Development of Mechanism to Improve Neonatal Rat Gastrostomy

Mid-Semester Report

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Abstract

Our client is currently in need of an improved surgical procedure to insert a feeding tube into neonatal rats. The rat pups are being used to test the effects of iron deficiency on the physiological development. The present procedure involves a polyethylene tube (PE-20) being inserted through a catheter into the stomach. It is secured to the stomach with three phalanges that are cut and molded at the tip of the PE-20 tube. The current procedure has less than a 50% survival rate. In order to improve this survival rate, our team has come up with several design alternatives. The designs focus on solving two separate issues: reducing the .56 mm diameter difference between the PE-20 tube and the catheter being inserted and securing the tube inside the stomach. Our alternatives include tightly molded curlicues, discs, and a balloon comparable to those commonly used in humans, and producing an enhanced version of the phalanges. In the future, we will look to incorporate expandable materials such as hydrophilic gels into these designs.

Motivation and Problem Statement

The goal of this project is to increase the survival rate of rat pups being tested for the effects of iron deficiency on their physiological development. According to Warren G. Hall, artificially reared rats are "indistinguishable from normally reared siblings in their initial responses to food at weaning and in their post weaning growth" [2]. Also, there are a large number of rats in each litter at a small cost. Due to their small size, a proportionate living space can be easily made to house the rats during the artificial rearing. All of these characteristics make rats the most studied species by means of the artificial rearing method [2].

The study of animals through the practice of artificially rearing began over fifty years ago [4]. Since then, there have been numerous efforts to better the overall process.

Individually hand rearing the rats is a very time consuming process and is comprised with too many variables for an experimental situation such as teaching the rat pups how to feed orally at a young age. Our task is to design a mechanism and/or procedure to secure feeding tube inserted through the abdominal wall in a neonatal rat's stomach.

Successfully completing this task without causing any disturbance to the rats would provide experimenters a control for their research. In order to obtain significant data, a control is needed to compare each group of rats. This is acquired through the means of gastrostomy. Gastrostomy is simply an opening directly into the stomach in order to control the type and quantity of food going into a species. One negative feature of artificially rearing rats is that the rat pups of only two days old are separated from their mothers [1]. In order to counteract this, an environment is simulated for the rats to dwell in.

In general, the use of rats in developmental studies provides data that can be compared to human infants. Information on the effects of alcohol on brain development and other dietary components has been collected through the process of artificially rearing rats. Furthermore, data has been collected on the effects of other nutritional and hormonal influences on intestinal cell growth. Data has also been collected involving nutrition's effect on metabolic rates and brain development [3]. Now, rats are needed to study the effects of iron deficiency on rat's physiological development with a new, more accurate means of gastronomy.

Current Procedure

Once the rats are two days old, they are ready for the Percutaneous Endoscopic Gastrostomy (PEG) surgery. First, three small prongs are formed by splicing the end of a 10 inch long intramedic polyethylene-20 (PE-20) tubing by using surgical scissors. The diameter of the inside of the tubing is .388mm with an outside diameter of 1.09mm.

Each slit is then pressed backward with the help of a small coil of copper wire and then placed in an ice bath to set the prongs. Ethanol and distilled water rinse the tubing. The ice bath is repeated, and the prongs achieve their structure. Once the prongs are made, the PE-20 tubing is inserted into a guiding sheath.

Next, the rat is anesthetized using chloroform. The rats white stomach is most prominent if the pup is on its back bent back slightly. The stomach is shoved to the edge of the abdominal wall so it can be poked through. The needle, with a different sheath over it, is injected directly into the pup's stomach without going deep enough to puncture the adjoining stomach lining. After successfully reaching the stomach with the sheath-covered needle, the needle is pulled out leaving only the plastic sheath. The guide sheath with the pronged tubing created in the first portion is now channeled into the rat's stomach. The tubing goes through both sheaths and enters the stomach. Finally, the two sheaths are removed leaving solely the PE-20 tubing in the rat's stomach.

Fig. 1: PE-20 tube being inserted through sheath into stomach

In order to secure the prongs against the stomach wall, the tubing is pulled drawing the stomach lining, abdomen, and skin together again. A plastic washer is pushed over the outer diameter of the tubing and slid toward the abdomen. The tension created by the washer pulls the prongs against the stomach wall. The tube stays in the rat for the duration of the experiment. Since the rat pups move around a lot when they are young, extra reinforcement is required. In order to reduce tension on the tubing, a guitar string is used to pierce the neck cartilage of the pup. The tubing is strong along with it and then exits the skin layer. A washer is placed on each side of the neck piercing.

