UNIVERSITY OF WISCONSIN-MADISON
DEPARTMENT OF BIOMEDICAL ENGINEERING
BME 200/300 DESIGN FALL 2011

Open Source Rat Phantom

Final Report

Team:

Alex Broderick - Communicator
Charlie Rodenkirch – BSAC
Chelsea Bledsoe – BWIG
Darren Klaty – Team Leader

Advisor:
Paul Thompson

Client:
Surendra Prajapati

12/12/2011

Table of Contents

Design Alternatives

Abstract

Once a medical scanning device is developed, it becomes necessary to test the device to ensure proper function and workability. This task falls to phantoms. Phantoms are used to calibrate scanning machines and determine whether the imaging equipment is producing scans with correct accuracy and reliability. Such phantoms can also be reconfigured to test a specific machine’s radiation distribution, see where different drugs travel throughout the scanning process, and even simulate tumors on various organs in the specimen being scanned. Our client is producing an open source combined radiation therapy (RT), positron emission tomography (PET), and computed tomography (CT) scanner. Thus, a rat phantom is necessary to calibrate the machine and test its imaging ability.

Problem Statement

The Rat Phantom project is controlled by a client that is currently developing an imaging and therapy system for small animals that integrates micro CT, micro PET, and micro RT scanning systems into one device. His project is open source, making all designs and specifications readily accessible on the internet so it can easily be replicated at low cost. The CT/PET/RT system will be used to treat and image rats, and thus requires a rat phantom for testing and calibration of the system. Specifically, the rat phantom will be used for the characterization of the micro collimator of the scanning device. The phantom will be based on the full CT scan of an actual rat, and is required to contain different density materials for various tissue types. Additionally, the rat phantom will contain inserts for radiation detectors and tumors to simulate the actual tests that will be performed on real rat specimens.

Background

Phantoms are used in the medical industry with the main purpose of testing imaging equipment such as CT scanners and MRI machines, like that show in figure A. They are also used in an educational setting to teach interventional imaging guided procedures to students and doctors. Finally, phantoms are frequently used by maintenance crews for servicing scanning equipment.

Figure A. *Combined PET/CT scanner at WIMR*

In the testing of an imaging device, a phantom must scan similarly to how the real specimen would. Thus, phantoms are constructed of materials that contain different densities to mimic various bodily tissues such as the muscle tissue, lungs, and organs. It is crucial that phantoms behave similarly to their real-life specimen, and therefore they are designed with careful attention to their anatomical correctness.[1]

There are many different types of phantoms to simulate proper scanning for animals and humans. While these phantoms are designed to be anatomically equivalent to their corresponding specimens, they often do not look anatomically similar to the animal or human they simulate. In fact, many phantoms are just objects that contain places for testing inserts that are utilized during the scanning process. Although they may not look like their designated specimen, they scan with extreme precision to mirror the animal or human they are portraying.[2]

Motivation

The open source rat phantom project is part of Thomas Mackie's larger venture of designing and producing a combined PET/RT/CT scanner for the imagining and treatment of small animals. Thomas Mackie is the chairman, co-founder, and co-inventor of TomoTherapy Inc. as well as a UW-Madison professor in medical physics. His focus is the construction of medical devices that can be used from research labs to clinical use, with the goal of improving current technologies.[3] Consequently, the scanner requires a rat phantom that can test, calibrate, and service the system so that it can be as successful as possible. Currently, one can purchase rat or mouse phantoms, like those shown in figure 1 from JRT Associates, for a significant amount of money. These types of phantoms, while durable and accurate, cannot be used in a scanner

Figure 1. *Water-filled mouse phantoms used primarily with CT scanners*

Figure 2. *Circular phantoms used to test CT dosage*[4]

such as that being developed by Thomas Mackie because they do not contain slots for thermoluminescent dosimeters (TLD), organ, and tumor inserts. Other companies produce sphere-shaped and block phantoms that contain such inserts, similar to those shown in figure 2, but these types of phantoms don't look like a rat. Thus, there is not presently another product on the market that both contains the necessary inserts and anatomically looks like a rat as this rat phantom will.

Since the rat phantom is to be designed as an open source project, it must be completed with minimal expenses so that it can be easily replicated for a reasonable price. This means that materials for the different tissue densities and the TLD inserts must be low-cost and easily obtainable for other locations so that the rat phantom can be produced worldwide.

Design Criteria

This project has the specific goal of creating a product that could be used with a custom CT/RT/PET scanner currently being developed as an open source project. The scanner itself is not near completion, causing some complications in creating design specifications for the rat phantom. It is difficult to design a product that will be used in a machine that has not been created yet. However, head contact Surendra Prajapati, provided the team with several initial specifications to get the design process started. It is already known that the scanner will have a 12 cm diameter chamber. Thus, the rat phantom has a diameter constraint of 12cm in width and height. This is not a difficult constraint because average rats do fall far below this size mark. The maximum weight of the phantom was set at 2 kilograms to ensure the machine would not receive excessive forces from the weight of the rat. Additionally, the client requested that the phantom be anatomically correct when scanned using CT or PET imaging, meaning that it must have an accurate skeletal structure as well as correct tissue densities corresponding to the muscle and organs.

