Abstract

Endovascular procedures require multiple guidewires (GWs) of varying diameters, lengths and stiffnesses depending on the blood vessel they are inserted into. Currently, when GWs are inserted into the body, there is no dispensing mechanism and the full length of the GW is exposed. Additionally, when the GWs are removed from the body, they are stored under a wet towel for possible later use. However, due to the GWs spring-like nature, they are easily tangled and deformed; which in turn, can increase the time spent in the operating room, as well as divert the attention of the medical professionals from performing necessary tasks. Additionally, storing the GW underneath a wet towel poses a risk for contamination as the lint from the towel may enter the patient's body. The aim of this study is to develop a device to optimize the organization and storage of GWs of varying lengths, diameters and stiffnesses in a sterile, isolated environment. Overall, this device aims to decrease the time it takes for surgeons to organize the wires, increase procedure efficiency, and increase patient safety. The device consists of two injection moldable parts, (1) a GW wheel that securely holds a GW in place and (2) a stand that holds three separate wheels. The device was tested with medical residents and cath lab techs to ensure all design requirements were met. It was concluded the device was compatible with GWs of varying diameters, lengths and stiffnesses and was more efficient in preventing entanglements during loading, storage, and dispensing GWs compared to competing designs. Therefore, the current design was proven to optimize the storage and organization of GWs.

Introduction

An endovascular procedure is a minimally invasive technique used to diagnose and treat vascular diseases. As chronic diseases increase and as the geriatric population grows, the need for minimally invasive procedures becomes more apparent. With today's advanced medical technologies, catheter-based intervention is replacing traditional surgery for many patients and is also reaching a wider range of patients, as it can be applied to patient groups where open surgery is not possible. These technologies rely on guidewires (GWs) and catheters to travel the vascular system and access the desired position. The use of GWs spans a variety of different surgical sectors including, but not limited to: angioplasty, stenting, pacemaker insertion, electrophysiology studies, atherectomy, thrombolysis, and endourology and therapeutic endoscopy of the gastrointestinal system [1].

In a single endovascular procedure, up to four GWs can be used [2]. Each of these GWs can vary in diameter and stiffness, as they have different purposes in the procedure. For example, during a coronary angioplasty, a flexible GW is used in angled vessels whereas a high support GW is used to provide more support in cases of tortuous anatomy and distal lesions [3]. A GW is inserted into the patient and then directed to the area of interest. From there, the catheter is fed along the GW to the correct area. Once the catheter is in the correct position, the GW is removed. To use GWs more than once during a procedure, GWs must remain uncontaminated and within the sterile field if intended for later use.

A problem lies in the lack of GW storage options. Currently, most doctors store used GWs under a wet towel. However, these towels may shed fibers onto the wire that have the potential to be displaced into the body. Lint contamination can cause serious harm to the patient, and lead to complications including: thrombogenesis, infections, amplified inflammation, poor wound healing, granulomas, adhesions and capsule formation [4].

Additionally, the excessive length of GWs also poses an issue. There is no form of dispensing mechanism for the GW, thus as it is inserted into the body, the remainder of the GW is fully exposed and unwound. This can cause disruption within the operating room as they become hard to manage and can get tangled. In a study about endovascular procedure complications, it was found that 13.3% of procedure errors were due to device failure, which could be attributed to GW knotting or tangling [5].

The aim of this study is to develop a system for storing GWs that also functions as a dispenser compatible with various GW lengths, thicknesses, and stiffnesses. The storing system hopes to increase procedure efficiency by having an organized system and procedure safety by alleviating the potential risks that current storage techniques pose.

Design requirements

The device consisted of two components: (1) a wheel to store a GW and (2) a stand to hold three wheels. This prototype had to satisfy multiple design requirements that are indicated below.

Compatibility With GWs. The device needed to be compatible with GWs with diameter sizes of 0.014 to 0.038 inches and varying stiffnesses. It was essential the GWs stay organized and unknotted when removed from the wheel while on the stand.

Req 1.1: The device must dispense the GW without tangling
Req 1.2: The device must load and store the GW without tangling

Wheel. The wheel was designed to be easily gripped by the operator (most likely a surgeon) to ensure maximum control, minimizing excessive movement. The wheel must also be able to function independently from the stand (while dispensing). A surgeon's hand needed to be able to easily slide into the wheel to load the GW. The average male surgeon's hand circumference is 213.5 mm (68 mm width) and female is 189.5 (60 mm width) [6]. The wheel needed to maximize storage and organization efficiency compared to current designs.

Req 2.1: the diameter of the wheel must be 140.0-160.0 mm with a loading opening larger than 68.0 mm to be suitable for various hand sizes
Req 2.2: the wheel must be intuitive and comfortable for use
Req 2.3: the wheel must efficiently load GWs when compared to competing designs
Req 2.4 The wheel must efficiently dispense GWs

Stand. A stand was needed to store the wheels in the operating room. The stand was designed to be compatible with the size of the GW wheels, stack three wheels, and allow the GW to be unloaded while the wheel is on the stand. The stand allowed for easy access to the GW at any point during a procedure. The stand device was non-slip on operating room surfaces.

Req 3.1: the height of the stand has to allow for three wheels to be placed on top of each other

Req 3.2: the stand allows for dispensing of GWs from any wheel while the wheel remains on the stand
Req 3.3: the stand has to be self-explanatory and comfortable to use

Biocompatibility. The materials used for manufacturing the wheel and stand were biocompatible to limit complications while in use.

Req 4.1: materials used for injection molding of wheel and stand are biocompatible and compliant with operating room standards

Design

Wheel Design. The important components of the wheel (FrissV2) included the following features: the wheel outer diameter, the loading opening, a chimney, the draft angle, and bottom faced holes (Figure. 1). FrissV2 was circular in shape with an outer diameter of 156 mm. The outer diameter had an inward radial force that kept the GW within the cavity. In order to load and dispense the GW, there was a 96 mm opening at one end of the wheel. The chimney in the middle of the wheel had an outer diameter of 55 mm. The chimney acted as a spool and prevented the GW from popping out. The draft angle was 1°, which is the angle measurement between the bottom surface and the walls of the wheel. In order for the wheel design to be manufactured through injection molding for mass production, the draft angle must be greater than 1°. The holes on the bottom face of the wheel allowed saline to flow through the wheel for sterilization of the guidewires during use. These holes were 32 mm in diameter.

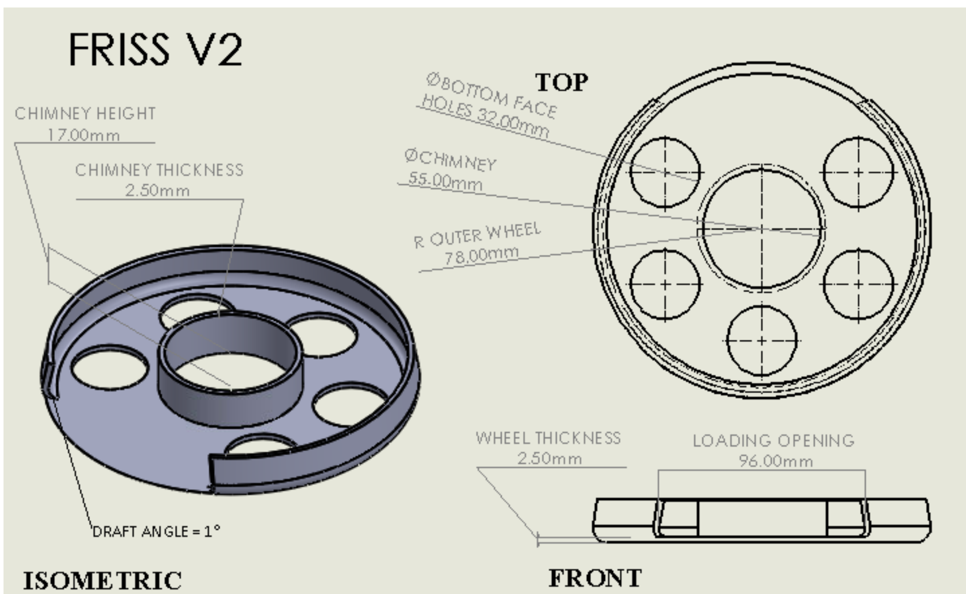

Figure 1. Annotated dimensions of the isometric, front and top view of the wheel design.

