High Throughput Quantitative Ex Vivo Murine Brain MRI Capsule

BME 200/300

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Abstract

Magnetic Resonance (MR) scanners are machines that are often used to produce high resolution images of organic tissue such as brain tissue. Dr. JP Yu uses MR-scanning in order to learn more about the human brain by conducting research on murine brain samples, and translating how his findings compare. The current techniques used to conduct this research are relatively crude, requiring extended time, and unnecessary expenses and risks. This process includes murine brains being inserted into modified syringes, and can take days to scan a large number of samples, not including post-processing time, as well as thousands of dollars per year on MRI scans. The client wishes to reduce the time spent loading samples and post-processing, and seeks an efficient and reproducible loading system that is air-tight, improves imaging quality and accuracy, and requires less resources. To do this, the team proposes a singular insert with built-in slots for brain samples, and is sealed with a stopper. In the future, the team will begin fabrication of the template, and perform mechanical, leak, and imaging testing.

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I. Introduction

A. Problem Statement

Dr. JP Yu's lab currently takes Magnetic Resonance (MR) scans of ex-vivo rat and mouse brains by loading the samples into modified syringes. This method of imaging involves individually loading and processing each brain separately which is inefficient and expensive. The team plans to streamline this process by working with the client to create an MR-compatible, 3D loading system for rat and mouse brains which will hold the samples in the correct alignment for a scan and be able to fit more samples per scan than their current procedure permits. Relative to the lab's current system, the capsules will be more efficient, both in terms of cost as well as ease of use. The design must be airtight and resistant to chemicals used during the process. This design must be reusable, reproducible, and it must establish a standardized, scientific procedure.

B. Motivation

Over 5 million people around the United States are estimated to have autism spectrum disorder (ASD) [6]. Dr. Yu's lab studies neurocognitive, neuropsychiatric, and neurodegenerative diseases such as ASD, which often goes hand in hand with illnesses such as schizophrenia and strokes. In order to do this, the lab tracks the biomarkers across rodent brains with these various neurodegenerative diseases [4]. When these biomarkers are observed, they can be connected to genes, environments, and gene-environment interactions in order to develop diagnosis and treatment. In Dr. Yu's lab, as well as many other labs across the country, the approaches to this are expensive, laborious, and cannot be reproduced. Thus, aiding the efficiency of his work will indirectly help the cause for learning more about not only psychiatric illnesses, but the brain in general. Researchers specializing in neurodegenerative diseases run into similar problems of needing to find an efficient way to scan animal brains. One lab even makes 3D models of each individual brain in order to create the perfect template [5]. When non-standardized methods are used, lab processes lack efficiency in regards to time, money, and resources. If these imaging techniques can be better standardized, it will be much easier to compare and contrast results from different studies.

C. Existing Devices/Current Methods

3D Printed Brain Cradle

While there is no substantial market of competing devices for ex-vivo rodent brain holders for an MRI coil, numerous laboratories that perform MR imaging of ex-vivo brains have reported their methods within research papers. One such research paper reported their solution to

holding ex-vivo marmoset brains in place while putting them through an MRI. First, they took an initial MRI of a specific marmoset brain by submerging the brain in an MR-compatible fluid (Fomblin) in a 50 mL syringe and padding the brain with gauze. This image was used to create a 3D printed brain cradle (Figure 1) which held the same marmoset brain exactly in place inside a 50 mL syringe for a second MRI [5]. While this method is ideal for creating a perfectly-dimensioned brain holder, it wastes time and money because it requires an additional MRI for dimensioning and it is specified to the exact dimensions of an individual brain, therefore, it is not reusable.

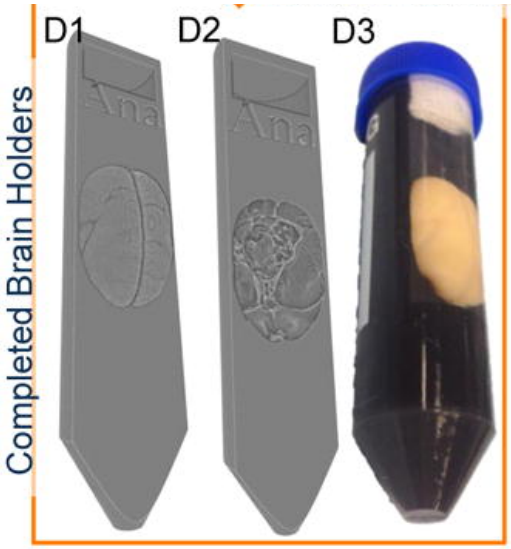

Figure 1. Image of 3D-printed brain cradle design. [5]

Modified Syringes

Another important existing design for imaging mouse and rat brains is the system currently in place at Dr. Yu's lab, which involves holding brains in modified syringes (Figures 2 and 3). First, the ends of the syringes are cut so that they do not take up excess space in the MRI coil; 35 mL syringes are used for the rat brains and 10 mL syringes are used for the mouse brains. The brain is placed in the opening of the syringe, then, a small rod is used to gently push the brain to the back end of the syringe. Next, an inert fluid necessary for ex-vivo imaging, Fluorinert, is poured into the syringe to fully submerge the brain. The syringe plunger is then inserted into the tube to seal it and expunge any air bubbles out of the syringe opening. When the syringe stopper is pushed up against the brain, the opening of the syringe is sealed with parafilm or a screw on cap to prevent Fluorinert from leaking out of the tube. Once the brains are individually loaded into separate syringes, the centerline of the brain is marked on the outside of the syringe with a marker and the syringes are bundled into stacks, allowing them to scan 6 mouse brains at a time or 3 rat brains at a time.

