UNIVERSITY OF WISCONSIN-MADISON

Device for Neurochemical Sample Collection of Freely Moving Monkeys

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12/6/2009

Contents

ABSTRACT

The timing of pubertal onset has developmental and social implications, yet researchers have not determined its triggers. To determine these triggers, Dr. Ei Terasawa studies the changes in brain chemistry of maturing Rhesus monkeys using a microdrive sampling system. The monkeys must not tamper with the neurochemical collection apparatus, as doing so may have serious ramifications on the experimental results and the monkey's health. Currently, tampering is prevented by confining the monkeys to chairs throughout the twelve-hour duration of the experiments. This is uncomfortable and stressful for the monkeys, which may affect test results, so the client would prefer to allow the monkeys to move freely. Though previous work has been done to design a protective device that permits greater mobility, none have fully met the client's requirements. Thus, three new design ideas were developed: a ski mask, bone screws, and a reverse cone. After considering factors such as safety and ease of implementation, the reverse cone was pursued. It was fabricated with two polystyrene half-shells lined with foam and attached together with cinch-locked bungee cord. Unlike previous designs, the weight is carried on the shoulders, not the top of the head. Preliminary testing on a monkey model has shown this design to meet the functional requirements. Future work is necessary to decrease the weight of the device.

BACKGROUND INFORMATION

Dr. Ei Terasawa and associates conduct research to determine the triggers of puberty. The timing of the onset of puberty is crucial to the health of an individual because earlier onsets can stunt growth and development. Though later onsets do not incur health concerns, it does apply discomfort from a social perspective. [1] In order to develop new treatments to prevent excessively early or late onsets, it is necessary to determine the specific triggers of puberty.

Current research suggests that there is a correlation between concentrations of neurochemicals, such as Gonadotropin Releasing Hormone (GnRH), around the pituitary gland and onset of puberty. [2] Dr. Terasawa conducts endocrine sampling experiments with young Rhesus monkeys every month during one and a half years of their early development. Because sex is expected to be a significant factor in the neurochemical composition during puberty onset, all animals in the experiment are female so results from all subjects can be directly compared.

The physical setup of this experiment consists of a sampling cannula positioned by a microdrive mounted to a pedestal on a Rhesus monkey (Figure 1). The pedestal, implanted into the skull months in advance of this study, consists of a rigid metal cylinder fitted into a bone window, stabilized with ample bone cement and several screws. On a sampling day, a sedated monkey is stabilized in a stereotactic fixture while the microdrive is carefully adjusted to position the end of a stainless steel cannula in a specific region of the monkey's thalamus. The cannula tip is a semi-permeable probe that neurotransmitters and other compounds can diffuse into during a twelve-hour period. The neurochemicals travel at 2 microliters per minute through one yard of tubing, which is why it takes hours to collect a useable sample. Also at this time, the client surgically removes the built-up granular tissue from around the pedestal.

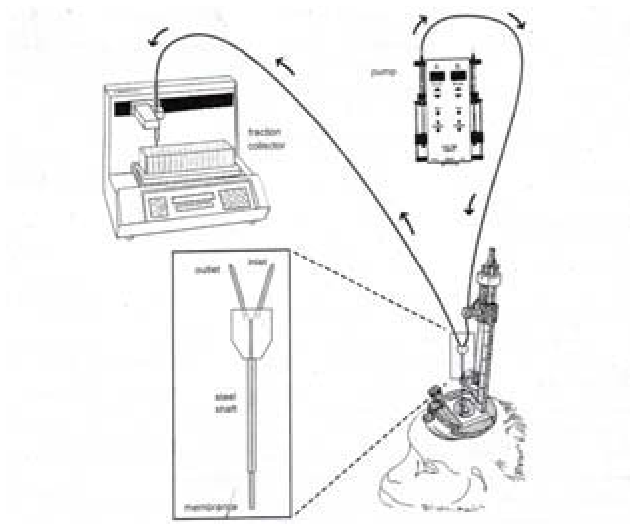

Figure 1. Schematic for neurochemical collection showing the cannula and pedestal.

Due to the invasive and extensive nature of the experiments, with no direct clinical benefit to the patient, humans aren't practical research subjects. Instead, Dr. Terasawa uses Rhesus monkeys to conduct these studies. Smaller animals, such as pigs, dogs, or rodents, are too physiologically dissimilar to humans for conclusions from their studies to be applicable. Fortunately, Rhesus monkeys show comparable endocrine patterns throughout their life cycle to humans. [3] Therefore, Rhesus monkeys are adequate substitutes to humans for this research.

Adult female Rhesus monkeys are 47 centimeters tall and weigh 5.3 kilograms. [4] Their life expectancy is 25 years. The ages of the monkeys in Dr. Terasawa's experiments fall around 1 to 2 years of age. Arm measurements are summarized in the anthropometric table in the appendix (Table 2).

