Metacarpal Glove Model for Impact Testing Simulation on Human Hand

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ABSTRACT

This poster presents the development of a finite element (FE) model of a Metacarpal Glove created with the Computer-Aided Engineering (CAE) module available in the Simulia/Abaqus simulation package. The purpose of the research is to create a simulation model to reproduce the impact of a small-sized and low-mass object impacting on the dorsum of a flattened hand protected with a metacarpal glove. The numerical model includes the complete bone structure, derived from high-resolution laser scanning of human hand bones, surrounded by soft tissue with material properties representing a human hand wearing a metacarpal glove used to protect against impacts. The simulations include impacts on the fingers, knuckles, and metacarpal regions of the hand. The impact reaction forces are computed and compared to controlled impact tests performed on synthetic and cadaveric hands. The ultimate objective is to develop a calibrated model that can assess the level of protection offered by diverse metacarpal gloves typically used in different industries.

1. INTRODUCCTION AND MOTIVATION

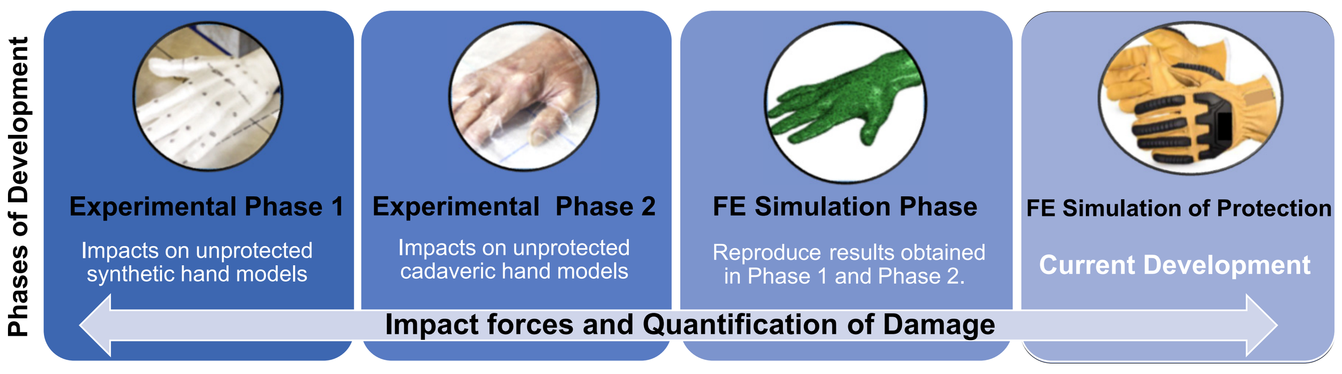
Hand injuries are a significant problem in all industries. Despite the continuous advancements in the technology and the safety procedures for production and maintenance tasks, there are still manual tasks with high-risk factors that can produce hand injuries with varying degrees of severity.

- The manufacturing industry is one of the most affected.
- 1/3 of the injuries occurred in upper limbs
- 66% correspond to hand injuries
- These injuries often yield a functional limitation or disability and may have significant economic implications and loss of productivity.

2. OBJECTIVE

<u>Main Objective</u>: Quantify the level of forces resulting of a relatively low-speed impact on the dorsum of a flattened human hand protected with a metacarpal glove.

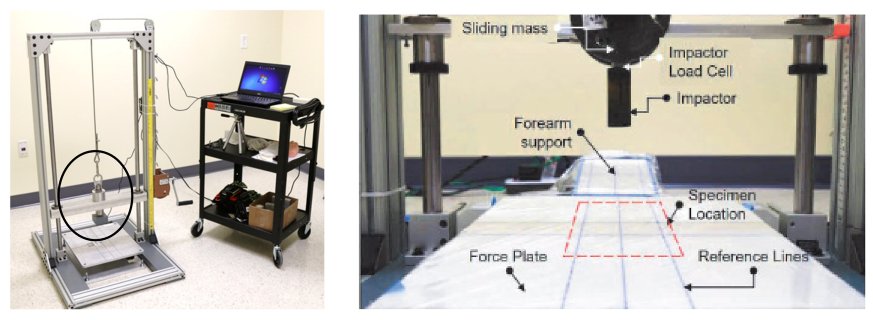
<u>Ultimate objective</u>: Develop a calibrated model that can be used to assess the level of protection offered by metacarpal gloves used in different industries.



