JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

Noninvasive Detection of Tibial Stress Fractures Using Surface Acoustic Waves

MHSRS 2026 26-5788 *Integrating Holistic & Technological Approaches for Musculoskeletal Injury Prevention Session*

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Disclosure

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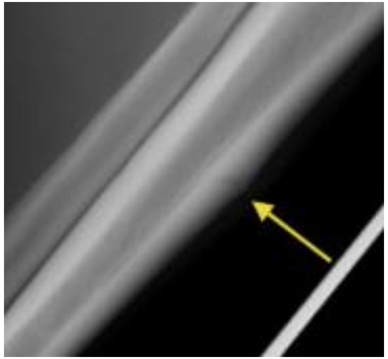
- A nonprovisional patent application covering aspects of this technology has been filed
- All authors have no conflicts of interest to report

Challenge: Tibial Stress Fractures (TSF) in Military

- **Stress fractures (SF), particularly in the tibia, are common to athletes and the military**
    - Affects 3 - 8% of recruits during training [1] due to significant increase in exercise activities with new shoes and gear
    - 86.5% of SFs occur in the tibia [1] resulting in a 21.1 week mean rehab [2]
    - Recruits are 4x more likely discharge after sustaining a stress fracture [3]

- **Currently, by the time TSF is detectable, it is already too late to mitigate impact on athletic performance**
    - Diagnosed by clinical x-ray with “dreaded black line” (~1 mm resolution)
    - Indication that irreversible injury already incurred

Stress fracture of tibia

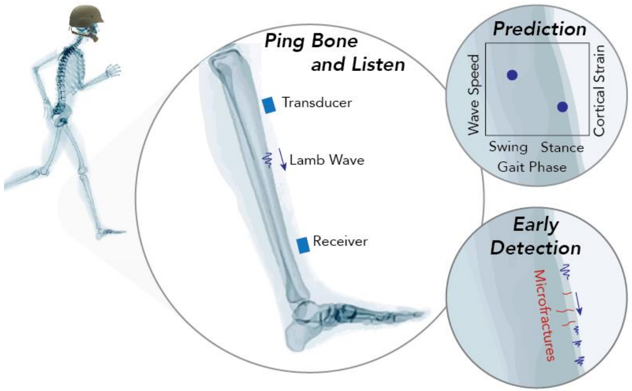


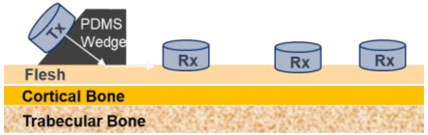
http://www.svuhradiology.ie/case-study/stress-fracture-of-tibia/

Earlier detection of TSF initiation, enabled by portable acoustic diagnostic technology, will help mitigate injuries and optimize their performance abilities

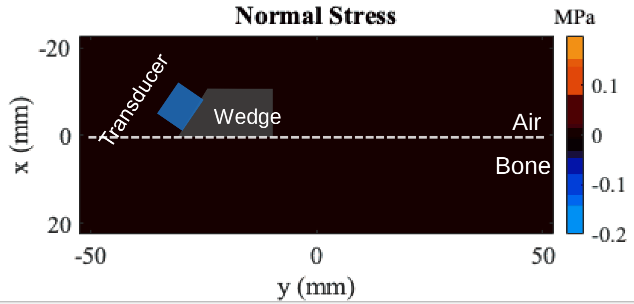
Solution: Acoustic Bone Surface Waves for TSF Detection

- **Portable non-invasive, non-ionizing surface acoustic waves can detect changes in bone structure with greater resolution than current x-ray systems**



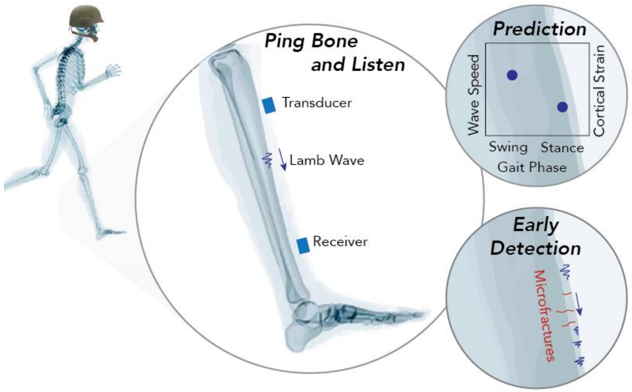


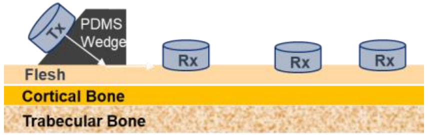
Simulations and surrogate testing used to select distances between transmit (Tx) and receive (Rx), and minimum detectable crack size: 2.25 MHz and 55 degree PDMS wedge allows sensing ~60 mm



