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Lower Extremity Loading Device During MRI

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Clients: Dr. Scott Crawford, Dr. Beth Meyerand

Overview

- Background and Problem Statement
- Competing Solutions
- Design Specifications/Criteria
- Preliminary Designs
- Final Loading Device Design
- Future Plans

Background

- Clients: Dr. Scott Crawford, Dr. Beth Meyerand
- Hamstring strain injuries (HSIs) [3]
  - Common in sports and recreation
  - Cause an elevated reinjury risk
- HSIs could affect neuronal–muscle signaling
- Functional MRI (fMRI) displays brain activity

Figure 1. Dr. Crawford (left) and Dr. Meyerand (right) [1][2]

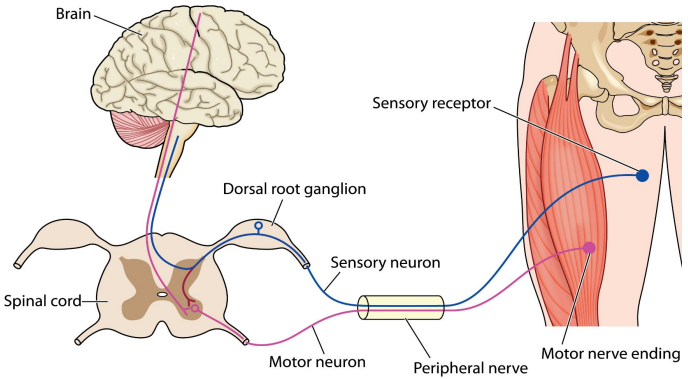

Figure 2. Nervous system signal pathway for leg muscle activation [4]

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Problem Statement

Produce a device for use in hamstring strain injury research in order to determine neuronal activation differences as a result of injury.

To accomplish this, the design will induce hamstring activation as an MRI of the brain is recorded, collecting resistance and knee flexion data.

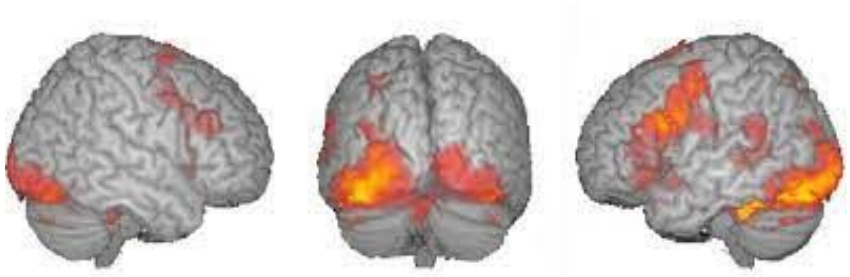

Figure 3. Brain MRI showing neuronal activation [5]

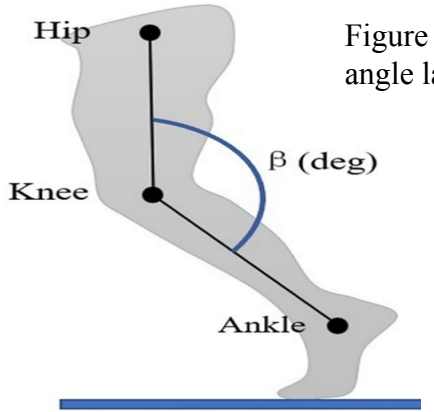

Figure 4. Knee flexion angle labeled as β [6]

Competing Solutions

- Emory University School of Medicine [7]
  - Inclined supine heel slide mechanism
  - fMRI for brain activation imaging
  - 12 camera array for motion capture
- Marsh–Bellofram Rolling Diaphragm [8]
  - Resistance from pneumatic pressure vessel
  - Variable volume = constant resistance

Figure 5. Emory heel slide setup with the MRI [7]