Stand Design. The stand featured a base plate with similar bottom facing holes that allowed for easy flow of saline around the GW (Figure. 2). The baseplate was 135 mm in diameter. There was also a long chimney, 75 mm in height, in the center of the base plate which allowed three wheels to be stacked at one time. The diameter of the chimney was 55 mm, matching the inner diameter of the wheel design. The hollow chimney allowed for minimal material to be used, minimizing manufacturing costs.

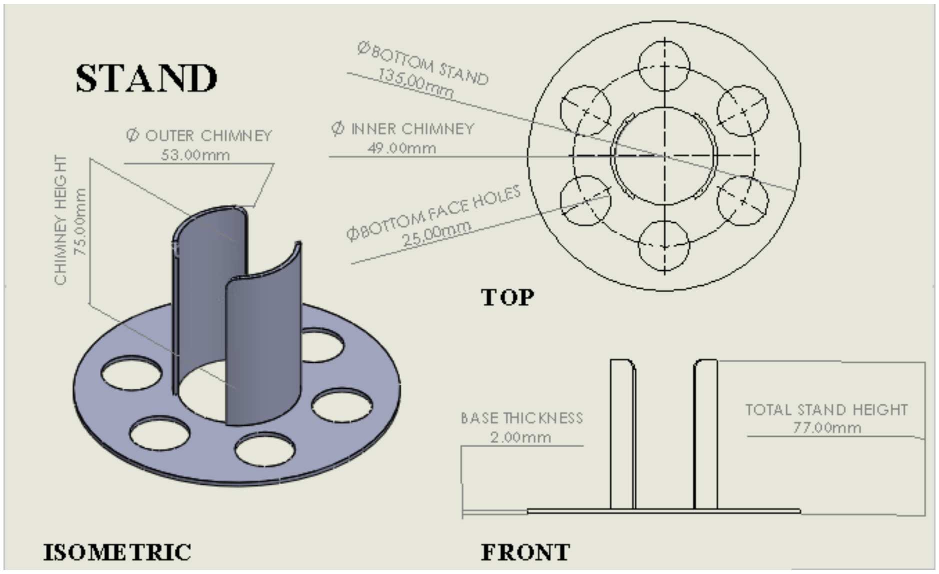

Figure 2. Annotated dimensions of the isometric, front and top view of the stand design.

Stand and Wheel Assembly. When the stand and wheel are assembled, the stand holds three separate wheels. There is 16.5 mm of excess space left between the last wheel and the top of the stand to ensure the wheels did not fall off.

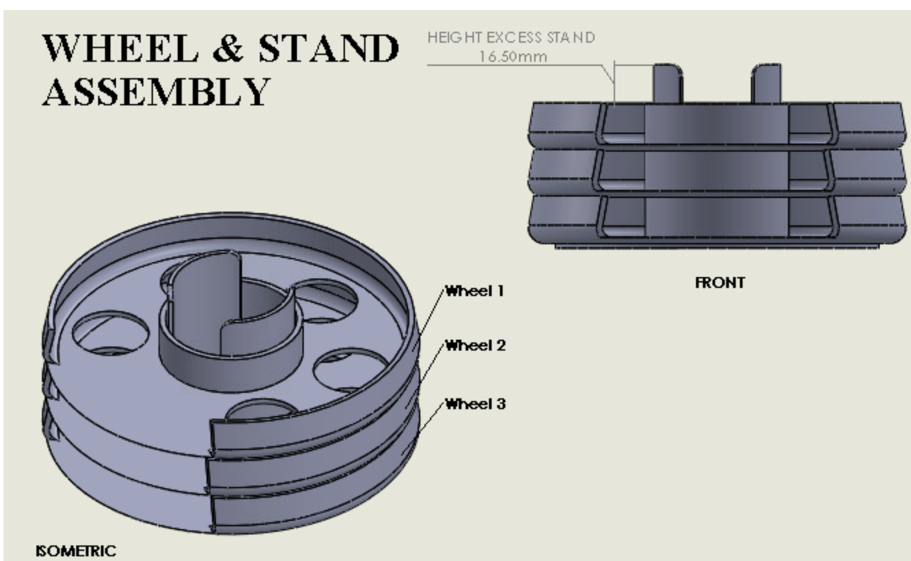

Figure 3. Stand and wheel Assembly.

Results

Compatibility with GWs. The device was designed to function with GWs of varying stiffnesses, lengths and diameters to prevent entanglement during loading, dispensing and storing of GWs. As the GWs were removed from the wheel while on the stand, the test administrator was required to rate the dispensing trial (Req 1.1). As the GWs were loaded into the wheel, the test administrator was also required to rate how the loading trial went (Req 1.2). These ratings allowed for a qualitative analysis of the device to be run to conclude it was compatible with GWs during testing and that the device has high organization efficiency. The ratings for each test were defined in the test protocols in **Appendix A.1.2** and **A.3.2**. The order in which the GWs were tested in each trial was randomized and noted during testing to ensure that every combination was tested equally and to guarantee that there were minimal effects of learning in between trials.

Wheel. The wheel was held by the user in one hand while the other hand was used to hold and load/dispense the GW to test the wheel's function independently from the stand. The diameter of the wheel was 156 mm, and the loading opening was 96 mm (Req. 2.1) [3]. This provided the most feasible design that maximized comfort and efficiency. The wheel comfort was evaluated based on a user-to-user basis. The users, cath lab tech and residents, were asked to complete a verbal evaluation of the wheel comfort for loading and dispensing (Req. 2.2). The user comfort ratings were based on a scale of 1-3 defined in **Appendix A.1.3** and **A.2.3**. Each user was asked to rate the wheel after each run in order to determine the average user comfort level. The time taken to load and dispense the GWs into and out of the wheel was also measured during each of the three testing trials as modeled in **Appendix A.1.1 and A.2.1**. Competing designs were also tested under the same protocols and the wheel was efficient (faster and/or equal times) compared to other designs (Req. 2.3).

Stand. Because the height of each wheel was 19.5 mm, and the chimney of the stand was 75 mm tall, the stand held three wheels at a time (Req. 3.1). To test GW dispensability, the users removed the GWs from the wheels as they were on the stand. The users completed three tests, one with the top wheel, one with the middle wheel, and one with the bottom wheel as modeled in **Appendix A.3.1** (Req. 3.2). These tests were timed during each test. The users, cath lab tech and residents, were asked to complete a verbal evaluation of the stand comfort for dispensing (Req. 3.3). The user comfort ratings were based on a scale of 1-3 defined in **Appendix A.3.3**. Each user was asked to rate each trial in order to determine the average user comfort level while the wheel was on the stand.

Biocompatibility. The wheel or stand device does not interact directly with the body, however, the wheel makes direct contact with the guidewire that is inserted into the patient's body. In terms of biocompatibility (Req. 4.1), the material *(insert material name when chosen)* that was chosen for the wheel and stand was biologically inert.

Discussion

This will be written at a further date once the team has testing results.

Acknowledgements

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Suarez-Gonzalez from the University of Wisconsin-Madison for her guidance, help, and support throughout this project.

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Appendix

Appendix A: Testing Protocol

Guidewire Holder Test Method

Loading

A.1.1 Loading

Prepare test subjects by giving them an unwound GW and the wheel and instruct them that they will wind the GW and place it into the wheel. Then test subject starts trial:

Test Subject Trial Instructions:

(Timer is started by test admin)

1. Wind guidewire by hand into a loop
2. Pick up wheel from table
3. Use one hand to hold wheel, one to hold wire-loop
4. Slide wire-loop into wheel
5. When guidewire is fully secured within the wheel, place wheel in one hand

(Timer is stopped by test admin)

*If the guidewire is not able to load properly, record load time as MT (mistrial)

A.1.2 Test Admin: Grade the Load Trial (0-3)

1. The test admin watches the test subject load GW into the wheel.
2. Based on the table below, the test admin grades the load trial.

