Quantifying Material Uncertainty in Computational Biomechanics

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Variability in Biomechanics Modeling

Role of Mechanics in Biology

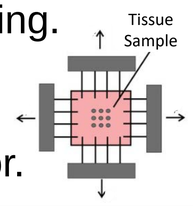
Mechanical stresses impact biological functions in healthy and diseased states and contribute to medical device efficacy.

Clinical Problem

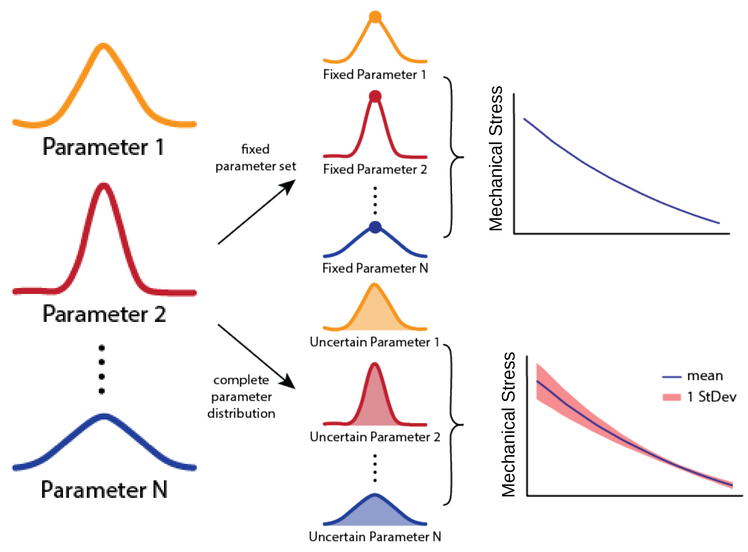
Need to provide confidence in simulation predictions and demonstrate results are ***safe & reliable***.

Simulation Inputs Have Variability

- Geometrical uncertainty from medical imaging.
- Tissue sample variability.
- Experimental testing methods.
- Mathematical model of mechanical behavior.



Parameter Distributions for Model Inputs



Traditional Deterministic Model

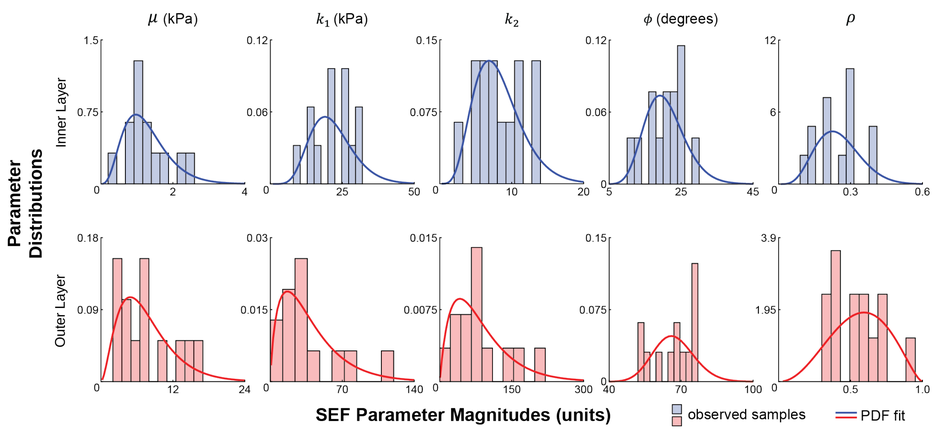
- ***Fixed*** model input parameter(s).
- ***Single*** model output.
- Lack of variability creates ***uncertainty*** in predictive model.