Solution: Acoustic Bone Surface Waves for TSF Detection

- **Portable non-invasive, non-ionizing surface acoustic waves can detect changes in bone structure with greater resolution than current x-ray systems**





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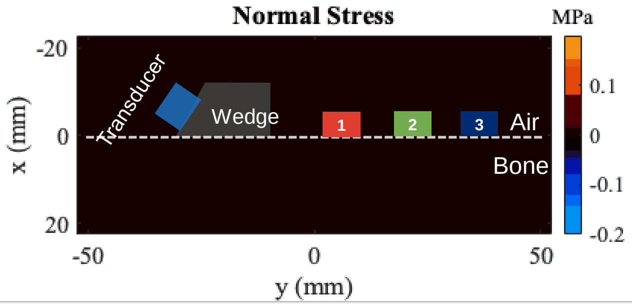

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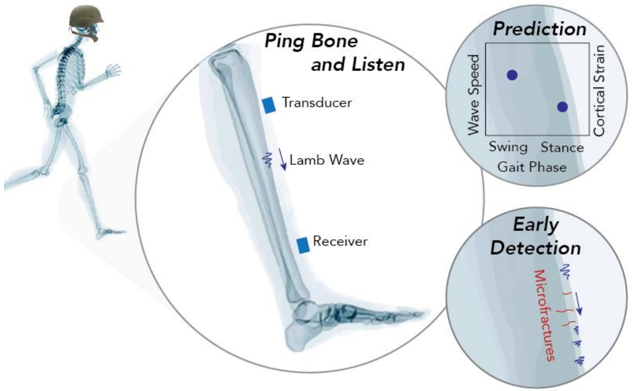

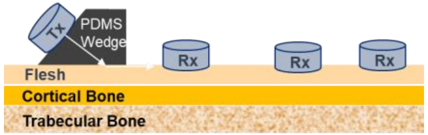

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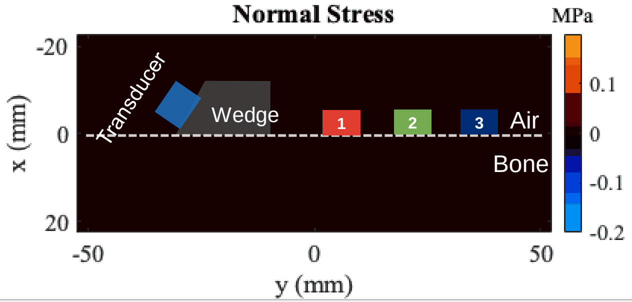
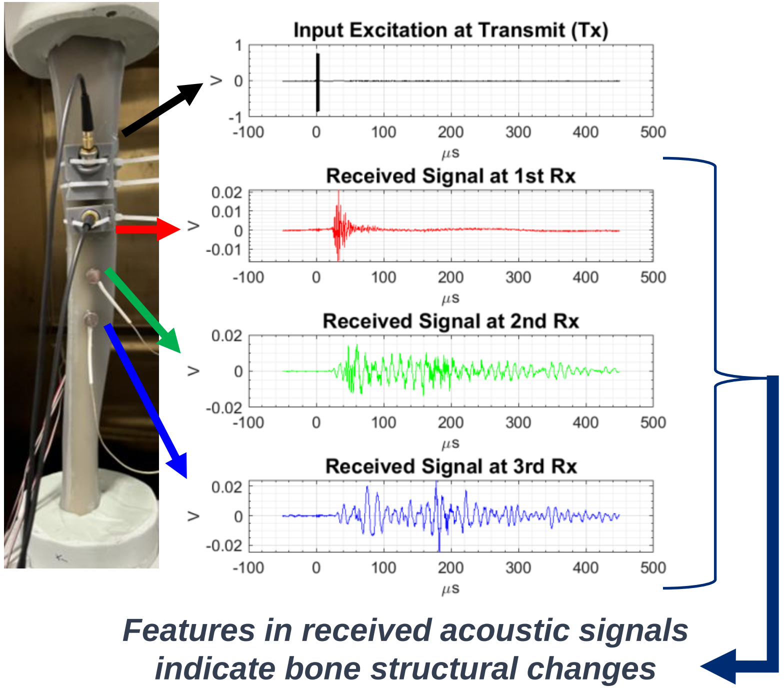
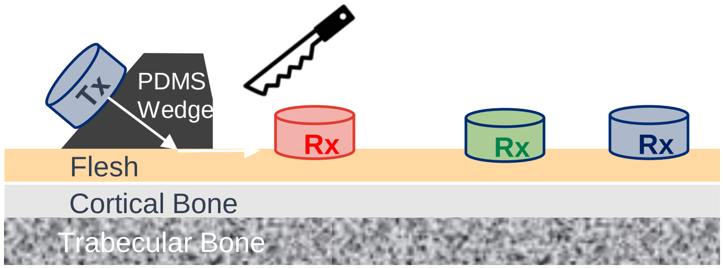
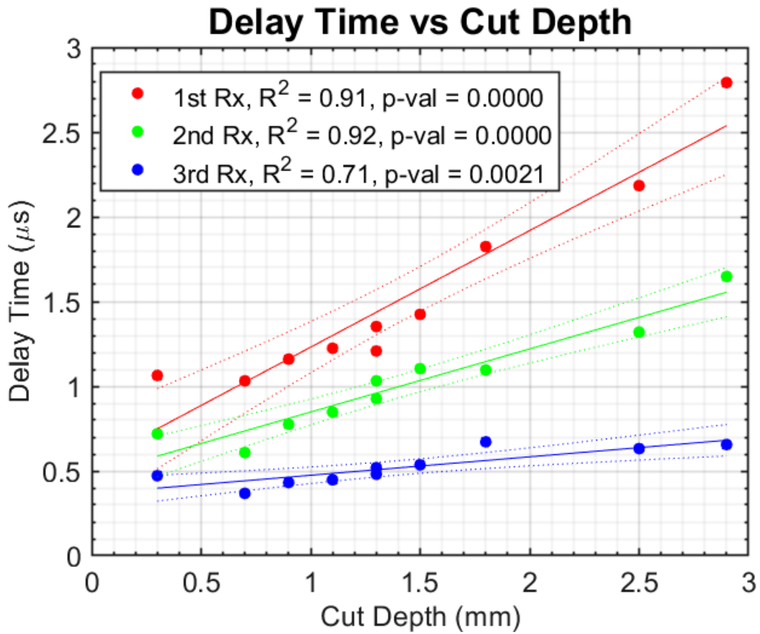




