Structural and Mechanical Function of Canine Forelimb

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Client: McLean Gunderson,

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The Problem

A realistic model of a dog's forelimb should be created to replicate muscle and bone interactions of the joints within the limb. The model should be easily moveable and act as a training model for veterinary students to learn the physiology and mechanics of canine anatomy

Background/Motivation

- Students learning complicated, three-dimensional structures benefit greatly from physical models
- Veterinary students at UW Madison are required to learn the musculoskeletal anatomy of canines
- Currently, there are no learning models available for students that incorporate the entire musculoskeletal system and are also flexible

Competing Designs

- Vetwho bone model: $78, detailed model of bones that does not include muscles
- Anatomy Warehouse canine model: $365, model of the whole dog that does not include bones and is stationary
- Dr. Gunderson's Model: modified bone model to include elastic muscles, muscles are not accurate in appearance or mechanical properties

Figure 1: Vetwho Bone Model [1]

Figure 2: Anatomy Warehouse Model [2]

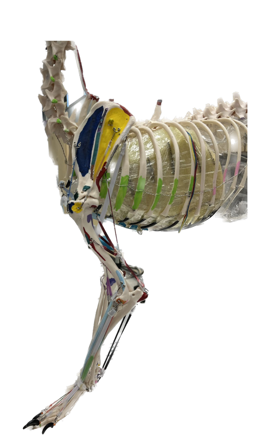

Figure 3: Dr. Gunderson's Model

Design Criteria

Durability: the muscle-tendon models should withstand forces up to 21.8 N and should be able to withstand at least 50 cycles of 25% strain with less than 5% relaxation

Accuracy: the model must have the four main bones of the forelimb and at least four muscle-tendon complexes, at least two of which are an antagonistic pair.

Final Design

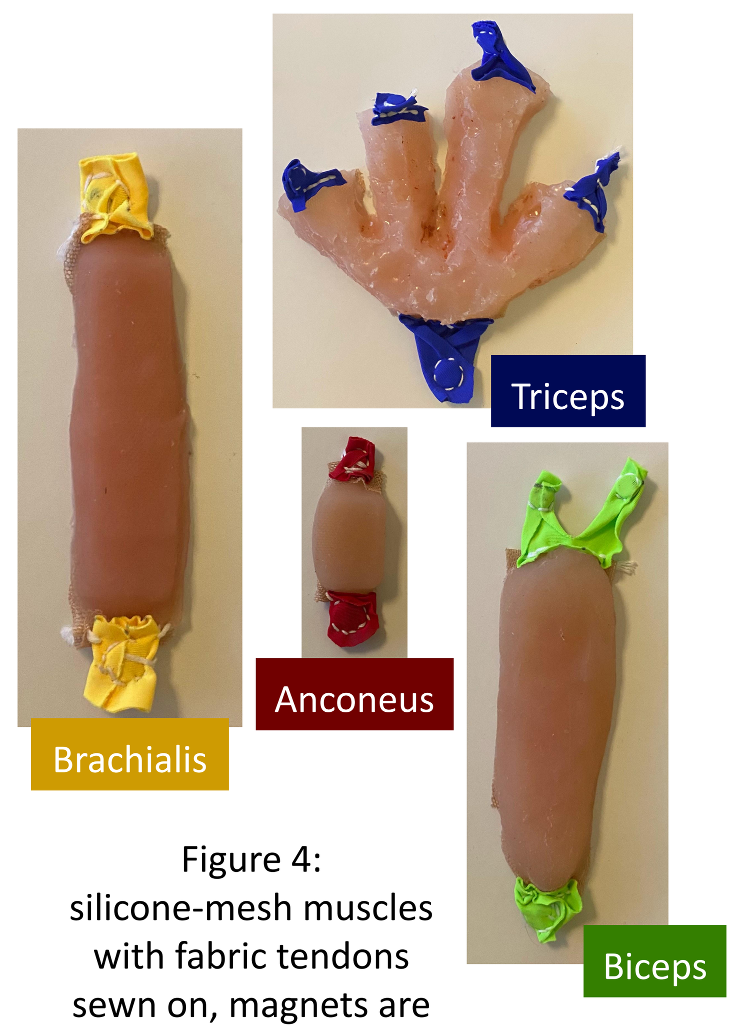

Figure 4: silicone-mesh muscles with fabric tendons sewn on, magnets are in the tendons to attach to the bones

