LOWER EXTREMITY LOADING DEVICE DURING MAGNETIC RESONANCE IMAGING

Nikhil Chandra, Ethan Rao, Caelen Nickel, Micah Schoff
Clients: Dr. Scott Crawford, Dr. Beth Meyerand
Faculty Advisor: Dr. John Puccinelli
BME 301, April 26, 2024

College of Engineering
UNIVERSITY OF WISCONSIN–MADISON

UW BME Design

Problem Statement

- An ongoing research project aims to characterize differences in neuromuscular control for individuals with hamstring strain injuries (HSIs)
- The research requires a device that can load an individual's hamstrings during a brain MRI while the user is lying supine
- The device must allow for constant loading in isometric, eccentric, and concentric lower leg movements

Motivation and Background

- Biomedical loading device would aid in understanding neuronal–muscle signaling in HSIs [1]
- 3 major hamstring muscles capable of inducing knee flexion
- Competing Solution: Emory Device (Inclined supine slider design)

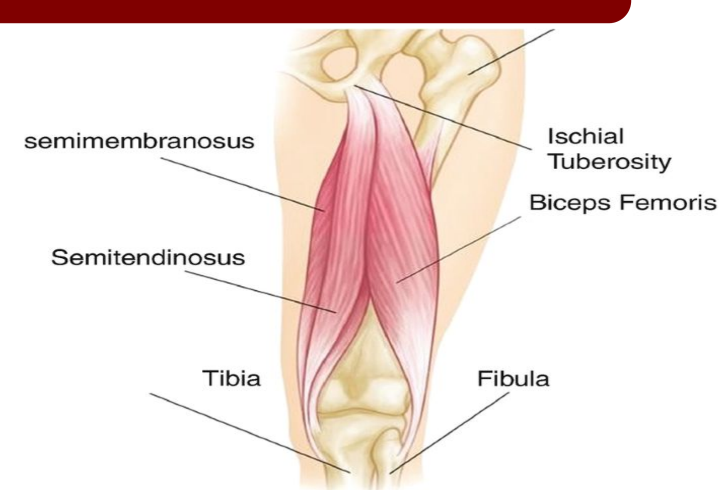

Figure 1. Anatomy of the hamstring [2]

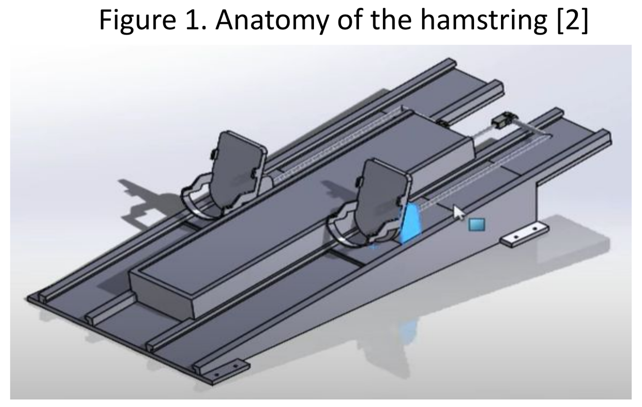
Figure 2. Emory heel slide SOLIDWORKS sketch [3]

Design Specifications

- Induce (20-30%) of max hamstring force
- Withstand ≅ 25 lbs. regularly [4]
- Maintain constant tension
- MR compatible (GE MAGNUS Scanner)
- Weight < 50 lbs
- Width < 26.5 in
- Life of service (5-10 years)


Figure 3: Example of hamstring loading device meeting majority of criteria [3]

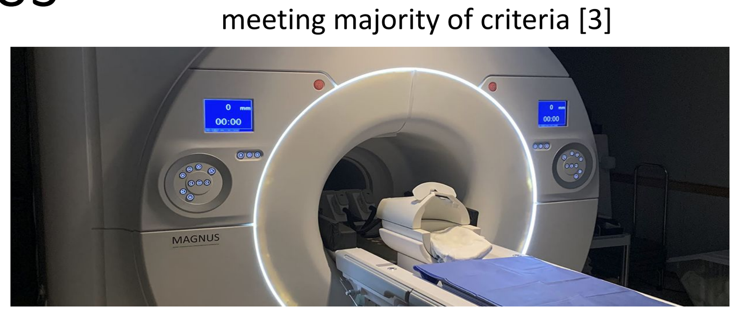
Figure 4. GE MAGNUS Scanner [5]

