Preliminary Report: Structural and Mechanical Function of Canine Forelimb

Biomedical Engineering Design

Department of Biomedical Engineering

University of Wisconsin-Madison

October 13, 2023

Client

Dr. McLean Gunderson

Advisor

Dr. Christa Wille

Team

Kaden Kafar (Co-leader)
Colin Fessenden (Co-leader/BSAC)
Samantha Kahr (Communicator)
Dan Altschuler (BWIG)
Jake Allen (BPAG)
Matt Sheridan (BWIG)

Table of Contents

Abstract

First-year veterinary students must learn the anatomy and physiology of canines in detail. This information is complex and can be difficult to learn, with physical models providing a valuable way to more quickly and accurately absorb this information. Canine cadavers are commonly used, but they fail to show the dynamic functions of muscles and can pose financial challenges. Therefore, a relatively inexpensive model that reinforces the mechanical and anatomical properties of a canine's musculoskeletal system is required. Current models fail to meet needs in an array of ways such as a lack of detachable muscles, dynamic movement, and contain visually inaccurate muscles among other anatomical issues. To attack this challenge, the team decided upon a model in which canine forelimb bones will be 3D printed using tough polylactic acid (PLA), and muscles will be molded from silicone with color-coded embedded fabric. The components will be connected at anatomically correct attachment points using neodymium magnets. These magnets will have a strength at which they can easily be attached and detached, yet not fail under the tension of the muscle. Spring force testing will be used to determine the strength of the muscle and the magnets ensuring the durability and accuracy of the model. Additionally, a survey will be given to veterinary students to assess the intuitiveness and accuracy of the model. An accurate and durable model will provide students with an effective and more cost-effective way to learn the anatomy and physiology of canine musculature.

1. Introduction

Motivation

First-year veterinary students must learn anatomy, histology, and physiology in great detail to prepare for the rest of their education and their careers. However, the structure and function of bones, joints, and muscles is very complex and therefore difficult to learn. Hands-on learning is the best way for students to gain a deep understanding of these concepts, but rigid cadavers do not help show the functions of different muscles and current models are inaccurate or incomplete. The motivation for this project is to create a simple and advanced model to reinforce critical anatomical and mechanical properties of the musculoskeletal system of an animal.

Competition

There are three competing solutions that currently exist. The first is a simple bone model made by Vetwho. It is sold for $78 and includes all of the bones found in the forelimb of a dog [1]. This model is good because it is able to bend at the joints, but it does not include any muscles. A near-identical model is also sold by Axis Scientific [2]. The second design is a full model of a dog with muscles and organs, created by Anatomy Warehouse. This is sold for $365 and does include muscles but is completely static and does not have bones [3]. The final competing solution is the current model being used to teach veterinary students. This model is an Axis Scientific bone model that has been modified with pins, hooks, and elastic bands to include detachable muscles that allow the model to move similarly to an actual limb. The largest issues with this model are that the bands do not look realistic, and the pins and hooks are a less intuitive attachment system. Additionally, there are problems with the bands stretching out and losing the tension needed to effectively counterbalance each other and hold the limb in the correct position.

Problem Statement

The group is creating a realistic model of a canine forelimb to replicate muscle and bone interactions in canine's forelimbs. The model should be easily moved and act as a training model for veterinary students to learn the mechanics of the important joints in those animals. This includes detachable muscles, muscles with similar mechanical properties to real muscle, and the model moving as expected when applied with external forces.

2. Background

Anatomy of Dog Forelimb

A canine's forelimb is a complex system of skeletomuscular systems. In order to gain knowledge on how the forelimb works Ron Shahar and Joshua Milgram studied the morphometric and anatomic aspects of a canine forelimb [4]. To conduct this research, they had to euthanize four healthy, adult, crossbred dogs. They slowly removed and recognized forty-four individual muscles and gained morphometric data on all of them. They were able to gain everything from the physiologic cross-sectional areas (PCSA) of the muscles to the position of insertion and origin of each muscle. Using this data, the team can ensure both proper placement of each muscle modeled but also that each muscle outputs and generates a similar force to the actual muscle in live dogs. For example, the biceps brachii has a mean mass of 27.92 g, a mean length of 11.05 cm, a mean fiber length, 2.65 cm, pennation angle of 15.89, and a PCSA of 2.04. Using this valuable data, it is possible to ensure the model can accurately represent that of an actual canine forelimb.