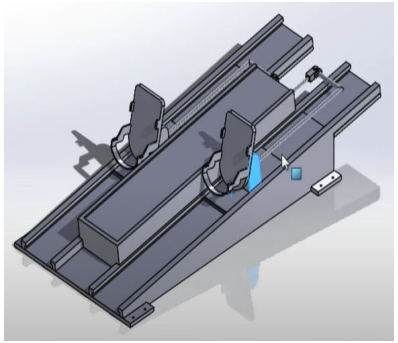

Figure 6. Emory heel slide SOLIDWORKS sketch [7]

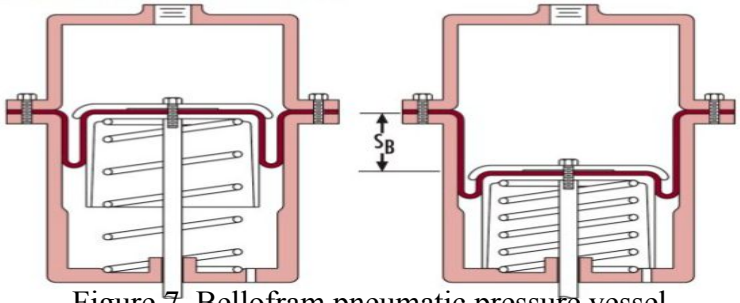

Figure 7. Bellofram pneumatic pressure vessel and piston illustration [8]

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Design Specifications

- Activate the hamstring (20-30%)
- Withstand ≅110.55 N regularly [9]
- Maintain constant tension
- MR compatible (GE MAGNUS Scanner)[10]
- Weight: < 50 lbs
- Width: ≈ 31 ⅞ inches [12]

Figure 8. GE MAGNUS Scanner [10]

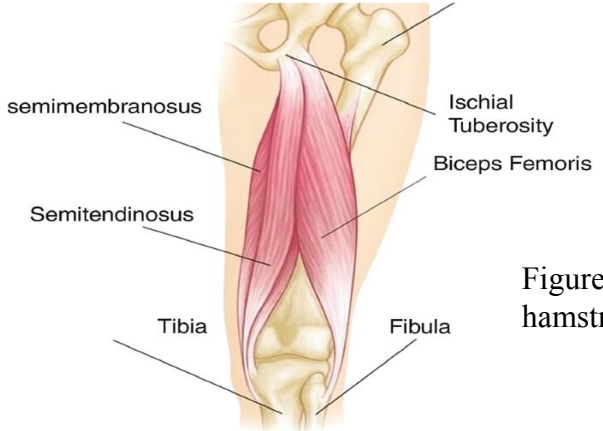

Figure 9. Anatomy of the hamstring [11]

Criteria for Design Matrices

- Hamstring Activation
- Adjustability
- Size
- Ease of Use
- Fabrication Ability
- Safety

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Resistance Designs

- Cable Stack: Similar to gym cable machines
- Friction: Motion causes resistance
- Elastic Band: Tension from straining elastic bands
  - No constant tension in bands or friction

Figure 10. Cable stack [13]

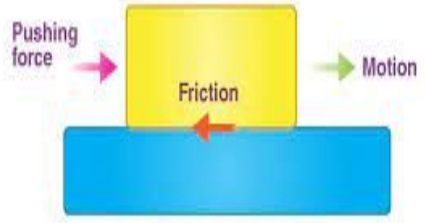


Figure 11. Friction illustration [14]

Figure 12. Elastic exercise band roll (left) and tube (right) [15]

Resistance Design Matrix

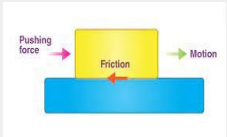
Design Categories (Weight)	Cable Stack 		Friction 		Elastic Band 	
Hamstring activation (30)	5/5	30	2/5	12	0/5	0
Adjustability (20)	5/5	20	3/5	12	1/5	4
Size (15)	2/5	6	3/5	9	5/5	15
Ease of Use (15)	5/5	15	2/5	6	3/5	9
Fabrication Ability (10)	4/5	8	1/5	2	3/5	6
Safety (10)	3/5	6	4/5	8	4/5	8
Total (100)	**85**		**49**		**42**	