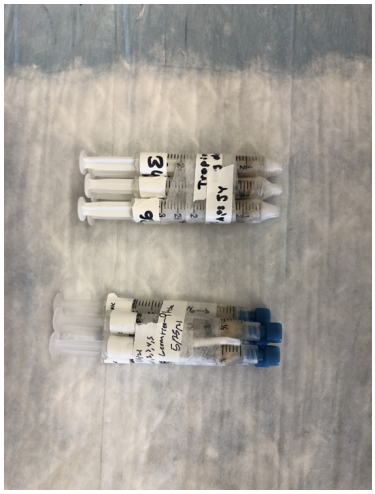

Figure 2. Bundles of rat and mouse brains in modified syringes provided by Nick Stowe and Ajay Singh.

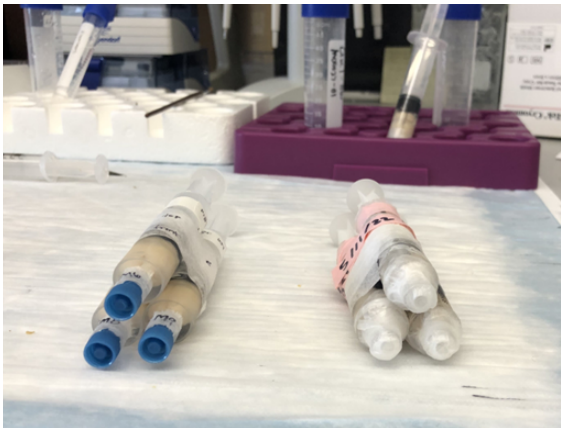

Figure 3. Front view of the modified syringes.

Computational Post-Processing

Dr. Yu's lab currently uses software written by a former employee of the lab to separate the multiple samples scanned at a time in the MRI. This software allows the lab to reorient the individual samples after they are scanned so that they exhibit a consistent orientation with each other. Other versions of this software that allows users to manipulate and rotate MRI images can be found online, such as Reorient [7] and NiftyReg [2]. While this software allows the lab to adjust the orientation of the brain samples, it does not solve the problem of how to load the brains into the MRI without damaging them, while also minimizing the use of Fluorinert, a very expensive fluid. Computational post-processing is an effective tool to reorient the brains if they are misaligned, but it takes a significant amount of time. A more streamlined approach to scanning rat and mouse brains is to maintain a consistent orientation amongst all samples as they are scanned in order to minimize post-processing time.

II. Background

A. Biological Research

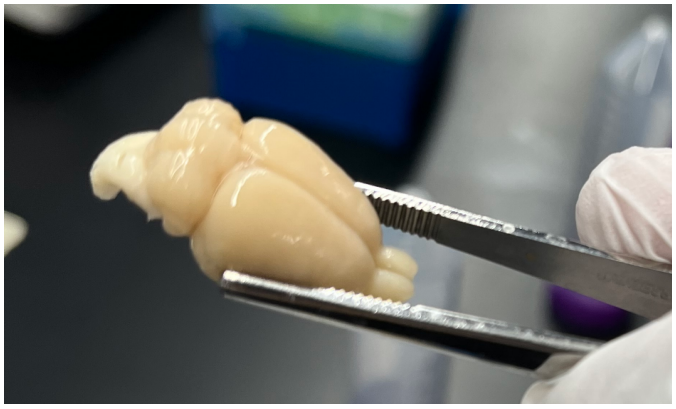

Figure 4. Rat brain donated by client for measurements and testing.

Mouse brains have a similar structure to humans with a cerebral cortex, brain stem, and olfactory bulb. However these components differ from humans in size proportionally, with the cerebral cortex and olfactory bulb being much smaller and larger respectively, in proportion to the rest of the brain. Mouse brains also have significantly fewer and smaller gyri and sulci than a human brain, which reduces neuron interactions and higher level thinking. Nonetheless, even though the human and mouse brain have many notable differences, they are still similar enough to find incredible value in studying them and comparing them to the brains of humans [8].

B. Material Research

MRIs are made of several large, powered magnets that surround organic material. The MRI's strong magnetic field causes the polar and magnetic water molecules in the organic material to be realigned, which produces faint signals. These signals allow for cross sectional imaging. These cross sectional images are 3D topographical images that are able to image deep in tissue that would be nearly impossible to obtain through other means. [9]

C. Client information

Dr. JP Yu is an Assistant Professor in the Department of Radiology at the University of Wisconsin-Madison and the Neuroradiology Fellowship Program Director. Currently, Dr. Yu's laboratory in the Wisconsin Institute for Medical Research performs MRIs of rat and mouse brains to examine the impact of genes and the environment on quantitative brain microstructure [3].