Mechanical Properties of Ecoflex Silicone and Canine Skeletal Muscle

A major goal of the project is for the muscle in the model to simulate native canine skeletal muscle as closely as possible. To do this, it is important to understand some mechanical properties of both silicone material and native canine muscle. A study was conducted by Jessica Sparks and other scientists comparing mechanical properties between Ecoflex silicone and native animal muscle tissue [5]. The method of this experiment was to quantify the stress/strain and biomechanical aspects of deep tissue injury by using Ecoflex 00-30 and 00-10 then comparing to that of animal muscle tissue. After performing tests, stress distribution trends in both the muscle [6] and Ecoflex 00-30 were quite similar, but the stress magnitudes were higher in the silicone than in muscle. This information can provide the team with a better understanding of how the silicone will mechanically replicate the native muscle tissue.

Client information

Dr. McLean Gunderson is a professor in the Department of Comparative Biosciences at the University of Wisconsin's School of Veterinary Medicine. She is the lecturer for Veterinary Anatomy, the class that all first-year veterinary students must take to learn anatomy, histology, and physiology of animals.

Client Requirements

The client requests an anatomically correct model of a dog's forelimb with accurate bone structure, functional muscles, and removable muscle attachments. Ideally, the model will have all of the muscles found in a dog's forelimb and will differentiate between muscle and tendon tissue. The model must be durable enough to withstand usage throughout four weeks, four times a week, by about 100 students, and then still be functional after long periods of storage. The model should be able to withstand this cycle of use and storage for several years. The muscles on the model must be easily detached and reattached to the bones to account for the range of physical abilities found in veterinary students. Additionally, the tensile strength of each opposing muscle group must be taken into account so that they do not overpower each other and affect the movement or structure of the model.

Design Specifications

The device is a model of the forelimb of a medium sized dog for the use of first-year veterinary students. The model uses 3D modeled bones and muscles to replicate the connections, functions, and appearance of the full limb of the dog. The model should be easily used by the students to get an understanding of muscle connections and functions. In terms of safety, the device should be made of materials that can be sanitized after many students repeatedly use it, and the materials should be strong enough and the tensions weak enough to prevent the model from snapping and hitting someone. Because the model will be used in a classroom, it will be exposed to regular room temperatures around 20-22 °C and typical conditions of 30-60% humidity. The weight of the model should not exceed 10 kg to allow for easy transportation. The materials for the bone must be durable and they must be usable in a 3D printer. The materials used for the muscles should be as close to real muscle as possible, most notably having elastic properties that do not degrade with time or use.

Preliminary Designs

Muscle Design 1: Elastic Bands

The elastic bands design consists of elastic bands of varying strengths that mimic the action of muscles. The bands would be made of different colors to distinguish between the different muscles. The size and shape of the elastic bands could not be manipulated to mimic the size and shape of real muscles, but the tensile forces could be varied such that opposing muscles could counteract each other in a way that mimics real muscles. The elastic bands will need to be attached to the muscle and bone using hooks, as magnets and Velcro will not be feasible attachments for elastic bands.

Muscle Design 2: Resin

The resin model would be molded by pouring the resin into 3D printed casts that could perfectly match the size and shape of specific muscles in a canine's musculature. The group will print the negative area of the muscle tissue using a PLA material, and sand it down to create a smooth material. Before pouring, the group would be able to easily dye the resin to match whichever color is decided to be used for our muscle material. Next, the group will pour the resin into this mold, and wait for it to harden. Next, either a magnet attachment will be added during the hardening portion, or a Velcro attachment will be attached using glue after the resin hardens.

Muscle Design 3: Silicone and Fabric

The silicone and fabric model would involve a similar method to the resin model. It would start by combining the design and solutions of an EcoFlex solution into a 3D printed cast. This cast would be done in the same way as the previous design choice, using PLA material. There are varying EcoFlex solutions of different hardness levels that will be chosen to mimic the tensile strengths of the different muscles. A chosen color of spandex fabric will be laid into the mold, and the chosen strength of EcoFlex silicone will be poured into the mold. The desired attachment would either be glued to the outside of the mold or placed in the chosen position before the silicone cures.

Attachment Design 1: Velcro

This attachment design consists of complementary Velcro pieces adhered to the modeled bone and muscle/tendon. The Velcro would be placed at the proper attachment point and cut down to match the anatomical muscle connection of a canine as closely as possible without substantially sacrificing the strength of the bond. Once cut, the Velcro pieces would be secured in place on the bone and muscle via glue. Users would then be able to intuitively attach and detach the muscle to bone by connecting and separating the Velcro.