For testing purposes, it is necessary that the phantom contain several places where thermoluminescent dosimeters, TLD's, could be inserted. These sensors measure radiation dosage levels and therefore are integral parts of the testing process to determine the effectiveness and accuracy of radiation therapy techniques. Since TLD's are radioactive upon being treated with radiation in testing, it is important that their radioactivity does not contaminate the rest of the phantom. A contaminated phantom would be useless for the client, as it would only be able to be used once. Also, the phantom must contain spaces for different organ and tumor inserts to simulate different diseases in the specimens being tested.

Phantoms are commonly assessed on their shelf life capacity, making it crucial that the phantom being designed be able to withstand repetitive use. The phantom will be used multiple times to test and calibrate the scanner. With this constant use, it is vital that the phantom produces predictable results that do not change over time. The phantom will act as a constant for the scanning device, and therefore must be reliable. Finally, the cost of all materials used to create the phantom must be kept to a minimum so that is can successfully be an open source product.

Design Alternatives

Design 1. Solid Design

Initial thoughts for a phantom design centered on the principal of a solid phantom body, as shown in figure 3. This solid phantom would contain a body that is cast modeled around an actual rat skeleton. Using a 3D printer, a drop cast for the mold could be produced using scans of a real rat. This would allow for an accurate representation of a rat exterior in addition to correct density, size, and placement of all the bones in a rat’s body. Gammex RMI, a phantom materials company from Middleton, Wisconsin, would provide materials to simulate internal organs, allowing accurate density and shape for all needed organs. Muscle tissue would be mimicked by an epoxy mix, allowing variation of its density in accordance with what is required by a rat’s muscle density. The advantage of a solid design is that all organs and different tissues would not be removable, thus making them less prone to faults and reduce their scanning accuracy when compared to a real rat.

After creating an initial phantom mold, slots for TLD detectors would be added. These slots would be cut out from the exterior, allowing for easy addition and removal of TLD sensors as necessary. Unfortunately, a solid design does not allow for interchangeable organs unless slots could be cut deep into the interior of the phantom. This is a major disadvantage to the design, as the client expressed strong interest in removable organs for testing purposes. However, there are major scanning benefits of a solid design.

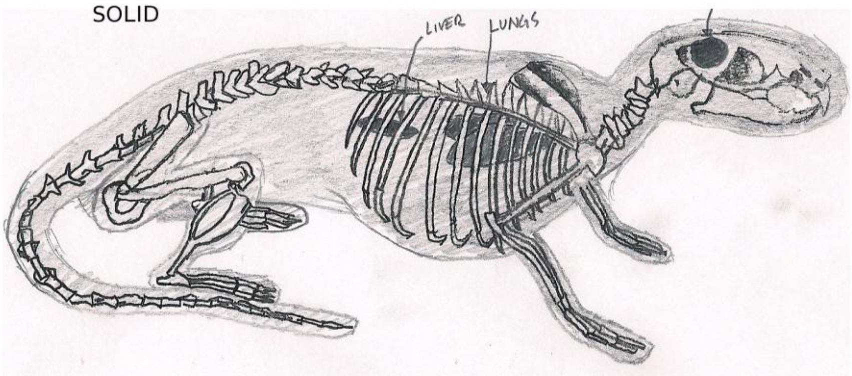

Figure 3. *Solid phantom design*

With a solid design, the phantom would most likely be able to withstand large amounts of use because it consists of a single part. In order to prevent radiation contamination to the rest of the phantom body from the TLD’s, the TLD’s would be wrapped in a flexible plastic such as plastic wrap. As for materials, this phantom would consist of all solids, preventing any loss of definition or warping over time. Additionally, the cost of this model would be within the budget as it would use minimal different materials and would have fewer chances of material erosion throughout its lifetime of use.

Design 2. Vertical Cut

The second design is based on the idea of containing easily removable TLD sensors and organs. This would allow for regular organs to be swapped with tumor laden organs so that different testing techniques can be utilized with the machine being developed. This was a high priority request by the client, who would benefit from having removable organ inserts. To accomplish this ease of removal, a phantom would be designed to consist of two parts, as shown in figure 4. The phantom would separate vertically from a cut in its spine right behind its ribcage. This cut would allow for access to the internal organs located in between the phantom’s ribs as well as access to the various TLD slots. In order to access these organs without deforming the phantom’s body, they will be housed within a softer material than the material used for the outer shell of the

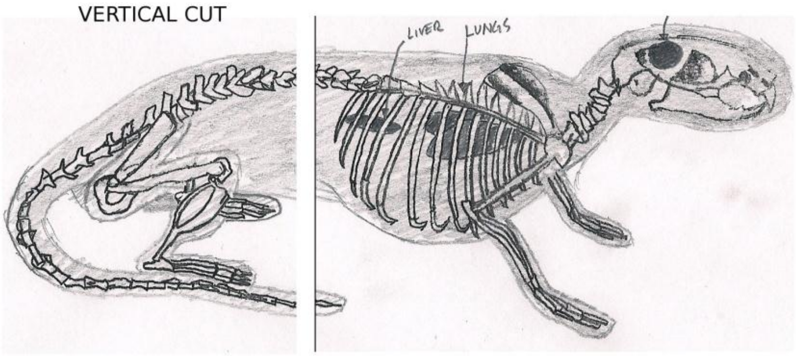

Figure 4. *Vertical cut design*

phantom. This will allow for ease of TLD and organ addition and removal, resulting in a higher degree of accuracy in the phantom's scanning abilities. Similar to the solid cut design, the TLDs will be wrapped in a plastic to prevent the exposure of radiation to the surrounding phantom body.

