Structural and Mechanical Functions of Bones, Muscles and Joints by use of 3D Models in Veterinary Medical Education

Product Design Specifications

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Section

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Function

In the first semester of veterinary school, students learn the anatomy and physiology of the dog in great detail, and greatly benefit from working with the bones and muscles that they learn about in class. Traditionally, this knowledge is solidified through the use of cadavers, but such methods pose many ethical, safety, and cultural concerns, along with the monetary cost required to obtain them [1]. With the rise of 3D printing technology, teachers have been moving towards using 3D printed animal models since they are cheaper, longer lasting, and safer [2]. Therefore, the client has requested that a durable, functional, and accurate 3D model of a dog hindlimb be constructed for use in veterinary education, which includes an anatomically accurate dog skeleton with correctly functioning muscles and joints.

Client Requirements

- The client requests an anatomically correct model of a dog joint with both accurate bone structure and properly functioning muscles and joints.
- The joint modeled should either be the shoulder or the hip of a dog skeleton, as students struggle with these areas the most.
- The joint should be mounted on a raised structure for appropriate use.
- The model should be of appropriate level of detail for first semester veterinary students, which ranges in ages but on average is 23 years old [3]. For the team's purposes, an appropriate level of detail for first year veterinary students is defined by skeletal diagrams in Miller's Anatomy of the Dog by Drs. Howard Evans and Alexander de Lahunta.
- The model must contain a simple and reliable way to attach and detach muscles to demonstrate movement.
- The muscles on the model must have accurate attachment points onto the bone, with reasonable mass and surface area measurements that match the anatomy of the dog.

Design requirements

1. Physical and Operational Characteristics

a. Performance requirements:

The model shall be able to perform reliably for 3 classes of 32 students each for 12 hours spread throughout three use sessions per week per class. Reliable performance may be defined as the ability to withstand 13.3 N (3 lbs) of tension on an MTS machine. The model must also have muscle attachments that are reliably able to attach and detach at correct insertion points on the model (see Section 1c: Accuracy and Reliability).

b. Safety:

The product must be safe for first-year veterinary students to use (ie. students must not suffer injury from any components during use). While there are standards regarding the use of small or detachable magnets in products, the use of them in this project would not require following the standards since educational products are exempt [4]. Other materials that may be used in the product, like Velcro and PLA, do not have any regulations or harmful effects on the user either. It should be noted, however, that bacteria may grow if the model is not properly cleaned, which could be unsafe for the user. Thus, the model should be sanitized weekly with a non-alcohol based cleaner (alcohols can cause plastics to crack) so that it will be safe for users and last longer [5]. While no safety warnings are required and sterilization of the product is unnecessary, light cleaning directions are recommended.

c. Accuracy and Reliability:

The veterinary model will be fabricated such that the modeled muscles can be removed and replaced in the correct position 100 times a day with no detectable decreases in attachment force or elasticity of the muscle models. The design must also be anatomically correct and represent a real dog hindlimb as evaluated by veterinary students.

d. Life in Service:

This product must be able to be used by about 96 students in small groups for 12 hours at a time. It should be able to last for about 5 years before needing to be fully replaced, but can be fixed with spare parts throughout that time. The model will be flexed and extended, along with the simulated muscles being removed and replaced by students, so the materials used must be durable enough to handle such use throughout the semesters for 5 years.

e. Shelf Life:

The model must be compact enough such that it can be easily stored in provided cabinets or shelving, which typically range from 40 - 61cm in depth [6]. The model should also be able to withstand typical indoor temperatures around 20-22 C (68-72 F) and pressures around 1 atmospheres [7], as it will be stored out in the skills lab or in a plastic storage container in the closet. If the model requires the use of adhesives and that replacement adhesives be stored in the facility, they must be stored between 25-28 C for up to 2 years (or prior to expiration date). The device itself should also not be subject to temperatures outside of this range in order to retain ideal bond strength of the adhesive [8]. Other than the potential use of adhesives, the product has no shelf-life considerations for components given that the model does not require batteries or contain chemicals.

f. Operating Environment:

The model should be able to withstand consistent use from first year veterinary students. This is defined by withstanding use by 96 students in small groups in separate sessions for a cumulative 12 hours per week for roughly 5 years with minimal maintenance. The bones themselves should not need to be changed in any multi year time frame. The device should be used indoors in a controlled environment (see Section 1e: Shelf Life) and should not be left in direct sunlight, as this could cause warping of the 3D printed components.

g. Ergonomics:

The product should be anatomically similar to a medium sized canine (54.6 cm to 62.2 cm in height, and 29.5 kg to 36 kg in weight), as evaluated by first-year veterinary students [9]. There should be no large discrepancies in dimensions between the model and real bones except for when modifications help in efficiency of design, aesthetics, and aid in better teaching as deemed by the client and students (ex: slightly thicker muscle attachment to aid in teaching and visibility). The device does not need to withstand the forces a normal canine may exert on their bones since this is a model used for seeing the movement and locations of anatomy and not for stress testing in any way. The model should be handled with care and in turn should not be dropped. The bones should be able to withstand double the forces expected during normal use (ie. 26 N of tension on an MTS machine) while extending and retracting the hindlimb and attaching/detaching muscles.