D. Design Specifications

This design must fit more than 6 mouse brains per scan and more than 3 rat brains per scan. It must maintain a consistent orientation of the brain, where the brain's midline is parallel to the center axis of the MRI bore cylinder (Figure 5), while having all the brains in the same cross-sectional plane (Figure 6). The materials of the design must be MR-compatible and resistant to chemicals used in the lab, and the structure of the design cannot damage the brains during loading, unloading, or scanning. The system must be reusable and must create a leak-proof seal so that the brains can be fully submerged in Fluorinert without the risk of leaks, while also minimizing air bubbles, which would create image artifacts. Finally, the design must establish a standardized, scientific procedure. (*See Appendix A*)

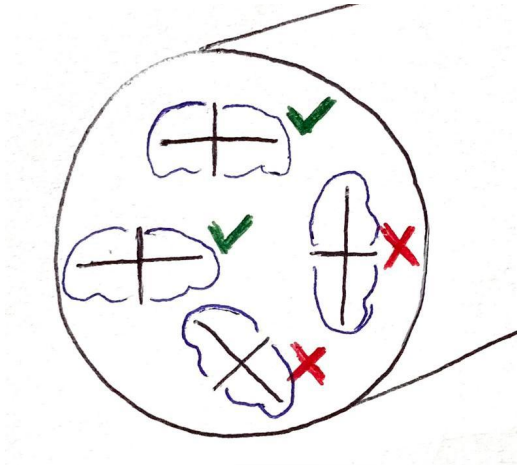

Figure 5. Brain's midline is parallel with the center axis of the MRI bore cylinder.

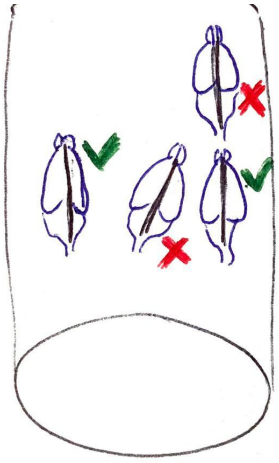

Figure 6. All the brains in the same cross-sectional plane.

III. Preliminary Designs

A. Cylinder Insert Design

The cylinder insert design is a combination of 3D-printed circular capsules and a 3D-printed complimentary insert. The capsules would hold the brain and have a fin to go in between the hemispheres of the brain down the longitudinal fissure (Figures 7 and 8). This would secure the orientation of the brain. The individual capsules would be filled with Fluorinert after the brains are inserted, and sealed with a cap that has a rubber O-ring to prevent leaks. The capsules would then fit into a larger insert with more notches that would hold the capsules and prevent the capsules from rotating once inserted (Figure 9). This insert would be the size of the MRI bore.

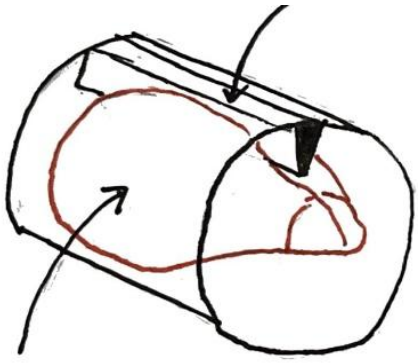

Figure 7. Visual representation of the function of the fin.

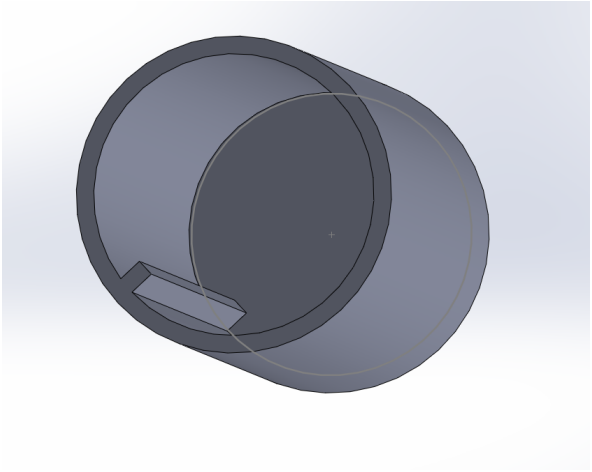

Figure 8. Individual brain capsule.

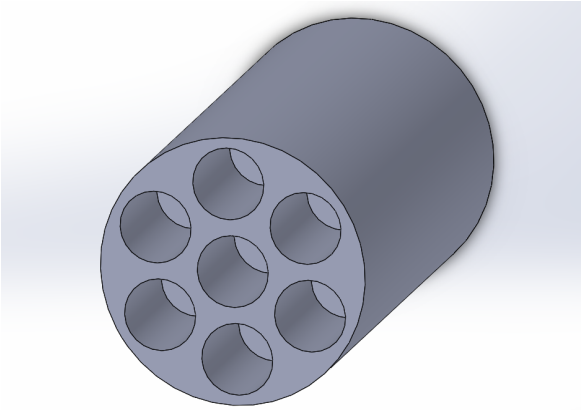

Figure 9. Insert to hold capsules.