Fig. 2: Molded tube wrapped around rat pup through the back of the neck.

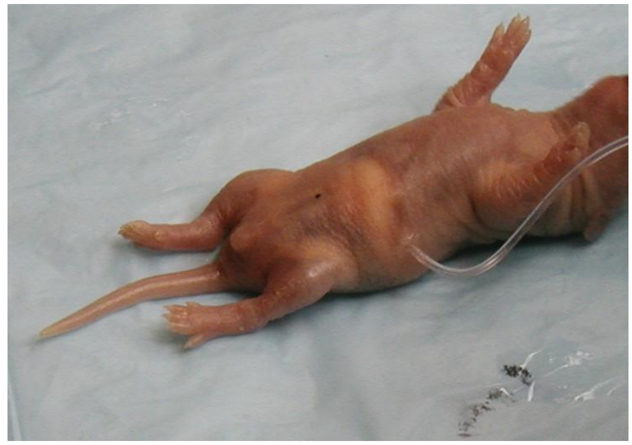

Fig. 3: PE-20 tube inserted into stomach after procedure

In order to have just one variable in the experiment, the rat's normal rearing environment is imitated. The rats are individually placed inside a deli cup that has been padded with 1/4'' cob bedding so that it is 1/4 to 1/3 full of bedding. This cup is then placed inside a separate cup with a washer attached to the bottom. Holes are drilled on the top of the cups to circulate air inside of the cup. The cups are then placed inside a distilled water bath kept at a constant temperature of 40.0 degrees Celsius. Styrofoam is added to the bath to keep the individual floating cups separated [5].

Problems with the Existing Procedure

The current procedure involves using a catheter to insert a small tube made from PE-20 into the stomach of a neonatal rat. This procedure has a less than 50% survival rate of the rats. Our ultimate goal is to increase the survival rate of the rats in order to decrease the amount of rats that are needed for the research. This survival rate is low due to problems with the existing procedure.

One of the main problems is that the needle creates a larger hole than the tubing. Our client uses a 16-gauge needle with a 1.651 mm outer diameter, whereas the tubing has an outside diameter of 1.09 mm. This 0.56 mm gap between the stomach lining and the tubing allows milk to be able to leak out of the stomach and into the abdominal cavity. Also, the hole created by the needle does not always heal properly around the tube. The larger this gap between the tubing and the stomach lining is, the longer the hole is going to take to heal and close up.

The phalanges cause the next problem associated with the technique. The phalanges are small and difficult to make. Our client needs a magnifying glass, very small medical scissors, and a lot of patience in order to make sufficient phalanges. Each phalange has to be the same length and width, which makes this process to be very tedious and time consuming.

Securing the phalanges against the stomach wall also involves a lot of practice. The phalanges do not always open up correctly after being threaded through the catheter. Since the phalanges pull the stomach up against the abdominal wall and the skin, there is a lot of tension the phalanges. This is the main source of two major problems. The first problem is that the tips of the phalanges can be sharp, thus, ripping or tearing the stomach lining. These tears allow milk and stomach acid to leak out. The next problem deals with the phalanges not functioning properly. Since the phalanges naturally want to bend back to their original shape, they have the tendency to bend back together and the whole tubing system can slip out of the stomach and rat completely.

The baby rats do not move very much at the beginning of the 10 days, but towards the end of the experiment they start to become active. This movement can cause a lot of tension on the tubing and can also cause the tubing to slip out of the stomach. Our client currently connects the tubing to the neck using plastic discs and wraps the tubing around the rat's body, which helps alleviate some of the tension on the tubing but it does not solve the problem completely.

This procedure is very time consuming and has a lot of room for error. In order to help improve the system, we need to design a catheter system that will alleviate tension, have secure phalanges, and have a smaller opening between the hole that the needle makes and the tubing.

Specifications

The tubing needs to be secured inside the stomach of the rat for 8 to 10 days. During these ten days the tubing needs to be secure enough so that no milk leaks out of the stomach. Since we are improving a research technique we need to keep the technique as close to the original one as possible so that there is still enough of a control to not have to redo all of the research. Our design needs to be reliable, repeatable, and have consistent results.

Since our project deals with animals there are a few ethical considerations that we need to take into account. Our team needs to make sure that the rats are weaned in the most humane way possible. In order to decrease the pain felt by the rat we need to decrease the amount of tension on the tubing. Also, this involves testing our design in order to decrease the amount of milk that leaks out of the stomach.

