Torque Values About Artificial Knee Using Braided Pneumatic Actuators*

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Abstract. A biomimetic bipedal humanoid robot was designed to use braided pneumatic actuators. The placement of these actuators

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1 Introduction

Biomimetic robots aspire to replicating the anatomical motions and biological systems of living organisms. Researchers and the general public are keenly interested in biomimetic bipedal humanoid robots. The design of humanoid robots with high fidelity to human systems can improve the understanding of both internal human systems and human biomechanics [Shin 2018][Asano 2017]. Experiments can be done with robots that would otherwise not be ethical to perform on humans. Modifying robotic platforms is potentially a faster and cheaper alternative to human observation studies. A first step in this direction is the task of engineering robotic systems to match observed biological principles.

For truly biomimetic humanoid robots to go a step beyond being merely bio-inspired, it is unclear how the actuator affects other aspects of the control. One requirement for proposed artificial muscle-actuators should be that they be able to produce isometric torque about humanoid joints that meets or exceeds values measured in humans. There are several interesting methods of actuating robotic joints, including artificial muscles, electric motors (either directly driving the joints or via cable systems), or via hydraulics. Electric motors tend to require a lot of power, and have torque curves unlike that of real muscles. They also can have heavy batteries and generate a lot of heat. Hydraulic systems are heavy. There are probably other things wrong with them. Electrically stimulated artificial muscles are new and don't produce very much force. McKibben style pneumatic artificial muscles (PAMs) are a promising method of actuation because they have low weight, high force/weight ratio, and a force-length curve that is grossly similar to actual muscle. Routing these muscles in a biomimetic arrangement can allow us to investigate and mimic the torque produced about joints by actual human muscle.

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Previous robots that use artificial muscles do not show significant design considerations for the forces and torques that the muscles will produce. However, these aspects are critical for further diving into understanding how muscles are controlled. As a consequence of this, these robots don't faithfully attempt to replicate the number of existing muscle actuators. They also tend to use a single degree of freedom (DoF) knee joints. Knee joints are better modeled as 2-DoF sliding and rotating joints. They instead focus on planar, uniarticular muscle arrangements. Our research diverges from these robots by attempting to correct for these deficiencies (i.e. our design includes muscles arranged in a biologically inspired pattern, with artificial muscle actuators that have a maximum isometric force similar to real muscles, and we include biarticular muscles).

Our previous research has laid the groundwork to start building a bipedal robot with biomimetic humanoid joints and artificial muscle actuator paths. Our previous research on the isometric force profile of 10 mm Festo Braided Pneumatic Actuators (BPAs, also called Pneumatic Artificial Muscle or PAMs) [Cite Hunt] showed muscles that have a similar isometric force profile to human muscle. Research on artificial knee [Cite Steele] allowed us to build a humanoid sliding knee joint instead of just a pinned joint. Recent paper on artificial muscle attachment locations in humanoid robot [Cite Bolen] produced theoretical isometric torque curves. Optimization of these muscle paths and attachment locations was done in Morrow [Morrow] paper. All of the concepts can be combined to build an artificial leg and test the validity of our theory.

Delete? These previous studies need to be combined and tested on a physical robot body. The 10 mm Festo BPAs have been characterized [Hunt], but the 20 mm and 40 mm BPAs have not been. In our previous work [Bolen][Morrow], moment arms have been calculated by the unit vector method presented in Hoy, et al., but not the change in length over change in angle method that Hoy [Hoy] and others [Yamaguchi?] have also used. It is not known if one method is more correct than the other. Knee Instantaneous Center of Rotation (ICR) differs in the Steele model [Steele] and the OpenSim model [Delp] model. This could affect moment arm. Concluding sentence **Delete?**

Hypothesis: Our design tools offer the ability to correctly predict the amount of torque we will achieve for each of the muscles on our robot at different configurations when gravity and friction can be disregarded.

The design tools we previously developed can be compared to measured isometric torque values produced by our artificial Vastus and Biceps Femoris Short Head BPAs about the humanoid knee joint, which will then be used to update how we design and analyze biomimetic joints in the future (including determining which, if any, method of calculating moment arm is the best).

Ending paragraph Concluding sentence

2 Methods and Materials

The outline of the materials and methods section has multiple parts. Pictures help with the description. It is important to talk about robot leg assembly. This includes dimensions.