Final Design

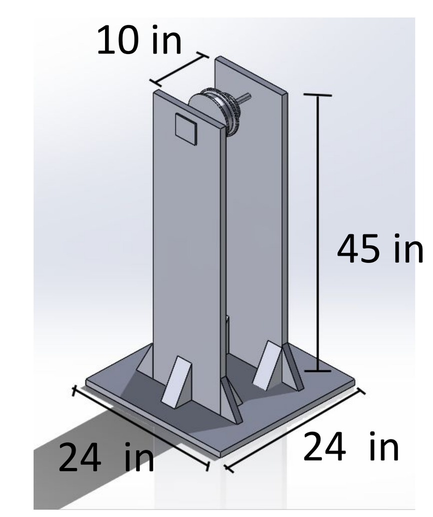

Figure 5. Isometric view of weight stack SOLIDWORKS model

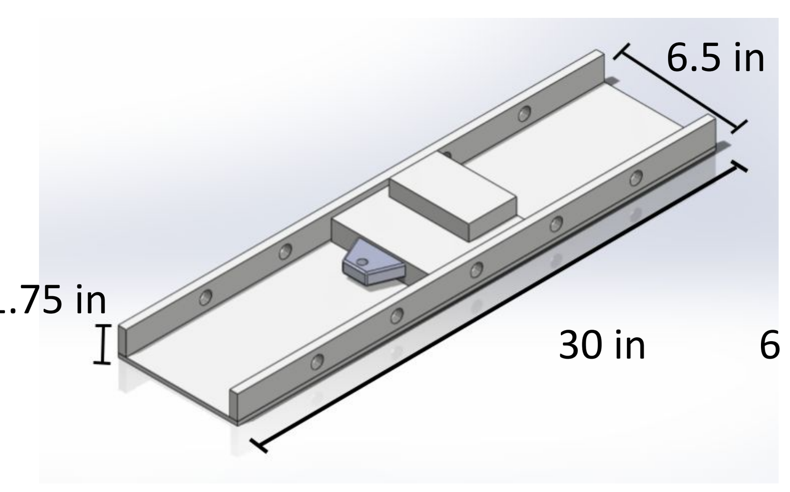

Figure 6. Isometric view of slider SOLIDWORKS model

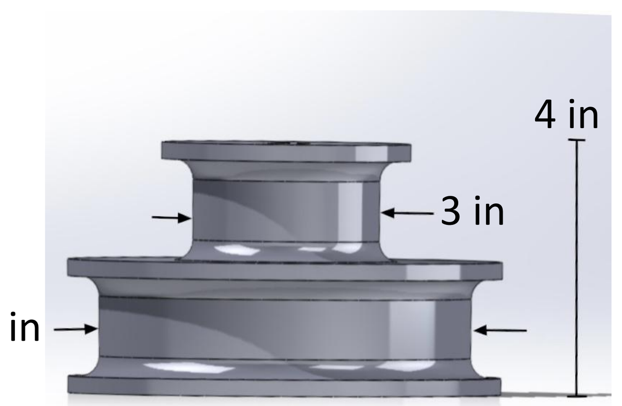

Figure 7. Side view of amplification pulley SOLIDWORKS model

- Slider rests on MRI table with pulley/weight stack on ground at table end
- Individual lying supine in MRI utilizes heel to pull slider towards their glutes
- Device activates hamstrings as the user performs knee flexion against tension

Critical Design Analyses

F_s = Cable Force from Pulley to Slider
W = Cable Force from Variable Weight
F_H = Simplified Hamstring Force