Design Alternatives

By incorporating various aspects of different, successful gastrostomy methods, as found in the literature, our team produced several design alternatives to solve the issues present in the current surgical technique. The designs are separated into two categories, one solving for the end of the tube that would secure the tube to the inside the stomach wall, and the other solving for the issue regarding the hole being of a larger diameter than the tube itself.

Tips (Solving for Stomach Securement)

To improve the method of securing the tube to the inside of the stomach wall, we first look at what minor adjustments could be made to make the phalanges a more viable technique. As previously mentioned, the tube often comes out of the hole. The client has looked at several of the rats that died, and found there to be a correlation between the size and consistency in each phalange to the rats dying. The rats seemed to survive most often when each phalange is the same size, and is longer (compared to the unsuccessful phalanges). If the team could solve this issue of inconsistent phalange length, the current use of phalanges could still be a good option.

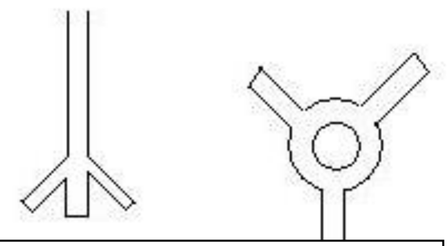

Fig. 4: Phalanges tip, side view and frontal view.

To make these phalanges, the process would remain the same as described above, where the phalanges are cut and then molded. The only difference is the phalanges would be cut using some sort of cutting tool that the team would fabricate. This cutting tool may consist of a system involving razorblades where the user puts the tube into the tool and then pulls a trigger, producing three identical phalanges at the tip.

The phalanges design, however, has several problems. The most critical is the fact that the method has a proven high failure percentage, and not all of the deaths can be attributed to an inconsistent phalange length. The cuts made can produce cracks that radiate down the tube, outside the stomach, so even when the phalanges hold the tube in the stomach, milk can leak out into the peritoneal cavity.

Another alternative to the phalanges is the “Disc tip”. This design is similar to the current phalange method, except instead of phalanges at the end of the tube there would be a circular disc. This method would solve the issue of possible cracks in the tube leaking milk outside the stomach because no cuts would be made. It would also create fewer pressure points on the inside of the stomach wall thus limiting the potential of the tip ripping out of the stomach.

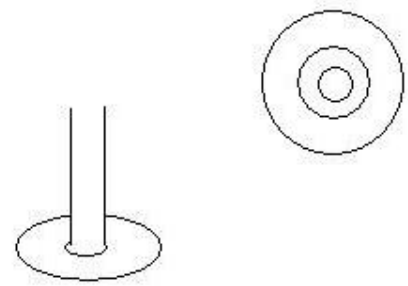

Fig. 5: Disc Tip (side view and frontal view)

The disc would be made is by melting the tip through use of an item like a hot plate or soldering gun. When the tip of the tube begins to melt, the tube is pressed against a flat surface to create the disc shape. This is immediately flattened in order to make the disc thin enough to fit inside the catheter. Early attempts have shown this method to be difficult because once the plastic melts, the disc it creates is too thick to be able to bend and fit inside the catheter.

Our third design, the “Curlicue Tip” incorporates a series of tight coils that would fit inside the stomach. The basis of this design originates from the pigtail catheter, which is widely used in humans. The curlicue method would also prevent the possibility of ripping out of the stomach, as it does not involve 3 specific pressure points but rather fairly well balanced circle of pressure.

The “Curlicue Tip” is made through use of a molding process similar to that described earlier in the current procedure to make coils that provide an ergonomic curve around the outside of the rat’s body. The end of the tube would be grasped by a pair of exceptionally thin surgical pliers and then wrapped repeatedly

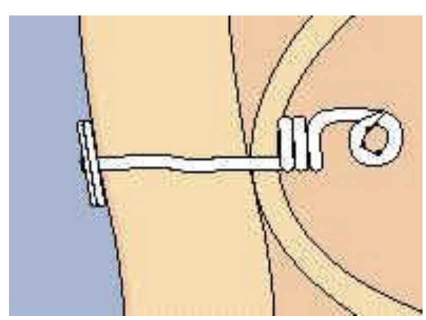

Fig. 6: Curlicue tip [6]

around the end of the pliers. Once this is done, the coiled tubing is emerged in hot water followed by an ice bath. It alternates between the two baths two to three times. The main problem with this method is that there is currently nothing in the design to prevent the tube from sliding completely out of the stomach slowly as the rat moves around.

Our final design is the "Balloon tip". It would operate in an identical method to that of the balloon catheter commonly used in humans. A sheath would surround the tube, which would be able to inflate at the tip. Once the tube has been inserted into the stomach, the sheath is then filled with water that inflates the tube.