2.1 Leg anatomy and materials

The test is to compare predicted versus actual robot knee torque values.

1. The test is to compare predicted versus actual robot output.
   (a) Describe the actual robot we built.
   (b) Components of the robot were knee, femur, tibia, patella, BPAs, artificial tendon, and attachment brackets.
   (c) The artificial bone components were built using Onyx material on a Markforged Mark Two 3D printer.
2. We used the sliding contact knee that was designed by Steele [Steele 2018].
   (a) Insert the spline for location of Instantaneous Center of Rotation (ICR) that Bolen measured.
   (b) The knee is sliding contact and was designed to reduce wear.
   (c) Difference between robot knee and human knee.
   (d) The knee attached to the femur and the tibia.
3. The tibia was a relatively simple design.
   (a) The tibia is of length XXX and average diameter of XXX.
   (b) It mounts to the knee with one M6 fastener.
   (c) Two artificial muscle insertion points are in the tibia's frame of reference.
   (d) These insertion points are connected to the tibia with brackets.
4. The femur is a two-piece design.
   (a) The overall femur length is XXX with a thickness of XXX.
   (b) The femur attaches to the knee with one M6 fastener.
   (c) The femur has two locations to mount brackets for the artificial muscle origins.
5. Talk about the patella if one is made.
   (a) Or talk about why one wasn't made.
6. Artificial muscle are the Festo BPAs.
   (a) We chose to use one uniarticular knee extensor and one uniarticular knee flexor.
   (b) Correspondingly, the Biceps Femoris Short Head is mimicked using a 20 mm Festo BPA.
   (c) The human vastus intermedius, vastus lateralis, and vastus medialis are mimicked using one over-strength robotic vastus intermedius PAM.
   (d) The robotic vastus intermedius is a Festo 40 mm BPA.
   (e) We designed our own end caps for the Festo BPAs.
   (f) One of the cap styles is designed to be pinned to the muscle origin location.
   (g) The other cap style is free floating and attaches to the artificial tendon.
7. Artificial tendon is supposed to be made with bike cable.
   (a) I still have doubts as to whether this will work.
8. Attachment points are in the tibial and femoral reference frames.
   (a)
   (b) Segue into calculations.

2.2 Human comparison calculations

1. Compare measured robot performance to robot calculations, but also to what we expect a human
2. The calculations we used as a benchmark were from Delp [Delp] and Hoy [Hoy].
   (a) simbodyXXXX was the anatomical comparison.
   (b) A pictorial description of the axes of rotation should be used.
   (c)
3. These calculations were moved into Matlab as described by Bolen [Bolen 2019], and further improved by Morrow [Morrow 2020].
   (a)
4.

2.3 Test Jig and Measurements

1. We build a test stand

3 Results

Introduce first results. Figure that shows torque over knee from hamstring (left side) and quadriceps (right side). Probably good to have multiple data measurement trials. Each trial could have a plot line (if torque steadily changes per trial) or if multiple trials are done at each location before position change, a box plot. Include lines for calculated robot values in the same plot. Figure could just be one piece, Since RoM is the same in both plots for the data, but this might make it too busy.

Compare torques for different muscle origin/insertion locations. Compare to human values. Since xxx location is closest to human, muscle size change.

Compare muscle size change torque values to 10 mm and human values for same location.

4 Discussion

Figure xxx shows that calculations are good or need a correction factor.

Figure xxx shows that one spot is more faithful to human values than the others.

Figure xxx shows that using muscle size xxx meets or exceeds human value.

Torque deadzone or RoM limitations, if needed. Difficulties in muscle assembly. Plastic deformation of artificial tendon. Bending of brackets. Accuracy of length and angle measurements.

Deviation of torque from expected value when the origin/insertion is no longer sagittal. Proposal for correction factor. Necessity of test like Hunt did but for 20 mm and 40 mm PAMs.

Exciting for confirmation of our design principles. Even if it is off a little then that is promising. If values are very different than expected a good reason should be given why, and a proposal for future experiments.

Future experiments with different knee linkage design to more closely mimic that of humans, or reflect our more recent knee designs. Future experiments with more muscles, different knee designs, different artificial tendon, and biarticular joint actuation.

5 References