# Mechanical Evaluation of Field-Improvised Exoskeletons for Extremity Fracture Stabilization in Prolonged Care

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## Background

- Casualty evacuation is expected to be delayed on the order of hours to days in future conflicts
- Transporting casualties with extremity fractures will drain human resources during Prolonged Care
  - 1 injury can remove over 5 people from the fight
- Field Improvised Exoskeletons (FIXes) are intended to preserve human resources by restoring function to injured extremities
  - Fewer hands carrying litters, more guns in the fight
- FIXes are constructed from materials scavenged from the environment [1]
  - Upper Extremity FIXes designed to support a rifle
  - Lower Extremity FIXes designed to offload the injured leg for independent ambulation
- In previous work, multi-disciplinary teams created 19 FIX designs for lower and upper extremity injuries [2]
- The **purpose** of this project is to test the **fracture stabilization ability** and **durability** of FIX designs

## Methods

*Fracture Model*

- Model lower and upper extremities were constructed from plastic replica bones and silicone
- 3 cm sections were removed from the "bones" to simulate fractures
- Reflective markers attached to the "bones" quantified fracture stability through motion capture

*Lower Extremity (LE) Testing*

- Model limb fitted with a FIX and positioned in a materials testing machine (MTM)
- Tested 17 FIXes using different materials for 4 distinct structures: i) **Suspension** that secures the FIX to the wearer, ii) **Support** that offloads the weight, iii) **Splint** that stabilizes the fracture, and iv) **End Effector** that engages the ground, and the (Fig. 1)
- Loaded to 1000N for 50000 cycles to simulate walking

*Upper Extremity (UE) Testing*

- 2 FIXes fitted to model limb supporting a rifle (Fig. 2)
- Ballistic pendulum repeatedly struck the barrel to simulate firing recoil for 1500 cycles

## Figures


***Figure 1:*** *Lower extremity design for a LE fracture in a MTM highlighting 4 distinct components: i) Suspension, ii) Support, iii) Splint, and iv) End effector. Components were constructed from different materials listed below.*

**LE FIX Components and Materials Legend**

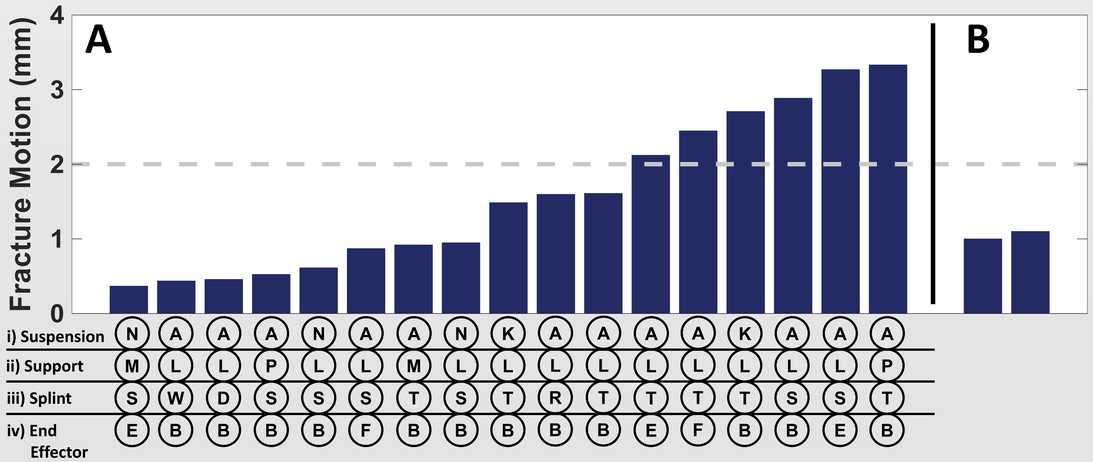
**i) Suspension:** Ⓐ = Pelvic Sling + Thigh Corset. Ⓝ = No Hip Belt. Ⓚ = A + Knee Wrap.

**ii) Support:** Ⓛ = Lumber. Ⓟ = PVC Pipe. Ⓜ = MRE Box.

**iii) Splint**: Ⓢ = SAM. Ⓣ = Traction Splint. Ⓦ = Balsa Wood. Ⓓ = Dowels. Ⓡ = Rope Traction.

**iv) End Effector**: Ⓑ = Boot. Ⓔ = Entrenching Tool. Ⓕ = Foam.

***Figure 2:*** *Upper extremity design for a radial/ulnar fracture being tested with a ballistic pendulum.*




***Figures 3:*** *Fracture motion across all A) lower and B) upper extremity designs. Horizontal dashed line represents threshold for allowable fracture motion. Icons under bars identify to the materials used to construct each LE FIX (see LE FIX Components and Materials Legend near figure 1)*

## Results & Discussion

- Both UE FIXes and 16 LE FIXes completed the fatigue trials without failure
  - One of the LE FIXes using MRE boxes as support failed after 2500 cycles
  - The other LE FIX using MRE boxes did not fail after 50000 cycles
- Fractures require less than 2 mm of space for callous formation [3]
  - 13 FIXes could provide enough stability for callous formation (Fig. 3)
- Test loads were constrained to a single axis, but devices will likely experience more complicated loads in the field
- Leg motion during walking is more complicated and may affect leg stabilization
- Environmental factors such as moisture and soiling may also affect durability
  - MRE boxes may not last long in moist environments

## Future Work

- Future experiments will focus on evaluating FIXes outside of the laboratory
- Evaluate how well FIXs can be constructed in the field
- Measure the speed and energy expenditure of a team transporting a casualty with a FIX vs. a litter over outdoor terrain
- Results will guide further development to provide warfighters with effective tools for prolonged care

References

1.Johnson et al 2023 Mil Med

2. Perry et al 2024 MHSRS

3. Rockwood and Greene's Fractures in Adults

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IRB

The San Antonio IRB has determined that this is not human subjects research