Grade	Definition
0	Unable to load GW
1	The GW was placed in the wheel, but there were significant issues (i.e. had to manually maneuver the GW to fit into the wheel), The wheel may be unable to dispense GW after load.
2	GW slid into the wheel with ease, but there were minor issues (i.e. the tip of the GW hung out too far, took longer to load the wheel than usual, etc.), and the wheel was ready to be dispensed.
3	GW slid into wheel without complications

A.1.3 By User: Comfortability (1-3)

1. The user loads the GW from the wheel
2. Based on the table below, the user grades the load trial.

Comfort	Definition
1	Uncomfortable and awkward to load the GW into the wheel

2	GW is loaded with some minor issues/awkwardness and required assistance (ie: Held the wheel device wrong, could not load guidewire, did not know what to do with wheel and guidewire)
3	GW is loaded without complications and no awkwardness, high comfortability and loading with ease (ie: the wheel device was intuitive, did not need any additional assistance)

A.1.4 Data Table

Trial	Guidewire Specs	Load Time	Test Admin Grade	User Comfortability

Dispensing (Solo Wheel)

A.2.1 Dispensing

1. Start timer
2. Use one hand to hold wheel, and one hand to thread guidewire out of loop
3. When wire is fully out of wheel, stop timer

*If the guidewire is not able to dispense properly, record load time as MT (mistrial)

A.2.2 Grade the Dispense (Thread trial) (0-3)

1. The test admin watches the test subject dispense the GW from the wheel.
2. Based on the table below, the test admin grades the load trial.

Grade	Definition
0	Unable to dispense GW.
1	The GW was partially removed from the wheel before tangling and popping out.
2	The GW was removed from the wheel without tangling but partially falls out of wheel during unloading
3	GW was removed from the wheel without complications.

A.2.3 Comfortability by User (1-3)

3. The user dispenses the GW from the wheel
4. Based on the table below, the user grades the dispense trial.

Comfort	Definition
1	Uncomfortable and awkward to dispense the GW from the wheel

2	GW is removed with some minor issues/awkwardness and required assistance (ie: Held the wheel device wrong, could not dispense guidewire, did not know what to do with wheel and guidewire)
3	GW is removed without complications and no awkwardness, high comfortability and dispensing with ease (ie: the wheel device was intuitive, did not need any additional assistance)

A.2.4 Data Table

Trial	Guidewire Specs	Dispense Time	Test Admin Grade	User Comfortability

Dispensing While on Stand

A.3.1 Dispensing On Stand

1. Start timer
2. Use one hand to hold stand and/or wheel, and one hand to thread guidewire out of wheel
3. When wire is fully out of wheel, stop timer

*If the guidewire is not able to dispense properly, record load time as MT (mistrial)

A.3.2 Grade the Stand Dispensing (Pull Trial) (0-3)

1. The test admin watches the test subject dispense the GW from the wheel on stand.
2. Based on the table below, the test admin grades the load trial.

Grade	Definition
0	Unable to dispense GW.
1	The GW was removed from the wheel on stand but significant effort was needed (2 hands, extra person utilized).
2	The GW was removed from the wheel on stand but minor issues occurred (i.e. GW caught on middle chimney)
3	GW was removed from the wheel on stand without complications.

A.3.3 Comfortability by User (1-3)

1. The user dispenses the GW from the wheel
2. Based on the table below, the user grades the dispense trial.

Comfort	Definition

1	Uncomfortable and awkward to dispense the GW from the wheel
2	GW is removed with some minor issues/awkwardness and required assistance (ie: Could not dispense guidewire from wheel while on stand, did not know what to do with wheel, guidewire and stand)
3	GW is removed without complications and no awkwardness, high comfortability and dispensing with ease (ie: the wheel device was intuitive, did not need any additional assistance)

A.3.4 Data Table

Trial	Guidewire Specs	Wheel Placement	Dispense on Stand Time	Test Admin Grade	User Comfortability

Appendix B: Design Process

A. ***Fall 2021***

Fall of 2021 was the team's first semester working on the guidewire organizer. We had decided on moving forward with just one stand design, the Storage Crate (Figure 1), and four initial guidewire designs. The Magnetic Wheel, Clamped Wheel, and the Guidewire Hoop were all compatible with the Storage Crate design that had 4 slots for 4 wheels of each design when placed in an operating room setting. The crate kept guidewires separate when multiple are in use, as it could fit each wheel with a width of 3 cm.

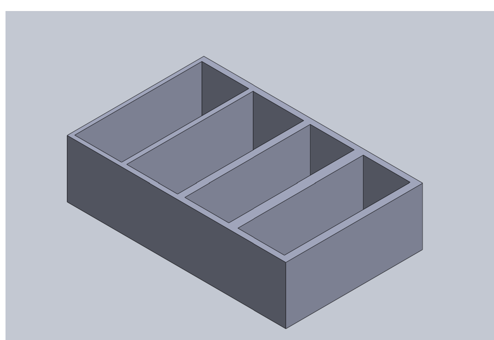


Figure 1. *Storage Crate.*
Dimensions: 13x30x15cm

The Storage Crate had 4 slots for 4 wheels of each design when placed in an operating room setting. It housed each wheel in a 3 cm wide cavity.

A.1 Magnetic Wheel

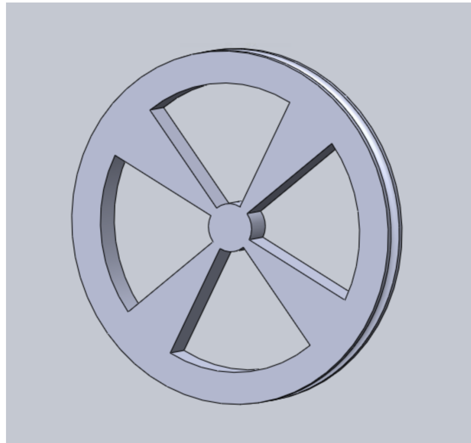


Figure 2. *Magnetic Wheel.*
Dimensions: Outer Diameter: 30cm. Inner Diameter: 28cm.

The goal of the design was to use a magnetized outer ring to keep the metallic guidewire in contact with the wheel while coiled around the magnetized wheel, in order to prevent uncoiling of the guidewire, and to have easier access to the guidewire. The guidewire was spooled around the outside of the wheel.

A.2 Clamped Wheel

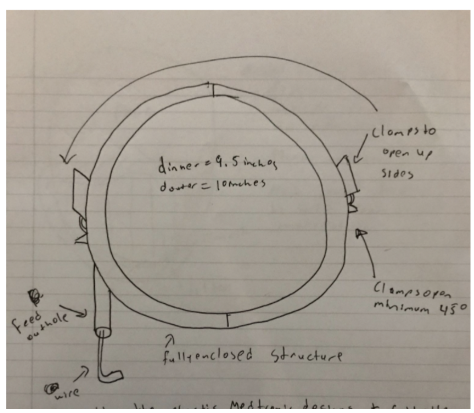


Figure 3. *Clamped Wheel.*
Dimensions: Outer Diameter: 25.4 cm. Inner Diameter: 24.13 cm.

The Clamped Wheel design, Figure 3, utilized a clamp mechanism on the outer surface of the wheel snapped open and closed when the guidewire was placed inside. The hollow circumference of the wheel would contain the guidewire once it is clamped shut. The wheel had a small protruding tube extending from the hollow interior of the perimeter of the wheel, which would contain the very tip of the guidewire for easier access to the wire.

A.3 Wheel of Magic

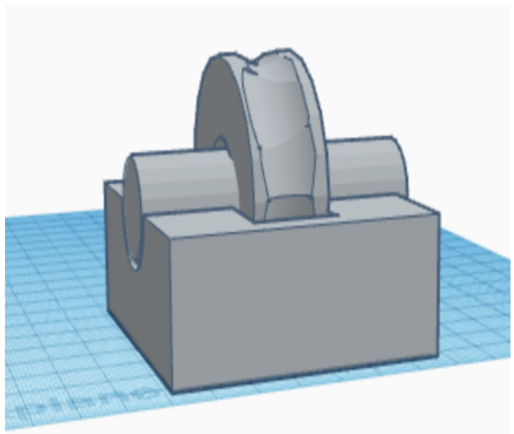


Figure 4. *Wheel of Magic.*
Dimensions: Outer Diameter: 30 cm. Inner Diameter: 15 cm.

The Wheel of Magic had three structures: the wheel, the middle rotating handles, and the lower crate portion. The wheel portion is used as a guide for the guidewire to be spooled around and had protruding handles on both sides to have easier access to rotate the wheel. The guidewire was spooled around the wheel within the concave lip and then placed into the lower crate. The crate for this design was different from the crate that is used for the other preliminary designs because it only fit one wheel per crate and had a ‘U’ shaped cut to account for the protruding handles on both sides.