Table 1. Resistance design matrix comparing resistance designs to design criteria

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Mechanical Design: Slider Design

- Heels strapped to frictionless slider
- User pulls slider inwards through knee flexion
- Hamstring and quad activation

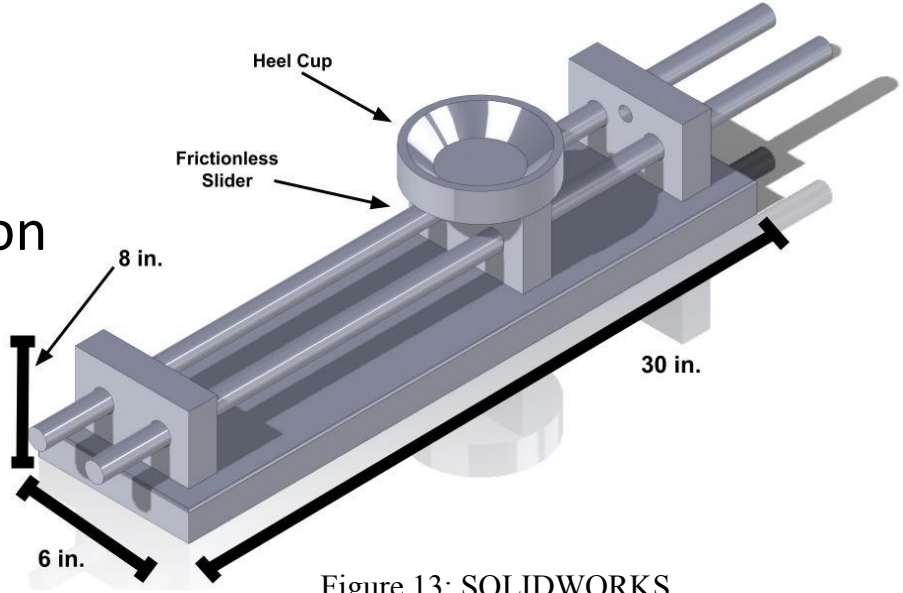

Figure 13: SOLIDWORKS drawing of Slider design

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Mechanical Design: Bike Pedal Design

- User moves elevated bike pedals in supine position
- Pulling pedals inward through knee flexion activates hamstrings
- Additionally activates quadriceps, glutes

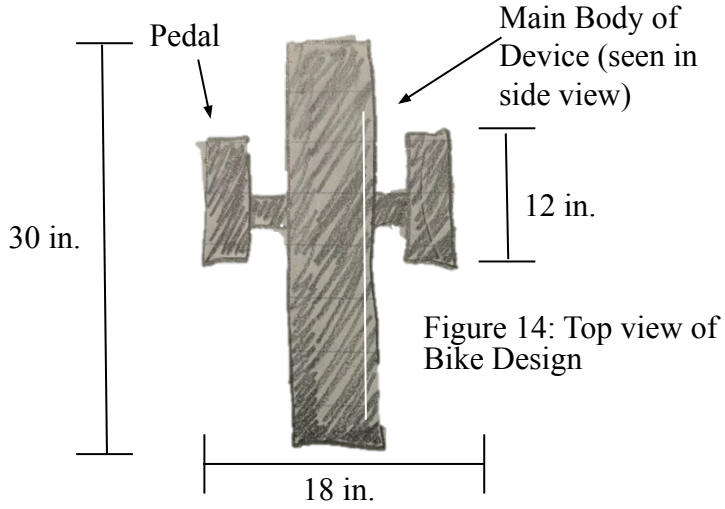

Figure 14: Top view of Bike Design

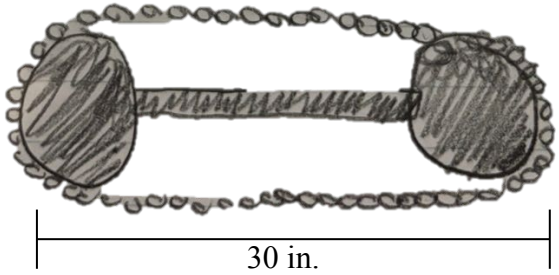

Figure 15: Side view of Bike Pedal Design without pedals

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Mechanical Design: Leg Support

