Joint Department of BIOMEDICAL ENGINEERING
UNC CHAPEL HILL | NC STATE UNIVERSITY

Applied Biomechanics Laboratory

Too Much Work: Revisiting Ultrasound-Based Estimates of Achilles Tendon Energy Storage and Return

Jason R. Franz[1] and Karl E. Zelik[2]

[1]UNC-Chapel Hill and NC State University, Chapel Hill, NC
[2]Vanderbilt University, Nashville, TN

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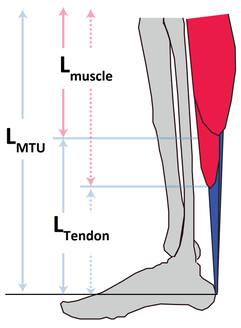
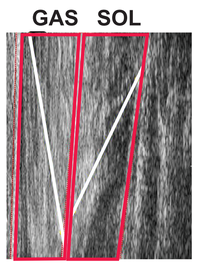
CREATE

1. BACKGROUND/SIGNIFICANCE





Longstanding Assumption: We can deduce *in vivo* tendon dynamics *indirectly* from measured muscle fascicle dynamics.

Work Loop "Litmus Test" - Passive, spring-like tendons should behave in passive, spring-like fashion (i.e., perform net negative work).

Dilemma: Indirect estimates fail this litmus test [e.g., 1,2]

PURPOSES: (1) Compute tendon work loops and apparent hysteresis loss using more Direct ultrasound estimates of tendon kinematics, and **(2)** Compare the results to previously reported values from Indirect estimates.

HYPOTHESIS: Unlike Indirect estimates, Direct estimates yield negative work loops for the human Achilles tendon across a range of walking speeds.

2. TAKEAWAYS & IMPLICATIONS [3]

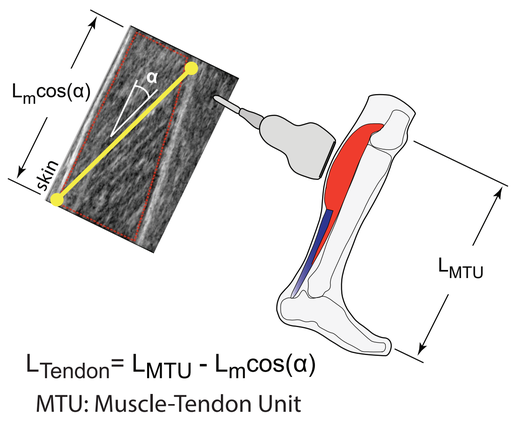
1. Compared to Indirect estimates, Direct ultrasound estimates of tendon energy storage and return are more plausible, and thus may be preferable for understanding tendon dynamics during human movement

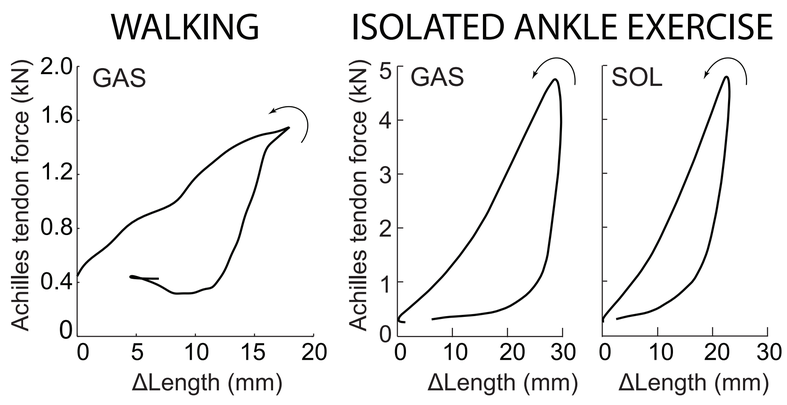
Highly relevant to:

- The degree to which tendon elastic energy storage and return facilitates economical locomotion, including applications in modeling and simulation.
- The bio-inspired design and prescription of assistive devices that seek to restore/augment human calf muscle-tendon function.

2. Highlights the need to understand the accuracy, precision, benefits, drawbacks, and assumptions of our measurement techniques in order to appropriately interpret the functional role of muscle-tendon dynamics during movement