Uncertainty Quantification of the Model

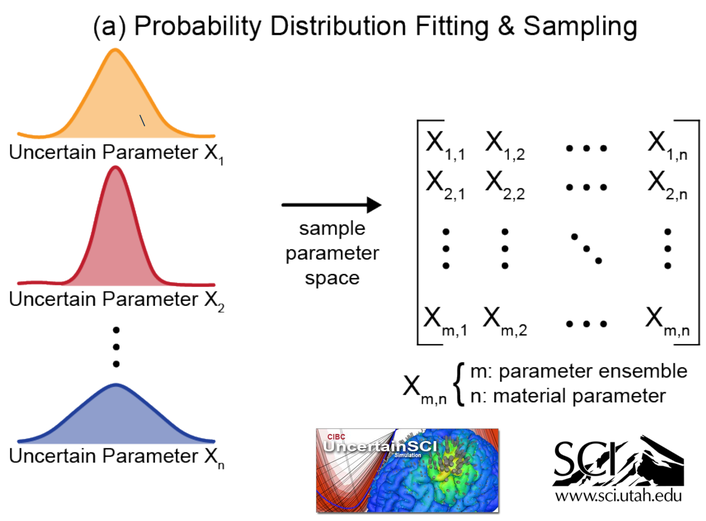
- Consider ***variable*** input parameter(s).
- ***Range*** of possible model output.
- Provide quantifiable levels of certainty for making model-based clinical decisions.

Leverage SCI Software to Quantify Simulation Output Variability

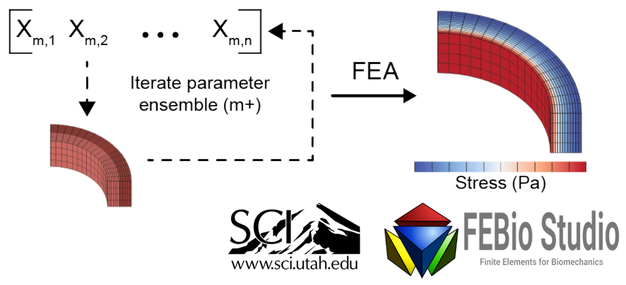
Perform mechanical testing to obtain material properties, then determine probability distributions.



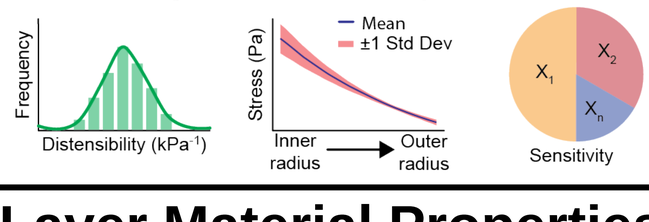
Sample probability distributions to generate parameter sets using UncertainSCI.



Run models across the parameter space using FEBio.

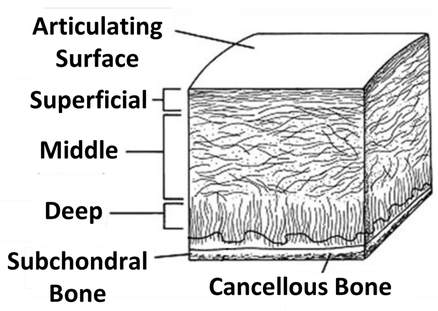


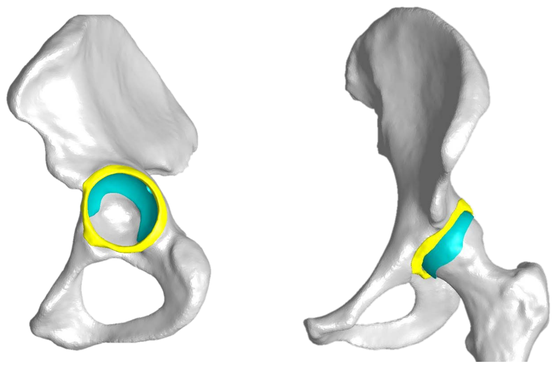
Relate variations in model inputs to uncertainty in model output.