Parallel to the solid cut design, a 3D printed mold will be used to cast the exterior of the phantom around an actual rat skeleton. After creating this mold and letting all materials set in place, the vertical cut will be added directly behind the rib cage. The cut will be made using some sort of machinery, most likely a band saw. A vertical cut directly behind the rib cage is the best location as it would only cross through the skeleton once and would allow access to both the lower and upper chest cavities. After making the cut, these cavities would be hollowed out so that muscle tissue can be added. In order to simulate a real rat's muscle tissue, the phantom will contain ballistics gel. Ballistics gels are designed to mimic living soft tissue, allowing it to very closely resemble the muscle tissue of a rat or another small animal that will be used with the combined scanner being designed.[5] Differing from the epoxy used in the solid cut design, the ballistics gel will be a more accurate representation of rat muscle. After letting the gel harden for 48 hours, pockets, created from small cuts using an small scalpel, will be formed in order to mount TLDs and organs in their anatomically correct locations. It is a significant advantage that the vertical cut design allows the organs and TLDs to be placed in anatomically correct positions. In testing situations, drug dosage and radiation dosage to a particular organ can be monitored with this design, whereas this would be much more difficult for the solid design.

Although there are many advantages to the vertical cut design compared to the solid design, it would not be as physically strong as the solid design due to the major cut in the middle of the phantom. However, it would still have a hard external shell which would protect the phantom from warping shape or having its interior weaker materials being disturbed. The vertical cut creates some problems with imaging as any air in the gap between the two pieces of the phantom creates imaging anomalies. To solve this problem we would have to create some sort of locking mechanism that holds the pieces together. The ballistic gel would be slightly more expensive than the epoxy used in the past design, but the increased accuracy would be worth the cost. Our current budget would have no problems with this design.

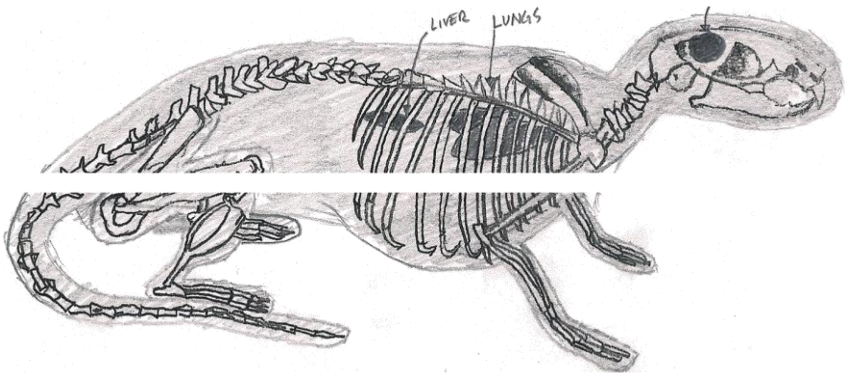

Figure 5. *Horizontal cut design*

Design 3. Horizontal Cut

The third design is very similar to the vertical cut design, but contains a single horizontal cut instead of a single vertical cut. This design is shown in figure 5 on the following page. A horizontal cut is another solution to the inaccessibility of organs in the solid phantom. The phantom will be created in the same fashion as the vertical cut design, utilizing a 3D printed mold and ballistics gel to encase a real rat skeleton. However, upon creating the mold with the gel and various organs, a single horizontal cut would be added using a band saw. This cut will require much more meticulous care than the vertical cut because it will go through several bones in the skeleton. The cut will need to span the entire length of the rat, cutting through all of the ribs, the front legs, the hind legs, and the tail. Nonetheless, this allows for much more access to organs and TLD’s than the vertical cut. Also, since the cut is horizontal, gravity acts on the two halves of the phantom to pull them together, avoiding air gaps between the two sections. This is highly advantageous because air gaps cause significant errors to scans. Thus, the horizontal cut design will have more image accuracy and accessibility than the vertical cut design, but will unfortunately cause an extreme amount of care unnecessary for neither the vertical cut design nor the solid design.

