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A NOVEL APPROACH FOR UNCERTAINTY QUANTIFICATION IN PATIENT-SPECIFIC CARDIOVASCULAR MECHANICS

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Patient-specific cardiovascular mechanics using computational methods such as the finite element method has gained a lot of interest during the last decade and has helped to improve the assessment of cardiovascular diseases. Whereas it is possible to obtain patient-specific geometries from CT scans, this does not hold for other patient-specific parameters such as constitutive properties. Hence, researchers almost exclusively use population mean values for "patient-specific" simulations thereby neglecting the inter- and intra-patient variations present in e.g. the constitutive parameters. In order to strengthen the trust in the predictive capabilities of finite element simulations in cardiovascular mechanics, the aforementioned variations have to be considered in the computational assessment of cardiovascular diseases. This can be achieved by using a probabilistic description for the varying parameters and an efficient Uncertainty Quantification (UQ) framework.

However, the large nonlinear patient-specific forward finite element models in combination with the typically high stochastic dimension render the current non-sampling based UQ approaches infeasible. In order to alleviate the computational burden that is posed even by advanced sampling based UQ methods, we use a novel approach that employs approximate models in combination with Bayesian formulations [1]. The use of a non-parametric Bayesian regression model allows to not only establish a quantitative connection between an approximate model and an accurate and expensive high-fidelity model, but also provides confidence intervals. By combining efficient numerical continuation schemes with nested parallelism in our in-house finite element solver the computational cost can be reduced to the equivalent of only a moderate number of runs of the high-fidelity model. Furthermore, this approach speeds up the computation such that results can be obtained within one day even for large forward models.

The flexibility and capabilities of the method are demonstrated by performing uncertainty quantification with patient-specific nonlinear finite element models of AAAs [2]. However, the approach is very general and can be extended to study e.g. the impact of uncertain wall thickness in AAAs as well. Additionally, the approach can readily be applied to other biomechanical problems.

Here we focus on inter- and intra-patient variations of the constitutive parameters of the aneurysmatic arterial wall, which are modelled by three dimensional, non-Gaussian random fields, the parameters of which are obtained using our own experimental results. Together with experimentally obtained constitutive parameters from more than 200 tensile tests, we have collected a set of non-invasively accessible patient-specific medical data for each of the tested samples. The data is comprised of the patients medical history and the results of biochemical blood analysis. Using this data as explanatory variables in a Bayesian regression analysis yield patient-specific parameters for the probability distributions of the random fields. Using our framework we assess the impact of the uncertain constitutive parameters on mechanical quantities, such as stress, strain, and strain energy since these quantities are typically related to AAA rupture risk [3].

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