Fig. 7: Balloon tip [7]

If the balloon tip is not ordered as its own part, the tip would prove to be difficult to make as it would most likely involve several different parts being welded together. Additionally, the rat's stomach is only 1-2 mL at this stage, and the balloon would fill a lot of this space up. Tests still need to be run to see how easy the balloon tip is to make and how much space it needs to function correctly.

Insertion Technique (Solving for Hole Size)

To solve the problems derived from the hole size being larger than the tube's diameter, the team produced several design alternatives that affect the insertion technique. The first idea came from a technique that has proven success in placing a gastrostomy tube in a neonatal rat. It involves lubricating the tube and inserting it through the esophagus. Once the tube reaches the stomach, it is pushed out through the stomach and abdominal wall. The tube is then pulled until the "tip" is the only part of the tube that remains inside the stomach.

Going through the stomach has been proven to be an effective method of inserting the gastrostomy tube. The only issue is that the procedure could prove to be too much of a change from the current procedure, possibly causing inflammation in separate areas than in the current procedure.

Another method involves having a sharp wire within the tube itself. The wire pierces the abdominal wall and stomach, which results in the hole, initially, being smaller than the tube itself. Then, the tube is pushed into the stomach. The key issue with this design is how to force the tube that is larger than the hole size into the stomach without tearing the tissue. Also how to keep the tip retracted until it has been inserted so that the hole does not again become larger than the diameter of the tube.

The third design alternative to solve for the hole size problem involves the use of expandable materials, like a sponge or nylon or some sort of hydrophilic gel that expands in contact with water. This design involves attaching the expandable material to the current size tube used and inserting it through the 16 gage catheter. When the tube comes in contact with the stomach fluids or the fluids of the peritoneal cavity, the material will expand filling in the gap between the edge of the tube and the stomach wall. This alternative would allow for the same sized tube and catheter to be used, except that hole size will no longer be a primary cause of failure.

Design Matrices

In order to evaluate our potential designs, two design matrices are set up. The design matrices are split into the two types of design alternatives. One design matrix focuses on the problems of the tip needing to hold the tube in the stomach while the other matrix focuses on the insertion method to decrease the hole size. The categories used to evaluate the designs are determined from our client specifications.

The design matrix for the tip designs is shown in table 1. The categories chosen to evaluate the designs are: function, ease of fabrication, consistency, size in stomach, and size for insertion. We define the function category as the ability of the design to hold the tubing in the stomach or anchor the tubing in place. Next, the ease of fabrication category looks at how simple it would be for our client to make this design for each tube for each rat. The consistency category determines how easily the design can be identically replicated. The size in the stomach category is to make sure the design does not take up too much room, block holes, or hinder the rat from digesting. Finally, the size for insertion category analyses if the design will be able to fit easily into the guiding sheath. Each category is given a rank from 1-4 with 1 being the worst and 4 being the best. The categories function and consistency are given double weight (x2) to emphasize their importance. All the scores are added for a total value out of 28.

Tip Designs						
	Function (x2)	Ease of fabrication	Consistency (x2)	Size in stomach	Size for insertion	Total
Disk	4	3	2	4	1	20
Curlicue	3	4	3	3	3	22
Phalanges	2	3	2	4	4	19
Balloon	3	2	4	1	3	20

Table 1. Design matrix summarizing criteria and results for tip designs. The curlicue design won due to its high scores in each category, especially ease of fabrication.

Even though the disk design has the highest score in function, it did not win due to problems with inserting the disk. The end winner is the curlicue design with high scores in each category and the highest is ease of fabrications.

The second design matrix reviews the designs for inserting the tubing. Table 2 shows the final matrix. The categories considered are feasibility, ease, hole size, and consistency. First, the feasibility category evaluates if the method is possible to do on the neonatal rats. The ease category looks at how easy it is for our client to perform these methods on the rats. The hole size category ranks how well the method is successfully able to decrease the hole. Lastly, the consistency category makes sure the method is able to produce the same results for each rat. These categories are also ranked from 1-4 with 1 being the worst and 4 being the best with a possible total of 16.

Insertion Methods					
	Feasibility	Ease	Hole size	Consistency	Total
Expandable material	3	3	3	3	12
Inserting through mouth	3	1	4	3	11
Wire	2	2	4	2	10

Table 2. Design matrix summarizing criteria and results for insertion methods. The expandable material idea won due to its high score in all the categories.