A.4 Guidewire Hoop

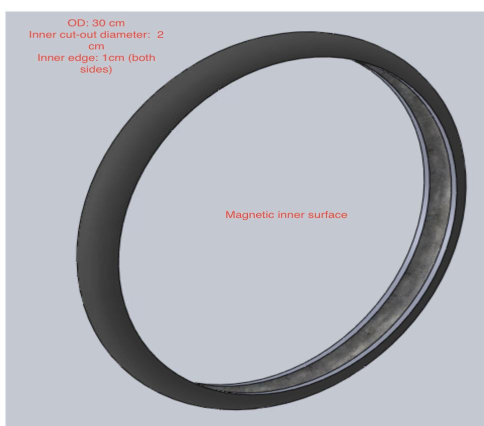


Figure 5. *Guidewire Hoop.*
Dimensions: Outer Diameter: 30cm. Inner Diameter: 29 cm.

The Guidewire Hoop had an internal concave lip that was magnetized. The internal concave lip utilized the radial force of the guidewire when coiled to contain the guidewire within the wheel.

A.4 Fall 2021 Design Matrix

The team moved forward with the Guidewire Hoop design.

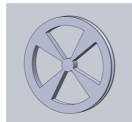
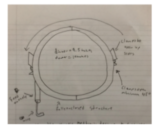
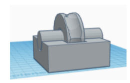
Design	 Magnetic wheel		 Clamped Wheel		 Wheel of Magic		 Guidewire Hoop	
Feasibility (30%)	4/5	24	3/5	18	4/5	24	5/5	30
Efficiency (25%)	3/5	15	4/5	20	2/5	10	5/5	25
Durability (20%)	3/5	12	3/5	12	3/5	12	4/5	16
Safety (10%)	5/5	10	5/5	10	5/5	10	5/5	10
Learning Curve (10%)	4/5	8	3/5	6	4/5	8	5/5	10
Cost (5%)	3/5	3	5/5	5	5/5	5	4/5	4
Total for each design:	**72**		**71**		**69**		**95**	

Table 1. Spring 2022 Design Matrix

B. Spring 2022

In the Spring of 2022, the team focused primarily on the design of the stand. Additionally, the team moved forward by testing 4 designs, all based off of a design provided by the client.

B.1 Proposed Wheel Designs

B.1.1 DYWheel

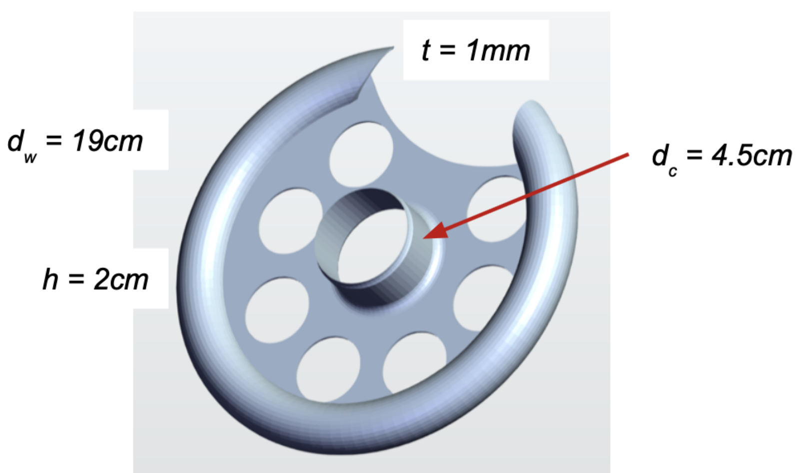


Figure 7. *DYWheel*

Dimensions: Outer Diameter (d_w): 19 cm. Chimney Diameter (d_c): 4.5 cm

The client provided the team with a preliminary wheel design shown in **Figure 7**. Various dimensions and basic characteristics of this wheel were changed and became their own individual prototypes. The wheel consisted of a deep inner cavity.

B.1.2 CutChimney

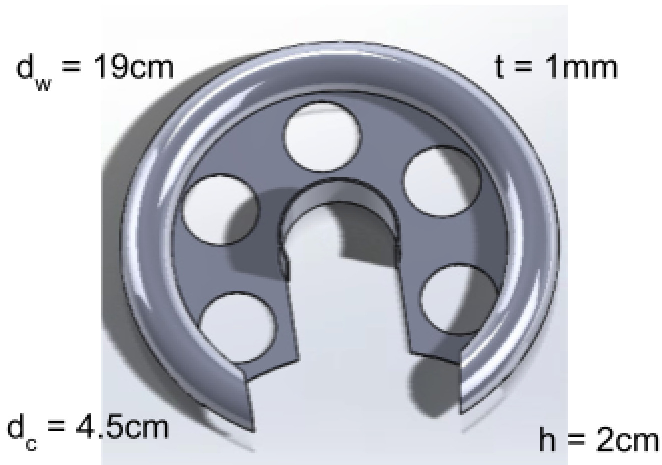


Figure 8. *CutChimney*
Dimensions: Outer Diameter (d_w): 19 cm. Chimney Diameter (d_c): 4.5 cm

CutChimney's inner chimney was semi-circular to allow it to slide off of the stand after the guidewire is unloaded. After unloading the guidewire, the wheel was able to be removed from any place on the stand.

B.1.3 CurveSpout

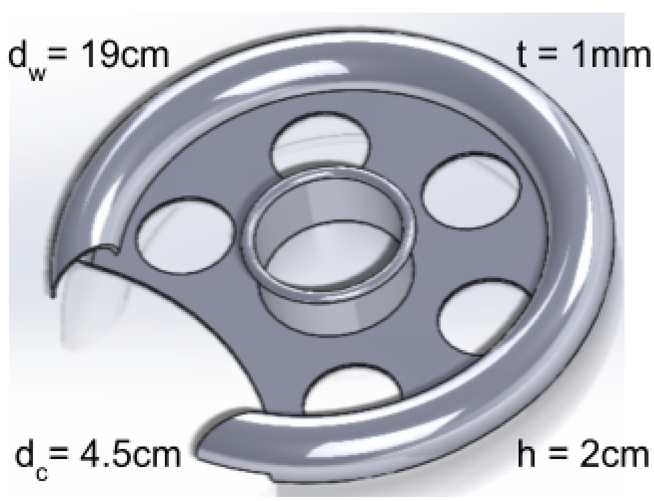


Figure 9. *CurveSpout*
Dimensions: Outer Diameter (d_w): 19 cm. Chimney Diameter (d_c): 4.5 cm

The CurveSpout design has an inner chimney that was curved inward. This modification was meant to ensure that when the wire was unloaded it did not slip up and past the inner chimney.

B.2 Proposed Stand Designs

B.2.1 DYStand

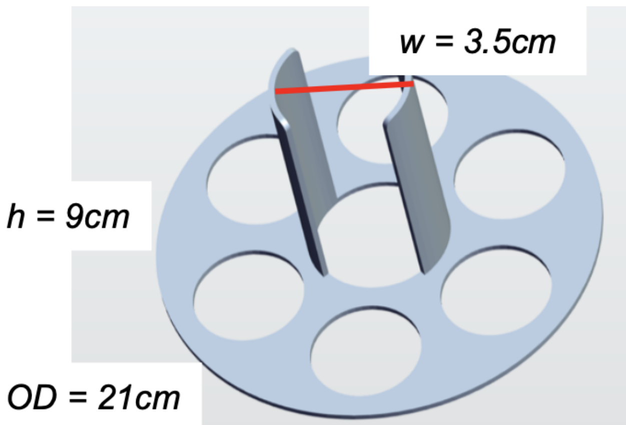


Figure 10. *DYStand.*
Dimensions: Outer Diameter (OD): 21 cm. Inner Diameter (w): 3.5 cm.

The DYStand **(Figure 10)** was 9 cm high and able to hold 3 wheels. The wheels are simply stacked on top of each other, with the inner support of the stand going through the wheel's chimney.