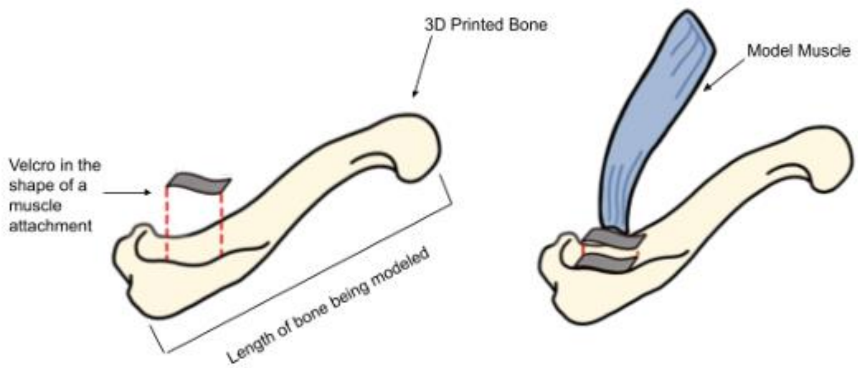


Figure 1: Velcro attachment design with a piece of Velcro on the bone and a matching piece on the muscle

Attachment Design 2: Magnets

The second attachment design uses integrated neodymium magnets to secure the fabricated muscle/tendon. Anatomically correct muscle attachment locations would be identified, and the 3D model of the bone would be altered to include an indented housing for a magnet in that area. One magnet would be inserted into the housing within the bone and another adhered to the corresponding attachment point on the muscle. The best method of adhering a magnet to the fabricated muscle would need to be tested; such as gluing the magnet to the surface of the muscle or embedding it during the muscle molding process. Once complete, users could easily remove and reattach the muscle from the bone through magnetism.

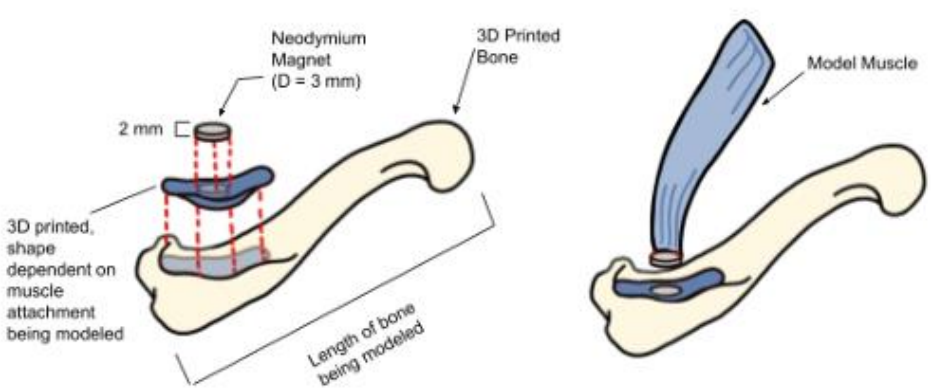


Figure 2: Magnet attachment design with embedded magnet housing

Attachment Design 3: Button Release Pin

The third design uses embedded pins with a button attachment/release to secure the fabricated muscles to the modeled bone via a ball and socket joint. A bolt with a round head would be inserted into an anatomically correct attachment location in the bone. The button head would be attached though the fabricated muscle so that the push button is on one side, while the insertion point is on the other. Users would then be able to attach the muscle to the bone by applying force at the attachment point and intuitively detach the connection by pressing in the push-button and pulling the two components apart.

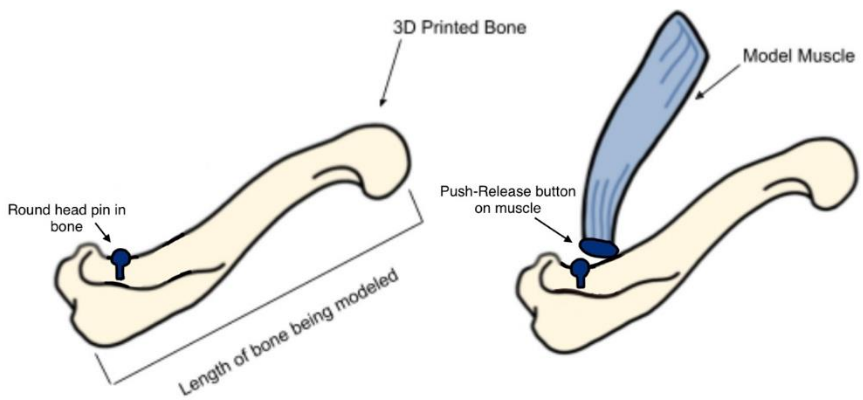


Figure 3: Button release pin attachment design with round head pin in bone and matching button on muscle