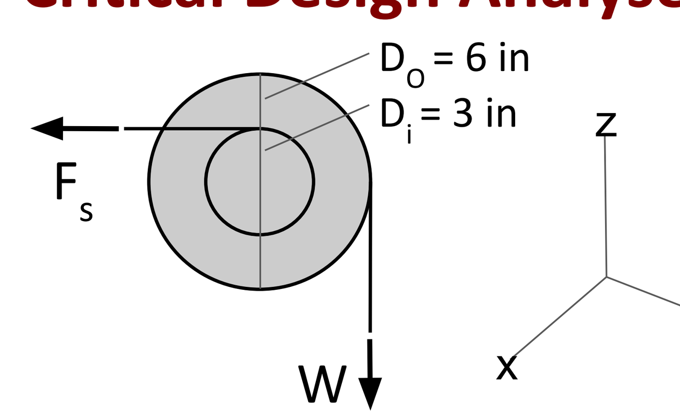

Figure 8. FBD of amplification pulley, side view

$$\frac{D_0}{D_i} = 2 \rightarrow \text{Pulley Amplifies Weight by 2x}$$

Equation 1. Pulley amplification equation

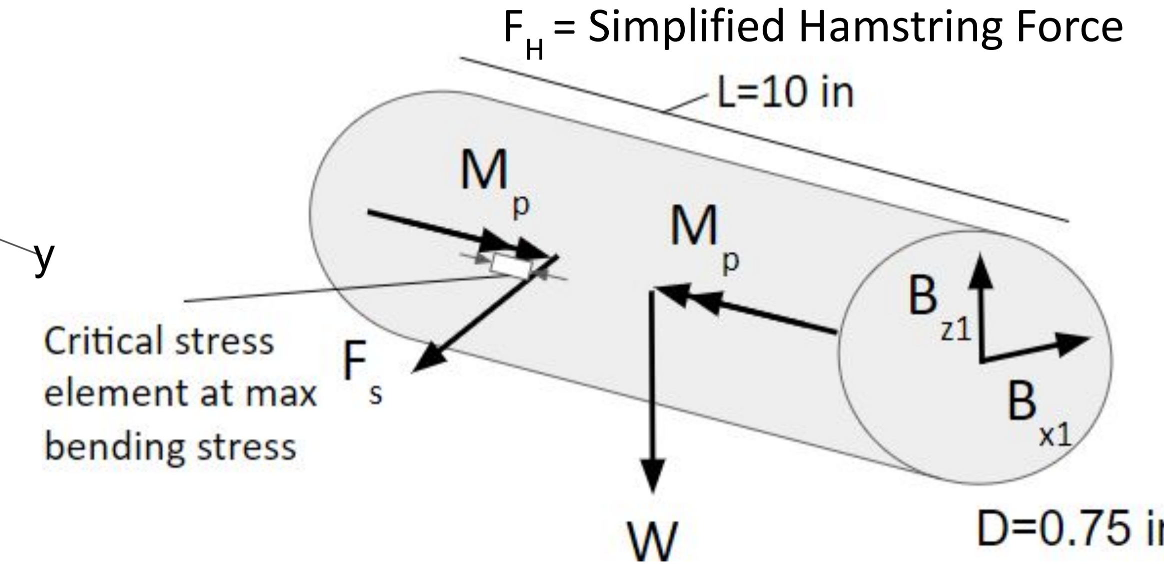

Figure 9. Static FBD of carbon fiber shaft, Isometric view

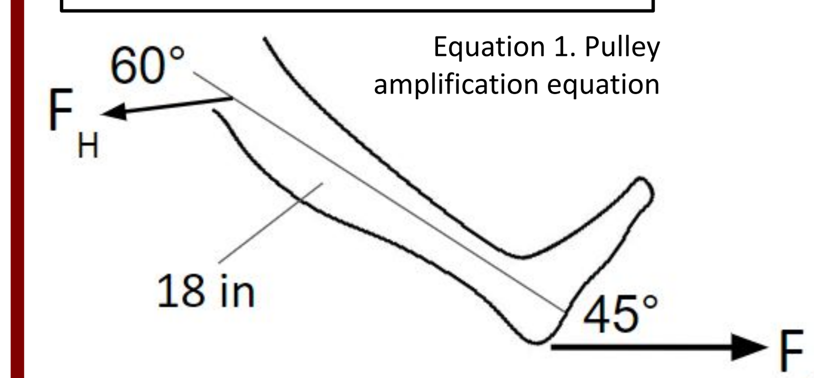

Figure 10. FBD of heel slide motion, side view

Safety factor of 3 given a carbon fiber rod (5000 MPa Strength) and a >120 lb amplified force (F_s) through the maximum normal stress theory