During the twelve-hour duration of each experimental collection, the monkeys are confined to chairs to prevent them from touching the neurochemical sampling system (Figure 2). If they were to disturb the cannula, which is positioned in the brain, it could cause serious injury. However, confining the monkeys to chairs is not ideal for two primary reasons. First, the monkeys are understandably uncomfortable. This is scientifically relevant because distress and lack of movement can affect brain chemistry, such that experimental results may not accurately reflect ‘normal’ conditions needed for good results. Second, Dr. Terasawa wants to extend the neurochemical collection duration to allow for anesthetics to wear off before sampling begins. Her team hypothesizes the anesthesia is adversely affecting their results. Therefore, Dr. Terasawa desires a device that completely protects the microdrive while the monkey is able to move about a cage. If possible, this device should minimize the weight and length of the tubing, alleviating some of the weight burden while also curtailing the denaturing of neurochemicals by extraneous environmental factors, such as low temperatures. Until a protective device is developed, considerations for tubing and docking are secondary concerns to be addressed later on.

Figure 2. Rhesus monkey confined to a chair during neurochemical collection.

PREVIOUS WORK

This project has been worked on during the past three semesters. During the first two semesters, the prototype development consisted of a heavy metal cylinder. The third semester’s design incorporated a lighter plastic shell to reduce the weight on the monkey’s head and neck. Both designs failed to completely meet the client’s expectations and inspired this semester’s work.

Metal Cylinder

The first design was an aluminum cylinder that would sit on top of the monkey's head and protect the microdrive (Figure 3). The microdrive would fit inside a channel within the metal cylinder. This would prevent the monkey from touching the microdrive, though if the cylinder were moved, the microdrive could be indirectly tampered. The cylinder was secured under the chin via a strap (Figure 4). However, the metal cylinder weighed 480 grams centered on top of the monkey's head. When the prototype was tested on the monkey, the weight of the design would overburden the head and neck. In addition, the chin strap irritated the monkey's neck and ears.

Figure 3. A photograph of the metal cylinder design.

Figure 4. A photograph of the chin strap from the metal cylinder design.

Plastic Shell

Because the metal design was too heavy, another prototype was built using a lightweight polystyrene shell (Figure 5). The plastic shell was fabricated using a thermoforming process and incorporated an inflatable air bladder for a custom fit to the monkey's head. It connected around the chin via a leather watch strap. Since monkeys do not have a defined chin as in the case of humans, the strap did not provide adequate stability and security.

Figure 5. A photograph of the plastic shell design.

PROBLEM STATEMENT

Since previous designs have not adequately met client requirements, this semester's work focused on developing a device for protecting a neurochemical sampling apparatus used during cranial experiments on non-human primates. This involves continued efforts to reduce the weight of the device, secure it around the monkey's head, and better able to protect the microdrive unit.

CLIENT REQUIREMENTS

The client requirements for the project are the following: weight, ease of use, reproducibility, comfort, safety, and aesthetics.

Weight Requirement

The weight requirement was based off the plastic shell design, since the client deemed it sufficiently lightweight. The plastic shell design weighed 265.9 grams. Thus, it was decided that the design needed to weigh any amount less than 265.9 grams if the weight was centered above the head. Though the previous designs placed the weight on top of the head, it would be ideal to bring the load closer to the shoulders and center of the body.

Ease of Use Requirement

The device needs to be easily secured onto the monkey while she is under anesthesia.

Reproducibility Requirement

The client would like multiple units to be made for simultaneous experiments. Multiple copies of the device are also necessary to account for the changing sizes of the monkeys as they mature.

Comfort Requirement

The device may be worn for up to 48-72 hours. From observing the previous prototypes, the client requested an alternative to chin straps as a method to secure the device. It was observed that the straps would irritate the monkey's ears. Therefore, avoiding contact between the ears and prototype is essential for comfort.

Safety Requirement

Safety is the most important of the client requirements. The design must protect the microdrive, such that the monkey cannot make contact with it. If tampering of the microdrive were to occur, not only would the experiment be compromised, but the monkey's health would be jeopardized. The design would also need to be compatible with sterilization to ensure that bodily fluids, such as blood, would not transfer infectious agents. Thus, the design needs to be able to withstand multiple cleanings via methods such as autoclaving, gas sterilization, or chemical wash. The design also needs to be able to withstand impacts from the monkey. From the force-pull test run in a previous semester, it was found that the design should withstand impacts of up to 100 N of force.

DESIGN ALTERNATIVES

Three design alternatives were developed in order to address the client requirements. These design alternatives were the Ski Mask, Bone Screws, and Reverse Cone designs, as described below.

Ski Mask

The ski mask design (Figure 6) consisted of multiple parts: a vacuum bag filled with beads, a ski mask, a plastic shell, and a harness to hold the monkey.