B.2.2 UHold

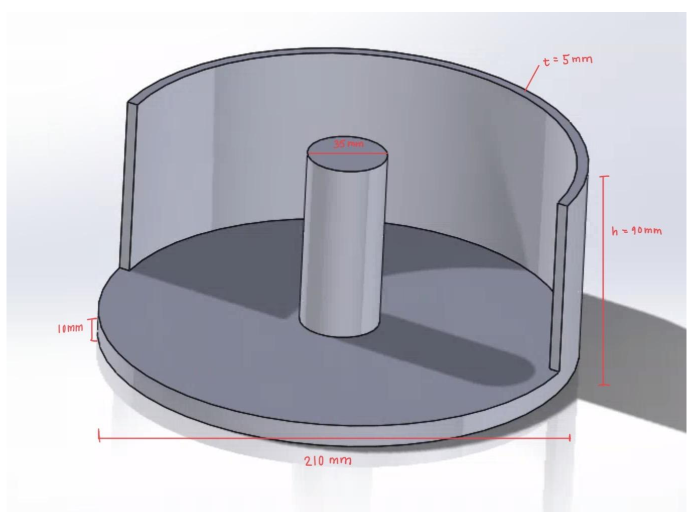


Figure 11: *UHold.*
Dimensions: Outer Diameter: 21 cm. Inner Diameter: 3.5 cm.

UHold had a backplate incorporated into the design to provide additional support to the wheel. This design had a 1 cm thick base plate where weights were added.

B.2.C Door

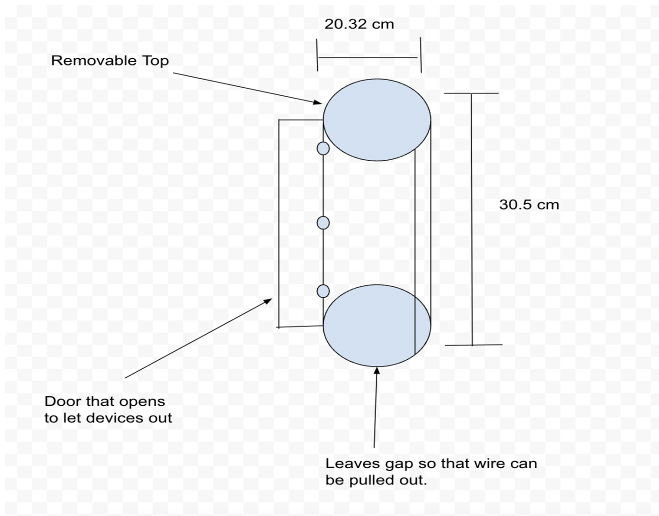


Figure 12. *Door.*
Dimensions: Outer Diameter: 20.32 cm.

The Door's additional height allowed for more wheels to be stacked inside. The top lid was detachable to allow for wheels to be placed through the top. The door design allowed for the wheels to be taken out in any order (not just top to bottom).

B.3 Spring 2022 Design Matrix

The team moved forward with the UHold design.

Endovascular Catheter Design Matrix

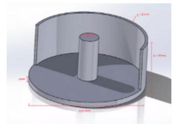
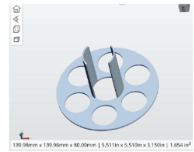
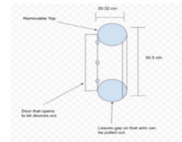
Design	 UHold		 DYStand		 Door	
Efficiency (30%)	5/5	30	5/5	30	2/5	12
Learning Curve (25%)	4/5	20	5/5	25	3/5	15
Compatibility (20%)	4/5	16	5/5	20	3/5	12
Durability (15%)	5/5	15	3/5	9	3/5	9
Safety (10%)	5/5	10	3/5	6	3/5	6
Total for each design:	**91**		**90**		**54**	

Table 2. Spring 2022 Stand Design Matrix

C. Fall 2022

In the Fall of 2022 the team focused on the wheel design to make it mass manufacturable from various manufacturing methods. However, it was found that injection molding would be the most feasible method to produce the wheel. The team moved forwarded testing various designs stemming from the original design provided by the client in ***Section B.1.1*** that were modified in the focus of being injection moldable.

C.1 Proposed Wheel Designs

C.1.1 XSHold

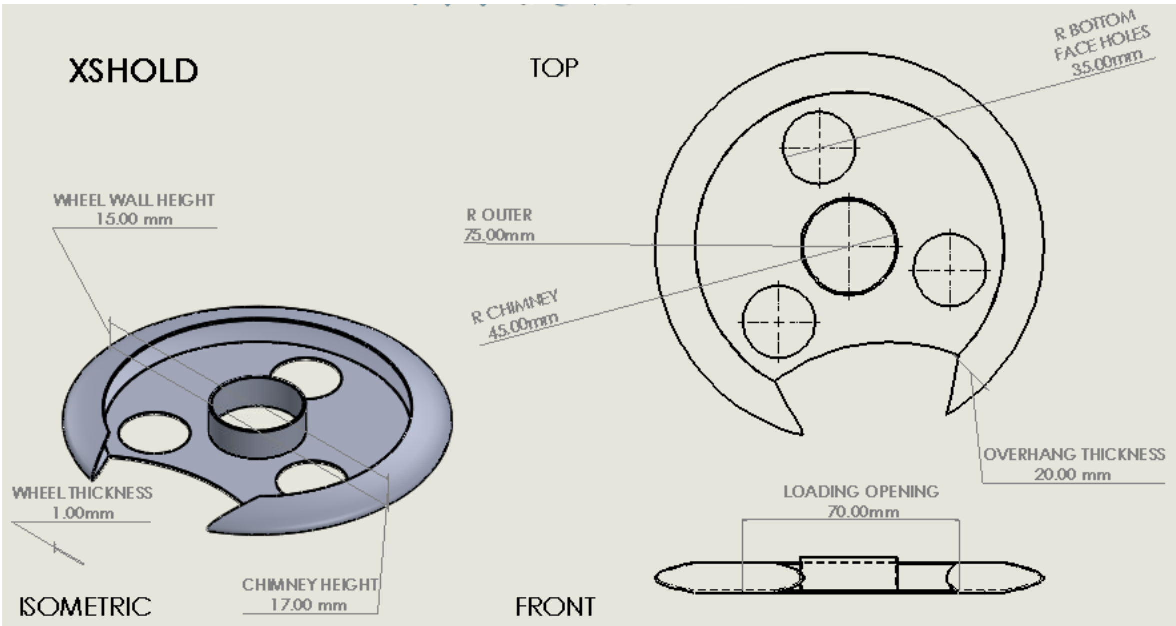


Figure 13. XSHold SolidWorks design.

The design variation seen in **Figure 13** allowed for a tighter hold of the guidewire as there is more force applied to the outer wall of the device. Less material was needed to build this wheel.

C.1.2 XtraHold

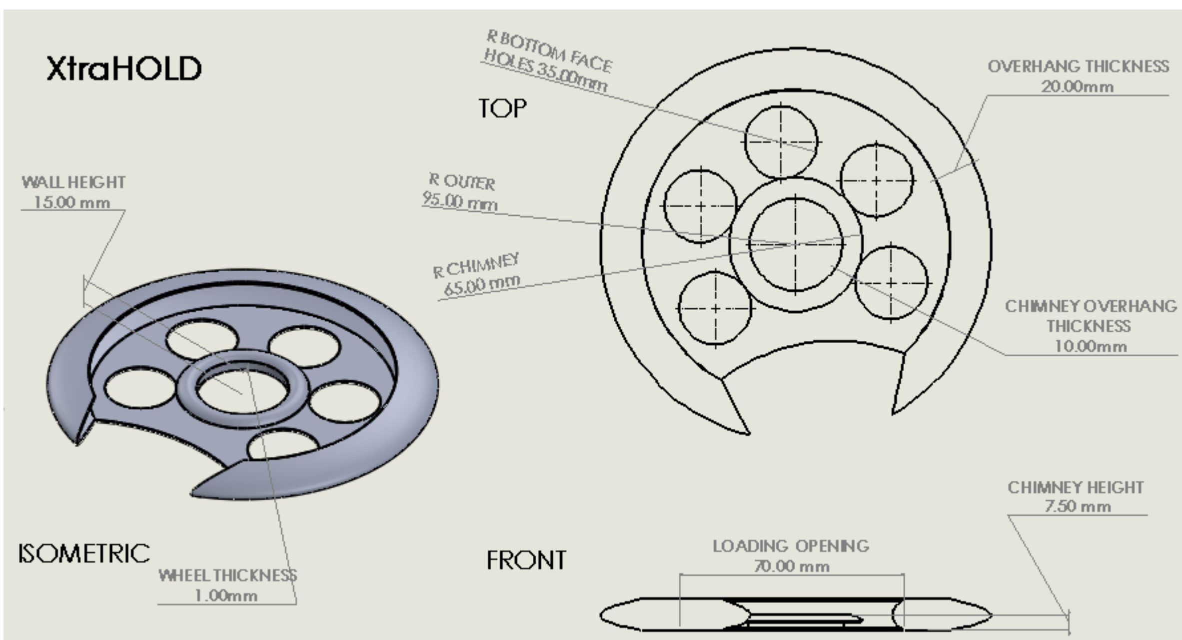


Figure 14. XtraHold SolidWorks design.