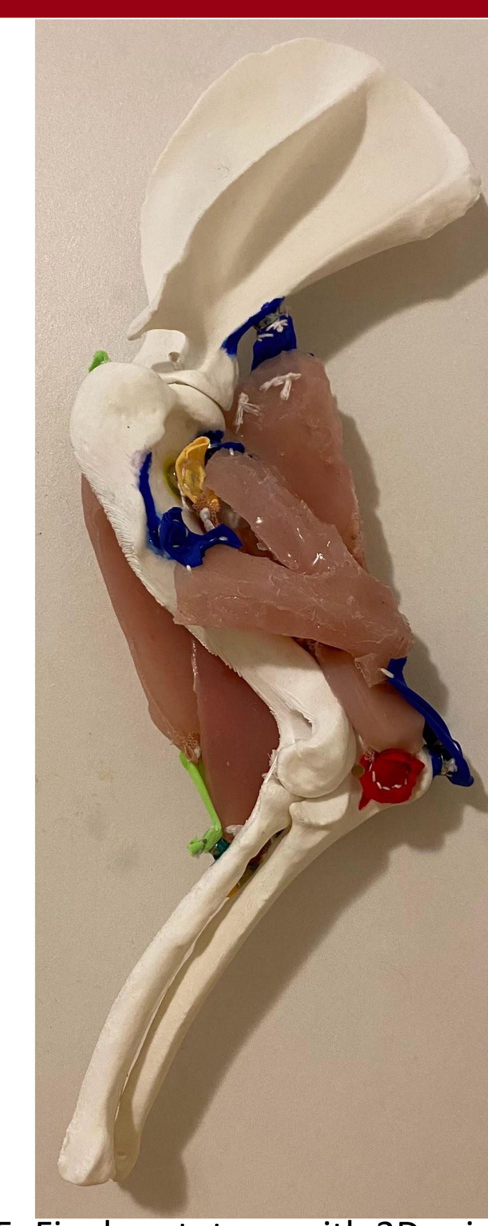

Figure 5: Final prototype with 3D printed bones, silicone-fabric muscle-tendon complexes, and magnet attachments

Materials:

Bones- 3D Printed tough PLA

Muscle-Tendons- silicone and mesh, cotton-rubber elastic fabric, neodymium magnets

Attachments- neodymium magnets, epoxy, colored marker

- Triceps (extensor) works against the biceps and brachialis (extensors)
- The four forelimb bones are included
- Each attachment site is colored to show where the muscle inserts, colors match the corresponding tendons

Testing

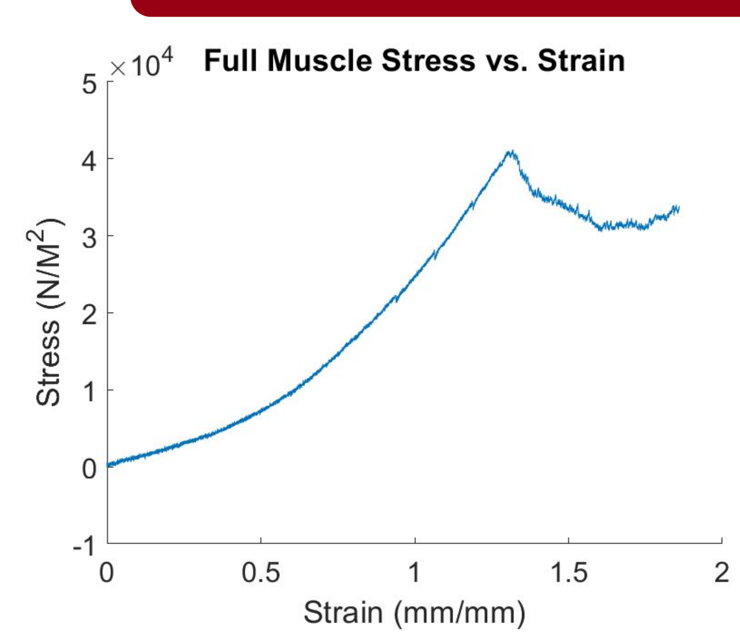

Figure 7: Full muscle model including muscle, muscle fabric, and tendon sewed on, stress vs strain curve.

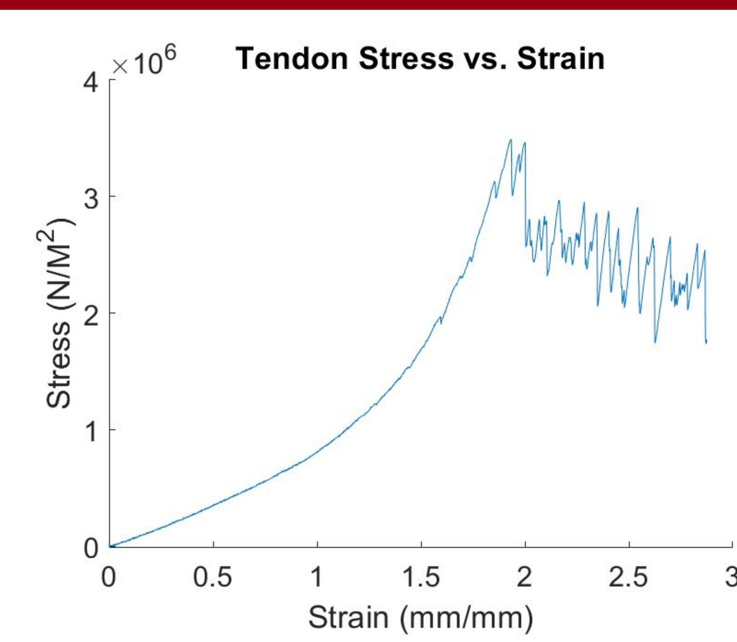

Figure 8: Muscle with silicone and fabric shaped in the form of a muscle, stress vs strain curve.