B. Honeycomb Design

The Honeycomb design is a honeycomb-like lattice of 3D-printed, separable hexagonal capsules which have a locking mechanism on the outside (Figure 10). The main inspiration for this design was the guaranteed orientation of the brains: the hexagonal shape would secure the orientation of the brain within the capsule. The interlocking mechanism would secure the orientation of the capsule as a whole, and allow for a modular design that could be changed for any size of MR-scanner.

One additional idea was to have a drawer that slides in and out of the hexagonal form. This idea was for ease of loading and unloading.

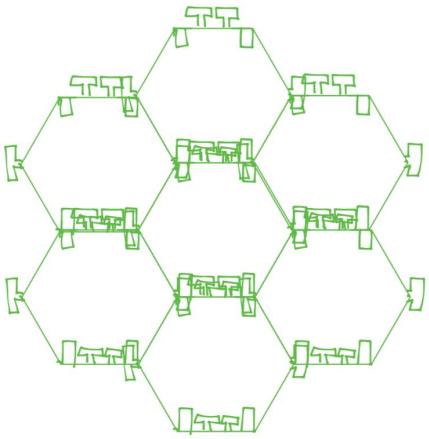

Figure 10. Honeycomb lattice: illustration of interlocking mechanism.

C. Integrated Insert

The integrated insert is a 3D-printed cylinder that perfectly fits the bore of the MRI coil. The holes for the samples are integrated in this plastic cylinder. Measurements used for this design were the averages of the sizes of the rat brains from the client-donated samples plus their standard deviation plus any other factors (*Table V, See Appendix)*. For example, the depth of the hole was determined as follows: the average length (28.75mm) + standard deviation (0.785mm) + 5mm for the stopper to enter. Ovular shapes were drawn with a minimum wall thickness of 0.8mm which was found to be the absolute minimum thickness for 3D printed nylon, the material of choice [10]. These outlines were then copied and pasted and aligned by eye.

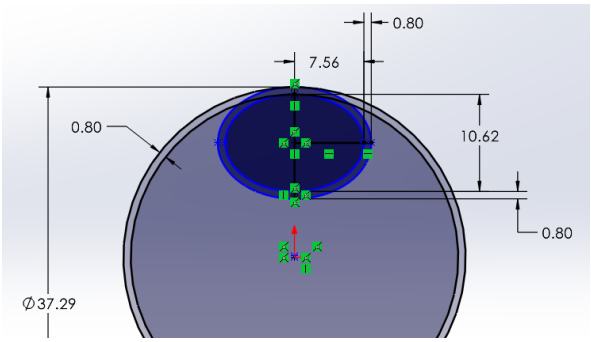

Figure 11. Overall diameter of the insert and dimensions used for rat brains.

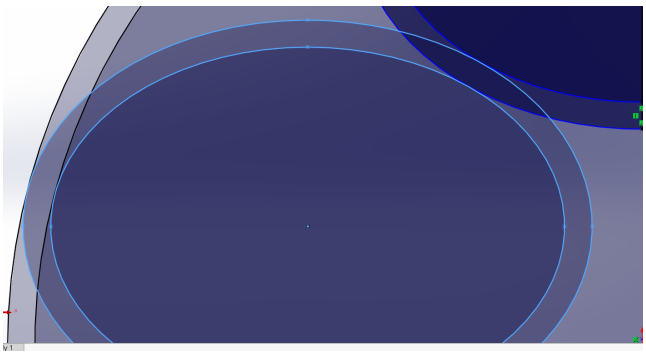

Figure 12. Aligning of the cells by eye and drag dropping with mouse, not using computer software.

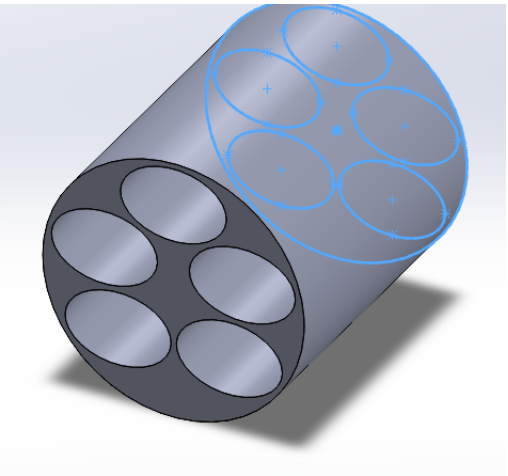

Figure 13. Preliminary "empirically based" design which would hold 5 brains.

The orientation is guaranteed in the Integrated Insert because the oval would fit the brain width and height of the brains stopping rotation around the axis of the MRI bore. There is also the added idea of implementing a ceiling ramp that would press against the front of the brain on its cerebrum with space for the olfactory bulb to fit under this ramp. The holes would then be sealed by individual stoppers or corks made of rubber. The holes would be filled to the brim and

when the stopper is inserted will cause the fluorinert to overflow. This overflowing methodology is meant to guarantee that no water bubbles are left in the hole.