Features in received acoustic signals indicate bone structural changes

Fracture Detection in Bone: Manual Cuts

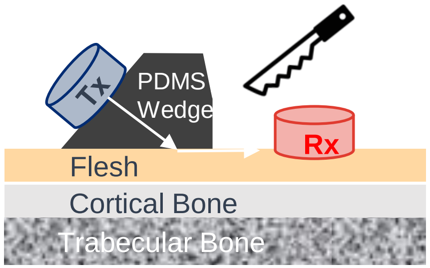


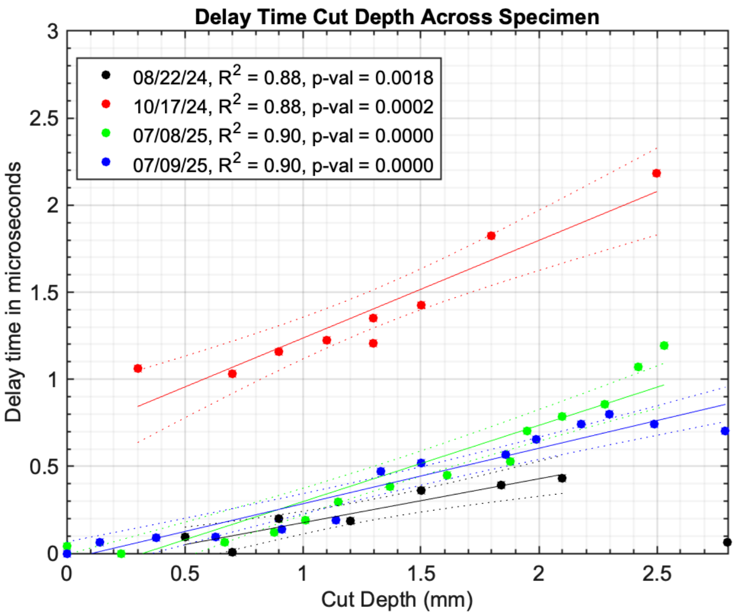


- Increase in time of flight with increasing cut depth
- Sensitive to cuts as small as 0.3 mm

System sensitive to detection of fractures under 1 mm, competing with the resolution of planar radiography