3. Preliminary Design Evaluations

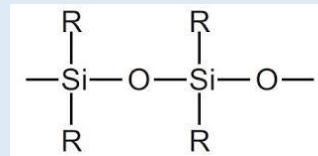
Design Criteria	Design 1: Elastic Band 		Design 2: Resin 		Design 3: Silicone 	
Ease of Fabrication (20)	**5/5**	20	**5/5**	20	**4/5**	16
Durability (20)	**4/5**	16	**4/5**	16	**5/5**	20
Mechanical Similarity to Muscle (20)	**3/5**	12	**2/5**	8	**4/5**	16
Safety (15)	**2/5**	6	**3/5**	9	**4/5**	12
Appearance (15)	**1/5**	3	**3/5**	9	**4/5**	12
Cost (10)	**5/5**	10	**4/5**	8	**5/5**	10
Total (100)	**67/100**		**70/100**		**86/100**	

Table 1: Design Matrix for Muscle Material

Muscle Design Matrix Criteria

Ease of Fabrication

The Ease of Fabrication category refers to the model's capacity for production during the prototype stage. It specifically relates to the capability to construct a functioning muscle prototype. The team decided to weigh this category as a 20/100. Although the main focus for this semester is to fabricate a prototype, the ability to fabricate the muscle material efficiently is important in terms of long-term manufacturing.

Durability

The durability of the model is how the muscle tissue will degenerate or wear over time. The material for the muscle tissue of the model needs to be strong enough to be used by many students over a long period of time. The model will be under intense use of around 100 first-year veterinary students for around 4-5 weeks, so the muscle material must not degenerate after being handled over time. With that being said, the team weighed this category as a 20/100.

Mechanical Similarity to Muscle

The mechanical similarity between the model muscle and actual native muscle tissue is crucial to accurately represent the physiological properties of a canine forelimb. To give veterinary students the most beneficial learning experience when utilizing the model, the muscle material must mimic key mechanical properties of native canine muscle such as hardness and flexibility. With this information in mind, the team weighed this criterion as a 20/100.

Safety

The safety category was weighted at 15/100. The model must be safe for its users; more specifically, the muscle material must not have any impurities that could cause harm. Additionally, the material should not be toxic chemically. Although there is minor risk when handling the muscle material, it is still a respected criterion for the design.

Appearance

It is best for the anatomical appearance of the muscles in the model to be similar to that of native canine muscle tissue. However, the physiological function of the model can still be adequate even if the model does not look like actual muscle tissue. The overall appearance of the muscles in the model can be helpful for visualization in learning. The weight of the appearance category for the muscle material received a 15/100 for said reasons.

Cost

The category of cost relies on the budget provided by the client of $500. While it is important to stay under budget and satisfy the clients' needs, the cost category was only weighed as a 10/100 due to the fact that the team is certain that the muscle material will be relatively inexpensive. With that, the cost category is low priority.

Muscle Design Matrix Explanations

Elastic Bands

The elastic band design received an overall score of 67/100, making it the lowest score out of the 3 designs. Although the design had some strengths, it had many points of concern compared to the other 3 designs. Some high scoring aspects of the elastic band design were the ease of fabrication and cost categories. These categories both scored a 5/5. The elastic band design is simple to fabricate as the team would just have to buy the bands and hook them to the model. Also, these bands are very inexpensive. On the other hand, this design had major flaws in safety and appearance categories. The elastic band design received a 2/5 on safety and 1/5 on appearance. The main concern of this design is the appearance of the bands on the bones. Since bands do not have the same size or shape as muscles, it may be difficult for students to learn the different muscles. Overall, this design was scored the lowest for its lack of educational functionality whereas the other designs excelled.

Resin

The resin design was the 2nd highest design score at a 70/100. Although only slightly higher than the elastic band design, the team believes that the resin provided better attributes overall. The resin has better appearance qualities as it has the shape and size of actual muscle; also, resin can be colored easily which can help students identify the different models. This model lacks mechanical similarity to muscle category as it scored a 2/5. The mechanical properties of the resin are not similar to that of native canine muscle which would negatively impact the learning experience for a veterinarian student. Overall, the resin design offered some advantages in terms of appearance, but its lack of mechanical similarity to native muscle poses a potential limitation for veterinary students' learning experience.

Silicone and Fabric

The silicone design was the highest scoring design at an 86/100. It was the leader of almost every criteria category and will be the team’s selected material. The ease of fabrication of the silicone model received a score of 4/5, slightly lower than the other two designs. The cause of this is that the silicone also needs to be poured onto a piece of fabric which is harder. The silicone’s most appealing qualities are the mechanical similarity ranked as a 4/5 and durability ranked as a 5/5. The team is able to purchase different types of silicone material that will set at a variety of hardness ratings. This will give the team the ability to replicate the mechanical properties of native canine muscle. Overall, the silicone design has the highest ratings and will provide the best muscle functionality for the model.