- Device supports and fixes upper leg
- User pushes leg roller inwards
- Isolated hamstring activation
- Knee flexion/extension
- Adjustable height/distance

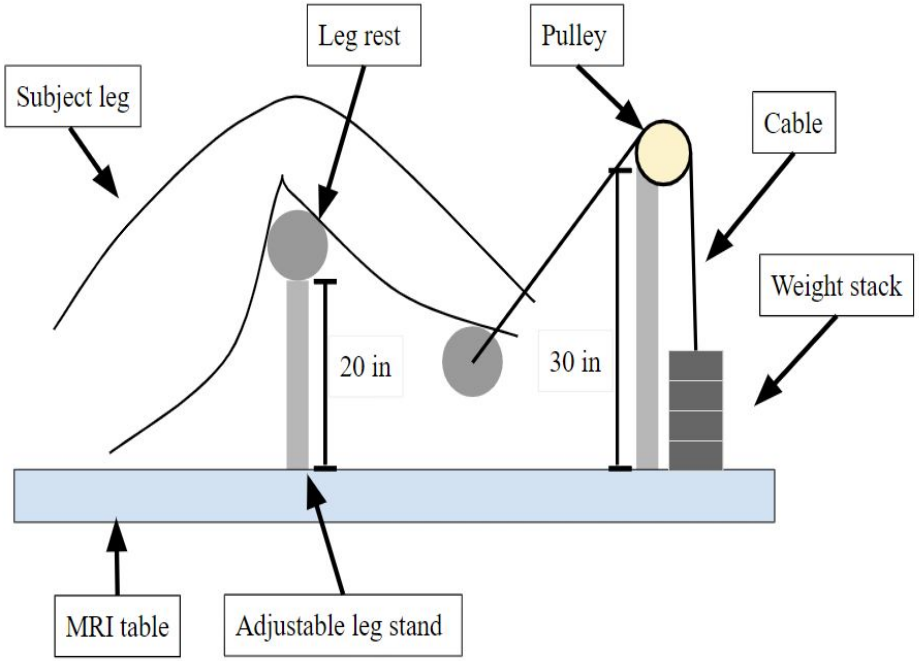

Figure 16: Side view of leg support design with cable stack

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Mechanical Design Matrix

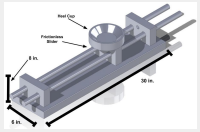
Design Categories (Weight)	Slider Design 		Bike Pedal Design 		Leg Support Design 	
Hamstring activation (30)	5/5	30	3/5	18	4/5	24
Adjustability (20)	4/5	16	2/5	8	5/5	20
Size (15)	4/5	12	3/5	9	3/5	9
Ease of Use (15)	4/5	12	2/5	6	3/5	9
Fabrication Ability (10)	5/5	10	4/5	8	4/5	8
Safety (10)	3/5	6	2/5	4	4/5	8
Total (100)	**86**		**53**		**78**	

Table 2. Mechanical design matrix comparing resistance designs to design criteria

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Final Design: Slider and Cable Stack

- Adjustability:
  - To account for subject leg length
  - Change in resistance values
- Minimizes upper body movement
  - Important for clean fMRI data
- Minimal footprint for on MR Table
- Provides constant calculable resistance
- Easy to set-up and use