Fracture Detection in Bone: 4 specimen to date

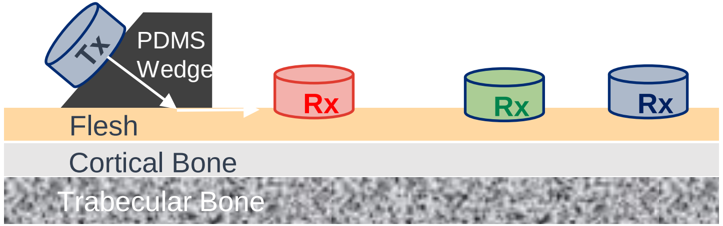


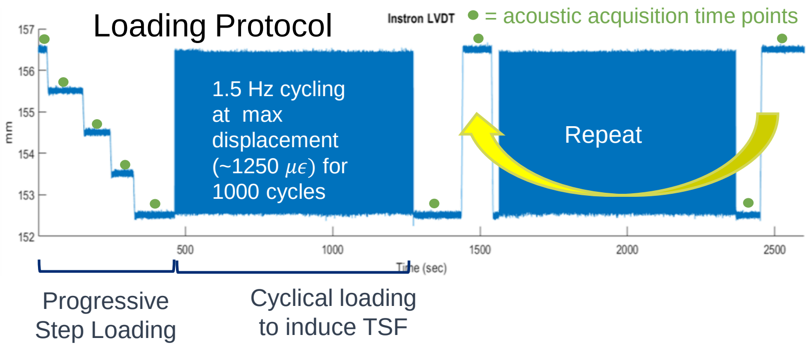


- Increase in time of flight with increasing cut depth
- Sensitive to cuts as small as 0.5 mm

Same slope/trend across 4 specimen to date

Fracture Detection in Bone: Fatigue Induced





- ~1,200 N load, 8 mm displacement
- 10,000 cycles at 1.5 Hz
- Acoustic data every 1,000 cycles
- Measured in intact human lower extremity

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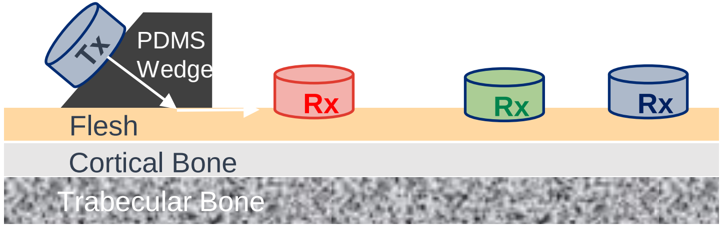