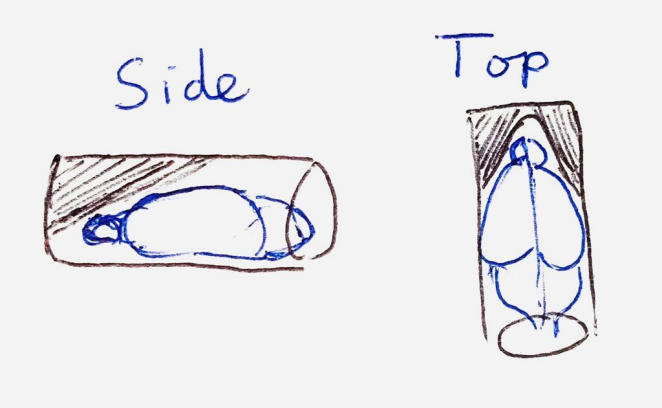

Figure 14. Ramp conceptual visualization.

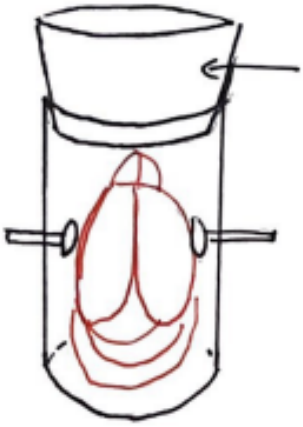

Figure 15. Stopper concept for sealing the holes.

Fabrication and Material Considerations for Design

Because the main focus of the designs was on the packing efficiency and orientation, not as much energy was spent discovering different ways of fabrication and different materials. 3D printing and nylon were chosen for all of the designs. 3D printing was chosen because of the detail of the designs and the precision would not be possible for the skill level in machining. Nylon was chosen because of its mechanical properties (*see Fabrication/ Development Process*).

IV. Preliminary Design Evaluation

A. Design Matrix

		points out of 5	adjusted weight				
Design Matrix		Honeycomb:		Cylinder Insert Design		Integrated Insert	
Criteria	**Weight**						
Packing and Unpacking Efficiency	30	5	30	4	24	5	30
Standardization and Consistency of Orientation	20	5	20	4	16	4	16
Airtight	15	3	9	5	15	3	9
Ease of Use	15	4	12	3	9	3	9
Durability	10	3	6	4	8	5	10
Time and Cost of Manufacturing	5	3	3	2	2	5	5
Safety	5	5	5	5	5	4	4
Total	**100**	80		79		83	

Figure 16 . Design matrix of three preliminary designs.

When evaluating the three proposed designs, the two most heavily weighted criteria were packing efficiency and consistency of orientation. The integrated insert and the honeycomb design scored well on packing efficiency because they both minimize the amount of plastic used in between brains. The honeycomb design scored highest in the consistency of orientation category because its hexagonal shape would prevent the brain from freely rotating. The airtight category accounts for both the degree to which the design would resist leaks as well as minimize air bubbles; the cylinder insert design won in this category because its individual capsule and its cylindrical shape would allow for efficient sealing. Ease of use was another criterion used to evaluate the designs; the honeycomb design won because it has fewer components than the cylinder design and it is stackable, which allows for easy assembly. All the designs scored the same in safety because they would all be made of 3D-printed plastic, which is MR-safe. The integrated insert design scored the highest overall.

B. Proposed Final Design:

Based on the criteria assigned and the scores given for each design, the final proposed design is the integrated insert. The team plans to make a version of the integrated insert for mouse brains and a separate version of the integrated insert for rat brains. This design incorporates the most important elements while also being simple to use. It also allows for the largest number of brains to be scanned at a time, which provides maximum efficiency.

V. Fabrication/Development Process

A. Materials:

The material used for the design will be Nylon. This material fits the criteria specified in the PDS (*See Appendix A)*. Nylon is both non-magnetic and non-polar, so it will not be reactive in an MRI. This, therefore, poses no safety concerns. It is non-biodegradable, so there would be minimal concern for the longevity of the product. Additionally, nylon is available to use in a 3D printer, which will be the primary mode of fabrication (*See Appendix B*).

B. Methods

The design will be fabricated by first 3D printing the insert using nylon material leaving 0.8mm in between each of the compartments for the brains. Each hole will have a height of 10.62mm. Finally a sealing method will be added such as a traditional lid that will snap into place, attached to the bottom. The lid will act as a stopper and will share the same radius as the insert.

C. Final Prototype

The team has not yet created a final prototype. Plans are currently being made to create this prototype in reference to the previous image (See Integrated Insert).

D. Testing

Material testing

One form of testing, prior to the fabrication of the product, would be mechanical testing of the material. The methodology would be as follows: 3D print a nylon cylinder (filled in of known height) and use the MTS machines to find the Young's Modulus. Then perform a mechanics analysis of the preliminary design and discover if the Young's Modulus can withstand the predicted stresses of the usage. Mechanical testing will consist of repeating manually the functionalities of the product. A more detailed protocol will be produced in the near future.