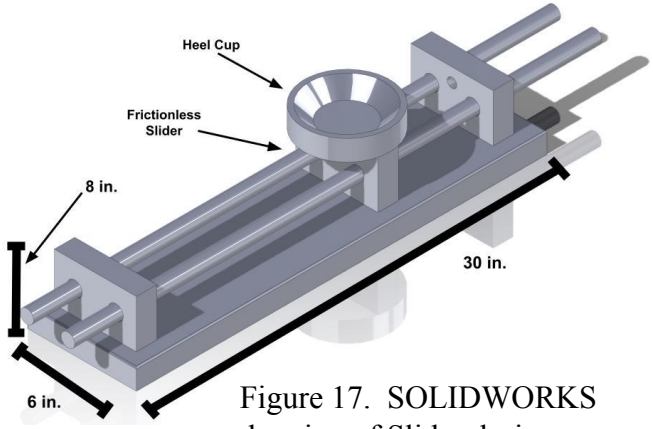
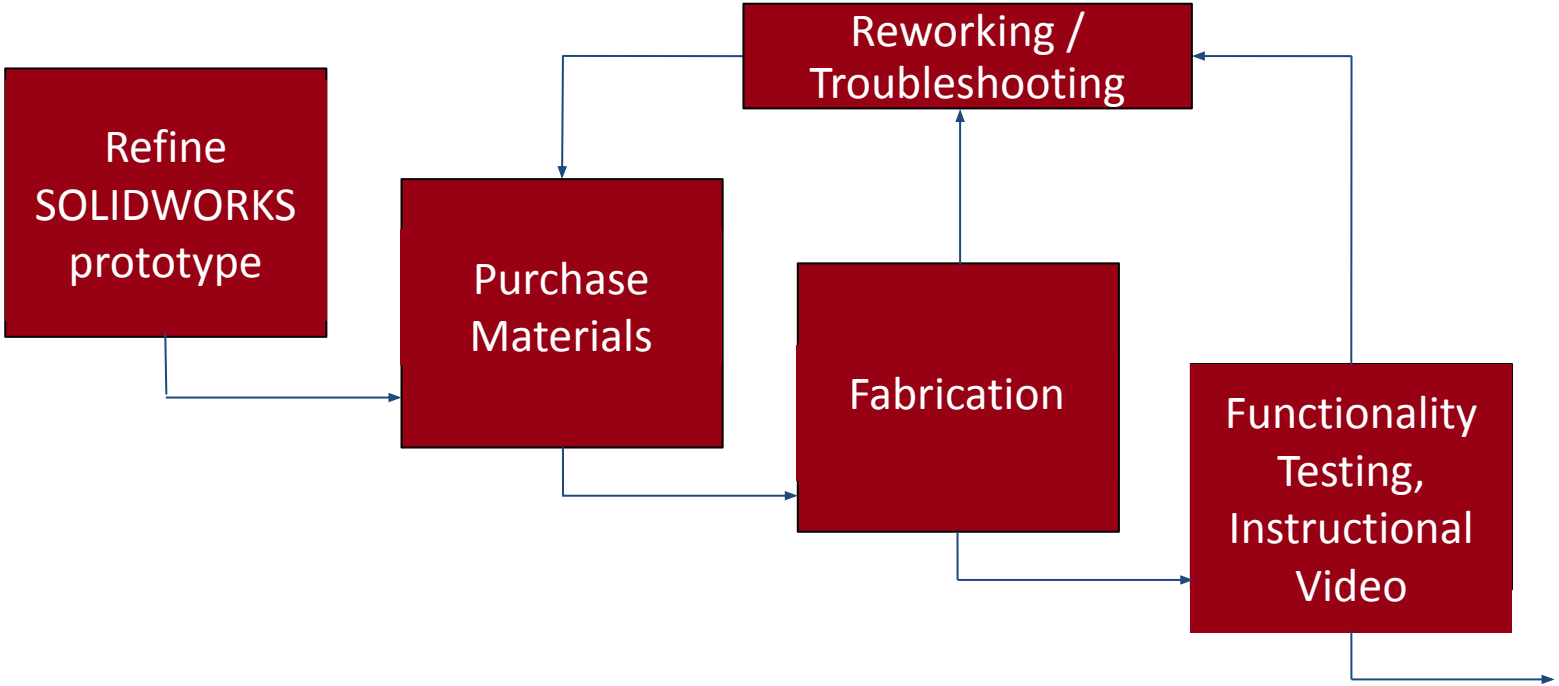


Figure 17. SOLIDWORKS drawing of Slider design

Figure 18. Cable weight stack with pulley

Future Plans



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Thank You!

