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UNCERTAINTY IN MODEL-BASED TREATMENT DECISION SUPPORT: APPLIED TO AORTIC VALVE STENOSIS

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Summary: Mathematical methods have been applied to gain insight into pathophysiology of the cardiovascular system as early as the 1900's, and are maturing to the point where clinical application may be feasible in the form of treatment outcome prediction. However, prior to use in a clinical environment, three essential points must be considered. Firstly, these models must be tailored to describe patient-specific haemodynamics, which is done by tuning model input parameters. Secondly, parameter tuning must be robust enough to handle the limited, noisy data available clinically. Finally, the predictive power of the model must be quantified to support clinical decision making.

Complex haemodynamic models require many parameters, many of which are often hard (if not impossible) to measure. As such, the patient is described with a lumped parameter model containing a minimal description of the circulation, including only the left heart, valves and left circulation. The model should be complex enough to determine patient haemodynamics, but simple enough for patient-specificity to remain feasible.

To increase parameter tuning robustness, first the most important model input parameters are determined via adaptive generalized sparse polynomial chaos expansion (agPCE). agPCE is a computationally efficient method, which computes a orthogonal polynomial-based meta-model, from which sensitivity indices can be determined analytically. Important input parameters must be tuned to describe patient measurements, while less important parameters can be kept at population-wide values. Parameter optimization is performed via an adapted unscented Kalman filter (UKF). The UKF not only filters the noisy clinical signals, but simultaneously produces an estimate of important model input parameters for each time-step during the heart cycle. The variation of input parameters across the heart cycle can then be interpreted as the estimation uncertainty or the quality of the patient-specific model, which used as input to determine output uncertainty via the agPCE method.

The method has been applied to test-data; results indicate the method is viable and will shortly be applied to clinical data which contain patient haemodynamics before and after a valve replacement procedure.