# Author's Accepted Manuscript




Uncertainty quantification for constitutive model calibration of brain tissue

Patrick T. Brewick, Kirubel Teferra

PII: S1751-6161(18)30061-4
DOI: https://doi.org/10.1016/j.jmbbm.2018.05.037
Reference: JMBBM2814

To appear in: *Journal of the Mechanical Behavior of Biomedical Materials*

Received date: 30 January 2018
Revised date: 14 March 2018
Accepted date: 26 May 2018

Cite this article as: Patrick T. Brewick and Kirubel Teferra, Uncertainty quantification for constitutive model calibration of brain tissue, *Journal of the Mechanical Behavior of Biomedical Materials,* https://doi.org/10.1016/j.jmbbm.2018.05.037

# Uncertainty quantification for constitutive model calibration of brain tissue

Patrick T. Brewick*, Kirubel Teferra

US Naval Research Laboratory, Washington, DC 20375, USA

Abstract

The results of a study comparing model calibration techniques for Ogden's constitutive model that describes the hyperelastic behavior of brain tissue are presented. One and two-term Ogden models are fit to two different sets of stress-strain experimental data for brain tissue using both least squares optimization and Bayesian estimation. For the Bayesian estimation, the joint posterior distribution of the constitutive parameters is calculated by employing Hamiltonian Monte Carlo (HMC) sampling, a type of Markov Chain Monte Carlo method. The HMC method is enriched in this work to intrinsically enforce the Drucker stability criterion by formulating a nonlinear parameter constraint function, which ensures the constitutive model produces physically meaningful results. Through application of the nested sampling technique, 95% confidence bounds on the constitutive model parameters are identified, and these bounds are then propagated through the constitutive model to produce the resultant bounds on the stress-strain response. The behavior of the model calibration procedures and the effect of the characteristics of the experimental data are extensively evaluated. It is demonstrated that increasing model complexity (i.e., adding an additional term in the Ogden model) improves the accuracy of the best-fit set of parameters while also increasing the uncertainty via the widening of the confidence bounds of the calibrated parameters. Despite some similarity between the two data sets, the resulting distributions are noticeably different, highlighting the sensitivity of the calibration procedures to the characteristics of the data. For example, the amount of uncertainty reported on the experimental data plays an essential role in how data points are weighted during the calibration, and this significantly affects how the parameters are calibrated when combining experimental data sets from disparate sources.

Keywords: Brain tissue constitutive properties, Bayesian model calibration, Ogden hyperelastic constitutive model, Hamiltonian Monte Carlo sampling

## 1. Introduction

Awareness of traumatic brain injuries (TBI) has been steadily growing due to its increasing incidence rate among the public [1]. This has led to an extensive amount of published work in this area with numerous

*Corresponding author at: US Naval Research Laboratory, 4555 Overlook Ave. SW, Washington, DC 20375, USA. Tel.: +1 202 767 1466.

Email address: patrick.brewick@nrl.navy.mil (Patrick T. Brewick)