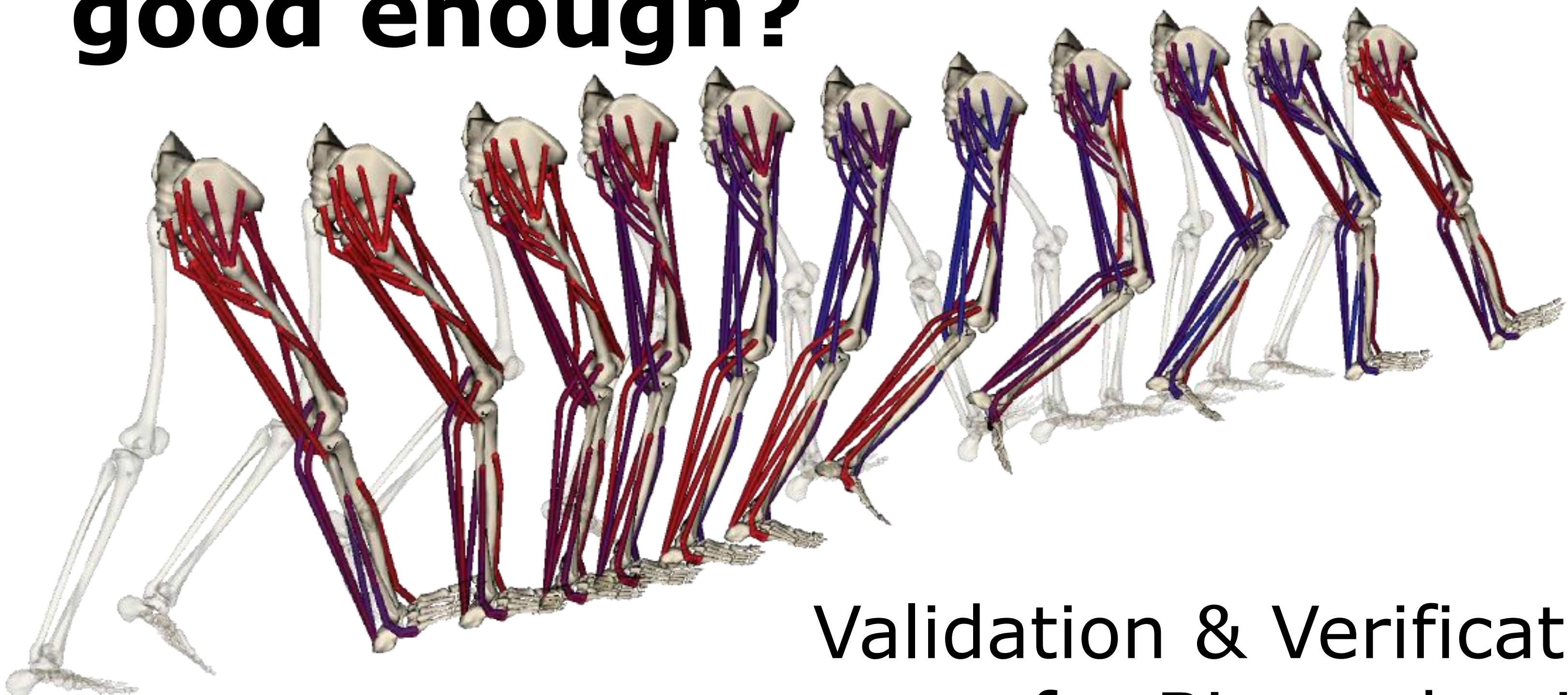
Is my simulation good enough?



Validation & Verification for Biomechanical Modeling and Simulation

OpenSim Workshop

Definitions: Validation and Verification

Verification

The process of determining that a computational model accurately represents the underlying mathematical model and its solution.

"solving the equations right"

Validation

The process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model.

