

Hierarchical Verification and Validation of Human Body Computational Models

Travis Eliason, Jessica Coogan, Daniel Nicolella

I. INTRODUCTION

Computational modelling is ideally suited to simulate complex biological structures subjected to dynamic loading conditions. Finite Element (FE) modelling of biological systems is increasingly used due to advances in both computational hardware and FE software that allow researchers to develop complex, high fidelity models. However, a significant challenge in applying computational methods effectively is model verification and validation (V&V). Traditionally model V&V has often consisted of calibrating a model to an experimental data set and graphically comparing the model predicted results to results from an experiment. If the model results fall within the standard deviation corridor of the experiment the model is considered valid. This *tuning* method of validation is particularly inappropriate in biological systems because the end result is a model that represents a single subject, specimen, or set of experiments. Here we present the implementation of a rigorous hierarchical V&V approach based on the ASME V&V-10 guide and the application of two quantitative model validation metrics.

II. METHODS

A hierarchical V&V approach differ from the traditional tuning methodology in that it uses a bottom up approach to ensure that not only does the final model give the right answer, but the right answer for the right reason. All computational models will give an answer but just because the overall response of a biomechanical model matches an experimental measure it does not mean the underlying physics of the sublevel components are correct. In order to perform a Hierarchical model V&V approach the full system model must be subdivided into its constituent subassemblies and components. Quantitative model V&V is then applied to each sub-model in the hierarchy (from the bottom up) and the performance of each sub-model is qualified using a quantitative validation metric. Here, this approach is applied to the development of a high fidelity probabilistic cervical spine model, which was broken up into four hierarchical levels. These levels consisted of, in increasing order of complexity, individual model components, two vertebrae motion segments, multi motion segment sub-assemblies, and the full cervical spine (Figure 1).

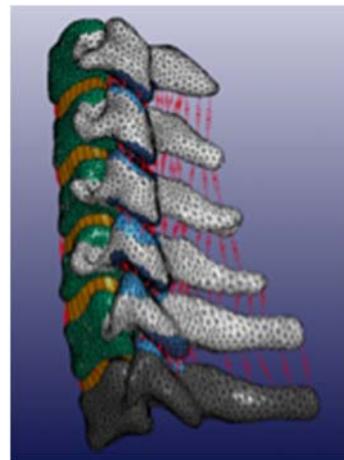
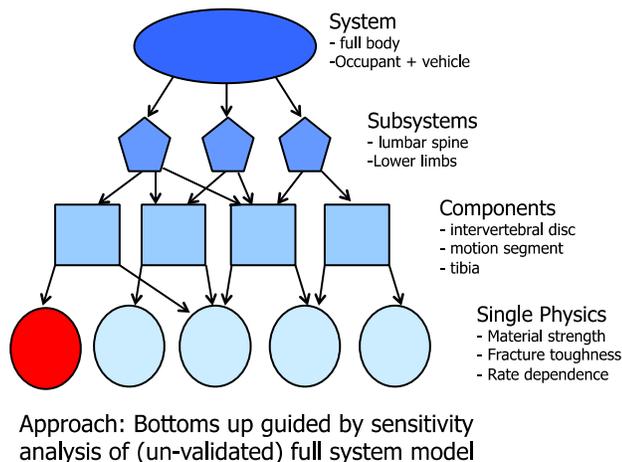


Fig 1. Example hierarchical structure increasing in complexity from the material properties up to the full spine model (left). High fidelity probabilistic finite element model of the cervical spine that was developed using the hierarchical V&V approach (right).

Starting at the lowest hierarchical step probabilistic model results were validated using a quantitative validation metric to ensure the model was behaving correctly and fit the experimental variability as well as the average response. By validating both the average response and the model variability we ensured that the model not only correctly represents an individual but also a specific population of individuals. Once the bottommost level of the model hierarchy is validated all material properties and model parameters are locked in and are not changed as the model increases in complexity, i.e., no tuning is performed. By locking in the model parameters at the lowest level we ensure that the physics are be correctly represented and the overall response is not just a product of creative tuning. At each hierarchical level validation confidence in the model is gained, as the model passes a rigorous set of challenges.

III. INITIAL FINDINGS

This model development methodology has successfully showed that it can quantitatively assess the predictive capability of complex biomechanical systems. Uncertainty and variability have been explicitly accounted for and their effect on model validation is quantified.

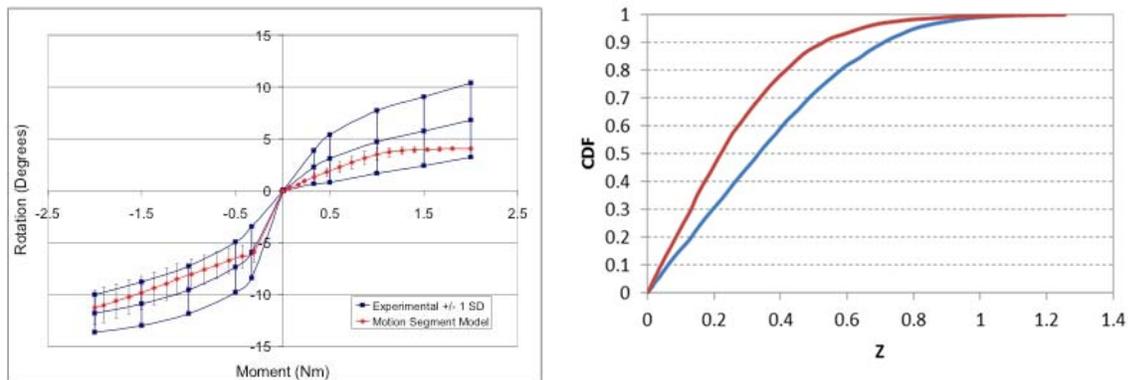


Fig. 2: Example model validation results for a motion segment. Traditional experimental corridors (Left) and quantitative Z metric (right).

With this validation, greater confidence can be gained in complex computational models in that the user would know that the correct answer was obtained for the right reasons rather than through arbitrary tuning. Quantitative metrics give concrete answers to how good the model fits the experimental data compared to the qualitative curve matching often employed in other validation strategies.

IV. DISCUSSION

The validation methodology presented here represents a powerful tool for the quantitative measurement of model predictive performance. The hierarchical organisation of this strategy ensures that not only is the target metric accurate, the underlying physics that drive the target are also correct. While the normalised metric does not give an absolute pass or fail number, an acceptable value cutoff can be determined based on the intended use of the model. In addition to setting a pass or fail criteria for the model, the quantitative measure of model performance also gives a direct measure with which to compare results between two or more models. While this overall modelling approach requires a great deal of work both computationally and in producing the necessary experimental data, we believe that this rigorous approach is necessary to ensure confidence in the model results. As models continue to increase in fidelity and complexity the desire to make actionable decisions based on the model outcomes also increases. Simple validation techniques are no longer acceptable for these complex systems and the V&V approaches must become more rigorous to ensure accurate results and overall research objectives are met.