3. INDIRECT: TENDON WORK LOOPS FROM MEASURED FASCICLE KINEMATICS



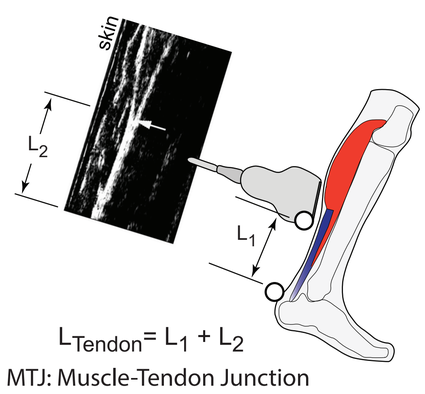


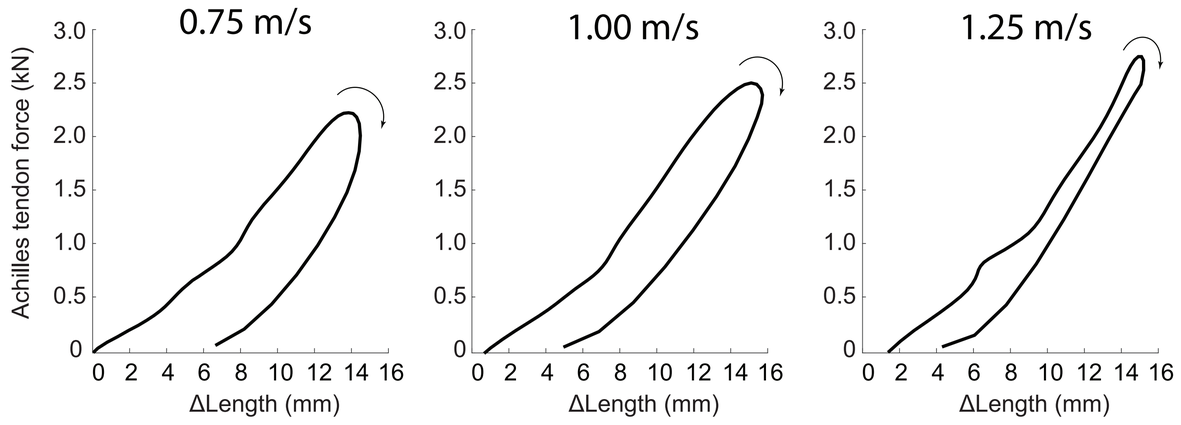
1 J Stored ⟶ 2-5 J Returned: Physiologically Implausible

Potential Sources of Error:

- MTU lengths based on regression equations from cadaver data [4]
- Assumes that the aponeurosis acts longitudinally and in series with muscles and tendons [5]
- 2D imaging may not represent complex 3D behavior
- Assumptions for decomposing ankle moments into tendon force (*Shared by all methods*)

4. DIRECT MTJ: TENDON WORK LOOPS FROM MEASURED MTJ KINEMATICS

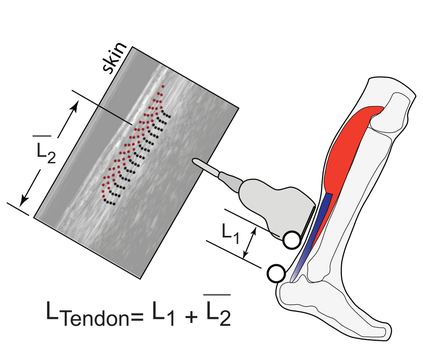


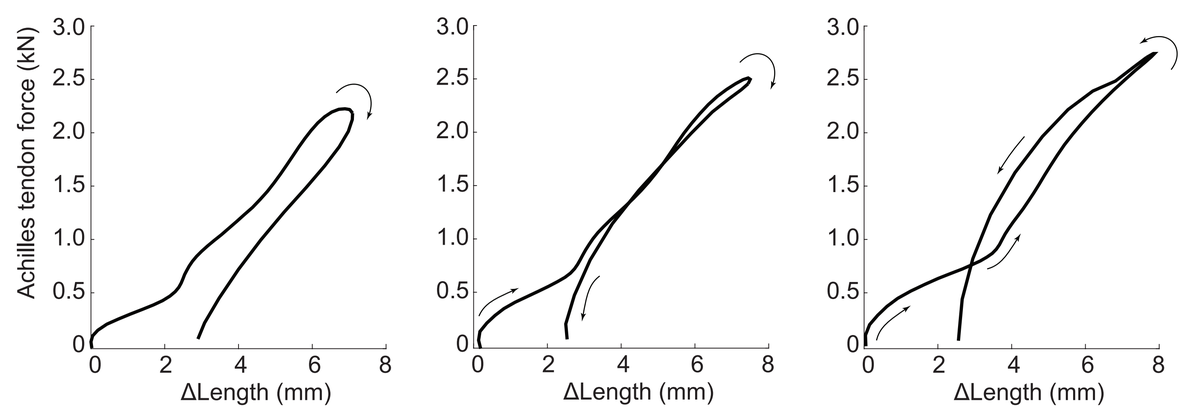


1 J Stored ⟶ 0.51-0.89 J Returned

	Walking Speed (m/s) 0.75	1.00	1.25
Hysteresis (%)	48.5	37.3	11.3
Net Work (J)	-9.0	-8.3	-5.2

5. DIRECT TENDON: TENDON WORK LOOPS FROM LOCAL TENDON ELONGATIONS





1 J Stored ⟶ 0.67-0.98 J Returned

	Walking Speed (m/s) 0.75	1.00	1.25
Hysteresis (%)	32.9	11.0	2.1
Net Work (J)	-3.4	-2.0	-1.2

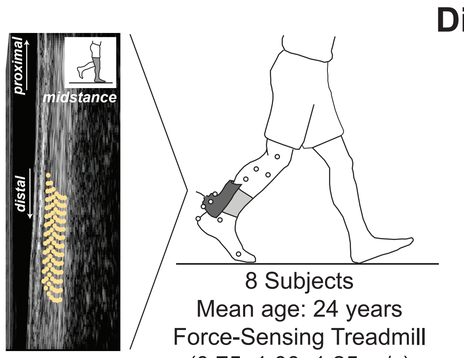
6. METHODS OVERVIEW

Indirect Tendon: From Data Digitization

Outcome measures digitized from prior publications that used the Indirect method:

Walking (1.4 m/s, N=8) [1]

Isolated Ankle Exercise ("Bouncing", N=7) [2]



8 Subjects
Mean age: 24 years
Force-Sensing Treadmill
(0.75, 1.00, 1.25 m/s)

Direct Tendon: 2D Speckle Tracking
Tracked localized tendon tissue displacements at 155 frames/sec

Direct Muscle-Tendon Junction
Manual Tracking at 70 frames/sec

Motion Capture Co-Registration
Heel marker used as a surrogate for calcaneal insertion

REFERENCES

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2. Sakuma et al., Eur J Appl Physiol 2012; 112: 887-98.
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4. Hawkins and Hall, J Biomech 1990; 23:487-94.
5. Epstein et al., J Biomech 2006; 39: 2020-25.

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