The design variation seen in **Figure 14** featured a shorter chimney for easier and more comfortable guidewire loading, and the overhang keeps the guidewire steady in place during guidewire removal.

C.1.3 LHold

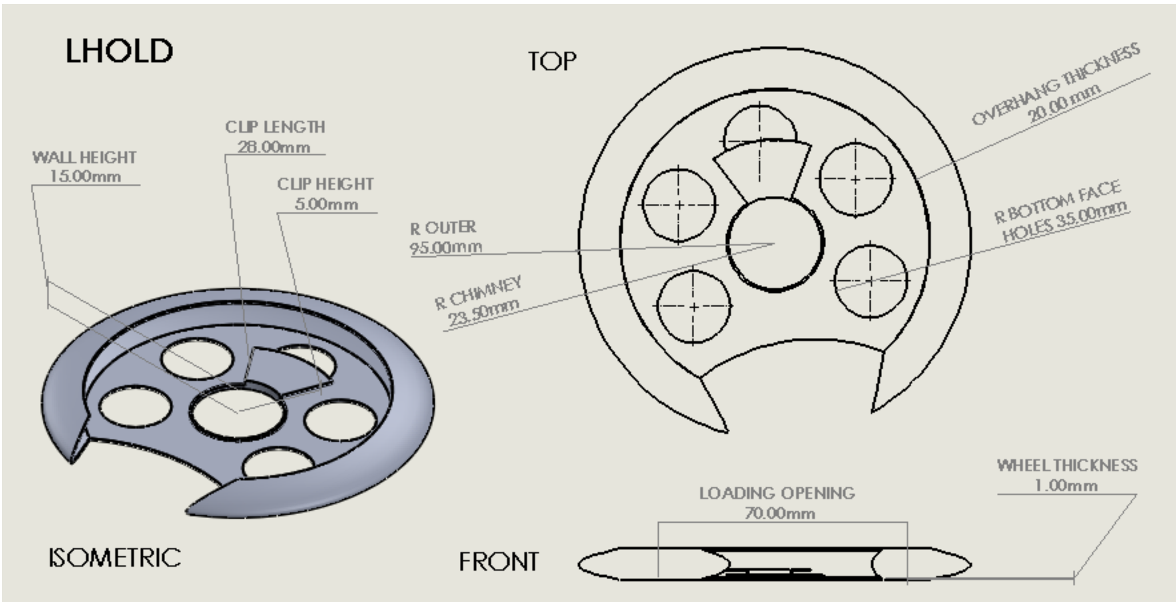


Figure 15. LHold SolidWorks design.

The design variation seen in **Figure 15** featured a overhanging clip piece in place of the cylindrical chimney utilized in DYWheel. Removing the chimney eliminates the obstruction that the chimney imposes on the user while loading the guidewire.

C.1.4 LGHold

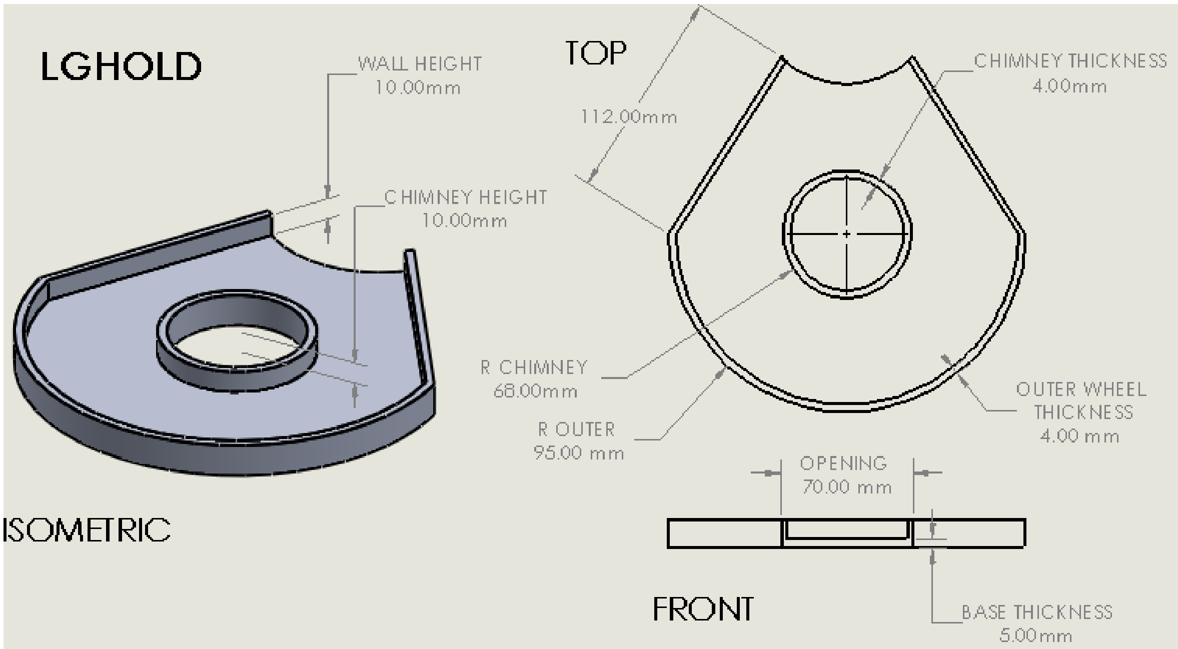


Figure 16. LGHold SolidWorks Drawing.

The design variation seen in **Figure 16** eliminated the overhang. This allowed the device to be injection moldable without any further modifications.

C.1.5 ADHold

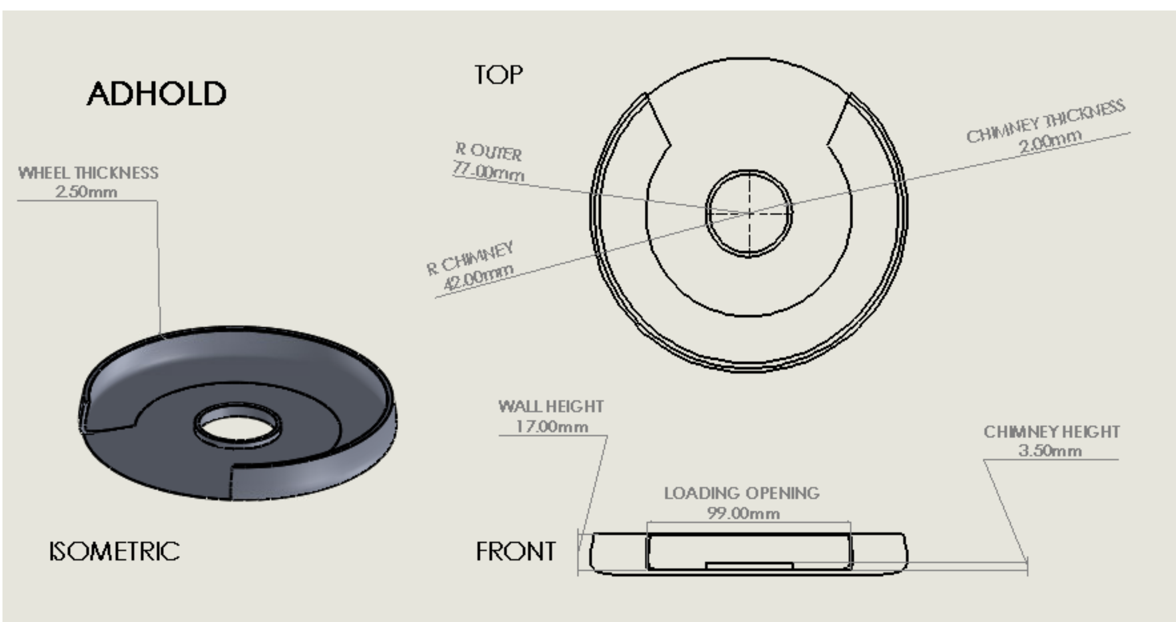


Figure 17. ADHold SolidWorks design.