Design Criteria	**Design 1: Velcro**	**Design 2: Magnets**	**Design 3: Button Release Pins**

						
Attachment Strength (20)	**3/5**	12	**4/5**	16	**5/5**	**20**
Ease of Fabrication (10)	**3/5**	6	**4/5**	8	**3/5**	6
Durability (20)	**2/5**	8	**5/5**	20	**5/5**	**20**
Ease of Use (15)	**3/5**	9	**5/5**	15	**4/5**	12
Appearance (15)	**3/5**	9	**4/5**	12	**2/5**	6
Cost (10)	**5/5**	10	**4/5**	8	**3/5**	6
Safety (10)	**5/5**	10	**3/5**	6	**5/5**	**10**
Total (100)	**64/100**		**85/100**		**80/100**	

Table 2: Design Matrix for Attachment Method

Attachment Design Matrix Criteria

Attachment Strength

The attachment strength category refers to the capability of the attachments to be strong enough to prevent slipping and falling off, but also weak enough to be easily removed. The attachment strength category was crucial during the design process, as last year's group ran into problems with their magnets lacking the required strength The client specifically requested we improve the connections, so it was rated a 20/100 as it is critical for the design to match the standards set by the client.

Ease of Fabrication

The ease of fabrication category was rated a 10/100 and involves the complexity of design with respect to each muscle. Since the attachments must connect to the muscles in specific spots to mimic tendons attaching muscles to bone, accurate fabrication was considered in this criterion. This category did not receive as much weight, as the time constraints of a semester should not present manufacturing challenges.

Durability

The durability category received the maximum weight of 20/100, matching the attachment strength criterion. Since the model will be under intense use of around 100 first-year veterinary students for around 4-5 weeks, making the attachments capable of detaching and reattaching without wear and tear is paramount. The model must also be able to sit in storage for around a year after the period of intense use without damage or deterioration.

Ease of Use

The ease-of-use criterion refers to the simplicity of the attachments on the model and received a weight of 15/100. The muscles on the model must be easy to detach and reattach, so making sure that the design is not too complicated was an important consideration of this criterion. Another factor considered was making sure the attachments were not too strong that they are impossible to remove, or not too weak where they can detach without use.

Appearance

The appearance category refers to how the attachments mimic muscle connections/attachments in an actual dog and received a weight of 15/100. A major consideration of this category was making sure the attachments did not appear too clunky or overbearing so that they did not detract from the appearance of the model. The coloration of the attachments was also considered so that they actually looked like tendons on a dog.

Cost

Cost corresponds with the budget allocated by the client of around $500. The client gave the impression that the budget was relatively fluid, so there was no truly defined maximum price for the design and fabrication of the model. While it is important to stay around the $500 figure given by the client for reference, the cost category was weighted 10/100 to reflect the lack of priority placed on the budget.

Safety

Safety for attachments refer to the connection points of the muscles not being able to harm the user and was weighted at 10/100. While user safety is integral for strong design, it did not receive as much weight/attention as other categories because there was not a terribly strong differentiator between proposed designs and their respective safety.

Attachment Design Matrix Explanations

Velcro

The Velcro design involved attaching cut pieces of Velcro to the 3D printed bone to connect the muscles and tendons. This design received a 64/100, the lowest of the three scores in the attachment design matrix, mostly because it lacked in areas weighted heavily, such as durability and attachment strength.

Velcro received a 3/5 for attachment strength because it can withstand 195 N of force in shear while fresh [7], but it is considerably weaker than other attachments available, like magnets, or even buttons.

Velcro received a 3/5 on ease of fabrication because it is not difficult to cut pieces of Velcro into useable slices for the model. It lost points because attaching these pieces of Velcro to the model could present issues.

Velcro received a 2/5 for durability mostly because the material is prone to wear and tear, and since the model will be under intense use for a prolonged period of time, Velcro would likely wear out before the 5-year life in service goal.

Velcro received a 3/5 for ease of use because it is able to withstand reasonable force, and not complex to detach and reattach.

Velcro received a 3/5 on appearance because it does not look very much like connections in tendons. It is also not able to be finely colored to match "muscle color." Compared to other design choices, this was not the worst choice, but is not at all comprable to magnets.

Velcro received a 5/5 on cost because it is very inexpensive. Along with being cheap, velcro is also available online or in stores and is not at all hard to find

Velcro received a 5/5 on safety because the connections would have no feasible way of causing user harm when detaching or reattaching. Velcro can't jam or pinch any fingers like neodymium magnets.