Design 4. Combination Cuts

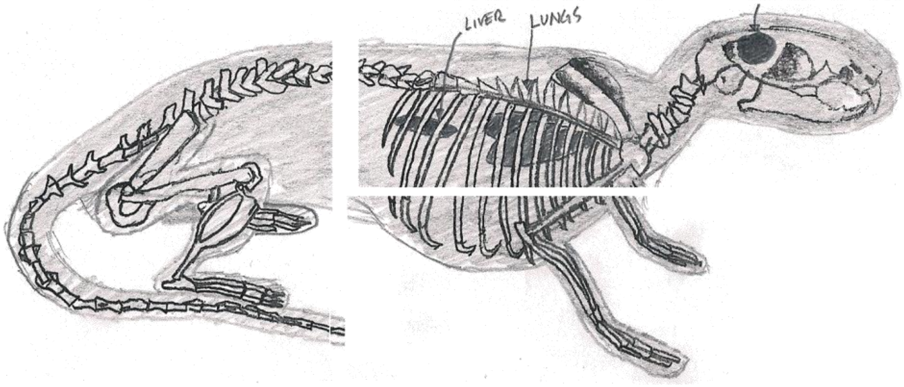

Figure 6. *Combination cut design*

The combo cut design, shown in figure 6, uses elements from both the horizontal cut and the vertical cut designs to create an incredibly accessible phantom. The phantom will be made of the same materials as the vertical and horizontal cut designs, but will contain two cuts instead of a single one. The vertical cut will be located directly behind the ribs, and the horizontal cut will run from the anterior part of the phantom to the center behind the rib cage where the two cuts meet. These cuts allow for the greatest amount of organ accessibility to put the TLD’s, organ inserts, and tumors. Additionally, there will be minimal air gaps in this design because the horizontal cut uses gravity to its advantage. To combat the air gaps caused by the vertical cut, some sort of locking mechanism will be implemented to keep the two pieces together. Additionally, the ballistics gel has a high coefficient of friction and will stick together, helping form minimal air gaps.[5]

Design Matrix

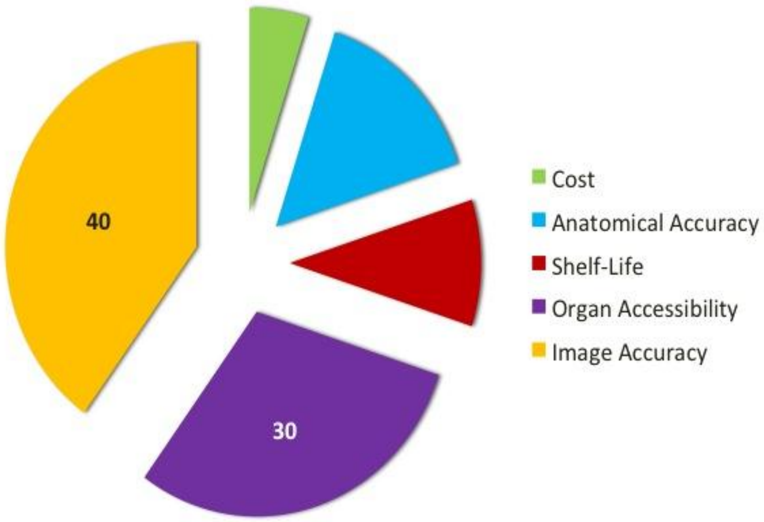

Figure 7. *Design Matrix*

In order to pick a specific design to continue the project with, a design matrix was created. The design matrix was split into 5 different categories that the team deemed important in the design decision process. These categories are cost, anatomical accuracy, shelf-life, organ accessibility, and image accuracy. Figure 7 illustrates the relative weighting of points for each of the individual categories, with image accuracy being the most important factor, followed by organ accessibility, shelf-life, and anatomical accuracy, and lastly followed by cost. In order to choose a design, each design alternative was analyzed using these 5 categories. Figure 8 below shows the specific breakdown of points for each category and each design, allowing us to

Category	Total Points	Design 1: Solid	Design 2: Vertical Cut	Design 3: Horizontal Cut	Design 4: Combo Cuts
Cost	5	2	4	4	4
Anatomical Accuracy	15	12	12	12	12
Shelf-Life	10	10	6	6	6
Organ Accessibility	30	7	21	23	30
Image Accuracy	40	40	24	33	30
	100	*71*	*67*	*78*	***82***

Figure 8. *Design Matrix*

determine which design would be most effective to continue our project with.

Cost, the first category, received minimal weighted points with only 5% of the total points given to each design. Although cost is a necessary part of the design matrix because it needs to me kept at a minimum in order to comply with the open source project requirement, all of the designs will be very similar in cost. Therefore, cost is not a major deciding factor in the design choice. The solid design received the lowest ranking for cost, 2, as the solid epoxy materials in the solid phantom are slightly more expensive than the gels and other materials used to produce the other three devices. The horizontal, vertical and combination cut designs will all use the same materials and vary only in the method of separating the pieces of the design. Therefore, the rest of the designs receive a ranking of 4.

Anatomical accuracy is the next variable reviewed, with a total of 15% of the total points. Anatomical accuracy of the design is an essential component for the design matrix as it is directly tied to the quality and usefulness of the final design. Also, the client was very adamant on having a phantom that looked like a real rat. Anatomical accuracy is closely related to image accuracy of the scans, and without it testing of the combined PET/RT/CT scanner will not be as successful. Since all of the designs will be using the same internal organs and bone structures, each design receives the same award of 12 points in this category. Although this category has no effect on determining a final design, it was included due to its vital role in the phantom device. All four designs incorporate major tissues such as bone, lung, liver, and muscle, allowing for an adequate testing ability to see how the scanner differentiates between different tissues in a rat.