The design variation seen in **Figure 17** was modeled to the geometry of a frisbee. This device had a slight curvature, which allowed the device to be injection molded.

C.1.6 TRHold

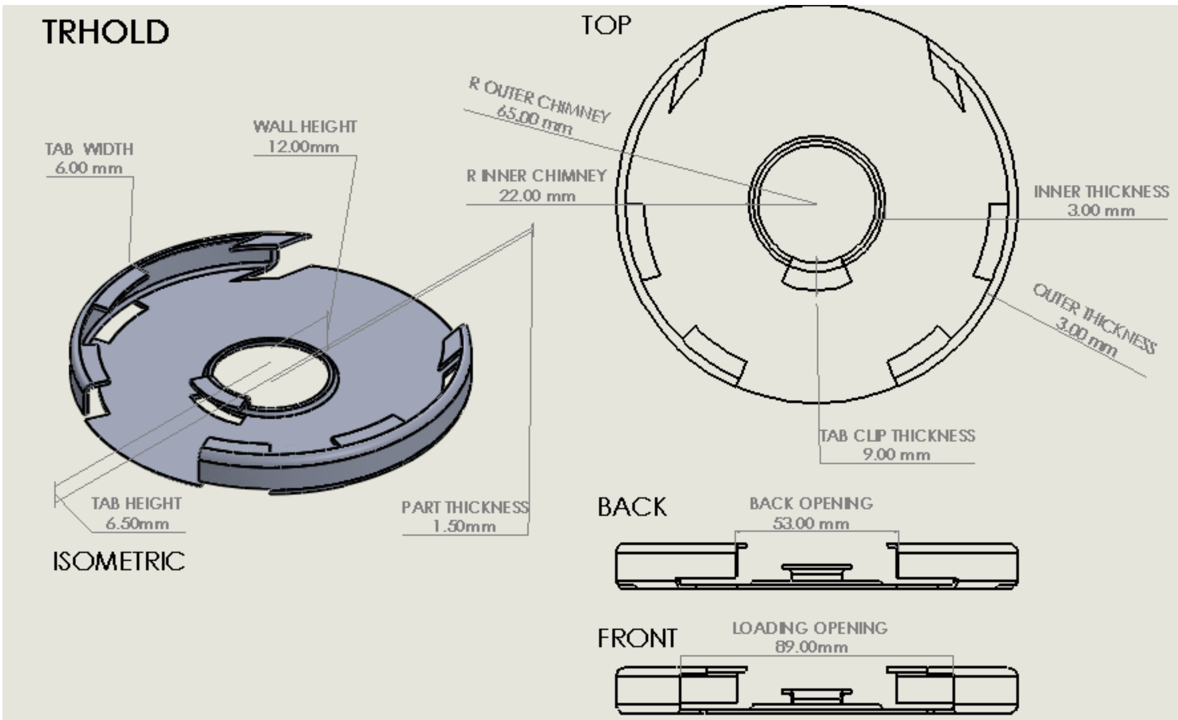


Figure 18. TRHold SolidWorks design.

The design variation seen in **Figure 18** attempted to eliminate overhangs that prevent the device from being injection molded. This device features cutouts below any tab-like extrusions in order to allow the device to be punched out of the injection mold.

C.2 Proposed Stand Design

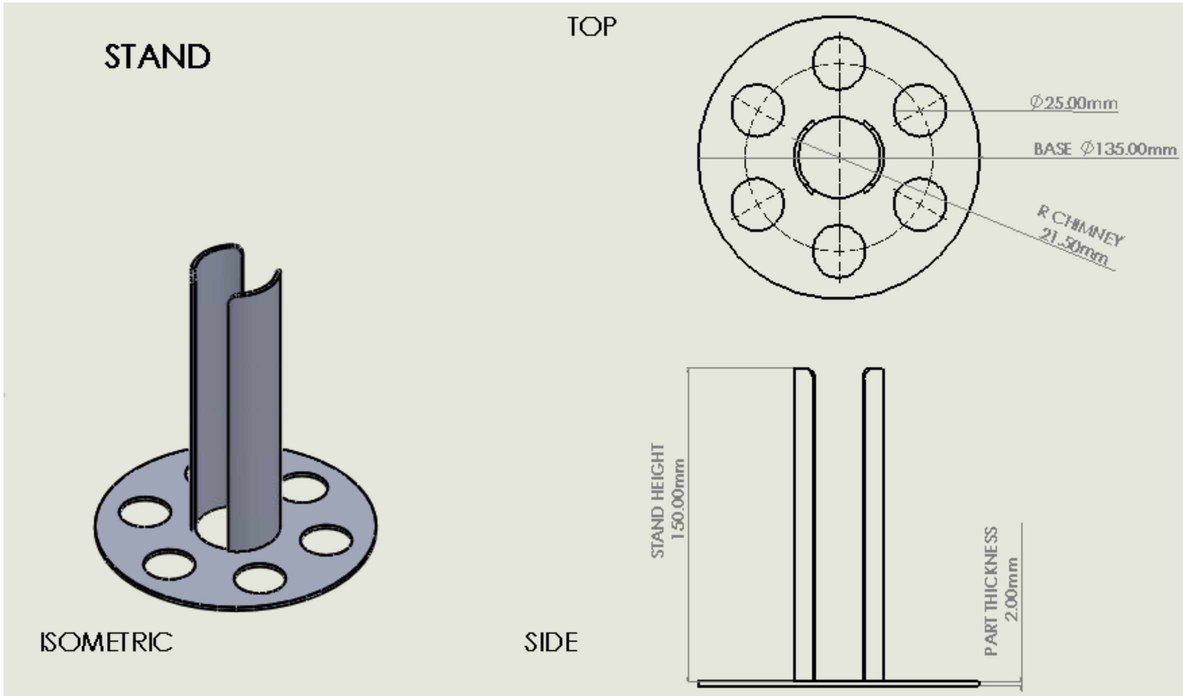
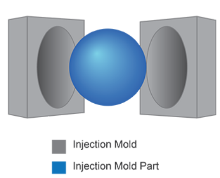
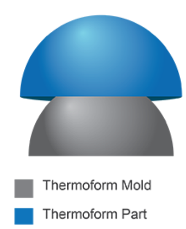


Figure 19. Stand SolidWorks design to hold guidewire organizers.

The stand design seen in **Figure 19** will be used in conjunction with the final wheel design. There was a long chimney in the center of the base plate to stack up to three guidewire wheels at one time.

C.3 Manufacturing Methods Matrix

In order to mass produce the final design, the final manufacturing process must be cost and time efficient. In **Table 3**, the team compared three different manufacturing processes: injection molding, 3D printing, and thermoforming.

Manufacturing Process		 **Injection Molding [6]**		 **3D Printing**		 **Thermoforming [6]**
Production Efficiency (25)	**5/5**	**25**	1/5	5	4/5	20
Ease of Manufacturing (20)	3/5	12	**5/5**	**20**	4/5	16

Cost Per Part (20)	**4/5**	**16**	2/5	8	3/5	12
Material Compatibility (15)	**5/5**	**15**	4/5	12	2/5	9
Lead time (10)	2/5	4	**5/5**	**10**	3/5	6
Accuracy (10)	**5/5**	**10**	2/5	4	2/5	4
Total	**82/ 100**	**82**	59/ 100	59	67/ 100	67

Table 3. Manufacturing Process Design Matrix. Individual criteria were graded on a scale of 1(Low) - 5(High), these scores were then multiplied by the predetermined weight of the criteria to calculate the weighted score. The highest scores for criteria are highlighted in yellow and total scores are out of 100.