Magnets

The magnet design involves drilling small bits into the bone model to insert magnets which would have an opposing magnet on the muscle for connection. The magnet design scored an 85/100 on our design matrix, the highest of the designs because of its strength and durability, which were highly weighted categories. The magnet design also scored highly on middle weighted categories like ease of fabrication and appearance.

Magnets received a 4/5 on attachment strength because while they can hold in place, they are not at all comparable to a button pin release system. The attachments would not be weak with the correct magnets for the size of the muscles.

Magnets received a 4/5 on ease of fabrication because magnets are very acquirable in many stores and also online. Small holes can be drilled into the tough PLA bone material to place the magnets, which would not take much effort.

Magnets received a 5/5 on durability because they would not wear down over time like Velcro. The strength of the magnets would not change after prolonged use, making them a durable choice for attachment.

Magnets received a 5/5 on ease of use because they are intuitive to users and are not complex to detach and reattach. Most users of the model would be familiar with magnets prior to usage and be able to use the ability to detach without any trouble.

Magnets received a 4/5 on appearance because the drilling into the bone material could be made small enough to not have the connections draw away from the design like a large button release system would. They would also be able to mimic muscle connections better than Velcro.

Magnets received a 4/5 on cost because they are inexpensive, but not comparable to a Velcro. They sit as the perfect middle between the cheap Velcro and the more complex and expensive button release pins.

Magnets received a 3/5 on safety because the neodymium magnets are able to pinch very hard. This pinching could cause damage to a user's hands if not safely operating the model.

Button Release Pin

The button release pins design involved attaching pins as muscle connections that could be clicked into place and detached using buttons. This design received an 80/100, a good score, but not enough to beat out the magnet design. While the button release pin won attachment strength, a majorly weighted category, but lost out in key areas like cost and appearance, weighing it down.

Button release pins received a 5/5 on attachment strength as they are easily attached and reattached through pins leading to no wear and tear that could impact attachment strength down the line. Size would also not have to be considered like with a smaller magnet.

Button release pins received a 3/5 on ease of fabrication because creating the system and then placing it on the bone material would involve more time and design than magnets. Since the attachment with magnets would be so simply created, the button system does not compare.

Button release pins received a 5/5 on durability because they would not wear down at all over time. They would also be able to withstand unaccounted forces applied by users. With respect to Velcro, the button system would be able to withstand much more prolonged use.

Button release pins received a 4/5 on ease of use because they are not quite as intuitive as the magnet system. While the design would not be complex, it could possibly jam and lock muscles into place, or even become unusable if the pins don't hold the attachment in place.

Button release pins received a 2/5 on appearance because the system would be large and clutter the bone material. The connection would also not resemble muscles at all and not be easily colored to the "muscle color."

Button release pins received a 3/5 on cost because the system would have to be large and therefore require the most outside purchases to create, especially with respect to the inexpensive Velcro. Even compared to the magnets which scored a 4/5, the button release system would be more expensive.

Button release pins received a 5/5 on safety because there is no likelihood of a user harming themself while operating the model. There would not be any pinch or jamming points like a magnet. The button release scored equal with Velcro in this category as there is no difference between them in terms of safety.