At a 45° heel angle relative to slider, the **hamstring muscles apply** a force **3.5x of the cable force**


Figure 11. Top-side view of fully assembled MRI leg loader. The slider mechanism is connected to the pulley and weight via cable


Figure 12. Side view of fully assembled leg loader with subject

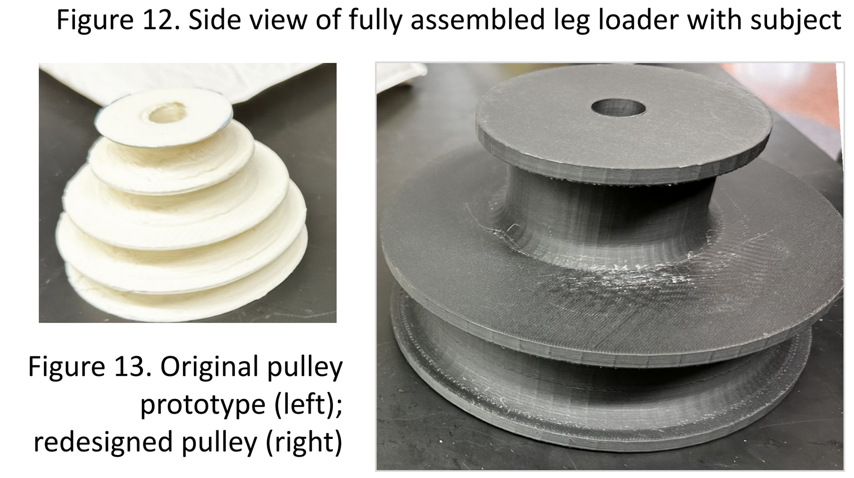
Figure 13. Original pulley prototype (left); redesigned pulley (right)

Testing & Results

- A spring gauge was attached to the end of the cable to measure the force generated by a test research subject
- The pulley force amplification was validated
- Linear least squares regression: $R^2 = 0.993$
- Sample slope = 2.1 compared to ideal amplification of 2.0

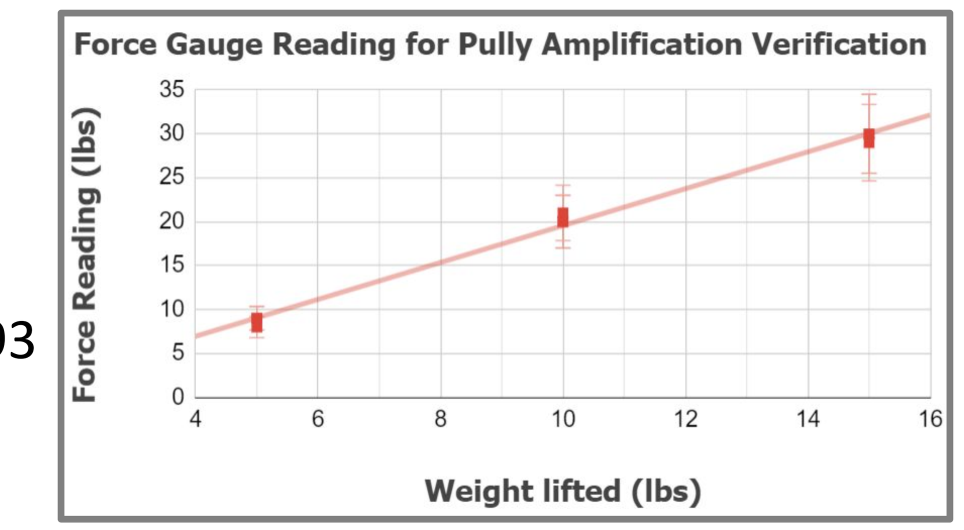

Figure 14. Graph comparing weight on either side of the pulley to calculate the experimental amplification factor