Next, the shelf life of each design was analyzed. The shelf life of the phantom is a crucial design requirement so that the phantom can be used repetitively for testing and radiation dosage distribution. Thus, the shelf life category is assigned 10% of the total points towards the design. The solid design received the highest ranking of 10 points as once the design is produced, it will have high durability because there are no cuts in the design to degrade or pull apart over time. Conversely, the ballistics gel used in the other three designs is softer and much more pliable than the epoxy used in the solid design. Additionally, the cuts made in the other three designs may result in slipping between the pieces over time, causing negative effects to the image quality of any scans done. Thus, all of the ballistic gel designs receive an award of 6 points. Another factor of shelf life is the use of TLD's to test for radiation distribution. However, all of the designs simply use plastic wrap around the TLD devices to prevent radiation contamination to the phantoms. This is a very necessary part of the design because once the design is contaminated with radiation, the phantom's shelf life significantly decreases. This decrease is caused by the half-life of the radiation, which is equivalent to 40 days. This half-life would result in an excessive amount of time to wait between testing trials, ultimately making the phantom inoperable after just one use.[6]

The organ accessibility for each of the devices was the next variable examined. This received a ranking of 30% of the total points because removing and inserting organs for testing while tumor progression is being modeled is a vital role of the phantom device. Also incorporated into this category is TLD placement and removal for radiation distribution testing. The solid design has no cuts and therefore organ accessibility is nonexistent. However, the TLD slots could easily be incorporated into the design through various cuts, thus earning this design 7 points. The vertical cut, conversely, receives 20 points when examined in this category. The vertical cut will be right behind the rib cage, allowing for much easier access to the organs that sit in the rear of the phantom. However, the organs in the front of the rib cage will still be

Figure 9. *This shows various TLD's that are used to monitor radiation dosage during testing procedures.*[7]

relatively difficult to access. The horizontal cut received 24 points as it contains high access to the organs throughout the rib cage and all along the body in the plane of the cut. The horizontal cut design also allows the TLDs, as shown in figure 9, to be easily inserted and removed. Lastly, the combination cut design received the highest point reward of 27 because the two cuts allow for maximum organ accessibility. The horizontal cut allows for access to the organs throughout the plane in the rib cage and the vertical cut allows for the organs that are not in the plane of the other cut to be accessed as well.

Finally, image accuracy of each design was examined. As the image accuracy is ultimately the final goal of the design, it has the highest ranking of all the categories, having a grand 40 points. Once again, the solid cut received the highest ranking with 40 points because it has no cuts or slots for air bubbles to negatively affect its image accuracy. Once the solid design is cast and dry, it should be a very reliable and durable testing device. Next, the vertical cut received the lowest ranking of 25 points because such a cut will be pulled apart by gravity, allowing air to get between the two pieces and thus lower image accuracy. An interlocking mechanism, similar to that of a puzzle piece, is thus necessary for this design to help hold the pieces together and counter the effects of gravity. However, such a locking mechanism most likely will not be enough to fully resolve the problem. The horizontal cut received a rank of 33 points because gravity will help to pull the two pieces together and eliminate air gaps. Lastly, the combination cut received an award of 30 points, right between the vertical and horizontal cut award. This takes into account the advantages of the horizontal cut design and the disadvantages of the vertical cut design. Since the vertical cut does not go all the way through the design, gravity will have less of an effect on creating air gaps between the pieces. Also, the horizontal cut will help the top and bottom pieces to mesh together and further eliminate any air gaps that are present.

Final Design (Initially)

After the design matrix was completed, the totals for each design were summed. The combination cut emerged as the winner in a relatively close margin. Although each design addressed certain variables better than others, the combination cut design consistently scored among the top of every test. The combination cut design adequately addresses all of the client's needs as all of the organs and TLD locations are easily accessible, its cost is low, the shelf life of the design should be adequate to properly test the scanner and run radiation dosage distribution experiments, and its high anatomical accuracy leads to high image accuracy. Therefore, this design will be most useful in testing the PET/CT/RT scanner than the other three designs or other standard calibration devices on the market today.

Budget

A very important aspect of any design project, and probably the most important aspect to the client, is the cost of the design. Keeping this in mind, the rat phantom's design attempted to use as many of the free resources as were available. One of these resources was access to the CT/PET scanner at the Wisconsin Institute for Medical Research, or WIMR. The operator of this scanner, Mohammed Farhoud, graciously allowed the team to scan a real average-sized rat free of charge. He also was a significant help with processing the resulting scan data for free. This was a remarkable gesture as the CT/PET scanner is usually booked solid and is quite expensive to reserve and operate. Another resource of use for no charge was the three dimensional printer in the basement of the Wisconsin Institute for Discovery (WID). The client's lab was located in this basement, giving the team authorization to use the printer to create a drop cast mold of the phantom for free, saving a few hundred dollars in printing costs.