The best design for the insertion method is the expandable materials design. Even though inserting the tubing through the mouth while using a wire to puncture the hole solves the hole size problem better, they are not chosen. Inserting through the mouth did not win because it is a difficult procedure. Our client does not want to change the procedure in order to keep previous research and current research methods uniform. The wire also lost due to the fact that it would be impossible to add a sufficient tip to the tubing. Therefore, it received a low score in feasibility. The expandable materials idea, however, does not change the procedure too much and is still effectively remedies the hole size problem.

Future Work

Combining our two best designs gives us a curlicue tip with expandable materials added to help seal the hole. This will be the design we will pursue for the rest of the semester. To make this design happen, we need to figure out how big we want to make the curls on the tip and how to add the expandable materials. The material we are looking at right now is a hydrophilic gel that swells when it is made wet. We will have to devise a way to add this gel so that it seals the insertion hole.

Our next steps are to finalize this design and order the materials needed to implement the design. The materials needed are the hydrophilic gel and small pliers to wrap the end of the tubing into a curl. Our client is receiving rats for her research in November and told us we will be able to test our design on these rats. Before we actually test on live rats, we will test on a simple model to make sure the gel swells the right amount, and that the curlicue is able to hold the tubing relieving some of the tension. After this, we may modify our design. Then, we will test on live rats for an increase of survival rate.

Conclusion

In conclusion, all of our design alternatives would improve the success rate of the surgical procedure. We will be looking for ways to make all of these ideas functional, but will concentrate on the curlicue design incorporating an expandable material. With this improved surgical technique, our client's procedure will be much more efficient and consistent making her data more accurate and significantly decreasing the amount of rat deaths.

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[5] Sharon Blohowiak

Figures:

[6] http://www.cecostomy.com/images/trapdoor_2.jpg

[7] http://www.rch.org.au/clinicalguide/cpg.cfm?doc_id=8407

Appendix A: PDS

Neonatal Rat Gastrostomy Procedure (PDS)
9/17/09

Gerhard van Baalen, Laura Platner, Karin Rasmussen, Scott Sokn

Function: This procedure is to serve the function of increasing the survival rate of rat pups being tested for the effect of iron deficiency on their physiological development. Our task is to design a mechanism and/or procedure to secure feeding tube inserted through the abdominal wall in a neonatal rat's stomach.

Client requirements:

- Repeatable and simple
- Noninvasive procedure (as humane as possible)
- Stable/secure (Won't move out of Stomach)
- Improve survival rate (~80%)

Design requirements:

1. **Physical and Operational Characteristics**
    a. *Performance requirements:*
        i. 8-10 days continuous use (to fruition)
        ii. 20 minutes per hour milk is pumped to Rat
        iii. Needs to be secured in stomach for entire time
    b. *Safety:*
        i. Can't puncture through opposite side of stomach wall
        ii. Shouldn't expand insertion hole
    c. *Accuracy and Reliability*
        i. Repeatable fabrication
        ii. Repeatable surgical procedure
        iii. Consistent initial securement for each rat
    d. *Life in Service:*
        i. 8-10 days for each procedure
    e. *Shelf Life:*
        i. Sterile before use
    f. *Operating Environment:*
        i. Inside Rats Stomach
        ii. Temperature (38-39° C)
        iii. Acidity (pH = 3-4)
        iv. Minimal friction and tension on stomach wall
    g. *Ergonomics:*
        i. Form to Rats body
    h. *Size:*
        i. Fit in Stomach (1-2)mL without impeding digestive tract
        ii. *Current PE-20 tubing dimensions:*

1. *.38 mm inner diameter*
2. *1.09 mm outer diameter*

iii. Catheter Dimensions: 16 Gauge (1.68 mm)

i. *Weight:*
   i. Light weight (does not harm rat pup)
j. *Materials:*
   i. Metal puncture device
   ii. Polyethylene
   iii. Wire
   iv. Velcro and/or tape
   v. Sponge, nylon, hydrophilic gel
k. *Aesthetics, appearance, and finish:*
   i. Function over aesthetics

2. Production Characteristics

a. *Quantity:*
   i. *Surgical Procedure* with prototype
b. *Target Product Cost:*
   i. *Saving a Rats life: Priceless*

3. Miscellaneous

a. *Standards and Specifications:*
   i. Follow rat handling ethical specifications
b. *Customer:*
   i. Customer must be able to perform procedure
c. *Patient-related concerns:*
   i. Survival Rate
   ii. Milk Leaking from Stomach
d. *Competition:*
   i. Feeding Tube through mouth procedure
   ii. Modifying current procedure