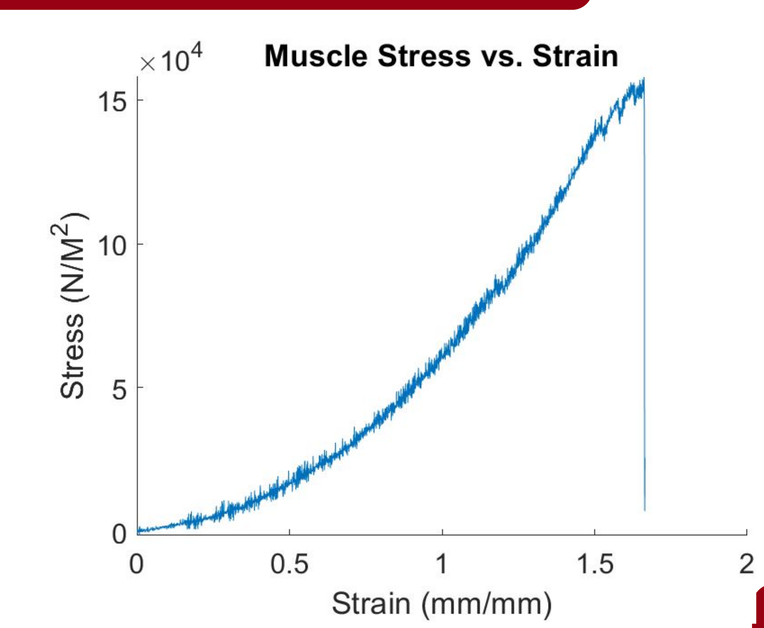

Figure 9: Tendon fabric material stress vs strain curve

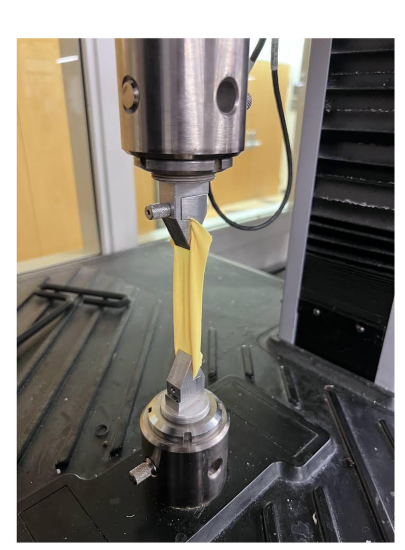

Figure 10: Image of MTS testing of tendon material. A tension test was conducted at a rate of 2 mm/min to obtain the stress vs strain curve seen above.

Testing was conducted using a Materials Test System (MTS) machine to conduct tensile testing of the different materials within the muscle in order to find breaking points of the muscle and the Young's Modulus of the muscle.

Results

Young's Modulus

- Silicone: 100 KPa
- Muscle Fabric: 5 MPa
- Tendon Fabric: 6 MPa
- Full Muscle: 160 KPa

Tensile Test:

- Test Muscle Peak Load: 24 N
- Magnet Peak Load: ¼"OD: 12.4N | ⅜"OD: 21.8N

Cyclic Loading Test:

- average change in length: 1.012%
- within 5% max relaxation

Failure:

- Failure occurs at the sewn area of the muscle when pulled
- Unable to achieve breaking point with MTS machine before material slipped out of grips, reached 18 N before slip.

Discussion and Future Work

- Improve accuracy in muscle fabrication with respect to length and thickness
- Address limitations presented by clay molds with 3D printed molds
- Consider adding more muscles to connect to the foot of the model
- Perform testing on veterinary students to confirm durability and practicality of model
- Ensure no slipping during testing
- Improve sewing to increase overall durability
- Goal Young's Modulus of 24.7 +- 3.5 KPa [3], the Young's Modulus of our muscle was too high at 160 KPa, goal is based upon rat skeleton muscle
- Increase flexibility of muscle to get material more elastic to make the Young's Modulus more comparable to goal.

References

[1]"The model of dog forelimb," Vetwho, https://vetwho.com/product/the-model-of-dog-forelimb (accessed Oct. 4, 2023).

[2]"Anatomy lab domestic canine (canis lupus familiaris) anatomy model," Anatomy Warehouse, https://anatomywarehouse.com/anatomy-lab-domestic-canine-canis-lupus-familiaris-anatomy-model-a-109171 (accessed Oct. 4, 2023).

[3] Ogneva, Irina V., et al. "Transversal Stiffness and Young's Modulus of Single Fibers from Rat Soleus Muscle Probed by Atomic Force Microscopy." *Biophysical Journal*, vol. 98, no. 3, 3 Feb. 2010, pp. 418–424, www.sciencedirect.com/science/article/pii/S0006349509016701, https://doi.org/10.1016/j.bpj.2009.10.028.

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