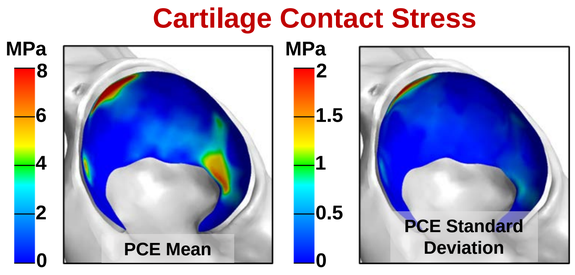
Application: Collagen Fibers in Hip Cartilage Dictate Stress Response During Walking

Cartilage Anatomy

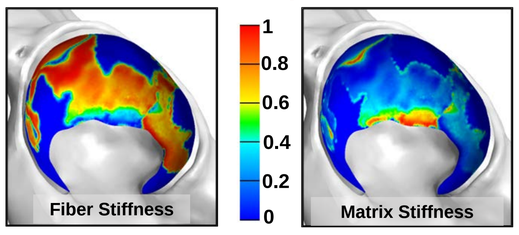




Cartilage Contact Stress



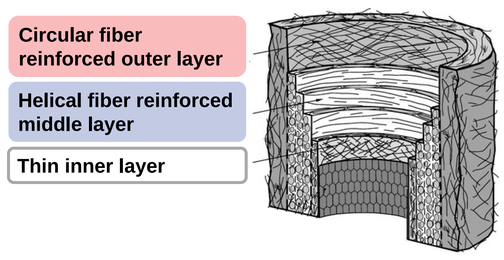
Parameter Importance



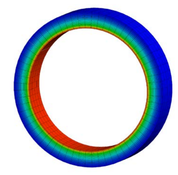
- Collagen fibers embedded in cartilage are the primary driver of the variation in contact stress.
- Cartilage matrix stiffness still plays a role in some regions of the cartilage.
- These results highlight the importance of modeling the unique anatomy & structure of cartilage.

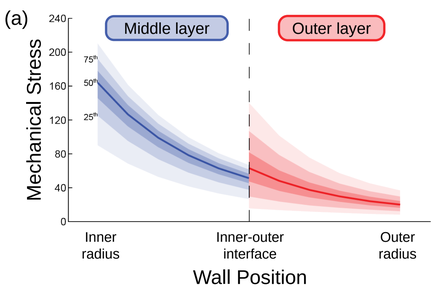
Application: Outer Layer Material Properties Drive Artery Stress Variations

Artery Structure

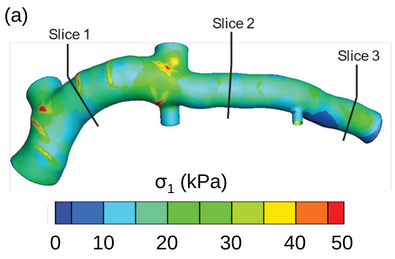


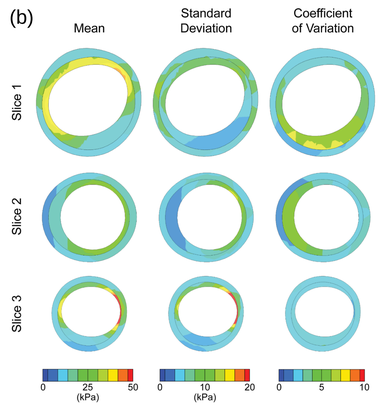
Idealized Model

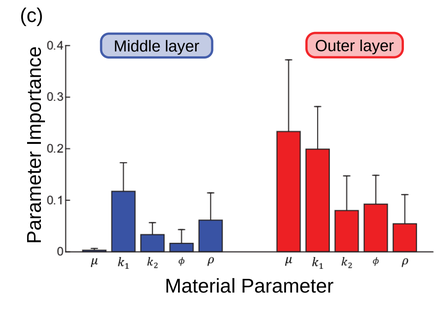




Patient-specific Model







- Highest stress variations in outer layer.
- Fiber-associated stiffnesses dominate stress variability across both layers.
- Data point to significance of fiber response in predicting artery stresses.

Impact of Uncertainty Quantification in Computational Biomechanics

- New computational methods from SCI enable quantification of biomechanical model sensitivity to variations in soft tissue material properties.
- Determine how uncertainty in predicted mechanics can drive disease development and prognosis and medical device interactions.
- Provide increased confidence in model-based decisions in the clinical setting.

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