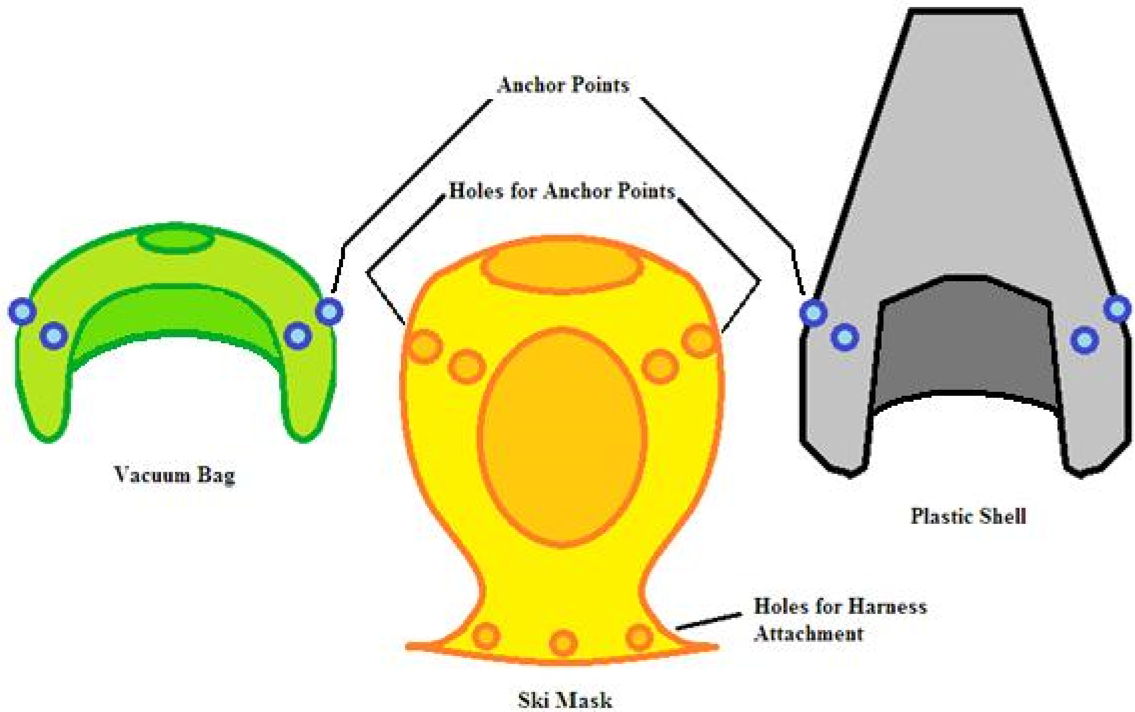

Figure 6. A cut-out view of the ski mask design, from the front.

The vacuum bag was developed from Dr. Larry Kaplan's research. [5] The principle of the vacuum bag involves using suction to draw out excess air from a bag filled with polystyrene beads to form-fit to the monkey's head. This would allow the device to conform to the monkey's head and serve as a foundation for a protective shell around the microdrive.

The suction device would then be sewed to the inside of a ski mask that would fit snugly around the back of the monkey's head, as well as the neck. The primary function of the ski mask would be to provide greater stability to the entire set-up, as well as connect the vacuum bag to the protective shell described below. The ski mask component would be similar to those worn by humans in the winter. It would avoid inconvenient stress points to the neck and ears, as opposed to a strap, as it disperses the weight of the protective shell. The bottom of the ski mask can attach to a harness already used for these monkeys to prevent lateral movement or rotation of the design.

The protective shell would be mounted on top of the ski mask around the perimeter of the head using snap-on buttons. The snap-on buttons would easy to use when implementing the device.

Theoretically, the combination of all the parts would create a device that is rigid and comfortable. However, it is a complex design and therefore difficult to fabricate. As a result, it would be difficult and more expensive to build multiple copies. A major disadvantage is that this design does not have any significant attachment points other than the snug fit of the vacuum bag.

Bone Screws

The bone screw design would use a cone-style helmet, just as the ski mask design, but would differ in the fixation technique. Instead of relying on a vacuum bag for fixation, this approach would anchor the cone to bone screws implanted in the monkey's skull. These bone screws would be implanted during the same procedure that is performed to create the pedestal. These bone screws would be located around the perimeter of the skull in a transverse plane. Possible screw locations are shown in Figure 7. After several months to heal and establish fixation, trials would begin where the screws would bear the load of the cone and brace against impacts incurred from the subject.

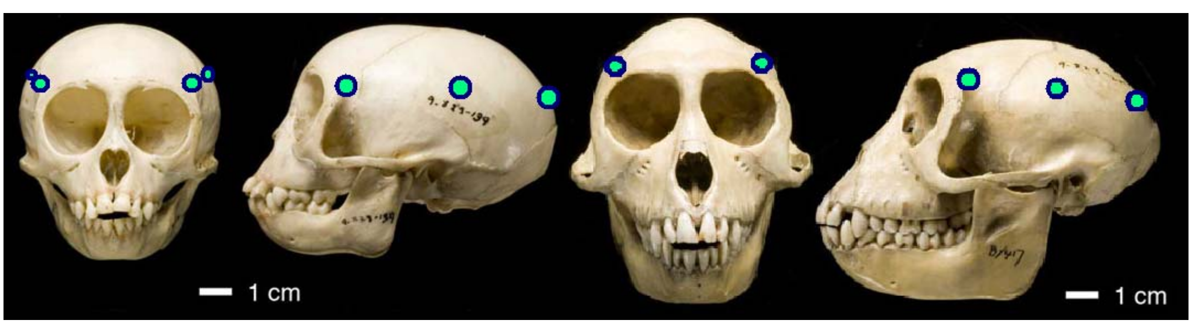

Figure 7: Proposed bone screw attachment points.