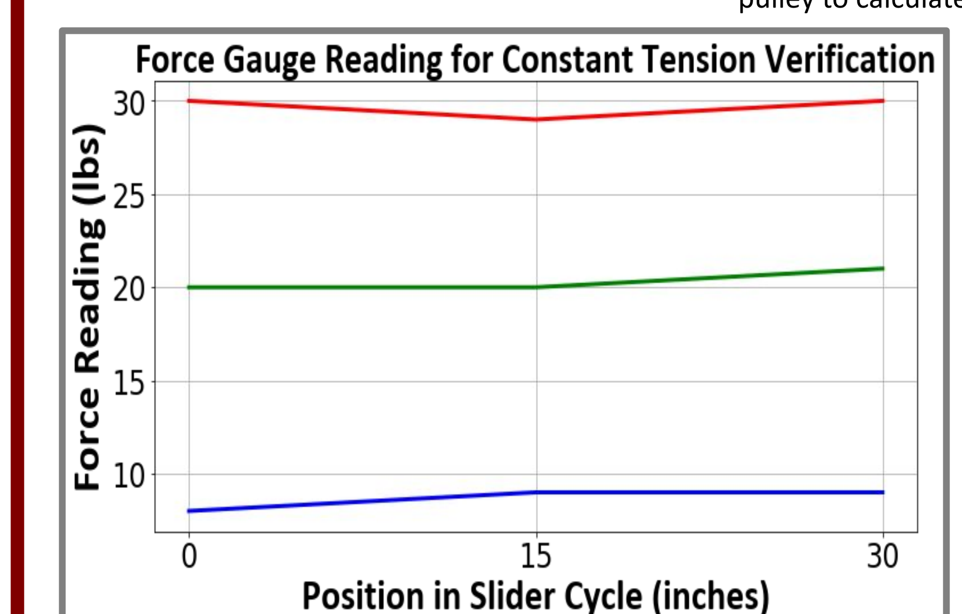

Figure 15. Graph of the weight at 3 positions in the slider cycle for a 5, 10, and 15 lb weight

- Verified constant tension over 3 distinct positions of the slider
- ANOVA p-value of 0.966
- No significant difference in force at each slider position

Conclusion/Future Work

PDS Criteria	Evaluation and Improvement
Constant Hamstring Activation	• Achieved p-value of 0.996 >>0.05 (ANOVA), indicates no significant difference in tension throughout sliding motion of the device
Supports a 25 lb alternating load	• Achieved a safety factor of 3 on load bearing rod relative to >120 lb amplified load • **Future work:** • Implementing high load bearings for pulley and shaft support • Use of stronger fasteners (stainless steel screws)
MRI Compatible	• All materials were non-ferrous: HDPE Sheets/Supports, Carbon Fiber Rod, Nylon Screws, 3D printed PLA Pulley

References

[1] "Impact of exercise selection on hamstring muscle activation", Accessed: Jan. 31, 2024. [Online]. Available: https://core.ac.uk/reader/159507467?utm_source=linkout
[2] Bisciotti, Gian Nicola, et al. "Return to Training and Return to Play Following Hamstring Injury." Return-to-Play after Lower Limb Muscle Injury in Football: The Italian Consensus Conference Guidelines, edited by Gian Nicola Bisciotti et al., Springer International Publishing, 2022, pp. 55–59, https://doi.org/10.1007/978-3-030-84950-4_9.
[3] "Neuroscience Research | Emory School of Medicine." Accessed: Feb. 29, 2024. [Online]. Available:https://m ed.e mory.edu/departme nts/orthopaedics/re search/sparc/imagin g-research.html
[4] Giakoumis, Michael, et al. "Eccentric Hamstring Strength in Elite Track and Field Athletes on the British Athletics World Class Performance Program." *Physical Therapy in Sport*, vol. 43, May 2020, pp. 217–23, https://doi.org/10.1016/j.ptsp.2020.03.008.
[5] "MRI." Waisman Center, https://www.waisman.wisc.edu/brain-imaging/mri/. Accessed 8 Feb. 2024.