Like any design project, it was difficult to completely eliminate costs. When initially starting the project, it was determined that the phantom would contain a real rat skeleton so that the bone density was exact to that of a real rat. The team looked into getting the skeleton from the veterinarian school; however, their best offer was a deceased rat which the team would then have to submerge in strong acid until all that remained was the skeleton. Then, the skeleton would have to be reassembled into its correct anatomical figure. Instead of undertaking this arduous, an assembled rat skeleton was purchased from Sand Castle Science for $71.87. Unfortunately, the skeleton took about 5 weeks to arrive, thus delaying the design process. Upon arrival, the skeleton was in a nice case and seemed to be in great condition. A second investment in the design process was the ballistics gel used to model the rat's soft muscle tissue. After looking into options for this purchase, it was determined that ballistics gel from a local grocery store would be the cheapest way to mimic rat muscle tissue. Thus, the ballistics gel was purchased for $9.37 from a local Copp's Grocery Store.

During the first client meeting, the requirement of anatomically correct models of a rat's organs, with proper tissue densities, was strongly encouraged for the phantom design. The team was informed that the best way to acquire these organs would be from a local materials company called Gammex RMI. Apparently, Thomas Mackie has strong connections at Gammex RMI, allowing the team to enlist their help with the rat phantom project. Initially, it was believed that this company would have no problem donating materials for organs as the material needed for such small organs would be considered scraps for them. However, as communication was attempted with the company throughout the semester, it became very apparent that this wasn't the case. After several weeks of emailing and telephone communication, the team was still not clear on what Gammex RMI would be able to offer. This communication culminated in Darren Klaty and Alex Broderick having to drive out to the company's headquarters to attempt to get some clarity, as their responses to our attempts at electronic communication were vague and far in between. There, it was discovered that the production of these organs would take many weeks and would cost hundreds of dollars. This was a majorly unexpected delay and its massive cost prevented the team from receiving materials for the rat's organs. Due to this unfortunate set back in both time and cost, materials for the lungs and liver of the phantom were not obtained, and thus not incorporated into the final design.

Second Final Design

After assessing the budget and the resources given to the team, it was decided that the final design needed to be changed in order to keep costs low and ensure that a prototype could be produced by the end of the semester. Mohammad Farhoud, the lab manager contact at WIMR, helped the team deiced upon the solid design because it would ensure top notch image accuracy. Since the phantom being designed is the first of its kind for this specific scanner, it should only focus on and master one specification. Therefore, the team decided that making the solid design would decrease costs, increase image accuracy, and be a successful first prototype for this project. Since organs could not be obtained through Gammex, the solid design would not contain organs as specified in the design alternative description. However, it would indeed contain the real rat skeleton and ballistics gel as muscle tissue. For the limited resources and budget, the solid cut design without organs would be a successful alternative to the previous final design.

Fabrication

Part 1: Phantom Mold Creation

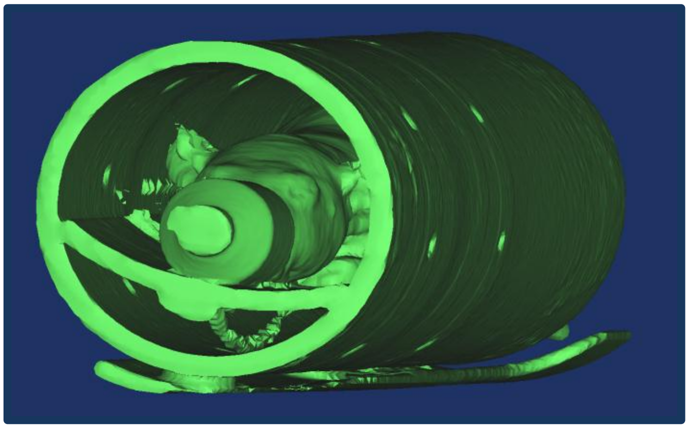

Figure 10. *Scan of rat before any editing was performed.*

The first process necessary for the fabrication of the phantom was the production of the mold that would form the exterior structure of the rat. Initially, a CT image of a live rat was obtained using the scanner at WIMR. The raw data from this scan consisted of a total of approximately 1200 very precise slices of the rat that contained finite details of the specimen. These images included the tube surrounding the rat, the table it was resting on, the respiration device that supplied the rat with a sedative to keep it calm, and the rat itself, as shown in figure 10. Once all of this data was obtained, it was imported into Mimics, the software program at WID used to edit all of the slices. Once the images were compiled to produce a 3D image of the scanned rat, a threshold was used that included the rat in its entirety while also editing out much of the interference that resulted from the scan. This threshold is an integral part of the production process, as setting the threshold too low reduces the quality of the mold and setting it too high can require extensive editing efforts in order to erase all the unnecessary components that may be included. Once a threshold was determined by examining the image produced using different values, editing of the scan began. The threshold process and editing process was supervised by Benjamin Cox at WID, who was our main contact for any computer work that had to be done during the semester. During editing, the table, respirator, and tube were cut away piece by piece until the only image remaining was the 3D image of the rat without any unnecessary components.