3. EXPERIMENTAL PHASE 2

3.1. Impact Testing Machine and Impactors

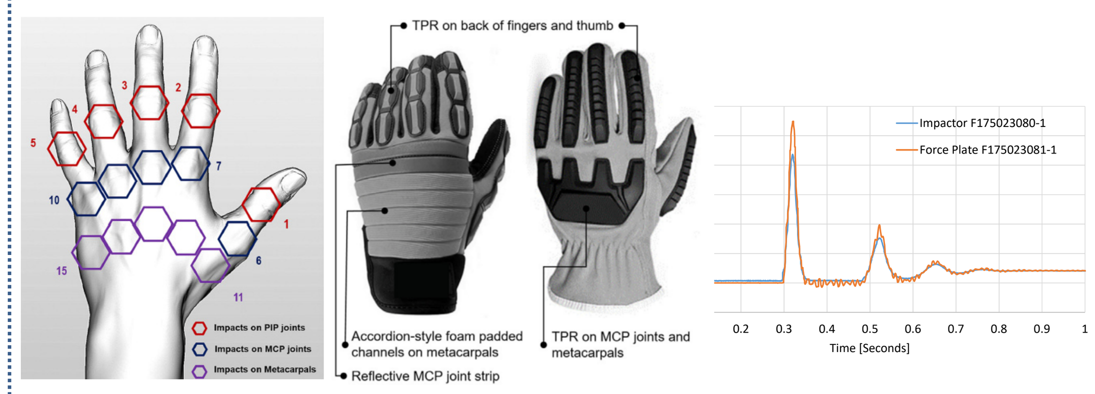
- Controlled Impacts
- Vertical sliding mass with Hexagonal impactor of 5.1 Kg
- Force plate and load cell connected to the impactors



3.2. Impact Tests (13 hand specimens (6 with gloves))

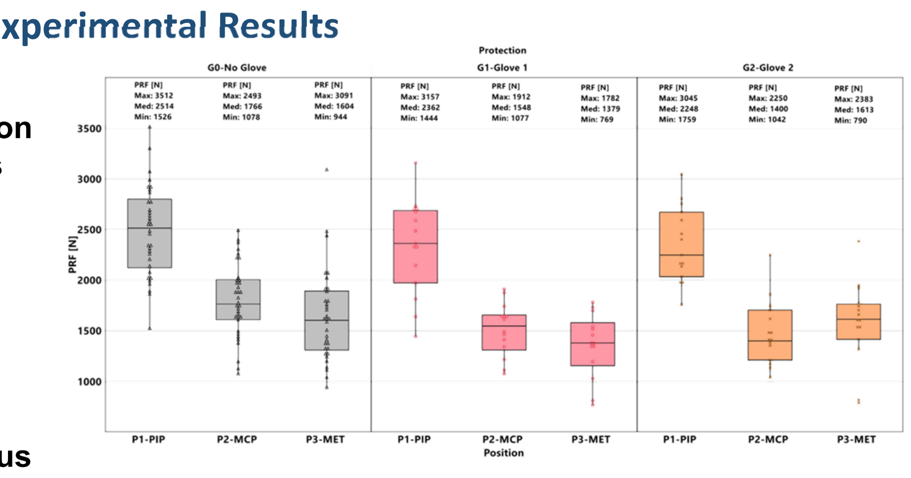
- <u>**Unprotected hands**</u>: Cadaveric hands, specimens provided by the WVU Health Sciences Center, Human Gift Registry, used for validation of models and forces.
- <u>**Glove G1**</u>: includes TPR reinforcements only in the finger region and foam padding (96% Polyester and 4% Spandex) on MCP joints and back of hand (metacarpal bones) region. The palmar side is composed of a foam pad layer.
- <u>**Glove G2**</u>: includes TPR reinforcements on the fingers, MCP joints, and the metacarpals region. Each of the anterior and posterior sides is composed of an external leather layer and an internal Kevlar lining layer. The palmar region is also supported with gel pads.
- Testing work recently completed and published in Journal of Biomechanics, March 2021, online at: **https://doi.org/10.1016/j.jbiomech.2021.110326**