Leak-resistance testing

The PDS specifies that the prototype must be completely leak-proof when sealed because the inserts will be filled with the chemical, Fluoinert, and chemicals leaking out of the prototype not only create an inconvenience for the user, but pose a hazard as the Fluorinert could leak into the MRI and damage the machine. In order to test the degree to which the prototype is resistant to leaks, the team will fill all holes of the integrated insert with water and secure the cap onto the holes. The person performing this test will then dry the outside of the prototype with a cloth, as some water will spill when the cap is secured. Then, the team will place the prototype upside down (cap facing down) for 2 hours, qualitatively checking for leaks every 20 minutes. Updates will be recorded in *Table II (see Appendix C)*. Then, the user will shake the device vigorously for 1 minute and examine if any water leaks out from under the cap after shaking, recording observations in *Table II.* If no leaks are observed from these tests, the design will be considered sufficiently leak-proof.

Qualitative specimen damage testing

As outlined in the PDS, this prototype must not damage the rat or mouse brains during the loading, unloading, or scanning process. To test whether this prototype does or does not damage the rodent brains, the team will use the following procedure. First, one of the mouse brains given to this team by Dr. Yu's lab will be photographed from 4 different angles: the top, the bottom, and both sides. Then, the brains will be carefully loaded in the prototype, the capsules will be filled with water or saline, and then the cap will be secured. The entire prototype will then be shaken with moderate strength, so as to simulate real-world conditions of moving the brain-filled prototype from room to room. After 2 minutes of moving the prototype around and shaking it, the brain will be manually unloaded from its capsule and rephotographed from the same 4 angles. The tester will then use the initial 4 photographs to qualitatively analyze whether any damage was done to the brain; they will then document observations in *Table III (see Appendix C*). Damage to the brain includes missing pieces, such a part or all of the olfactory bulb, indentations on the outside of the brain, or parts of the brain deformed or bent into a new shape. This test will be repeated two more times with different mouse brains and three more times with rat brains. If no damage is present after these tests, the prototype will be considered sufficiently safe for the lab. If damage *does* exist, images of the brain before and after the test will be sent to Nick Stowe and Ajay Singh, in order to determine whether the damage is significant enough to warrant changes to the prototype. If changes are made to the prototype, these tests will be performed again.

Image quality testing

Image quality testing will test for any image distortions or artifacts present in an MRI scan with the prototype as well as any changes in orientation of the brains. One of the specifications in the PDS is that air bubbles in the Fluorinert must be minimized because they can cause image artifacts [1]. The PDS also states that the brains must be held in a consistent alignment with each other throughout the scanning process, with a tolerance of 2 degrees. In order to test for these factors, the prototype will be given to Dr. Yu's lab to do a testing scan. One of the team members will show a lab member how to load and unload the brains from the prototype, and they will help them load the prototype for both rat and mouse brains. Nick Stowe and Ajay Singh have informed the team that they will need at least one week to run a scan of the prototype and get the imaging results. Once the test scan is completed, one of the team members will visit the lab and view the results with either Nick or Ajay to inspect for image distortions, and to determine to what extent the brains had to be rotated using their software to align all the samples with each other. The degree of rotation necessary for each brain will be recorded in *Table IV (See Appendix C)*. If the average rotation necessary in post-processing is less than 2 degrees, the prototype will have met the specifications for orientation consistency. Any image artifacts or distortions will be documented in *Table IV*. If image artifacts are not present or negligible (according to either Nick or Ajay), the prototype will be deemed sufficient in facilitating a high-quality image. Due to time and monetary constraints, this test cannot be repeated unless Nick and Ajay specifically request to do so.

VI. Results

Because a final prototype has not been fabricated, no tests have been conducted thus far.

VII. Discussion

The space of the MRI bore is very small, less than 4 centimeters in diameter. From the integrated designs and accompanying calculations, the only way the team could increase the packing efficiency from 3 to 5 for rat brains is if the 3D printed plastic is strong enough with only a thickness of 0.8mm. The implication is that, unless this is the case, the team will only be able to fit exactly 4 rat brains no matter which design the team uses, meaning that the design should be reevaluated and should cater more to the less significant specifications that the client asked for.

If this is the case, it is likely that the design for the rat brains will differ from preliminary design of the integrated insert. However, this does not mean that the design and product for the mice brains cannot utilize or adhere more closely to the planned integrated insert.

If the prototype fails to be leak-proof, the team must reconsider the lid mechanism. There is a possibility the team will need to add material incorporated on the edges of the openings, or maybe the team would need to redefine the dimensions.

VIII. Conclusions

Dr. JP Yu's lab needs the team to streamline the process for loading and unloading the brains into the coil by controlling for the proper orientation and fitting more brains. The final design is an integrated insert where the brains are inserted into holes on one large insert covered by one large lid.

The team expects the product to perform well overall with greater packing efficiency, being able to store more brains per scan, and being able to retrieve fluorinert, saving the lab potentially thousands of dollars. The team also expects the design to save Nick and Ajay time loading and unloading the brains from the syringes, and time in post-processing in order to get the correct alignment.

After testing, the team expects to find that overall the design worked well. The integrated insert design should be a massive improvement from what Nick and Ajay were using to load the brains before, with the design being able to load more brains as well as having a greater ease of use, reducing the amount of air bubbles, and keeping the brains better oriented. However, the team expects that one area that may not work as expected is keeping the brain oriented properly within 2 degrees. This is because the method of keeping the brains oriented may not allow for that strict of a tolerance.