The best aspect of this design is the stability of the anchor points. The position of the cone or helmet does not rely on a snug fit or covering a large area of skin. Of course, the screw positions would not be absolute as the monkey matures and grows, as seen in a comparison between a juvenile and mature skull in Figure 7. Multiple shell sizes would be needed to correspond with the changing skull dimensions and ensure a good fit. A simple cone, similar to the plastic shell design, would be installed over the bone screws, as shown in Figure 8.

There are several aspects of this design that are cause for concern. First, bone screws for higher loading applications such as this require more bone thickness for sufficient fixation. According to Greg Gion, three to four millimeters of healthy cortical bone is ideal. For rhesus monkeys, in particular the juveniles, skull thickness varies from one to two millimeters. Skull fracture, bleeding, and other health risks would be of high concern with such thin bone to work with. Besides the mechanical performance, the aesthetics would also be an issue.

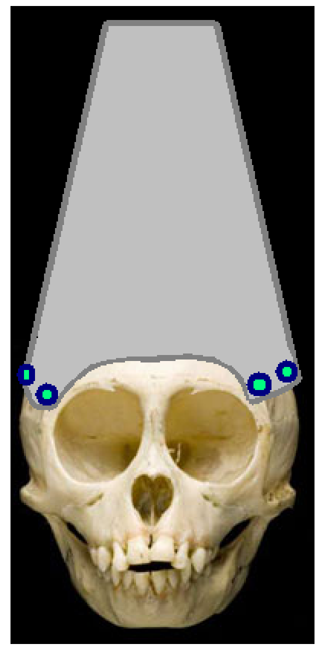

Figure 8. Proposed plastic shell attached with bone screws.

Research requiring monkeys to be implanted with Frankenstein-esque screws around their skull would draw fierce criticism from animal rights advocates and the public in general.

Reverse Cone

The primary component of the reverse cone design is a plastic conical device similar to those worn on cats and dogs with neck injury (Figure 9). The base would rest on the shoulders, and it would be tall enough that the monkey cannot reach up and touch the microdrive. In order to allow the monkey to breathe and eat easily, the device would have a hole cut out for the face.

This hole would be lined with foam for a tighter fit, thereby preventing the monkey from slipping the hands under the hole to touch the microdrive. At the base of the device, there would be holes to attach to a harness via zip ties to prevent the monkey from rotating the device. The client stated that zip ties would provide sufficient means of connection to the harness.

A notable feature of the reverse cone is that it flares out from the neck, increasing the distance from the microdrive and thus further preventing the device from making contact with the microdrive. It would be made of plastic that is rigid enough that, despite impact by the monkey, the sides of the cone would not touch the microdrive or fracture. In addition, the plastic would need to be able to undergo the thermoforming process by which the device would be fabricated.

Overall, this is a simple design that would be inexpensive and easy to fabricate. This would make it feasible to fabricate multiple copies for the differently sized monkeys. It would also make it easy to implement while the monkey is under anesthesia.

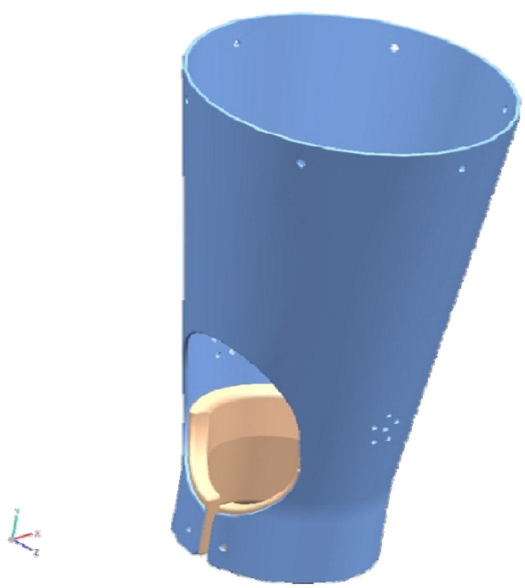

Figure 9. Computerized rendering of the reverse cone design.

DESIGN MATRIX

In order to determine the design that best suits the client's requirements, a design matrix was created. The design matrix consists of six of the most important criteria according to the client (Table 1). These criterion include: Safety, Ease of Implementation, Practicality of Production, and Comfort.

Category	**Weight**	**Ski Mask**	**Bone Screws**	**Reverse Cone**
Safety	40	25	30	**35**
Ease of Implementation	30	25	10	**28**
Practicality of Production	20	10	15	**18**
Comfort	10	7	5	**8**
Total	100	67	60	**89**

Table 1: Design Matrix used as one of the methods to choose the best design.

Safety is the most important aspect according to the client. As detailed in the Client Requirements, the main safety concern focuses on the ability of the device to protect the microdrive. The ski mask provides little prevention of side to side movement, thus increasing the possibility of altering the position of the cannula. Although bone screws provide a strong anchor to the monkey, additional surgical procedures increase the likelihood of infection. The reverse cone was the best choice, because from a special standpoint, it decreases the likelihood of making contact with the microdrive.