Dr. John Puccinelli
Sarah Edwards
Dr. Scott Crawford
Dr. Beth Meyerand

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References

[1] “Crawford, Scott,” Kinesiology. Accessed: Feb. 29, 2024. [Online]. Available:https://kinesiology.education.wisc.edu/fac-sta ff/crawford-scott/
[2] “Meyerand, PhD, Beth,” McPherson Eye Research Institute. Accessed: Feb. 29, 2024. [Online]. Available: https://vision.wisc.edu/staff/beth_meyerand/
[3] “Impact of exercise selection on hamstring muscle activation”, Accessed: Jan. 31, 2024. [Online]. Available: https://core.ac.uk/reader/159507467?utm_source=linkout
[4] “The Central Nervous System – Scottish Acquired Brain Injury Network.” Accessed: Feb. 29, 2024. [Online]. Available: https://www.acquiredbraininjury-education.scot.nhs.uk/impact-of-abi/physical-impairments-related-to-movement/normal-movement-and-movement-following-acquired-brain-injury/the-central-nervous-system/
[5]“Functional Magnetic Resonance Imaging (fMRI),” Thesen Lab. Accessed: Feb. 29, 2024. [Online]. Available: https://med.nyu.edu/thesenlab/research-0/research-functional-magnetic-resonance-imaging-fmri/
[6]V. Chhoeum, Y. Kim, and S.-D. Min, “Estimation of Knee Joint Angle Using Textile Capacitive Sensor and Artificial Neural Network Implementing with Three Shoe Types at Two Gait Speeds: A Preliminary Investigation,” Sensors, vol. 21, no. 16, Art. no. 16, Jan. 2021, doi: 10.3390/s21165484
[7] “Neuroscience Research | Emory School of Medicine.” Accessed: Feb. 29, 2024. [Online]. Available: https://med.emory.edu/departments/orthopaedics/research/sparc/imaging-research.html
[8] “Marsh Bellofram - Bellofram Rolling Diaphragm Design Manual - Marsh Bellofram - Page - PDF Catalogs | Technical Documentation | Brochure.” Accessed: Feb. 29, 2024. [Online]. Available: https://pdf.directindustry.com/pdf/marsh-bellofram/marsh-bellofram-bellof ram-rolling-diaphragm-design- manual/11788-27709-_5.html
[9] 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.
[10] “MRI.” Waisman Center, https://www.waisman.wisc.edu/brain-imaging/mri/. Accessed 8 Feb. 2024.
[11] 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.
[12] G. Crowley, “Control-X – Phoenix – Elevating Radiographic Table,” Advanced Medical X-ray, Mar. 24, 2016. https://cr-pacs.com/phoenix- eleva ting-radiographic-table/ (accessed Feb. 08, 2024).
[13] “Wall Mounted Cable Column | Strength Training | BLK BOX.” Accessed: Feb. 29, 2024. [Online]. Available: https://www.blkbo xfitness.com/products/blk-box-wall-mounted-cable-column
[14] “Coefficient Of Static Friction - Definition, formula, S.I Unit, Explanation,” BYJUS. Accessed: Feb. 29, 2024. [Online]. Available: https://byjus.com/physics/coefficient-of-static-friction/
[15] “Amazon.com: THERABAND Resistance Band 50 Yard Roll, Medium Red Non-Latex Professional Elastic Bands For Upper & Lower Body Exercise, Physical Therapy, Pilates, & Rehab, Dispenser Box, Beginner Level 3 : Sports & Outdoors.” Accessed: Feb. 29, 2024. [Online]. Available: https://www.ama zon.com/THERABAND-Resistance-Non-Latex-Prof essional-Dispenser/dp/B00EAR6 Q02/ref=asc_df_B00EAR6Q02/?tag=hyprod-20&linkCode=df0&hv

Questions?

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