3.3. Impact Zones (15 impacts in each specimen)

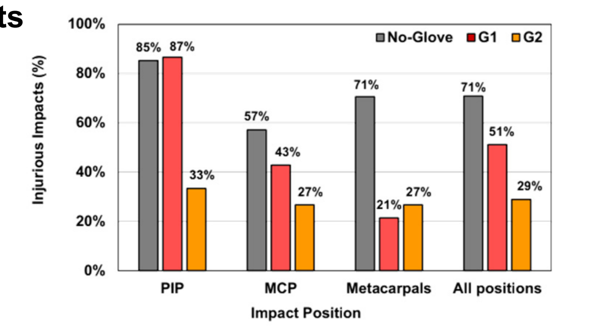


3.4. Experimental Results

Peak Reaction Forces



Injurious Impacts

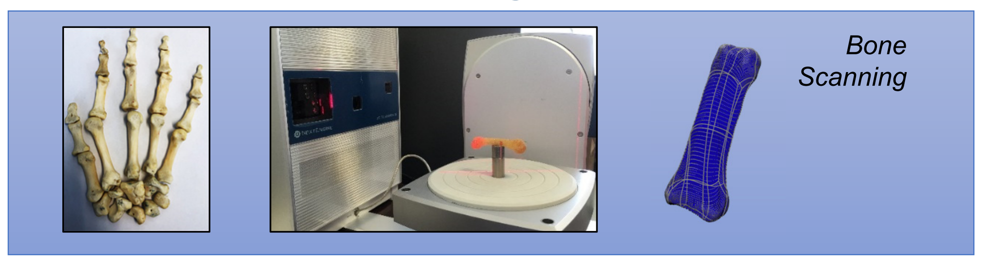


Glove G1:
- 3.0% in falanges
- 10.0% in knuckles
- 12.6% in metacarpals

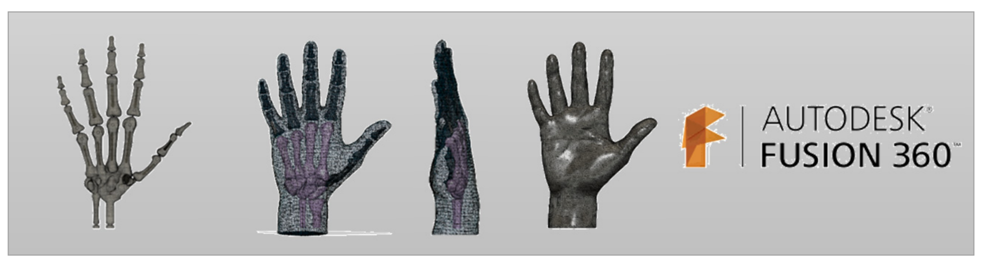
Glove 2:
- 13.7% in falanges
- 23.4% in knuckles
- 4.3% in metacarpals

4. SIMULATION PHASE

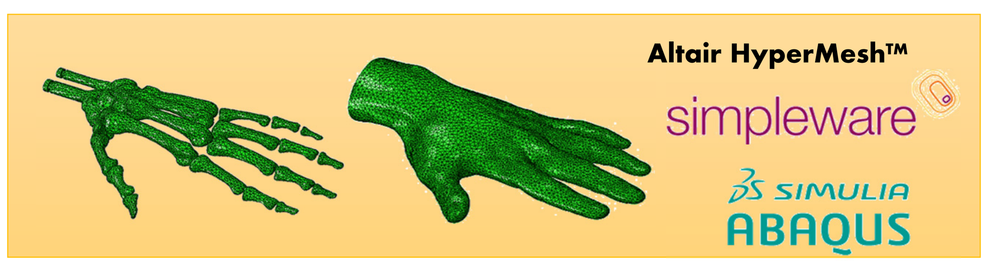
4.1. Creation of FE Modeling



Next Engine® Laser Scanner
- *Set of bones facilitated by WVU HSC*
- *Individual bones scanned with 0.1 mm precision*
- *Surface and STL format files*

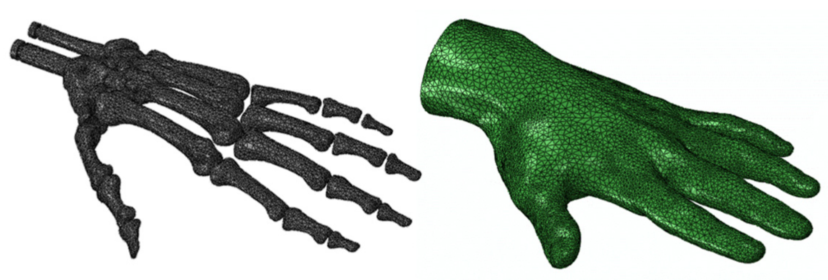


CAD Model
- *Soft tissue definition*
- *Assembly of soft tissues and bone structure*
- *Scaling to 50th percentile*
- *.iges files of bones and soft tissues*