Because it is essential that the client can easily attach the device to the monkey while under anesthesia, it must be quick and simple to implement. Therefore, ease of implementation was the second most important criterion. The ski mask was comprised of numerous parts, each of which would need to be implemented separately, thus taking more time. Bone screws would require additional attention to ensure that no infection had developed, and that there were no other complications as a result of the surgery. In contrast, the reverse cone consisted of one outer shell, which could be attached to the monkey in a single step.

The next criterion was practicality of production. The engineering team and the client both desired a product that is easy to create such that it would be easy and inexpensive to fabricate multiple copies. The ski mask, as mentioned previously, has many components and would be labor-intensive and expensive. Bone screws would be easy to obtain, since they are commonly used in animal research. However, the surgery itself would require additional money, time, and administrative work. Because the reverse cone has fewer and readily available components and a relatively simple process, it would be easy and inexpensive to produce multiple sizes and copies.

Comfort of the device on the monkey’s head was weighted the lightest of the criteria. This low ranking was based on of the client’s request. Before the client uses the device, the monkeys will be adapted to the device for a month before testing. If any discomfort is seen at first, the client believes it will be desensitized after approximately a month. Because the weight of the reverse cone is on the shoulders, closer to the center of gravity of the monkey, the load should be dispersed, and therefore the design should be more comfortable.

Overall, the reverse cone was the most practical design. It is simple, easy to implement, and safe, making it the best of the three designs. The details of the final design are found in the following section.

FINAL DESIGN

The reverse cone design is a completely different approach than taken in semesters past. Instead of tightly securing a helmet to the top of the monkey's head, this design attaches near the base of the neck and flares out, giving the microdrive excellent buffer space to avoid collision with the walls. The primary components of this design are the shell, foam lining, and base collar.

Shell

The shell geometry is modeled after veterinary collars used on cats and dogs to limit their ability to nibble or chew on stitches after surgery. Elizabethan collars, which are narrow at the neck and flare out at the head, limit the access the wearer's head has to the body. [6] For monkeys with a microdrive on their head that must not be tampered with, the need is just the opposite, but the solution is quite similar.

By extending beyond the reach of the monkey's arms, they are unable to reach back into the cone and touch the microdrive or tubing. While this does add to the "bulkiness" of the design, it is still light-weight, and only a few inches taller than previous designs. A screen or mesh covering may be deemed necessary in the future, should the monkey make a habit of tossing objects into the cone that could interfere with the procedure.

The openness of the cone offers three major benefits. One, the researchers and veterinarians can see the microdrive by looking in from the top. They may need to check for tangling or pinching of the tubing, or assess the healing around the cement base where built-up granular tissue was removed. Second, this design allows for excellent air circulation. The skin is able to sweat and breathe without the moisture being trapped, and the site around the cement base can readily heal. Third, the microdrive has significantly more buffer space with the walls to avoid a potentially disastrous collision. The cone moves with the monkey's neck and head. This avoids the pitfalls of other designs, where straps and tight fits for stability were uncomfortable or vulnerable to tampering by the wearer.

Primates anatomically differ from cats, dogs, and other quadrupeds in the way their spine articulates with their skull. [7] Quadrupeds can easily look out of the cone, whereas a primate would be strained to do so. This issue is resolved with a face hole, positioned to allow the jaw to extend comfortably beyond the cone profile. The face hole allows for the wearer to easily eat, drink, breath, and see. This should reduce their anxiety as they should be able to engage in normal activities during the sampling period.

Foam Lining

The foam lining inside the shell is a protective measure for the wearer. Over the course of forty-eight hours, if this cone is loading a single point or region on their head, ear, etc, this could become irritating or painful. The foam used is polystyrene, because it is lightweight, cheap, and safe if accidentally ingested by the wearer. Obviously, ingestion is not desired, and in future work this foam will be coated in a rubberized layer that can't be picked at. The placement around the neck and around the face hole reflects the areas where this cone will be closest to the wearer. The thickness and shape of the foam may be modified in the future as more testing is completed.

Base Collar

The base collar is currently used in primate research for leashing and moving primates without the use of anesthesia. It is made of metal and securely fastens around the wearer's neck such that they can't pull it off and over their head. These collars come in several sizes, depending on the age and build of the wearer. This collar was intended to serve as another security measure for stability and wearer safety. After testing of assembly weight, it was deemed this component would not be implemented with the final prototype.

Final Assembly and Use

Manufacturing

The shell was originally conceived as a single body that could be slid over the monkey's head by flaring out the collar flanges, then securing the assembly with zip ties. While appealing in concept, the size and shape created a manufacturing dilemma. For simple and inexpensive construction, a two-half approach was pursued. A cast modeling half of the inner geometry of the cone, was machined from wood according to specifications on the draft prints (Appendix 3). A polystyrene sheet was heated in a 200°C oven until visibly pliable, then pressed over the cast to take its final three dimensional shape. Excess material and sharp corners were removed to minimize weight and ensure safety. Flanges on the lateral edges of two halves were aligned and drilled with holes for lacing the bungee cord. Until this point, the two halves were identical, making for simple production. One side was machined further to add the face hole. The position of this face hole was based on anatomical information gathered by the client. The two finished halves were fastened together using bungee cord laced through the halves (Figure 10).

