flow conditions." Similar to our project, the designers wanted to address the problem of a lack of proper imaging done on patients with dynamic or irregular flow rates. They concluded that their phantom was "capable of producing accurate and reproducible results which can be predicted and quantified". Their device/protocol was also compatible across different CT devices as well as MRI and PET machines.

Link: https://pubmed.ncbi.nlm.nih.gov/21928658/

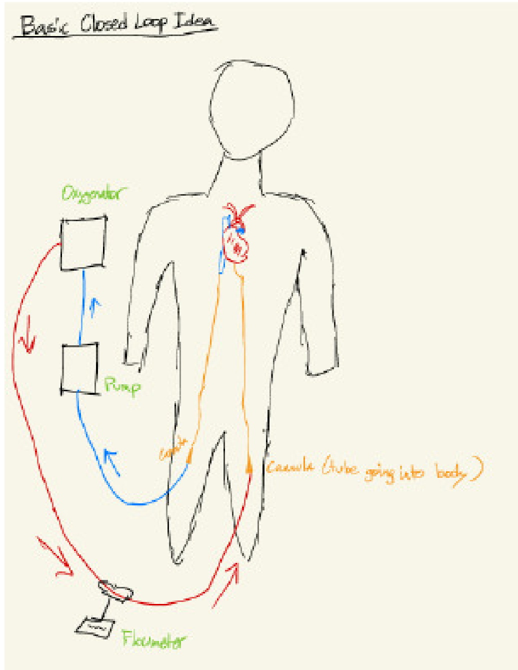
Another device was created because photoacoustic (PA) spectroscopy, while useful, was found to be too slow. Dynamic PA flow cytometry (PAFC) platforms have fast-moving cells that can have velocities from 20-50 cm/s which does not work with most blood phantoms that involve static flow. The team created a device that resembles the properties of whole flowing blood and CTCs (circulating tumor cells). Their device used silicone and "Layer-by-Layer" assembled capsules that had hemoglobin and "natural melanin micro- and nanoparticles". They found it challenging to make these objects seem similar to the real things and to "simulate their optical properties". Finally, their device represented different cell types and used "scattering-absorbing medium" and plastic tubing. It was successfully used to test "high speed signal processing in PAFC". Hollow polymer and silica capsules correctly simulated blood cells and melanoma markers which allowed the device to resemble blood in its optical and dynamic properties.

Link: https://www.nature.com/articles/s41598-020-80487-8

Conclusions/action items: Add relevant information to the PDS and share with team for review. Using this information, I have a good background on the subject and I can prepare for the upcoming initial client meeting. After the meeting we can update our PDS and begin brainstorming preliminary designs. During the client meeting we need to ask about their specific wants for the device and if they have any phantoms or designs that we can look at to learn more about the project in general.

9/24/23 Initial Preliminary Design Brainstorming

JACK STEVENS - Sep 24, 2023, 9:38 PM CDT



Download

9_24_Preliminary_Design_Ideas.pdf (4.18 MB)

JACK STEVENS - Sep 24, 2023, 9:40 PM CDT

Title: Initial Preliminary Design Brainstorming

Date: 9/24/23

Content by: Jack Stevens

Present: No one

Goals: Brainstorm ideas for preliminary designs to be able to share with team at group meeting in order to get started on the fabrication process eventually.

Content:

Pump Sources: https://www.grundfos.com/content/dam/global/page-assets/learn/ecademy/pdfs/master-36-module-5-Centrifugal-pump-types.pdf

https://www.emergency-wash.org/water/en/technologies/technology/radial-flow-pump#:~:text=A%20Radial%20Flow%20Pump%20(also,all%20phases%20of%20an%20emergency.

https://www.zoompumps.com/article/the-difference-between-axial-flow-pump-and-centrifugal-pump/#:~:text=The%20axial%20flow%20pump%20maintains,pump%20is%20greater%20than%20500.

https://www.dxpe.com/different-types-centrifugal-pumps-applications/

Flowmeter: https://www.macnaughtusa.com/products/turbine-flow-meters

DIY Flowmeter: https://blog.arduino.cc/2021/04/30/building-a-low-cost-flow-meter-for-environmental-monitoring-projects/

Conclusions/action items: Meet with team tomorrow to discuss research on preliminary design ideas and come up with design matrices for our main preliminary designs. Then, we can start to think about the specifics of fabrication and how we want to build it. We can also divide up the work and assign each part of the fabrication process to different members of the group.

