AN MRI-COMPATIBLE DEVICE FOR OBTAINING PATIENT-SPECIFIC PLANTAR SOFT TISSUE MATERIAL PROPERTIES

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BACKGROUND

- More than 60% of all nontraumatic lower-limb amputations occur in people with diabetes [1].
- Diabetes has been shown to increase the stiffness of the plantar soft tissue in cadaveric samples [2].
- A previous Magnetic Resonance Imaging (MRI) study measured internal deformation of the foot *in vivo* under static loading [3].
- **Purpose:** to develop an MRI-compatible device for obtaining patient-specific plantar soft tissue material properties using *in vivo,* dynamic loading.

METHODS

- A cyclic, displacement-controlled, compressive load will be applied to the foot while gated MRI obtains internal tissue deformation data at multiple points on the loading/unloading curve.
- An inverse finite element analysis (FEA) will then be solved for the material properties of the plantar skin, adipose, and muscle tissues.

Loading Device Features (Figure 1)**:**

- Tap water-filled hydraulic system
- Stepper motor-powered linear actuator drives a master piston
- Valve and syringe air-bleed system
- High-pressure, vacuum-resistant nylon tubing
- Outputs:
  - 1 Hz triangle-wave displacement
  - maximum amplitude of 15mm
  - maximum load of 1500N

MRI-Compatibility:

- Equipment inside the imaging room is non-metallic, except for emergency-stop (E-stop) button spring and three screws.

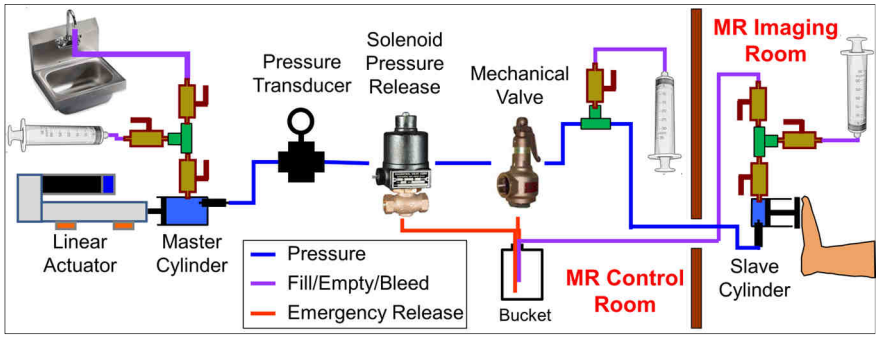

Figure 1: Hydraulic loading device schematic.

MRI-Compatibility, continued:

- The test subject holding fixture (Figure 2) is designed to:
  - adjust the loading platen location to facilitate forefoot or hindfoot testing of either foot
  - restrain the subject's foot, leg, and torso in order to minimize movement of the imaged volume

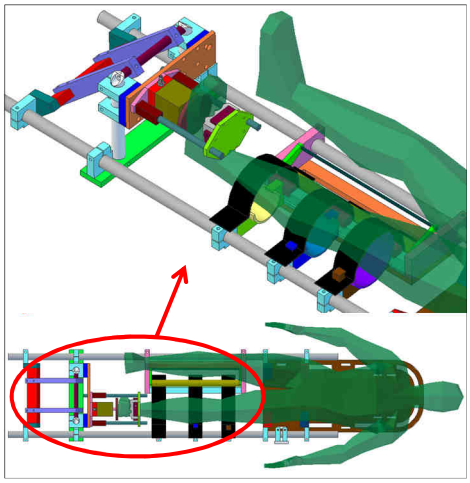

Figure 2: Test subject holding fixture.

Test Subject Safety Features:

- A system pressure-releasing solenoid valve is triggered by:
  - test subject E-stop button
  - test operator E-stop button
  - over-pressure detection by code
- A mechanical valve releases system pressure above test maximum.

Gated MRI Protocol:

- Gated MRI synchronizes imaging with phases of periodic motion to minimize motion-induced artifacts.
- Triggered via LabVIEW-generated Peripheral Pulse Unit (PPU) signal.

Experiment Outputs:

- Force on test subject's foot (from hydraulic system pressure)
- Sixteen 3D MR images of the foot in incremental states of loading (8 images) and unloading (8 images)
- Master piston displacement
- Gating signal trigger

RESULTS

Assembled and Tested:

- Motion control components
- Gating signal trigger
- Data acquisition components
- LabVIEW code

Bench Top Testing Underway:

- Hydraulic system
- Safety system
- Test subject holding fixture
- Actual vs. measured force
- Actual vs. prescribed loading platen displacement

REFERENCES

1. Centers for Disease Control and Prevention, National Diabetes Fact Sheet: General Information and National Estimates on Diabetes in the United States, 2007.
2. Pai S., et al. *Journal of Biomechanics*, **43**:1754-60, 2010.
3. Petre M, et al. *Journal of Biomechanics*, **41**:470-4, 2008.

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