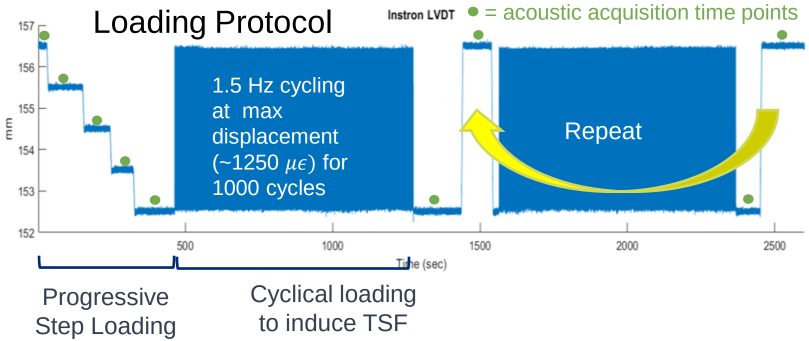

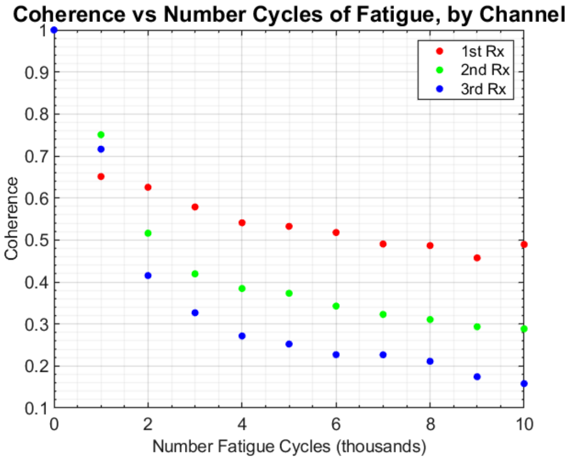

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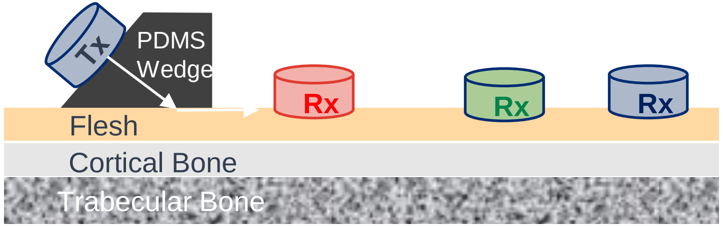
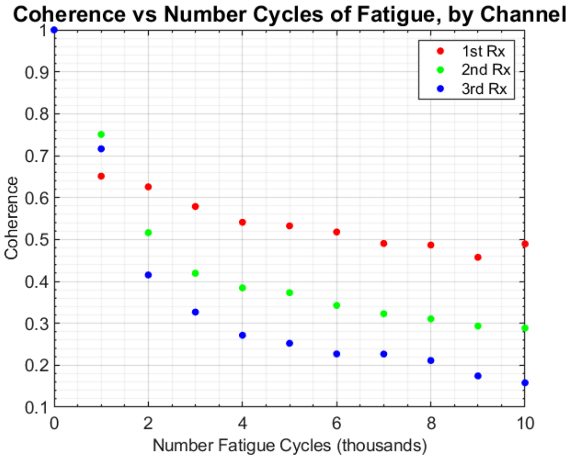
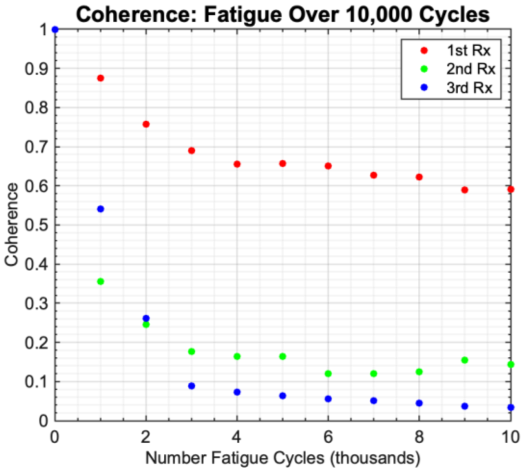
Coherence of surface acoustic wave degrades over time during biomechanically relevant fatigue loading

Fracture Detection in Bone: Fatigue Induced







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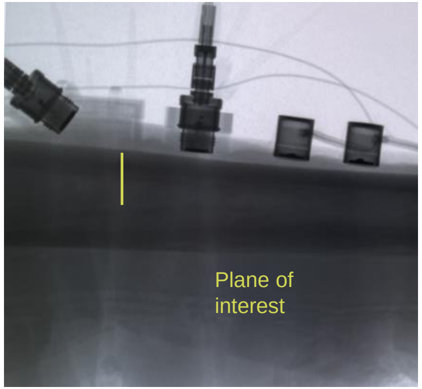
Coherence trend holds over two specimen to date