10/19 Injector Site and IV Injector Research

JACK STEVENS - Oct 19, 2023, 11:57 AM CDT

Title: Injector Site and IV Injector Research

Date: 10/19/23

Content by: Jack Stevens

Present: No one

Goals: Conduct research on injector sites and IV injectors in order to incorporate it into the tubing in our design

Content:

- Tubing must be primed to get rid of any air in it which can mess with data and results
- "Reducing the contrast media volume for tube voltages of less than 120 kV and increasing the iodine delivery rate for higher kV settings is the most effective approach"
- Link: https://pubmed.ncbi.nlm.nih.gov/28448412/
- Hand crank method was built to allow for manual force on a steel part that would push the syringe and add the contrast into the tubing system at a high enough pressure to be properly viewed on the CT scanner.
- 
- Link: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8210644/
- "Pressure limiting" protects the syringe from bursting during injection by limiting how much pressure can be applied to it, does this by reducing the flow rate when pressure inside syringe gets too high
- Higher flow rate = higher pressure
- Thicker the liquid = higher pressure
- longer and thinner tubing = higher pressure
- Some injectors have two syringes, one with contrast and the other with a flush saline solution. These are single use
- Link: https://attendice.com/wp-content/uploads/2020/02/Introduction-to-Contrast-Injectors.pdf

Conclusions/action items: Share information with group, start working on fabricating the pump and tubing part of the project.

10/25 Flow Calculation Background Research

JACK STEVENS - Oct 25, 2023, 12:59 PM CDT

Title: Flow Calculation Background Research

Date: 10/25/23

Content by: Jack Stevens

Present: No one

Goals: Conduct research on flow calculations to understand how fluid will flow through our device

Content:

Pressure Equation:

Pressure (to the phantom) = Pressure (inside the tubing from the fluid) - Pressure (exerted by phantom onto tubing)

In a cylindrical tube with Laminar flow, a Newtonian liquid is used to calculate the pressure difference and flow according to the tube diameter.

Poiseuille Equation: Q = (pi * d^4 * delta p) / (128*mu*L)

d = diameter

delta p = pressure difference from two ends of the vessel

mu = dynamic viscosity

L = length of the vessel

Hoop Stress of the tube = (Pressure of liquid flow * tube diameter) / 2*wall thickness

Link: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8004077/

Flow rate for a roller pump:

The suprarenal flow profile used in this study was based on Lee et al[15] where the flow rate Q in L/min was represented by a trigonometric formula as shown in Equation (1)

Q = C1 + C2cos(2pi*t / T) + C3cos(4pi*t / T) + C4sin(2pi*t / T) + C5sin(4pi*t / T)

t = time (sec)

T = period

For this equation, the C values are: $C_1 = 1.281$, $C_2 = 0.064$, $C_3 = -1.03$, $C_4 = 0.885$, $C_5 = -0.166$

"The period T and coefficient C_1 were modified from 0.83 and 2.891 to produce zero end systolic velocity (ESV) and 60 beats per minute or 1 Hz (T =

1 seconds), resting heart rate"

Source: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7496437

Conclusions/action items: Share information with team to work on calculating the right flow rate for our device, work on fabricating the pump and tubing to connect with the phantom part of the device.

11/9 Fluid and Pump Research

JACK STEVENS - Nov 09, 2023, 12:07 PM CST

Title: Fluid and Pump Research

Date: 11/9/23

Content by: Jack Stevens

Present: No one

Goals: Research how to measure and calculate flow pressure and velocity through our tubing

Content:

We will most likely use 3/8" plastic tubing. We can use a flowmeter to measure the fluid's velocity as it measures how much (volume) fluid moves through it in a certain amount of time. Flowmeters consist of a primary device, transducer, and transmitter. The transducer "senses the fluid that passes through the primary device". Then, the transmitter produces a "usable flow signal from the raw transducer signal".

Equations:

Q = A * v

Q = volume of fluid passing through the flowmeter

A = cross sectional area of the pipe

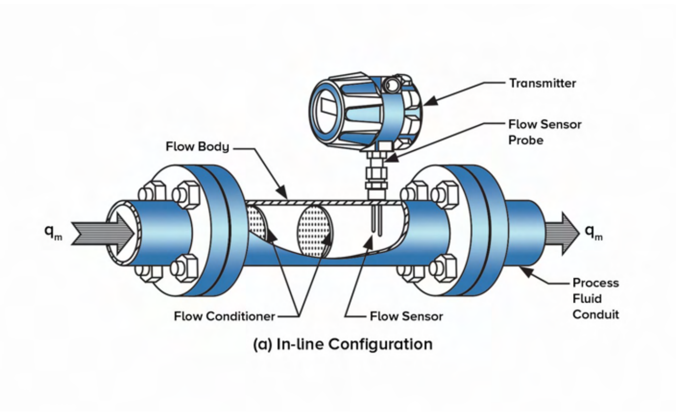
v = fluid's average velocity

W = r * Q -----> The mass flow of fluid passing through the flowmeter = fluid density (r) * the volume of the fluid (Q)

Make sure to install flowmeter so that it is filled with fluid when added to the circuit otherwise the geometry and accuracy of the flowmeter can be affected

Kinks or elbows in the tubing, especially upstream from the flowmeter can mess with measurement accuracy

Source: https://www.flowmeters.com/how-flowmeters-work#:~:text=Flowmeters%20consist%20of%20a%20primary,one%20or%20more%20physical%20devices.