Currently, the preliminary designs have been restricted to rat brains for simplicity. Since the team has a direction for the overall design, the team can now resize the design for the mice brains and have a very similar positive result in terms of packing efficiency.

Then the team can fabricate a prototype. This involves having calculated CAD drawings that are suitable and accurate for 3D printing.

IX. References

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X. Appendix

A. PDS

The Product Design Specification (PDS)

High Throughput Quantitative Ex Vivo Murine Brain MRI Capsule

Client: Dr. JP Yu, Radiology

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Team:

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Function

Dr. JP Yu's lab currently takes Magnetic Resonance (MR) scans of murine brains by loading the samples into modified syringes. This method of imaging involves individually loading and processing each model separately which is inefficient and expensive.

Our team plans to streamline the process by working with the client to create MR-compatible 3D loading capsules for murine brains which will hold the samples in the correct alignment for a scan and be able to fit more samples per scan than their current procedure permits. The capsules will be more efficient, both in terms of cost as well as research throughput. It will allow for more reproducible scientific methodology, it will be reusable, and the design will ensure the capsule is airtight and resistant to chemicals used during the process.

Client requirements

High Priority Requirements (Highlighted by client as most important)

1. **Packing efficiency**

Must be able to fit more than 3 rat brains and more than 6 mice brains per MRI scan. These numbers are based on the amount that they are currently able using their current methodology. Each MRI scan takes 24 hours and costs $500, which highlights the importance and value of this requirement. It should be noted

that only once in the last 5 years was a brain rescanned due to poor quality of image, therefore all the time is spent during post processing to adjust and fix any problems with the scan.

2. **Orientation of murine brains**

Must have the brain's midline parallel with the center axis of the MRI bore cylinder, and all brains must be in the same plane (plane being perpendicular to the axis). At the moment, the client loads the brains into syringes (cylindrical) and the midlines are marked with a pen on the outside of the syringe. Then directly before scanning, 3 syringes are taped together with the midlines oriented in the same direction based on the marking on the outside of the syringe. However, because the brains do not fit the syringes, they can twist or turn within the syringe and the midlines become misaligned when transporting the brains to the MRI from the lab. This does not necessarily decrease the quality of the scan, however, it does significantly increase the post processing time. This background explains why the orientation must be kept consistent.

Other Requirements

3. Have a complimentary scientific procedure to make the process standardized and reproducible.
4. MRI compatible: Material must not obscure image.
5. Reusable
6. Must not damage brains or deform brains during loading, unloading, and scanning (they study microstructure of the brain)
7. Airtight Seal in Fluorinert: Air must not interfere with imaging.

Non-Essential Specifications

- Be able to resize the device for both mouse and rat brains
- Be able to retrieve fluorinert (cost consideration)
- Decrease the amount of fluorinert required (cost consideration)
- Be able to retrieve the brain safely without damage (for further research)
- Decrease the loading time of the brains
- Minimize vibration of the capsules and components to improve MRI scan
- Can contract or restrict the size slightly to secure the brain during the MRI
- Have points of reference to align midlines of brain with the MRI machine bore axis
- Have space for a watermark

Design requirements

1. Physical and Operational Characteristics

a. Performance requirements:

Must increase loading efficiency to higher than the current rates of 3 rat brains per MRI scan and 6 mice brains per MRI scan, which currently take long increments of time to insert and remove from individual syringes. Shall not increase scanning time to more than 20 hours. The device should also minimize air bubbles introduced to the brain samples.

b. Safety:

MRI machines and rooms cannot contain any magnetic elements or metals, which will react dangerously with the magnetic fields produced by the MR-scanner.[1] The product should not have sharp edges as the client will be loading the specimens by hand.

c. Accuracy and Reliability:

Brain samples should remain in correct alignment during the MRI scan within a margin of error of 2 degrees. Samples should fit compactly within the capsules in order to minimize shaking from mechanical vibrations caused by the MR-scanner, which could cause imaging issues. The capsules themselves should allow for simple alignment within the scanner to allow for standardization of image location. The capsules should also be easily reproducible for mass production.

d. Life in Service:

Must be in service for approximately 24 hours minimally, however, should be able to be used as a storage device for the brain samples for at least one year. Minimally must be able to be both sealed and reopened once, but preferably can be reused over the course of a year (approximately sealed and opened once per month).

e. Shelf Life:

The client did not specify a specific shelf life; we estimate that the product should have a shelf life of 1 year.

f. Operating Environment:

Strong magnetic fields will be applied to the device in the MRI machine, which require high voltage and current to power the device possibly causing high temperatures, however, the MR-scanner itself has its own cooling system to mitigate this. Nonetheless, while the machine is powered the device will be exposed to high noise levels as well as vibration, and will likely be handled often. In addition, the device will be in contact with Fluorinert often. Thus, the device itself should be sturdy, and should not move within the scanner.

g. Ergonomics:

Should have the ability to sustain the force of a vacuum seal (exact force to be determined) without deformation. Brain should not be damaged during loading and unloading, and allow for simple and quick insertion and extraction, and should also protect brain samples during scanning.

h. Size:

The device(s) must fit in a cylinder bore with a diameter of 37.29mm and a length of 50.35mm. The brains must be positioned within the relatively small scanning length of the coil (50.35mm), however other parts of the device can extend outside of the coil.

i. Weight (redundant):

The device should weigh less than 15 kg when combined with brain samples as well as fluorinert.

j. Materials:

Magnetic metals should not be used since the product will involve MRI imaging. The product must not contain polar molecules that would be affected by the magnetic coil and decrease imaging accuracy. A non-biodegradable, waterproof material that is compatible with Fluorinert is preferred.

k. Aesthetics, Appearance, and Finish:

The capsule will preferably be transparent for ease of visualizing the brain positioning. Texture should be smooth to avoid damage to the brain and coil when loading and unloading.