Fracture Detection in Bone: Fatigue Induced

MicroCT
Inspection of Bone
Structure



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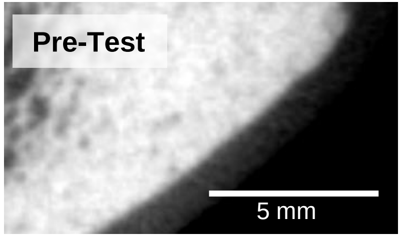
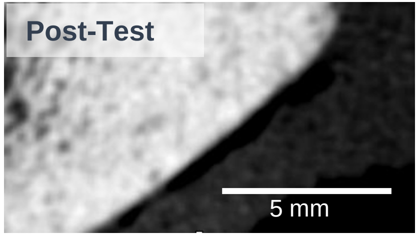
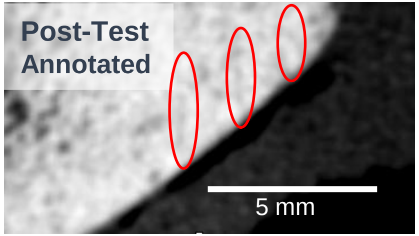
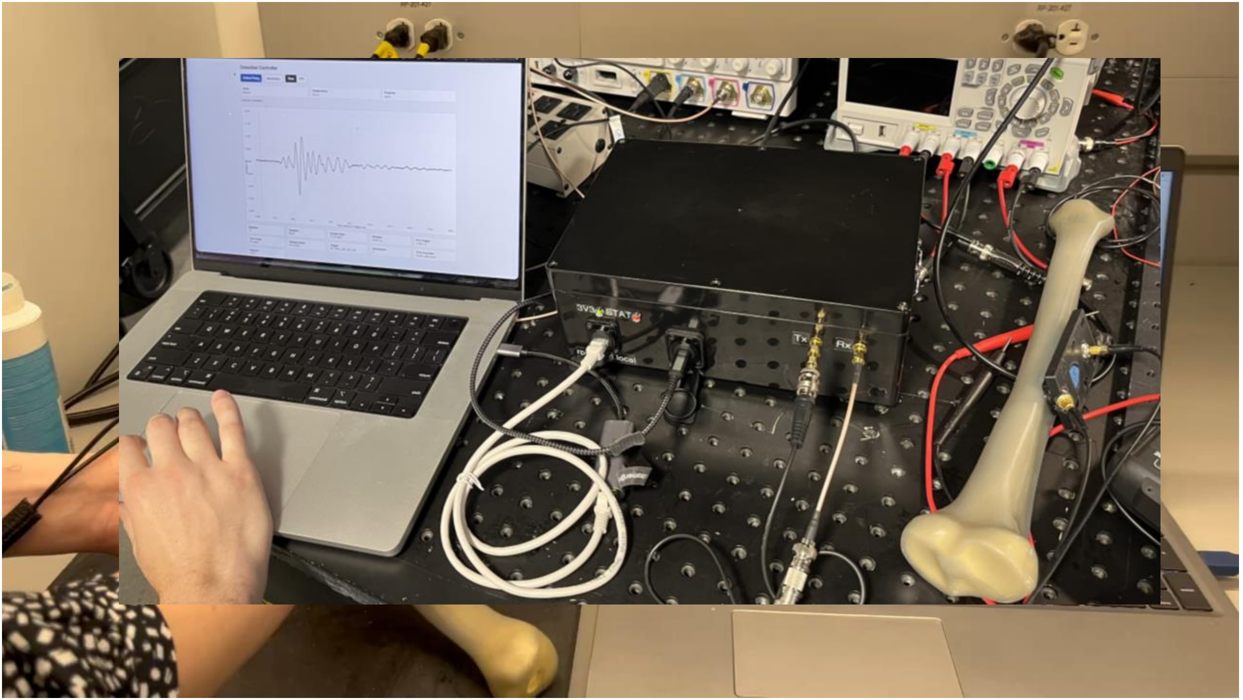


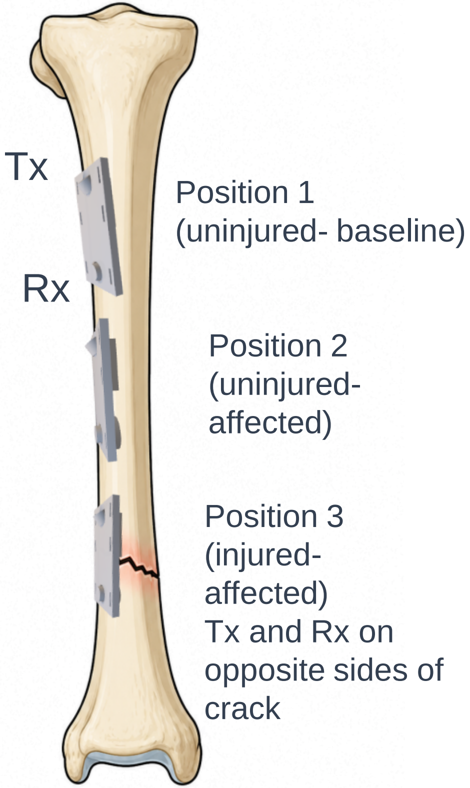




Coherence metric is validated with microCT, meaning acoustic signature is a first measured non-invasive metric of bone fatigue

Developing a Deployable Solution





- SWAP: Previously hardware 30 lbs, Updated SWAP: ~3 lbs, runs on USB-C, processing works on a phone application
- Non-provisional patent on “Inv P07907: Tibial Fracture Detection with Surface Acoustic Waves”, filed June 9 2025 no. 19/232,568 with the U.S. Patent & Trademark Office

Next Steps

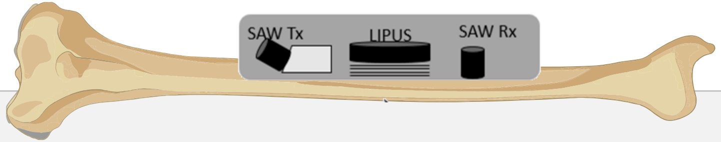
Research

- Optimize Sensing Technology
  - Improve SNR
  - Reduce SWAP
- Validate in Preclinical Models
  - Conduct additional PMHS studies (n = 4)
  - Establish baseline variability across tibia, subjects, operator
  - Correlate acoustic signal with crack size, validate with microCT