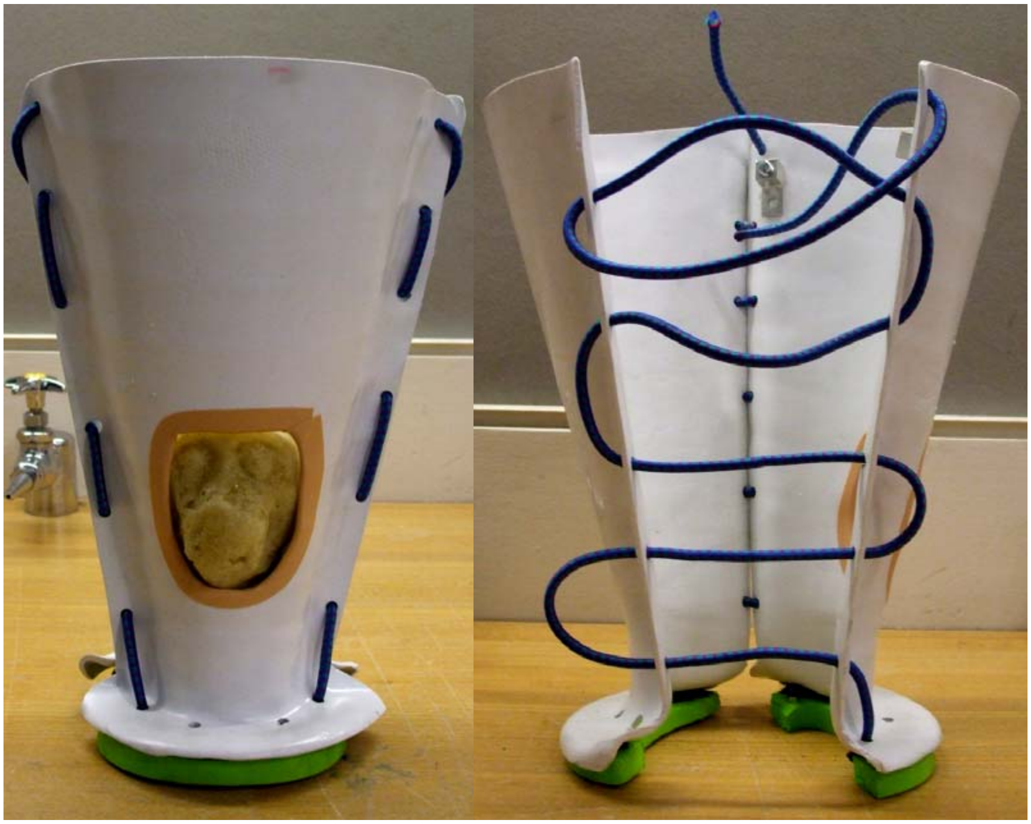

Figure 10. Front and side views of the completed prototype.

The bottom brim of the cone was lined with dense foam to improve comfort, as the shoulders are where much of the weight will be applied. The perimeter of the face hole was layered with moleskin tape as a precaution against the hard edge irritating the monkey's jaw during the experiment. These foam components are removable and replaceable, should they become soiled during the study.

Integration with Experimental Procedure

The client has concerns that the anesthesia is compromising the integrity of the samples in their studies. By doing the experimental set-up a day in advance of the twelve hour sampling period, the effects of the anesthetics should be negligible. Thus, the preparation for each sampling session would be as follows. At the leisure of the client, cones of various sizes would be prepared with moleskin and foam, ready to be trialed for fit on surgery day. The monkey would be anesthetized and taken to surgery for setting up the microdrive and cannula. Once the cannula is in place, the cone would be placed around the monkey's neck and head, then laced and cinched tightly. For simplicity, the client may opt to leave one side laced and opening it like a clamshell, leaving only one side to be laced and tightened. There will also need to be steps for threading tubing through the cone to a port in the jacket. The details of tubing implementation aren't yet known, as a future semester of work is needed to determine tubing and harness logistics. The still-anesthetized monkey would be connected to the sampling system and would remain so until after the experiment is complete. Upon sampling completion, the monkey would be sedated for removal of the cone and microdrive. The used cone would then be disassembled and cleaned using ethanol and water- based products. The cone is never to be autoclaved, as the heat (upwards of 120°C) would irreparably ruin the geometry as the polystyrene softens at 100°C. [8]

Testing

The first phase of testing determined the weight of the prototype. Originally, a base collar weighing 300 grams was attached to the bottom of the polystyrene shells for greater support. However, the prototype alone weighed 550 grams, so the combined weight was 850 grams, well above the desired weight of 250 grams. Since the shells were securely attached to each other without the base collar, and the diameter of the prototype was the same as that of the base collar, the base collar was deemed redundant. As a result, the base collar was removed from the final prototype.

The second phase of testing used a model of a monkey head. The prototype was secured to the model as it would a monkey, and team members simulated impacts similar to those seen by the monkeys by applying approximately 100 N of force to the shells. The prototype walls did not deform and maintained at least a three centimeters clearance with the microdrive unit. These results suggest that the prototype is ready to be tested on actual monkeys.

FUTURE WORK

For additional work, the first priority will be to test the device on a live monkey. This should involve observing how the monkey interacts with the device. Changes to the final design (foam type, wall thickness, etc) will be made in accordance to these observations and other qualitative data collected during testing.

Because it is hypothesized that the device is too heavy for the monkey, testing of a shell made from a thinner polystyrene sheet will be done in order to lighten the device to approximately 250 grams. 1/16- inch and 1/32- inch polystyrene sheets will be tested for use as the outer shell.

The tubing used to deliver samples from the monkey's head to an analysis device must still be implemented into the design. The client and veterinarians prefer to run tubing out of the reverse cone shell and down through the harness worn by the monkey. As such, minimal extra weight will be carried by the monkey, and it likely will go unnoticed on their back.

To accommodate the height added by the cone, a special cage must be created. The researchers currently use a cage approximately two feet tall. A coned monkey would be unable to sit or stand with this limited clearance. The client proposed creating a double-tall cage that could be produced by machinists in their department. This expense is not unique to the reverse cone design, as any protective device for the microdrive would create the need for additional vertical clearance for the monkey during sampling.

With the completion of shell manufacturing, tubing installation, sufficient fit and comfort testing, and cage modifications, the client may begin to conduct freely moving monkeys.

ETHICAL CONSIDERATIONS

Since this project revolved around a device for monkeys, ethical considerations pertaining to their well-being was particularly important in the design process. First of all, it was important that all aspects of the design, from placing the device on the monkey during the experimental set-up to having the monkeys wear the device for twelve hours, addressed any concerns that the veterinary staff or the Institutional Animal Care and Use Committee (IACUC) might raise. These include preventing the monkeys from incurring any diseases or infections from the device and preventing excessive surgical procedures. This was the main reason that bone screws were not ideal for this project, for it would require additional surgery and increased potential for infections. In addition, it made plastics that can be autoclaved a preferable choice for materials. The team also considered comfort of the monkeys throughout the design process. It was necessary to cut a hole for the monkey’s face so that they can eat and drink throughout the experiment.

In addition, the client requested this device to make the experimental process more comfortable for the monkeys. The research appears to be necessary to develop puberty-related treatments for humans and monkeys alike, so it is preferable to minimize the amount of distress experienced by the monkeys. Overall, the team regularly consulted with the clients and veterinarians to ensure that the design would address any animal care concerns that would arise.

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APPENDIX 1: PRODUCT DESIGN SPECIFICATION

Problem Statement:

This team's goal is to develop and produce a device that protects a neurochemical collection apparatus used during cranial sampling experiments on non-human primates. This involves continued efforts to reduce the weight of the device, secure it around the monkey's head, and better cushion the micro-drive unit.

Client Requirements

Final product must:

- Withstand repeated forceful blows and other tamper efforts from the wearer
- Integrate into and not interfere with researchers' data collecting processes
- Require no modification of current micro-dialysis apparatus
- Incur no limitation to wearer's limb's freedom of motion or be excessive in size/weight
- Detach readily only by researchers and staff, but not the wearer
- Either be completely reusable or includes cheaply producible disposable components

Design Requirements

1. Physical & Operational Characteristics:

a. **Performance Requirements:** The device must be strong enough to not fracture or deform significantly when 100N (rough estimate) is applied in order to protect the expensive micro-drive unit from damage.

b. **Safety:** The device must not contain sharp edges or other protrusions that may injure the wearer or researcher. The materials that are used must be non-toxic.

c. **Accuracy & Reliability:** The device must accommodate various head sizes of juvenile and near-adult non-human primate wearers as well as withstand repeated 100N blows

(10@1/sec) without critical damage.

d. **Life in Service:** Remain secure and intact during a 12+ hour session, and either be sterilization compatible or include cheaply and easily replaced components.

e. **Shelf Life:** At least 5 years.

f. **Operating Environment:** Standard laboratory environment for non-human primate research.

g. **Ergonomics:** The device must not restrict the wearer's limbs or infringe on their comfort beyond a temporary "desensitization" phase

h. **Size:** The base of the device should be based on the upper and lower estimates of juvenile and adult female rhesus monkey skull size. The height of the device must accommodate the micro-drive when extended to position "28".

i. **Weight:** Less than 0.500kg, with no lower limit. Ultimately the assembly must not be a burden for the wearer.

j. **Materials:** Non-toxic, compatible with sterilization if reusable, cost-efficient if disposable, and sufficiently light-weight.

k. **Appearance & Finish:** Aesthetically pleasing, ready to use "as-is" without obvious reason to have concern for wearer or researcher health or safety.

2. Production Characteristics:

a. **Quantity:** 1 reproducible device. Smaller and larger sizes may be pursued in future development and construction.

b. **Budget:** Up to $1000 for materials and any other incurred costs.

3. Miscellaneous:

a. **Standards & Specifications:** The design and construction of the device must comply with USDA regulations and NIH guidelines, subject to approval from the attending veterinarian.

b. **Customers:** Primarily for research with Dr. Terasawa, but potentially other medical professionals dealing with delicate brain/head cases.

c. **Patient-Related Concerns:** It should create significantly less stress for the wearer than the current method (primate chair) and allow for better mobility.

Competition:

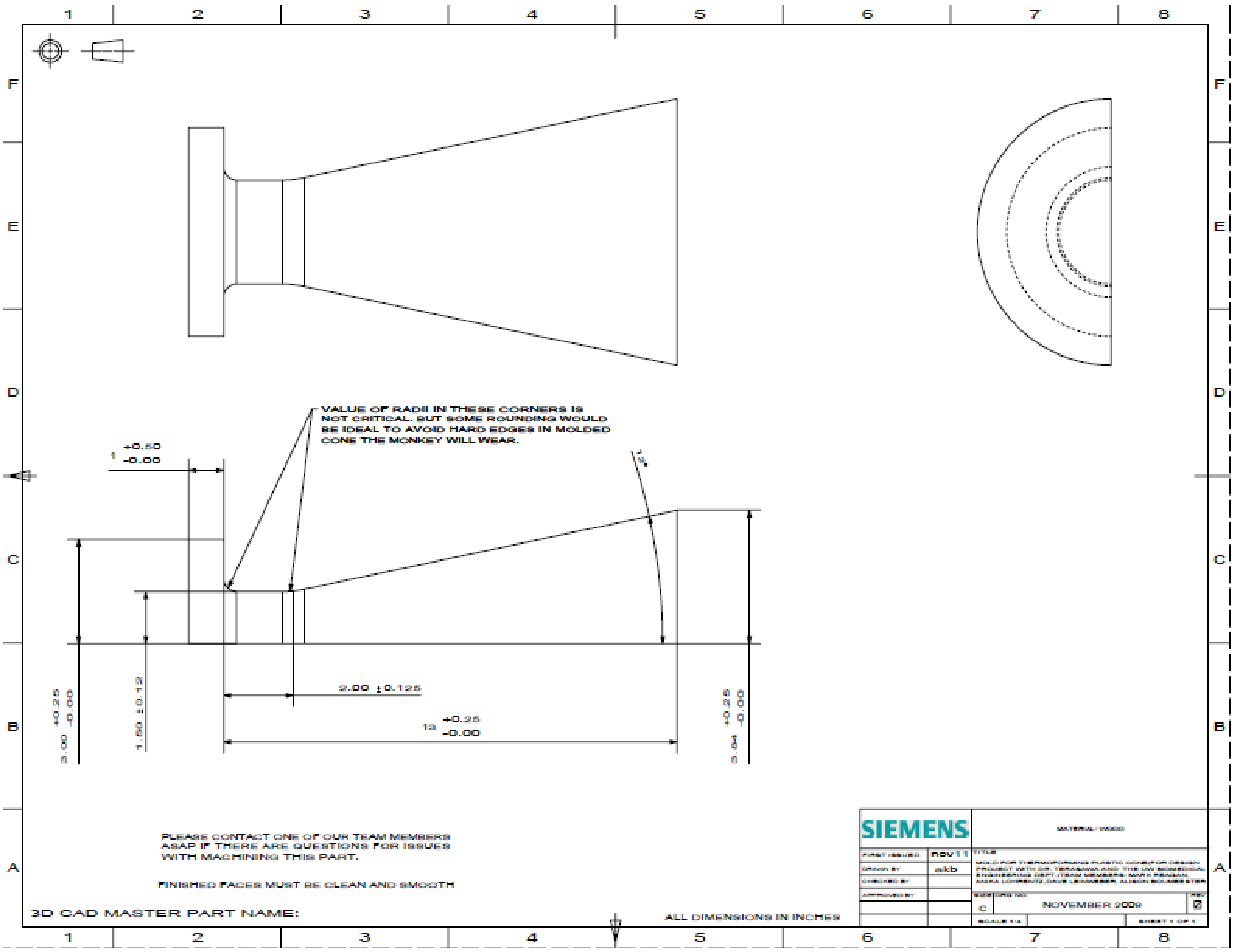
No currently known products specifically address the need to protect the microdrive unit during cranial neurochemical collection studies on non-human primates.

APPENDIX 2: ANTHROPOMETRIC TABLE OF RHESUS MONKEY ARM LENGTHS

	Small Monkey	Large Monkey
Shoulder to Elbow	4.125 inches	5.625 inches
Elbow to Wrist	4 inches	4.625 inches
Wrist to Fingertip	2.325 inches	3.5 inches
Total Length of Arm and Hand	10.5 inches	13.75 inches

Table 2: One of the researchers, Kim Keen, took the measurements above to help the design team determine the appropriate dimensions of the prototype.

APPENDIX 3: DIMENSIONS OF MOLD FOR REVERSE CONE



APPENDIX 4: EXPENSES

Item Description	Quantity	Cost
High Impact Polystyrene Sheet, 48"x60"x1/8"	1 sheet	$40.00
Screw Locking Cinch, two pack	1 pack	$1.68
Bungee Cable, two pack	1 pack	$2.10
Moleskin Tape, 5yd roll	1 roll	$7.28
Krylon Plastic Paint	1 can	$7.00
Velcro, Adhesive-backed	5 feet	$8.45
Open-cell Soy-based Foam, 24"x24"x1"	1 sheet	$3.14
Dense Craft Foam	2 pieces	$2.10
Poster	1 sheet	$36.00
	Total	**$107.75**