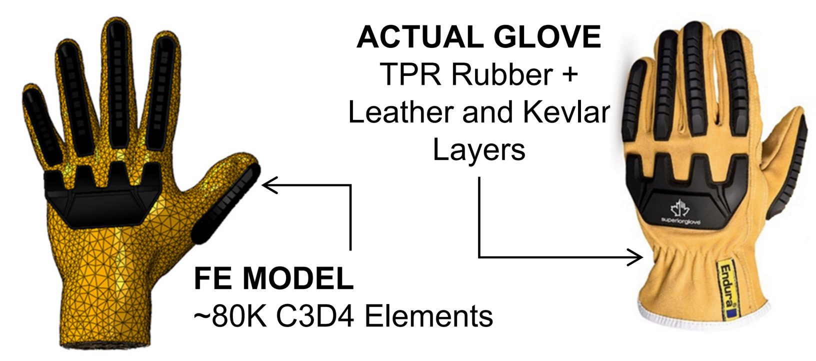
FE Simulation Model
- *Finite element discretization*
- *Materials definition*
- *Loads and boundary conditions*
- *Contact pairs definition*
- *Data visualization*

4.2. FE Main Components

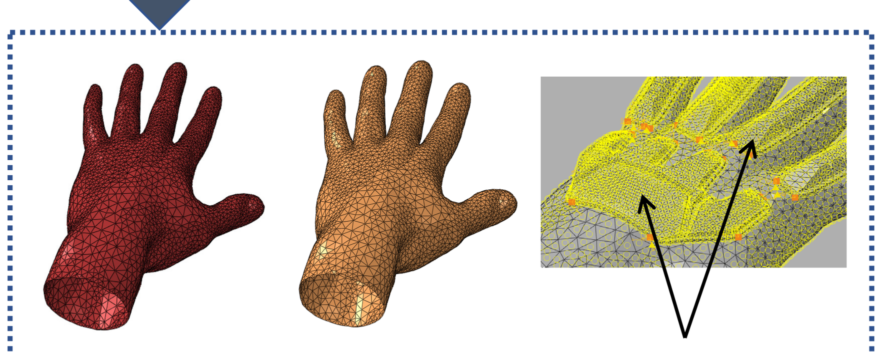


BONE STRUCTURE
~30K C3D4 Elements

SOFT TISSUE
~110K C3D4 Solid Elements



METACARPAL GLOVE

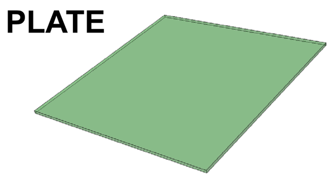


Inner Kevlar Layer
~15K M3D Elements

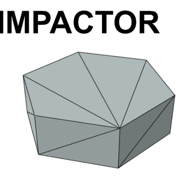
Outer Leather Layer
~15K M3D Elements

Thermo-Plastic Rubber (TPR) Metacarpal and Finger Protections
~50K C3D4 Elements

RIGID PLATE



RIGID IMPACTOR



Problem Definition:
- Abaqus/Standard: Hand positioning on rigid plate (Time: 1 second)
- Abaqus/Explicit : Freefall of the impactor (Time: 0.5 seconds)

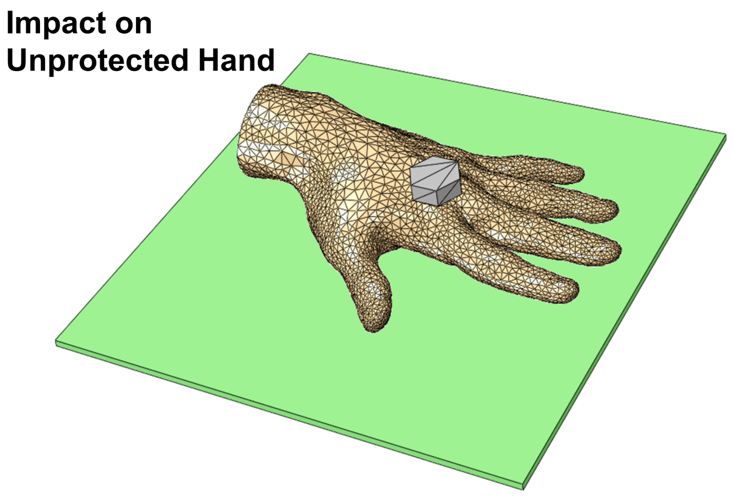
Types of Contact Interactions:
- Tie for bones and soft tissue, ties between glove and external surface of soft tissue and interior of glove to ensure compatibility of displacements.
- General contact between hand, impactor and rigid plate, and between hand and glove.