"solving the right equations"

ASME Committee (PT60) on Verification and Validation in Computational Solid Mechanics, 2006

Key Principles for Validation and Verification

1. Define your research question.
2. Understand and evaluate your methods.
3. Assess sensitivity.
4. Compare to experiments and other models.
5. Make real-world predictions and hypotheses.

Validation Challenges for the Field

- Create more gold standard datasets
- Share models and simulations so others can reproduce and extend
- Ensure that the model you are using is validated for your application
- Develop tools to help automate validation and sensitivity testing
- Learn and teach others what is inside the “black box”

Rules of good practise - Scaling

- Rely on **anatomical landmarks** and functional joint centers (FJC)
- Scaling is an iterative process. **"preview static pose"** option in the GUI.
- Check **marker errors**:
  - maximum marker errors for bony landmarks should be less than 2 cm.
  - RMS error should typically be less than 1 cm.
  - Pay close attention to errors in the bony landmark and FJC markers when assessing the quality of your scaling results.
- Visualize model and verify model fit.
- **Adjust** the virtual markers and marker weightings to improve your results (NOT anatomical and FJC)

Rules of good practise – IK/ID

- Weight **"motion" segment markers** (technical markers) more heavily than anatomical markers
- **Relative marker weightings** are more important than their absolute values
- **Verify the marker error**
  - Maximum marker error should generally be less than 2-4 cm, and RMS under 2 cm is achievable.
- Check with other 3D Mocap Software
  - Do not expect absolute agreement
    - Cfr offset of pelvis coordinate system and hip angle.
    - Cfr ankle angle kinematics due to subtalar joint.

Suggested papers on these topics

Is My Model Good Enough? Best Practices for Verification and Validation of Musculoskeletal Models and Simulations of Movement

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Computational modeling and simulation of neuromusculoskeletal (NMS) systems enables researchers and clinicians to study the complex dynamics underlying human and animal movement. NMS models use equations derived from physical laws and biology to help solve challenging real-world problems, from designing prosthetics that maximize running speed to developing exoskeletal devices that enable walking after a stroke. NMS modeling and simulation has proliferated in the biomechanics research community over the past 25 years, but the lack of verification and validation standards remains a major barrier to wider adoption and impact. The goal of this paper is to establish practical guidelines for verification and validation of NMS models and simulations that researchers, clinicians, reviewers, and others can adopt to evaluate the accuracy and credibility of modeling studies. In particular, we review a general process for verification and validation applied to NMS models and simulations, including careful formulation of a research question and methods, traditional verification and validation steps, and documentation and sharing of results for use and testing by other researchers. Modeling the NMS system and simulating its motion involves methods to represent neural control, musculoskeletal geometry, muscle–tendon dynamics, contact forces, and multibody dynamics. For each of these components, we review modeling choices and software verification guidelines; discuss variability, errors, uncertainty, and sensitivity relationships; and provide recommendations for verification and validation by comparing experimental data and testing robustness. We present a series of case studies to illustrate key principles. In closing, we discuss challenges the community must overcome to ensure that modeling and simulation are successfully used to solve the broad spectrum of problems that limit human mobility.
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On validation of multibody musculoskeletal models

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Verification, validation and sensitivity studies in computational biomechanics

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Computational techniques and software for the analysis of problems in mechanics have naturally moved from their origins in the traditional engineering disciplines to the study of cell, tissue and organ biomechanics. Increasingly complex models have been developed to describe and predict the mechanical behavior of such biological systems. While the availability of advanced computational tools has led to exciting research advances in the field, the utility of these models is often the subject of criticism due to inadequate model verification and validation (V&V). The objective of this review is to present the concepts of verification, validation and sensitivity studies with regard to the construction, analysis and interpretation of models in computational biomechanics. Specific examples from the field are discussed. It is hoped that this review will serve as a guide to the use of V&V principles in the field of computational biomechanics, thereby improving the peer acceptance of studies that use computational modeling techniques.

Keywords: Verification; Validation; Sensitivity studies; Computational modeling; Biomechanics; Review