Proposed Final Design

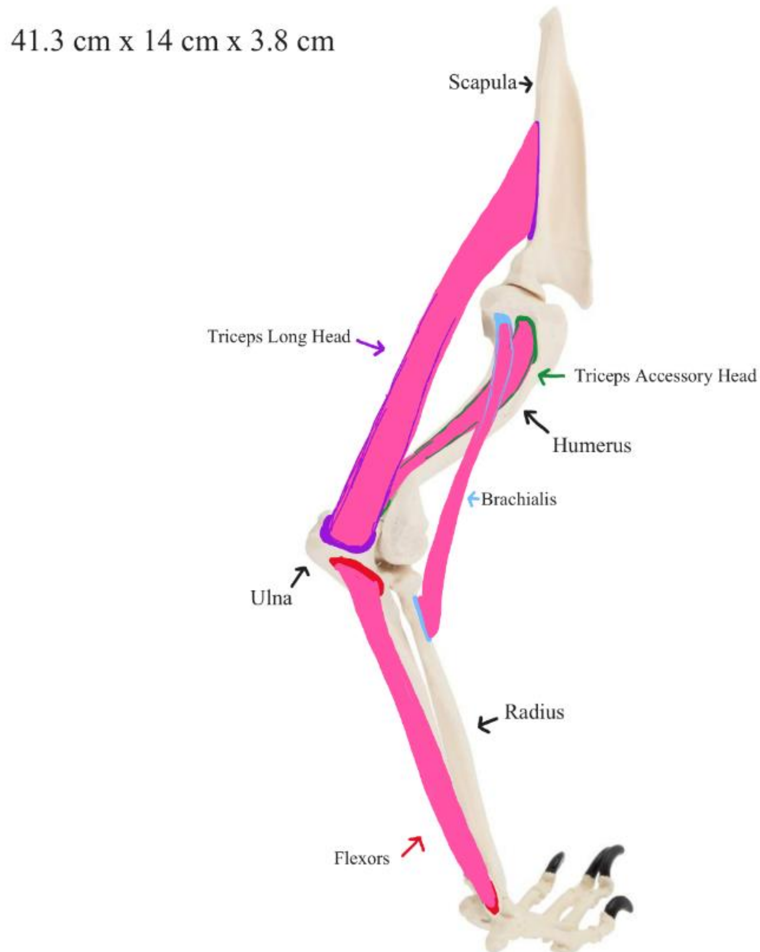


Figure 4: Proposed Final Design with magnet attachments as previously described and silicone muscle groups

The proposed final design consists of 3D printed bone, silicone and fabric muscles, and magnet attachments to model the forelimb of a canine. The bone will be modeled based on the bones of a beagle and printed using tough polylactic acid (PLA). The bones will be held together by string to tie the joints together. Silicone and fabric are used to most accurately represent the mechanical properties and appearance of canine muscle. Tendons will be represented by different colors and denser fabric to identify individual muscles and give them a denser feel than the muscle itself. Magnets are utilized for the attachment of the muscle to allow for easily removable and long attachments that can withstand movement and constant use of veterinary students. The model will be held up with a test tube stand and frame to keep the model vertical and elevated.

4. Fabrication and Development Process

Materials

The bone of the canine model will be printed with tough polylactic acid (PLA). It was chosen based on its easy and affordable fabrication. It is just 8 cents per gram of filament from the UW-Makerspace [8]. Tough PLA also has mechanical properties like bone as seen by the previous year's testing [9]. The stress versus strain curves is seen to show similar young's modulus to that of canine femurs.

The muscle material is made from Eco flex silicone that is lined with a swimsuit fabric material given by the client [10]. The material is used to mimic the elasticity of muscle to properly display muscles in compression and tension within the forelimb of the canine. The fabric is used to represent the muscle fibers and to allow a direction for the silicone to follow when compressing and stretching. Denser fabric and fabric with other colors can be used on the ends of the muscle to represent the tendons and offer easier differentiation of the muscles.

The attachment method will be made from neodymium magnets that are attached to the bone and muscle [11]. The bone will be altered from the original STL file to allow for a fit for the magnet that is then epoxied in the slot. The muscle will then be formed with slots for the magnets built into the muscle. The magnets would then be epoxied into the slot to create our attachment.

Methods

The bone will be 3D printed at the makerspace using Ultimaker printers using tough PLA [X]. The STL files will be obtained by scanning beagle bones given to use by the client with handheld 3D scanners and scaling up to one and a half scale to make it easier to allow for magnet attachments. The bones will then have holes near the joints that are tied together using string to allow for the swivel around the joints.

The muscle will be fabricated using a inverted 3D printed mold. The silicone first part of the silicone will then be poured into a dish and mixed with a small amount of red dye to give it a muscle color. The dyed first step of the silicone will be then mixed with the second part and quickly poured into the mold once properly mixed. While in the mold, muscle fabric will be added that is less dense and represents muscle fibers throughout the silicone and then adding colored, thicker fabric to the ends of the muscles to represent the tendons of the muscles and make them easily identifiable.

Testing

There are many tests available to test the reliability of the model. The muscles will be tested using a MTS machine to measure tensile strength in order to properly replicate the tensile strength on muscles. The attachments will be tested using a spring scale to test the total force needed to separate components. The overall appearance and functionality of the model will be tested by survey of veterinary and biomedical engineering students through google forms to get their opinions on the model.

5. Conclusions

The team has been tasked with designing and producing an anatomically accurate model depicting the bone structure and major muscles of a canine forelimb. This model is to be used primarily by first-year veterinary students. To fulfill this request, a design was devised that consists of silicone-molded muscles and tendons embedded with color-coded fabrics of varying resistance, along with 3D-printed bones made of tough PLA. These components are attached at designated points via magnets; one adhered to the fabricated muscle, and another set into the 3D-printed bone.