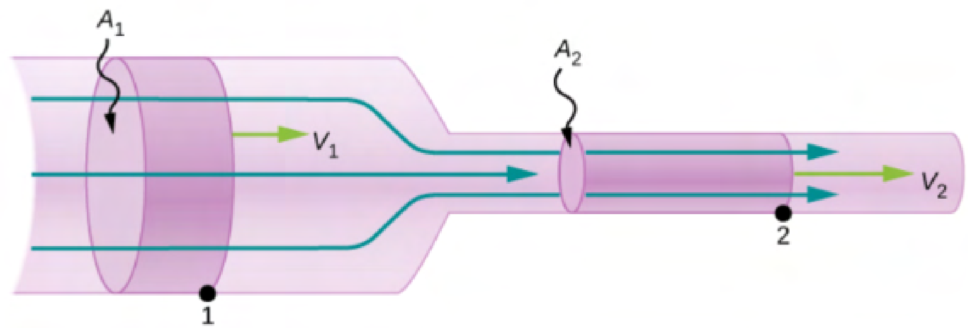


Link: https://www.sierrainstruments.com/rep_news/wordpress/wp-content/uploads/2017/08/thermal-mass-low-meter-configuration.jpg

(Figure) shows an incompressible fluid flowing along a pipe of decreasing radius. Because the fluid is incompressible, the same amount of fluid must flow past any point in the tube in a given time to ensure continuity of flow. The flow is continuous because they are no sources or sinks that add or remove mass, so the mass flowing into the pipe must be equal the mass flowing out of the pipe. In this case, because the cross-sectional area of the pipe decreases, the velocity must necessarily increase. This logic can be extended to say that the flow rate must be the same at all points along the pipe. In particular, for arbitrary points 1 and 2,

$$\begin{aligned} Q_1 &= Q_2, \\ A_1 v_1 &= A_2 v_2. \end{aligned}$$

This is called the *equation of continuity* and is valid for any incompressible fluid (with constant density). The consequences of the equation of continuity can be observed when water flows from a hose into a narrow spray nozzle: It emerges with a large speed—that is the purpose of the nozzle. Conversely, when a river empties into one end of a reservoir, the water slows considerably, perhaps picking up speed again when it leaves the other end of the reservoir. In other words, speed increases when cross-sectional area decreases, and speed decreases when cross-sectional area increases.



If the cross sectional area decreases, velocity will inversely increase.

Link: https://courses.lumenlearning.com/suny-osuniversityphysics/chapter/14-5-fluid-dynamics/

Mixing two liquids (for us it will be water and iodinated contrast):

1) A pipe will not mix longitudinally, so both flows need to be accurately metered. I once had a project where we conveyed a water solution through 4800 feet of 2" pipe. There was a concentration meter at each end. Step changes in concentration at the supply end came through as identical step changes at the receiving end an hour later.

2) If you have turbulent flow (Hint: calculate the Reynolds number), then you should get transverse mixing if the pipe is long enough. You can improve transverse mixing by injecting through a perpendicular nozzle sized to get reasonable velocity, adding some elbows, or by adding a static mixer.

3) Is your system open loop (set the flows, hope for the right ratio), or closed loop (measure the mixture with a concentration meter and feed back to the supply valves / pumps? If closed loop, make sure that the fluids are fully mixed before entering the concentration meter, and that the concentration meter is as close as possible to the supply valves/pumps. The flow time from the supply to the concentration meter is a delay, and delays make for really ugly control situations.

4) How to control flow is determined by viscosity, flow rate, pressures, necessary flow accuracy, line losses, and a few other variables. We need a lot more information to make recommendations on how to control flow. Start with a flow diagram that includes all available information.

Link: https://www.physicsforums.com/threads/mixing-fluids-in-a-flow.973431/

Reynolds number = (density of the fluid)(flow speed)(linear length) / fluid's dynamic viscosity

Conclusions/action items:

9/11/23 Possible Questions for First Client Meeting

JACK STEVENS - Sep 11, 2023, 6:46 PM CDT

Title: Possible Questions for First Client Meeting

Date: 9/11/23

Content by: Jack Stevens

Present: None

Goals: Prepare a list of questions to ask our clients at our first meeting in order to learn more about the specifics of our project.

Content:

- What are the main goals/desired outcomes for the project? What are their expectations?
- Is there a certain design shape that the clients are looking for?
- How often or how many times are they looking to use the device?
- Do the clients want a user-friendly way to adjust flow rates?
- What measurements are needed to be gained from testing the device?
- Do the clients have other phantoms that they can show us to better understand the design process?
- How similar must the phantom be to a real human/ ECMO machine?

Conclusions/action items: Meet with the team to prepare for the first client meeting and then meet with the clients to decide how to go forward with the project. We will then begin to create preliminary designs and determine which is the best one to focus on for our project.

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: