Veterinary Bone Marrow Aspirate Model

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Client: Dr. McLean Gunderson – Advisor: Dr. Randy Bartels
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Problem Statement

Veterinary professionals commonly collect bone marrow aspirates from three main sites in dogs and cats: the iliac crest, the trochanteric fossa, and the proximal humerus. As no veterinary bone aspiration models exist, veterinary students practice on cadaver dogs which may only be used for about 5-10 aspirations. This project aims to create an affordable and anatomically correct model of a dog forelimb with relevant tissue structures, mechanically accurate bone models, and the potential to store "bone marrow" for collection, allowing veterinary students to practice the skill of bone marrow aspiration.

Background and Motivation

Background

- The purpose of bone marrow aspiration is to examine both the fluid and the tissue of the marrow.
- A small incision is made above the site where the sample will be collected.

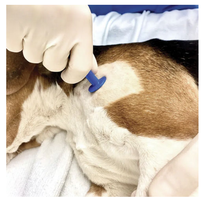

Figure 1. Popping the aspiration needle through the stab incision [4].

Figure 2. Bonnie Bone Marrow Biopsy Skills Trainer [3].

- An Illinois needle is then inserted at a perpendicular angle to the bone and pushed in a "clockwise-counterclockwise" rotation until it has fully advanced into the marrow cavity [1].
- A syringe is used to aspirate roughly 0.5 mL to 2 mL of bone marrow [2].
- There exist human aspiration models, such as the Bonnie Bone Marrow Trainer ($2,214) [3].

Motivation

- Currently veterinary students use a cadaver to perform the bone marrow aspiration but are unable to retrieve any bone marrow, so students are unable to know if they performed the procedure correctly.
- Practicing bone marrow aspiration on models helps students develop skills and improve technique before working on live animals.
- Models exist for the human anatomy but are very costly and no veterinary models for the aspiration procedure exist.
- Cadaver bones are in rough shape after only a few uses, requiring multiple cadavers for all the UW vet students to be able to perform this procedure.

Design Specifications

- **Performance requirements:** Anatomically accurate dog scapula, humerus, proximal forelimb; manipulatable shoulder joint; replaceable aspiration site
- **Safety:** Allows for harmless use of Illinois bone biopsy needle
- **Accuracy:** Dispels 0.5 - 2 ml of bone marrow, shape of 13.6 kg dog
- **Life in Service:** 5 years in class use; punctured humerus replaced every 5 punctures; muscle every 20 punctures
- **Shelf Life:** 12 years in a cool environment
- **Ergonomics:** Puncture allows similar feel to that of a real humerus
- **Weight:** No more than 2 kg, transportable
- **Materials:** Similar look and feel to that of a dog limb
- **Cost:** No more than $1,600, low cost replaceable components

Modeling and Prototyping

- Creating the bone structure:
  - In order to have an anatomically correct structure, the model was based off of bones from a beagle.
  - The right humerus, scapula, radius and ulna were 3D scanned and converted into STL files that could be processed to create the model.
  - These files were then converted to editable CAD files using Fusion, and then edited using Solidworks.
  - The two most important components of the model that needed to be added to the scanned parts were the shoulder joint, and a replaceable component that could be aspirated and replaced without having to replace the entire humerus.

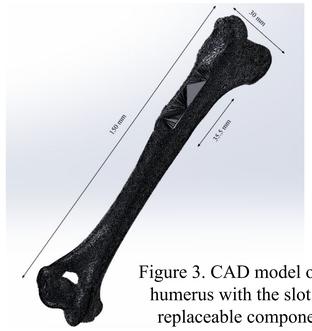

Figure 3. CAD model of the humerus with the slot for replaceable component

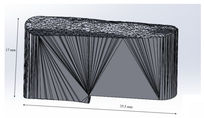

Figure 4. CAD model of the replaceable component.

Figure 5. Ball and Socket Joint.

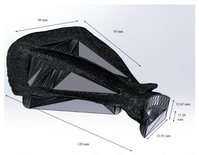

Figure 6. CAD Model of the Scapula.

- Creating the Shoulder joint:
  - Two options for the shoulder joint were explored, the first was a U-joint, which would allow for realistic flexion and extension. However this was not as effective for rotating the humerus, which is critical for the aspiration procedure leading us to use a ball and socket joint.
- Creating the replaceable component:
  - To create the replaceable piece a section of the bone was cut out that went through the bone so that it could be removed when pushed out from the extrusion in the back.

Testing and Results

Material and Thickness Testing

- Qualitative testing conducted by Dr. Schmidt.
- Samples of PLA, ABS, and PETG at 1 mm, 2 mm, and 3 mm punctured with an Illinois needle over a styrofoam block for pass/fail assessment.
- 2 mm PLA, 3 mm PLA, 3 mm ABS passed (Figure 8).
- PETG failed due to being weak and too slippery for needle.
- PLA's strength and texture were found to best mimic bone, with 3 mm thickness feeling most accurate to the procedure.

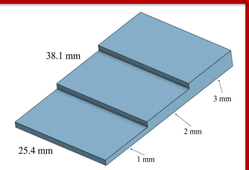

Figure 7. Sample material CAD design.

Material	Pass (mm)	Fail (mm)
PLA	1, 2	3
ABS	3	2, 3
PETG		1, 2, 3

Figure 8. Material pass/fail results.

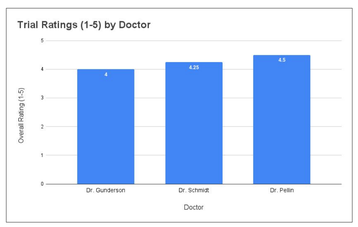

Figure 9. Ratings of the model by doctor.

Figure 10. Dr. McLean Gunderson testing the model.

Replaceable Component Testing

- Three doctors tested the model's aspiration functionality by piercing the replaceable component three times (Figure 10).
- Ratings (5.0 scale): Dr. Pellin 4.5, Dr. Schmidt 4.25, Dr. Gunderson 4.0 (Figure 9).
- Dr. Pellin and Dr. Schmidt observed that holding and puncturing the bone felt realistic.
- Dr. Pellin noted splitting of the replaceable component after the first puncture, indicating that the PLA should be thicker.
- The doctors recommended silicone tape instead of nitrile muscle, as the tape also secures the replaceable component.
- Average rating: 4.25 ± 0.25, indicating high accuracy with minimal variability.

Final Model

- The final model features the humerus, scapula, and the proximal forelimb 3D printed in PLA to simulate bone properties.
- A purchased carbon steel ball and socket joint is used to simulate the rotational motion of the shoulder joint, while the elbow joint is is fixed in place.
- The replaceable component inserts directly into the humerus at the aspiration site, mimicking the surface texture of the bone. It is secured with silicone tape which also accurately mimics the thin layer of surrounding tissues.
- The replaceable component includes backside access to fill bone marrow fluid or foam, and a tab to enersure insertion in the correct orientation.
- Skin is fabricated in the client's lab using neoprene coated in pourable silicone and a strip is secured at the aspiration site using silicone tape to conserve material.
- The limb is secured to a portable Masonite base plate with slip-resistant rubber feet and a faux fur covering.
- The final cost to fabricate the model was $26.68 and each replaceable component costs $0.11 to 3D print at the UW Makerspace.

Figure 11. Final model.

Future Work

- A blueprint of the design, materials, and detailed instructions for fabrication will be provided to the client and her team for assembling additional models.
- Bone marrow fluid will be fabricated by the client for in class use of the model.
- Using the techniques learned from the creation of this model, additional models for different sized humerus aspiration sites could be created, as well as additional models of the other sites that are used for bone marrow aspiration.
- Create a port system with tubing that refills the simulated bone marrow fluid as negative pressure is applied to the humerus by aspirating.

Acknowledgements

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