Moving forward, attachment methods will be tested and improved, and components will be fabricated following the processes in the Fabrication and Process section. The 3D scanning of the canine bones is underway, and many materials have been inherited from the previous group's efforts. After the fabrication of our initial prototype is complete, it will be tested to determine its effectiveness as it relates to the client's requests. This design will then be iterated until a suitable foundation is produced and additional muscles will be added. Ultimately, the goal of the final produced model is to be anatomically accurate, dynamic, and durable to aid veterinary students as they learn about canines.

6. References

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7. Appendix

Product Design Specifications

1. Physical and Operational Characteristics

a. Performance Requirements:

The device will be used four times a week by roughly 100 first-year veterinary students for the first four weeks of the fall semester (16 times annually). This is not accounting for unscheduled usage.

b. *Safety:*

The primary safety concerns of this device are the muscles causing either the bone or muscle to snap towards an individual using the device, or the device not remaining sanitary after being used by many students repeatedly touching and using the device.

c. *Accuracy and Reliability:*

The device should be able to accurately represent the anatomical bone and muscle connections of the forelimb of a medium-sized dog. The device needs to have muscle connections that can reliably be removed and added hundreds of times a day with no significant change in strength or connection.

d. *Life in Service:*

The model must be able to withstand usage throughout a four-week period, four times a week, from over 100 students each year. These periods of time would involve near-constant removal and attachment of the muscles, so the attachments must not wear down over time. The model should also last for several years.

e. *Shelf Life:*

The model must be able to maintain functionality during nearly a year in storage, without the attachments wearing down.

f. *Operating Environment:*

The model will be exposed to normal room temperatures of around 20-22 °C and typical conditions of around 30 to 60 percent humidity. The device will be highly used for some periods of time and will go long periods of time without use.

g. *Ergonomics:*

Opposing muscles must have equal tensile strengths, and tensile strengths must allow the user to be able to easily remove and attach the muscles.

h. Size:

The size of the model has no true restrictions. However, a larger muscle will cost more, and a smaller muscle will make accuracy and strong connections more difficult. The client suggested modeling from a medium-sized dog such as a retriever or pit bull.

i. *Weight:*

No weight requirements are given by the client; weight will be dependent on the selected size. The weight should not exceed 10 kg to allow for easy transportation.

j. *Materials:*

The material used for the bone must be durable and able to be 3D printed. A plastic filament such as Polylactic acid (PLA) will likely be used. The material for muscle must have the same qualities as the muscles of the animal. The material needs to provide spring force and be able to snap back to its original shape without any issues over heavy usage.

k. *Aesthetics, Appearance, and Finish:*

The model will be formed accurately to the bone and muscle structure of a medium-sized retriever. The bones will be colored white/off-white with rough texture. The muscles and tendons will be textured as similar to living muscles and tendons as possible while having easily differentiable colors.

2. Production Characteristics

a. Quantity:

One model forelimb of a canine will be produced; more if time allows for it.

b. *Target Product Cost:*

The budget given is $500, but more can be allotted if a larger quantity of limbs is created.

3. Miscellaneous

a. *Standards and Specifications:*

There are no standards- neither national nor international- to meet because the product will not be patented or regulated by the Food and Drug Administration (FDA). Additionally, the model will be used for educational purposes which makes it exempt from many regulations.

b. *Customer:*

The customer liked the start of the previous year’s model. She thought they had a good start but wants this model to be more complex and have a higher quality. Namely, our design should have more muscles that can lock the joints in place when attached and accurately represent the agonist and antagonist properties of muscle pairs. Also, we need to find a better way to attach the muscles to the model because last year’s team had difficulties finding strong enough magnets for some of the smaller attachments.

c. *Patient-related Concerns:*

This device is recommended to be cleaned with non-alcoholic cleaners as many students will be touching and manipulating the model within a short amount of time. It should be cleaned more often during frequent use to help prevent unsafe bacteria and viruses from collecting and transmitting from the device.

d. *Competition:*

There are similar competitions with this device that our client has access to. The currently used device mimics the muscles with elastic bands instead of the designed muscles. A bone model on the market is relatively inexpensive and can bend at the joints but does not include any muscles. Conversely, a different model on the market has all of the muscles and organs of the dog but cannot move and has no bones.

Materials List

Expenses

Item	Description	Manufacturer	Part Number	Date	QTY	Cost Each	Total	Link
								Component 1
Ecoflex 00-35 silicone	part fast acting silicone 2 rubber	Ecoflex	00-35	N/A	1	0	0	Client
								Component 2
Swimsuit Fabric	Muscle colored fabric	Unknown	N/A	N/A	1	0	0	Client
								Component 3
Beagle Bones	Scapula, humerus, radius, ulna	N/A	N/A	N/A	1	0	0	Client
:TOTAL	**$0.00**							