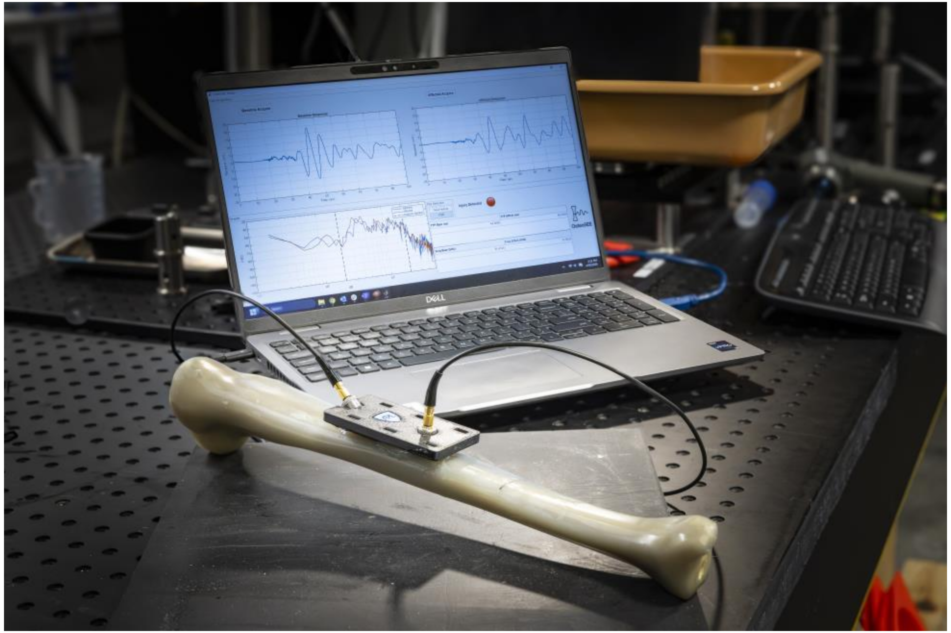
Operationalization

- Translate to Human Subjects
  - Establish clinical partnership
  - Conduct healthy volunteer studies
  - Longitudinal training cohort
- Develop Predictive Models of Acoustic signature mapping injury risk
- Enable Injury Prevention & Treatment
  - Inform individualized training
  - Guide intervention
  - Monitor healing & integrate therapeutic ultrasound

Actively seeking clinical, collaborative, and transition partners



Questions?



OsteoSEE

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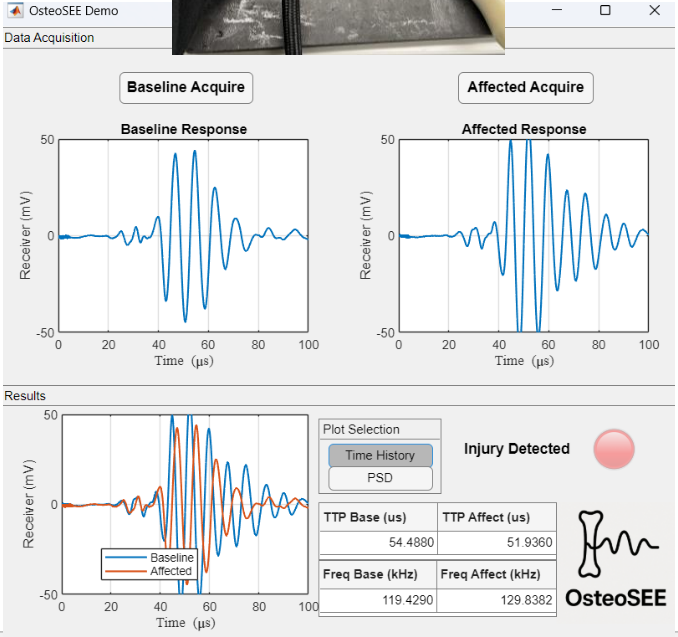
Live Demo