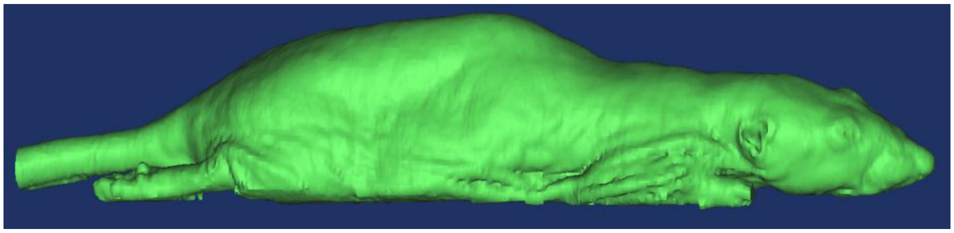

***Figure 11**. Edited scan of real rat, 3D model used for printing phantom mold*

Once this clean 3D image of the rat was obtained, as shown above in figure 11, it was placed inside the structure of a box large enough to contain the rat with enough clearance on each side to allow for ample structural integrity to prevent the mold from breaking. This process converts the model into a negative of the rat, allowing for the production of a negative that can be printed and filled with phantom materials. A small vertical cut was then added to the box down the length of the rat to allow the mold to be removed from the phantom once the ballistics gel hardened. Additionally, a lip was added to the box, with holes cut into the lip, so that each side of the mold could be bolted to the other to ensure no ballistics gel leaked out during the hardening process. This final negative image was then sent to the SLA printer for processing. The SLA printer forms very thin layers of the resin in the necessary position, with each layer requiring UV light to be applied to it so that it could harden before the next layer is applied. After each side of the mold was produced, the mold had to be cured in an oven to dry it and continue the hardening process. Once all of these steps were completed, the team had a mold of the phantom and could proceed with the production of the phantom. This mold is shown in figure 12.

Figure 12. *Half of the printed mold for the rat phantom*

Part 2: Phantom Production

After creating a mold for the phantom, materials needed to be purchased and utilized to form the phantom prototype. The main component of the phantom consists of ballistics get to mimic the rat’s soft muscle tissue. This material required the most extensive amount of work before the phantom could be completed. Test trials were performed with the gel to determine the proper technique that produced the best results with the least bubbles and best quality. Such tests experimented with curing the gel in a freezer, fridge, or at room temperature two determine the most efficient yet successful way of hardening the gel material. After these tests concluded that letting the gel harden in the fridge was the most successful method, production of the phantom continued. The skeleton was placed in the mold in the correct position to ensure an accurate skeletal representation of a rat, a main requirement by the client. Since the skeleton procured from the online site was in a different position than the scanned rat used to create the mold, the bones had to be disassembled and reassembled in a proper position that coordinated with the mold. The rat skeleton was initially in a natural standing position while the scanned rat was in a “sandbagging” position due to its sedated state. Instead of standing upright, the rat was collapsed on the scanning table with its feet folded under itself. Each of the limbs had to be taken off of the skeleton and repositioned in their proper place in the mold. Finally, the spine was straightened to fit the changes made to the skeleton and the tail was cut off as it is not an important part of the rat during PET, RT, or CT scanning. Once all the bones were in place, ballistics gel was heated to its liquid state and poured into a hole at the top of the mold. The mold was then placed in a refrigerated state to allow the gel to properly harden, as shown by the previous materials tests performed. Once hardened the molds were removed from the fridge, the plastic cast was removed from the phantom and the final phantom design was obtained.

Testing

Producing ballistics gel of the right consistence and quality required adequate testing and trial runs to see what worked best. The initial step to producing the ballistics gel involved proper mixing of the gel into the water using appropriate amounts of each. It was determined that the mixture that produced the best results involved a cup of water to each ounce of Knox Gelatin used. The gel then had to be poured into the water very slowly and thoroughly mixed to prevent the fewest number of bubbles possible from forming in the final design. When mixed properly, the gel and water mixture reached an applesauce consistency. Once the mixing of the gel had been completed, the entire concoction was placed in a refrigerated state for two hours to allow it to' bloom,' where it increased in size and decreased in density. After the blooming process, it had hardened and needed to be thawed out and reheated back to a liquid state. The best results were obtained at a very low heat of 100-150 degrees Fahrenheit. Once all the gel had become a liquid, it was then poured into the mold while each side was bolted to the other. The mold was then placed in the fridge for 36 hours to allow it to properly cure and form its final state.

Making a product to be used in a device that has not been developed yet has its advantages and disadvantages. Since the combined PET/RT/CT scanner that the rat phantom is to be used for is still in the design process, the rat phantom specifications are still flexible, allowing the team to incorporate any and all ideas into the design. However, once a prototype is produced, there is no scanner to test the phantom on in order to determine its effectiveness. Thus, after making the rat phantom in this project, the team was unable to get any scanning tests done. Another appointment to use the combined PET/CT scanner at WIMR would take a few weeks advanced notice to book, and unfortunately the delays in the design process prevented this appointment from being made. Consequently, there have been no scans run on the phantom prototype to test its image accuracy.