Loads and Boundary Conditions:
- Hand subjected to self-weight calculated based on bone and flesh densities.
- Impactor with a mass of 5 kg falling by gravity from an elevation of 100 mm.
- Base rigid plate is fixed, and impactor can only move vertically.

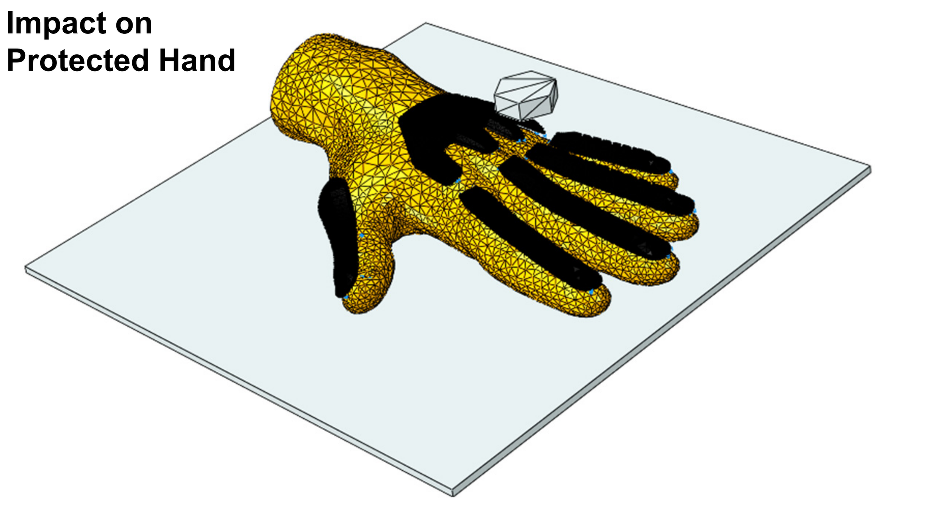
5. PRELIMINARY RESULTS

5.1. Full FE Model

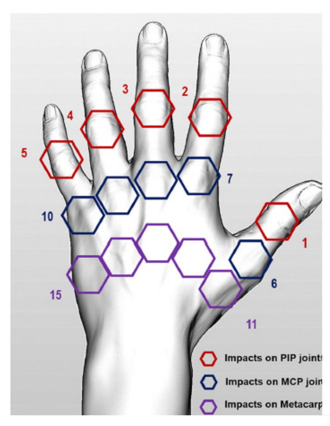
Impact on Unprotected Hand



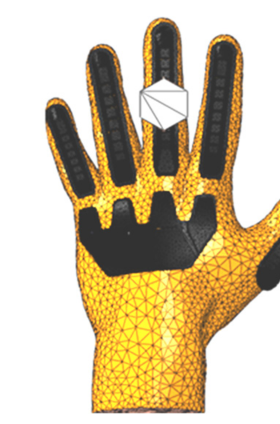
Impact on Protected Hand



5.2. Impact Map



Experimental Map

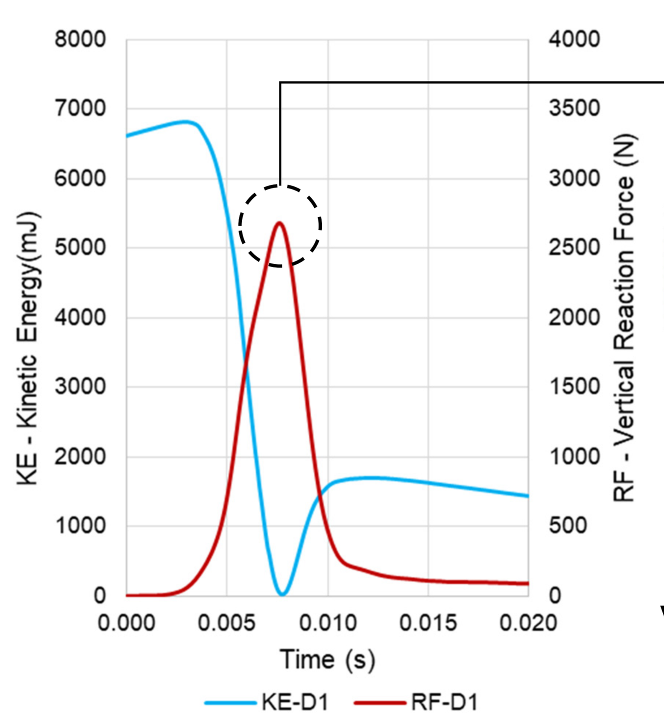


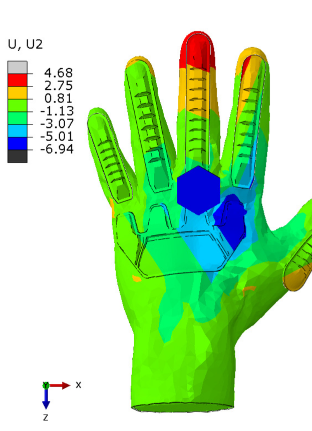
3rd Digit, on Phalangeal Inter-Phalangeal Joint (PIP-3)

3rd Digit, on Metacarpal Inter-Phalangeal Joint (MCP-3)

3rd Digit, on Central region of Metacarpal Bone (MET-3)

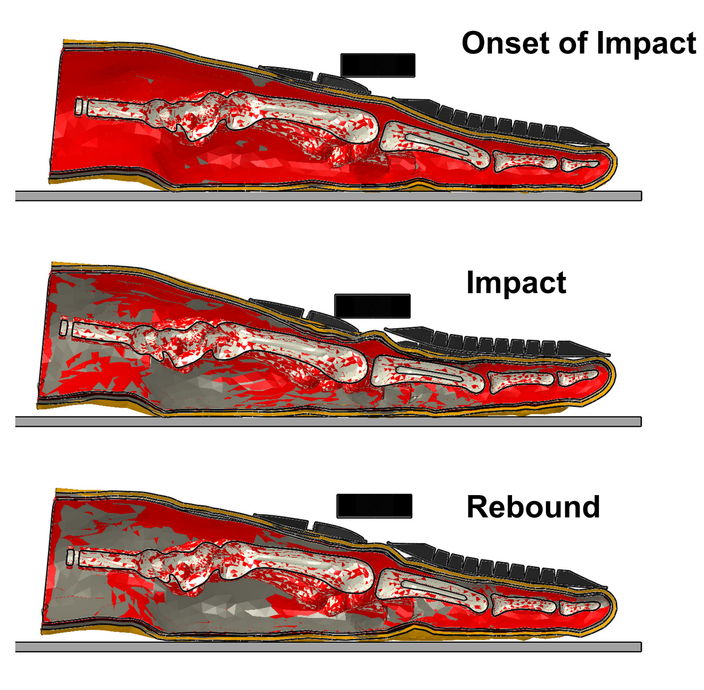
5.3. Peak Reaction Force and Kinetic Energy Variation





Vertical Displacement (U2) contour at peak reaction force

5.4. Deformed Shape during Impact



OBSERVATIONS

A 3D FE simulation model has been developed to analyze the forces resulting from a localized impact. Preliminary results indicate that:
- **The peak reaction force of the FE model is in the range of forces measured during the experimental phases with synthetic and cadaveric hands.**
- **The model still requires some fine tuning to better replicate experimental tests.**
- **The prediction of behavior of an unprotected hand provides a baseline for comparison with models that include a protective layer provided by different types and designs of metacarpal and other industrial gloves.**

FUTURE STEPS

- **Obtain and adjust material properties of hand's soft tissues to compare with results obtained from experiments with cadaveric hands.**
- **Complete material testing to obtain more accurate coefficients for hyperelastic models corresponding to the actual medical-grade synthetic gel used in the experiments.**
- **Incorporate more geometric details to create a more accurate model (tendons, joints, etc.)**

Acknowledgments

This research work is supported in part by:
- **The financial assistance provided by the Arch Coal Inc. Endowment for Mine Health and Safety Research in the Statler College of Engineering and Mineral Resources (CEMR) at West Virginia University.**
- **The financial support provided by Universidad Carlos III of Madrid through the "Aid for mobility research program" and the OPTIMUM-CM-UC3M Research Project at Universidad Carlos III of Madrid.**

Poster Presented at the 37th International CAE Conference and Exhibition | 2021, November 17 - 19 | Vicenza, Italy | Hybrid event

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