2. Production Characteristics

a. Quantity:

The client wants 4 - 8 units of the product and the ability to reproduce the product. Since the client performs experiments on both mouse and rat brains, this quantity will double to 8-16 total.

b. Target Product Cost:

The target product cost should not exceed $30. Additional costs from test printing prototypes should not exceed $50, for a target total cost of $80. Currently, the Yu lab is using 3.5 mL and 10 mL syringes to hold each rodent brain. This is likely costing them approximately $2.00 per syringe. This does not include costs from fluorinert and imaging film, which should be reduced by our design.

3. Miscellaneous

a. Standards and Specifications:

ASTM STP1438-EB is the standard for determining whether a device or material is safe for a Magnetic Resonance environment. The most critical factor of determining whether a material is MR safe is that the material does not contain any metallic or magnetic components. [1]

b. Customer:

The customer and user is our client.

c. Patient-related concerns:

There is no patient interacting with the product, and thus this section is not applicable.

d. Competition:

No competing devices or patents were found. One study that was cited numerous times by other articles showed scans with 4 brains in one array. The brains were oriented with the top of the cerebrum toward the center axis in a radial formation.

Sources

[1] T. Woods, "MRI Safety and Compatibility of Implants and Medical Devices," *ASTM International*, pp. 82–90, doi: 10.1520/STP11156S.

B. Materials

Table I: Materials.

Item	Description	Manufacturer	Part #	Date	QTY	Cost Each	Total	Link
Main Body								
Nylon	3D printed	UW-Makerspace			29.66g	$.12/g	$3.56	
						TOTAL:	$3.56	

C. Testing

Table II: Leak-resistance testing.

Time Elapsed (min)	Observations
20	
40	

60	
80	
100	
120	
Observations after shaking:	

Table III: Qualitative specimen damage testing.

Brain	Observation / descriptions of any damage
Mouse 1	
Mouse 2	
Mouse 3	
Rat 1	
Rat 2	
Rat 3	

Table IV: Image quality testing.

Brain	Degree of rotation necessary	Observations of image
Mouse 1		
Mouse 2		
Mouse 3		
Mouse 4		
Mouse 5		
Mouse 6		
Mouse 7		
Rat 1		

Rat 2		
Rat 3		
Rat 4		
Rat 5		
Average		

Table V. Rodent brain measurements.

	Rat 1	Rat 2	Rat 3	STDV Rat	Avg Rat	Mouse 1	Mouse 2	Mouse 3	Avg Mouse	STDV Mouse
Max Length	28.7	27.99	29.56	0.78619 33604	28.75	13.72	13.95	15.41	14.36	0.91656 96918
Max Width	14.76	15.1	14.99	0.17349 35157	14.95	8.68	8.64	8.36	8.56	0.17435 59577
Max Height	10.66	10.23	10.46	0.21517 43479	10.45	6.69	7.49	5.99	6.72333 3333	0.75055 53499
Length of cerebrum	15.59	13.98	14.65	0.80876 44898	14.74	8.59	8.6	9.11	8.76666 6667	0.29737 74257
Length of cerebellum	6.32	6.68	5.68	0.50649 11977	6.22666 6667	3.21	3.73	5	3.98	0.92081 48565
Width of cerebellum (no ficculus)	12.03	11.59	11.58	0.25696 95183	11.7333 3333	7.38	7.93	7.16	7.49	0.39661 06403
Height of brainstem	6.36	4.56	5.19	0.91340 02409	5.37	2.52	3.08	2.01	2.53666 6667	0.53519 46686
Length of brain stem	2.95	4.87	6.47	1.76242 2575	4.76333 3333	5.05	2.95	5.15	4.38333 3333	1.24230 9677
Width of brain stem	3.7	4.06	3.77	0.19087 51774	3.84333 3333	5.32	2.7	4.8	4.27333 3333	1.38713 1332
Olfactory bulb height	4.38	6.32	5.73	0.99450 15502	5.47666 6667	3.18	3.09	2.83	3.03333 3333	0.18175 07451
Olfactory bulb length	3.98	3.36	2.83	0.57558 66572	3.39	3.2	2.3	2.87	2.79	0.45530 20975
Olfactory bulb width	5.43	5.94	4.97	0.48521 47291	5.44666 6667	3.91	3.18	3.7	3.59666 6667	0.37581 02358

Measurements of the mouse and rat brains provided by the client. Measured using a digital caliper.