Future Work

The next step in the rat phantom design process is to test the first prototype on the combined PET/CT scanner at WIMR. To do this, an appointment needs to be made with Mohammad Farhoud, and the phantom can then be brought over for a quick 10 minute scan. After obtaining this scan, it will be compared to the scan of a real rat to test its image accuracy and if the materials used are of the correct densities. Then, changes can be made in the materials until a successful prototype is found.

Future teams that work on this project may decide to add organ components and/or incorporate a vascular model to show blood flow. These are complex steps that would take much time and effort, but would significantly increase the effectiveness of the phantom to come up with useful information during testing. Once these prototypes are created, they could be tested on the scanner at WIMR as well. However, final testing cannot be done until the combined PET/CT/RT scanner is finished.

References

1. The Phantom Laboratory. http://www.phantomlab.com/documents.php

2. Sigma-K Corporation. 2011. http://www.omniphantom.com/Home_Page.php

3. Morgridge Institute for Research, Wisconsin Institutes for Discovery. 2011. http://discovery.wisc.edu/home/morgridge/about-morgridge/leadership/thomas-mackie/

4. "CT Dose Phantom." Universal Medical Inc. http://www.universalmedicalinc.com/CT-Dose-Phantom-CIRS-007-p/007.htm

5. "Institute for Non-Lethal Defense Technologies Report: Ballistic Gelatin." N.C. Nicholas and J.R. Welsch. Februray 2004. PDF file: http://www.nldt.org/documents/ballistic_gelatin_report.pdf (page 7)

6. "Radiation Protection." U.S. Environmental Protection Agency. July 2011. http://epa.gov/radiation/understand/health_effects.html

7. "Medical X-Ray Instruments." Toreck Co. http://www.toreck.co.jp/english/medical/index.html

Appendix

Project Design Statement

Problem Statement: This project is for the design and development of a mouse phantom that will be used to characterize and test the micro collimator of an open source small animal imaging and therapy system. This machine includes micro CT, micro PET, and micro RT tests, and thus the mouse phantom must be compatible with all three systems. Ultimately, the system will be used to treat and image mice, rats and other small animals. The phantom will be designed for effective calibration and testing of the device while also researching the effects of radioactive materials placed inside the device to track radiation dosage distribution.

Client Requirements:

- Appear anatomically similar to a rat
- Fit the 12cm diameter bore of the scanner
- Physically scan similar to a rat
- Be able to detect radiation via inserts
- Contain radiation inserts without contamination to the rest of the phantom
- Contain 3 different tissue types of accurate densities: bone, muscle, lung
- Contain inserts for vital organs such as the heart, kidneys, lungs, and liver
- Separable in different pieces with minimal air gaps

Design Requirements:

1. Physical and Operational Characteristics

a. Performance requirements: The phantom should be able to fit inside the 12 cm diameter tube of the scanner while attached to the loading table. The phantom may be submitted to repetitive use depending on the needs of the researchers.

b. Safety: The device will not be used on human subjects so there are little safety concerns involved. When radiation is used in conjunction with the device safety precautions will have to be taken to avoid human contact with any harmful elements.

c. Accuracy and Reliability: A high level of accuracy is required in the design, as it will be used to calibrate the scanner being built. The phantom will need to mimic the anatomical features of the rat, including the bones, lung, and muscle tissue.

d. Life in Service: The phantom should be able to withstand repetitive use. Also radioactive materials will be used that must not be allowed to contaminate the device.

e. Shelf Life: The shelf life of the phantom should be an indefinite amount of time. The device should maintain working order until the machine is built and testing has been completed.

f. Operating Environment: The phantom will be exposed to radioactive material and must be able to withstand the radiation while remaining un-contaminated. It will be used at standard room temperature and exposed to the elements of the RT, PET, and CT scanners.

g. Ergonomics: The device should experience little human contact besides the placement on the scanning platform and the removal of the device for storage.

h. Size: The phantom needs to be able to fit inside the 12 cm diameter scanner tube. Also the phantom is to come apart into two or three pieces. This will allow for removal of the bones and possible radioactive material placement.

i. Weight: The device should not exceed 2 Kg.

j. Materials: Material restrictions are limited to densities that mimic the real rat tissue while also being capable of placement in all three scanners

k. Aesthetics, Appearance, and Finish: The physical shape and form of the phantom should resemble the anatomical properties of a rat, as the goal of the project is to make sure the device scans like a rat.

2. Production Characteristics

a. Quantity: One phantom is initially to be designed. Depending on the final design decided on a mold might be produced that will allow for multiple phantoms to be produced.

b. Target Product Cost: Product cost should not exceed a few hundred dollars.

3. Miscellaneous

a. Standards and Specifications: FDA approval is not required.

b. Customer: Customer is willing to try a variety of tactics to reach the final goal as long as the phantom accomplishes the desired functionality.

c. Patient-related concerns: The main concern for the cleanliness and storage of the device if only one is produced is that the radioactive materials used in the test trials not contaminate the device.

d. Competition: There are similar items that exist on the market today but they cost large sums of money. The goal of this project is to create an inexpensive, yet effective, alternative to these devices, which also accomplishes the necessary calibration and research.