D. Spring 2023

Throughout the Spring of 2023 the team is focusing on finalizing the wheel dimensions in order to make it injection moldable by eliminating the overhang of the outer edge of the wheel. After our testing results from Fall of 2022, the team is moving forward with the ADHold (**C.1.5**) and is modifying the wheel to incorporate the diameter of XSHold in **Figure C.1.1.**

D.1 Proposed Wheel Designs

D.1.1 FrissV1

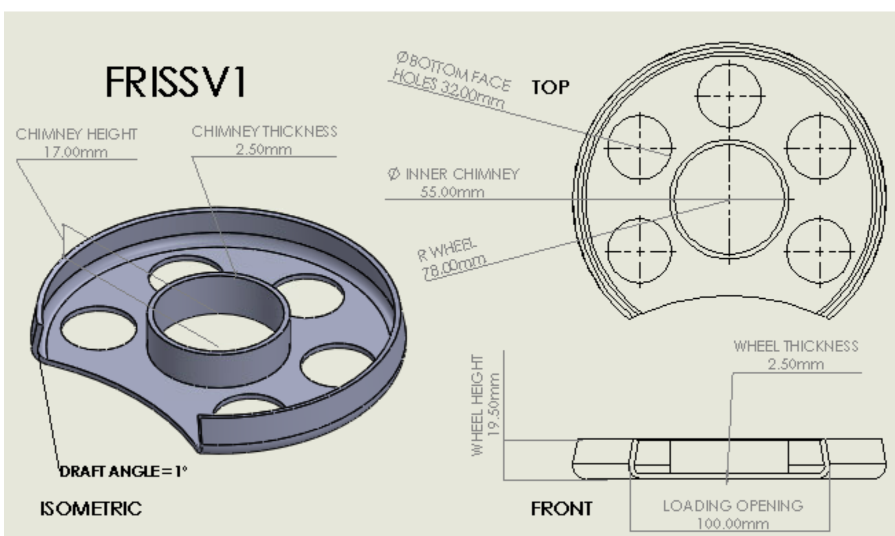


Figure 20. FrissV1

This design variation is identical to FrissV2, however, the top of the wheel where the guidewire is inserted and dispensed is cut down to aid in easier loading of the wheel.

D.1.2 FrissV2

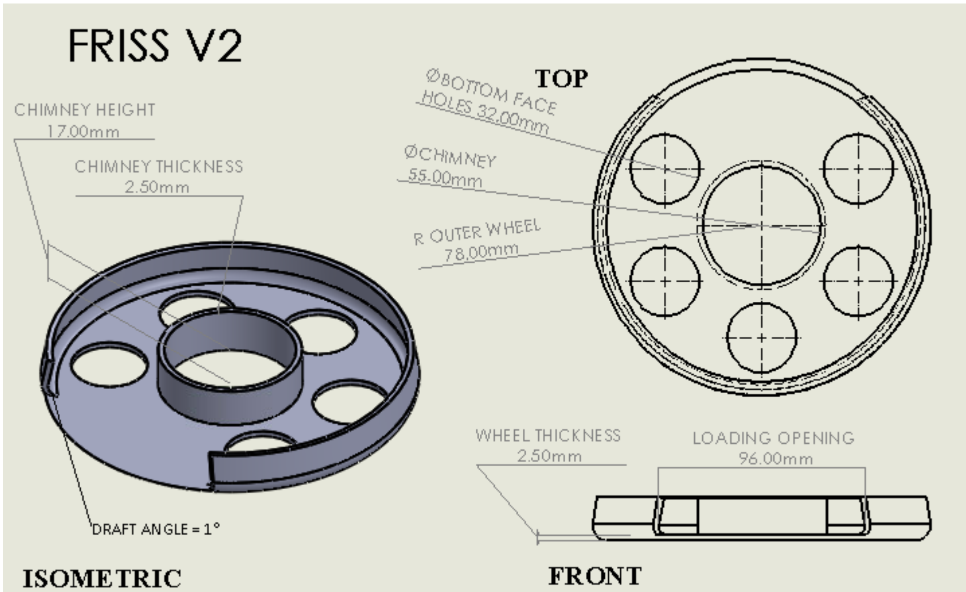


Figure 21. FrissV2

This design variation incorporates the holes for saline flow, chimney, and smaller diameter from the XSHold (**C.1.1**) into the ADHold (**C.1.5**). The wheel aims to be injection moldable by modifying the extreme overhang into a slight overhang.

D.1.3 DiscGolf

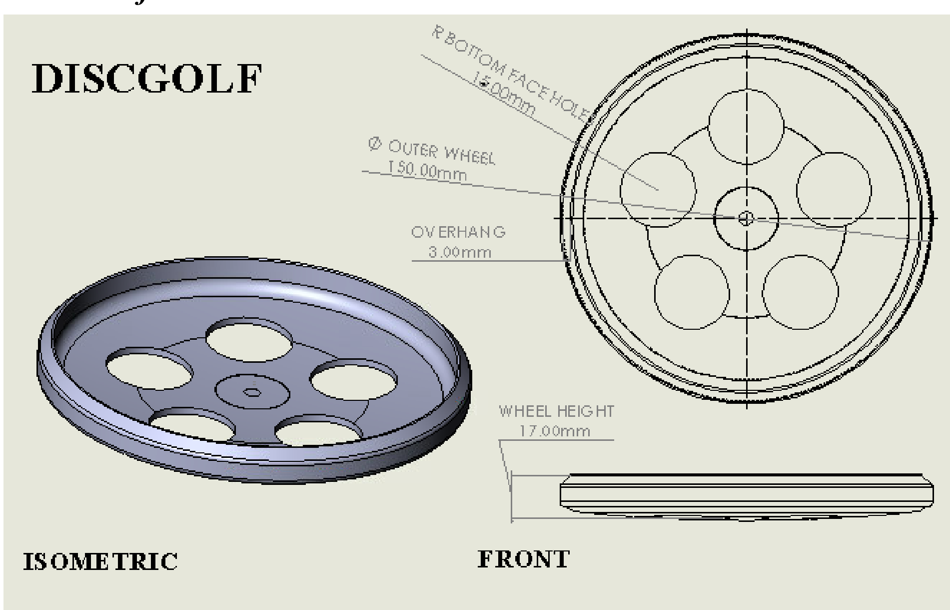


Figure 22. DiscGolf

This design variation was made from a CAD model of a discgolf frisbee. The holes for saline flow were added to the top surface and the diameter was changed to 150.00mm to match the target size of our wheel design.

D.2 Proposed Stand Design

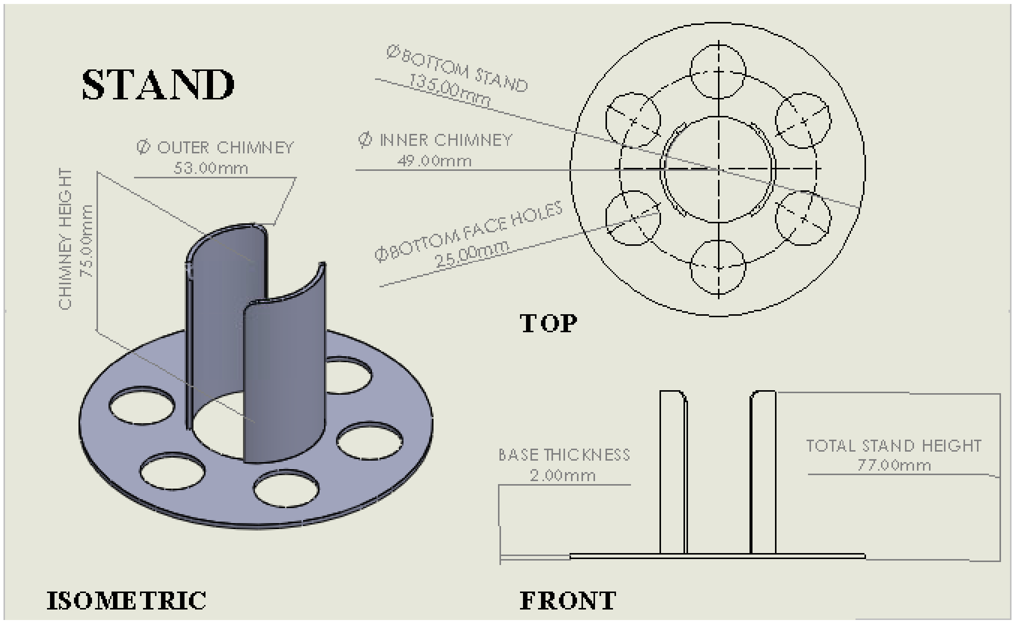


Figure 22. Stand 2023

The stand design was slightly modified from Fall of 2022 (**C.2**) by shortening the height of the stand and enlarging the diameter of the middle shaft to better secure the wheels.