Baseline

Uninjured



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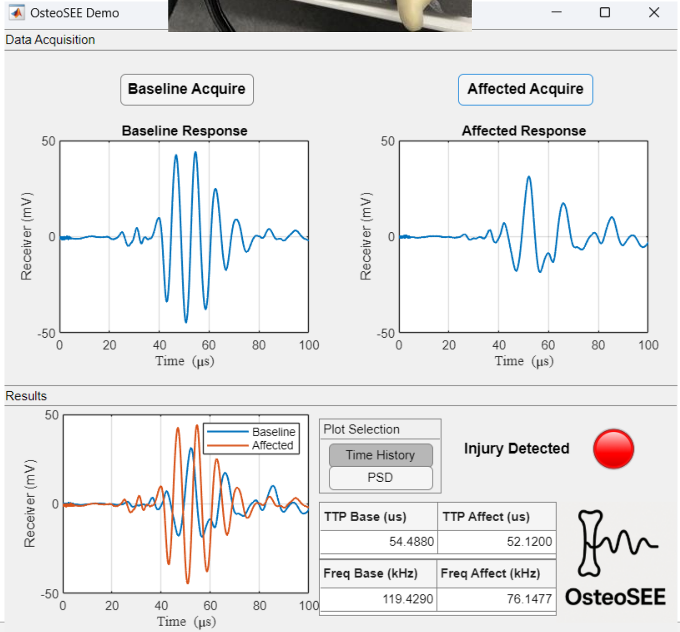

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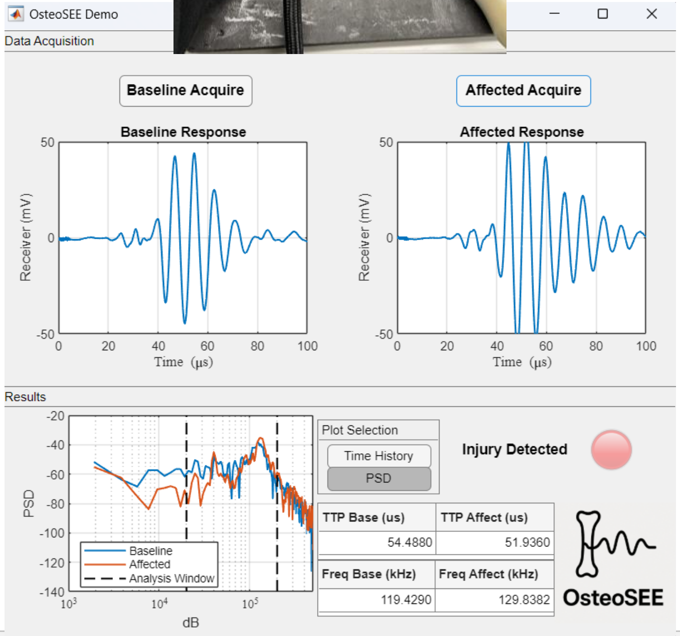


Injured

Specimen Loading Protocol

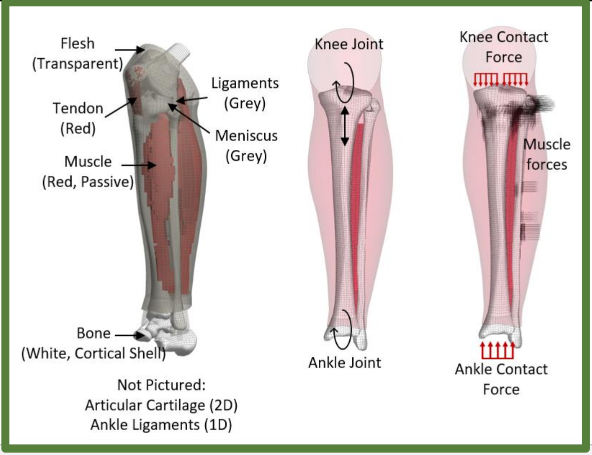
Objective: Apply cyclic physiologic loads representative of running to human tibia specimen. Should be well-controlled to allow us to…

- Identify elastic wave signatures representing distal anteromedial cortical strain and damage accumulation
- Compare these signature across test specimen
- Avoid damaging equipment

Candidate Loading Protocol applied on per-specimen basis

1. Apply instrumentation (strain gauges, acoustic transducers)
2. Align and pot specimen in test fixture
3. Load once at 1 mm
4. Determine **reference displacement** of crosshead at which 1000 με anteromedial strain is reached
   - **<u>In one specimen this is 6 mm, in the other 8 mm</u>**
5. Sinusoidal cyclic loading using displacement control up to **reference displacement** at 1.5 Hz for up to 10,000 cycles
   - Pause every 1,000 cycles at max and min displacement to acquire acoustic data

Test Characteristics	Literature	APL Multiscale MSK-FEM
Comp. Force	2-12x BW[3,5,6,7,12]	8.6x BW
Bending Moment	10-100x BW-mm[5]	51.2 BW-mm
Cortical Strain	500 – 5,000 με[1,2,3,4,11]	1,250 με
Strain Rate	0.01 – 0.03 ε/s [4,8]	0.025 ε/s
Cycles to Stress Fracture	1k – 10k[2,3]	-



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