h. Size:

This product should be anatomically correct with exceptions that can facilitate better learning or a more economical design (see Section 1g: Ergonomics). The model should attach to a stand and should be able to comfortably fit in a 2 foot by 2 foot cardboard box.

i. Weight:

The product does not have strong limitations with regards to weight. The density of bone structure in the 3D printed model will differ significantly from the density of an actual dog bone, therefore, a minimum or maximum weight cannot be decided until materials have been obtained. However, the 3D model cannot contain over 5 lbs of 3D printed material, as this will result in over-spending (see Section 2b: Target Product Cost).

j. Materials:

The model bones will be 3D printed. The material must also have a coefficient of friction less than 0.5 to allow for natural canine movements at the joints [10]. The bones should not deform at all when being handled. Potential materials include PLA, Tough PLA, and other plastic filaments [11].

The model muscles can be 3D printed or made of existing stock materials. The material needs to withstand being elongated to twice the original length 100 times a class (12 hours a week per class for 9 weeks each semester) for about 5 years. The material also must return to its original shape after every elongation. Potential materials that meet these requirements include Formlabs Elastic 3D printer filament, rubber, silicone, elastic, and various fabrics [11].

k. Aesthetics, Appearance, and Finish:

The model bones need to resemble real bones to the greatest extent possible, as verified by first-year veterinary students. If not using a color-coded method in the design, this requires that the model bones must be white or cream in color, accurately shaped and sized when compared to real canine bones, and rough in texture. Also, the model muscles need to have attachment points that replicate the surface area of real attachment points in medium sized canine dogs.

2. Production Characteristics

a. Quantity:

One model canine hindlimb will be manufactured this semester.

b. Target Product Cost:

The product should not exceed $500 to prototype and manufacture, a budget determined by the client.

The 3D printing of the bone model will be the most expensive aspect of production, and should not exceed $300. This was determined by the approximate cost of 3D printing filaments and resins along with the maximum expected weight. For example, the bone model itself is expected to weigh under 2.26 kilograms. It is expected to use plastics such as PLA; however, the possibility of resin must not be ruled out. If the product weighed 2.26 kilograms and was made out of PLA, the cost of production would be $180.80. The highest cost expected would be $293.80 if CPE was used. In general, resin is 24 cents per milliliter [11].

Therefore, if the cost of 3D printing the bone model must be kept under $300, the cost to manufacture the muscles should not exceed $200, in order to stay within the predetermined budget of $500.

3. Miscellaneous

a. Standards and Specifications:

It is not required that the product meet any international and/or national standard due to the fact that the product will not be patented or regulated by the FDA.

b. Customer:

The customer expressed a variety of preferences and dislikes during client meetings. The customer prefers that the model be able to detach and reattach muscles one at a time to allow for students to properly understand the function of each muscle. She also indicated that the muscles should be color coded, as this would support ease of memorization of muscle function. However, she was concerned about students overly associating the muscles with a color instead of the name and function of the muscle. The customer has a strong interest in having a detailed model of the dog skeleton that accurately depicts all of the bumps and ridges of the bone. She specified that plastic models that can be purchased online are not accurate enough. The customer dislikes that the original model only connects to the bone at a single point rather than the full surface area of muscle attachment.

c. Competition:

In terms of price, there is a lot of competition and variety. You can find models as cheap as $26.95 made by 4D Master [12]; it includes few details of muscle, bone, and even organs, but the model is not articulated, has reduced detail, and is not to scale with an actual dog.

Higher quality, mid-range dog models, like one made by Axis Scientific, can cost anywhere between $200 unarticulated [13] and $400 articulated with a base [14], but none of these models contain muscles for students to identify, attach/detach, and understand their use. It is also possible to buy sections of skeletons made by Axis Scientific for $72 [15], but again none of these models contain muscles; they are just plastic bones. Other models are made of real dog bone and can be moved at the joints properly, but they do not include muscles and cost thousands of dollars. For example, 3B Scientific has an articulated dog skeleton that costs roughly $2100 [15]. There are also 3D models that show the movement of a dog's muscles and their connections to the skeleton [16], but most of these are online simulations that do not allow the students to feel and see the actions of each muscle individually like the client requests. Following a search for patents on anatomical dog models, it was found that Ms. Pawana Chuesiri has three patents for anatomical dog models [17]; however, these are not patents in the U.S.. The customer attempted to create a model; however, there are two primary elements she would like to change. Firstly, on her model, the attachment points are just at one point on the muscle rather than the full surface area where the muscle would normally attach. Secondly, the muscles are simply represented by rubber bands and do not mimic the real shape; this project will create muscles that mimic the shape and function of real dog muscles.

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