

Supplementary Material

Uncertainty quantification and sensitivity analysis of left ventricular function during the full cardiac cycle

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1. Uncertainty propagation and sensitivity analysis

We report here the results of uncertainty propagation and sensitivity analysis of the all the experiments considered in this work. For each case, we report: (i) pressure-volume relationship with the 90% prediction interval and (ii) sensitivities of all quantities of interest at both early ejection and end-systole phases of the full LV cycle.

1.1. Experiment 1

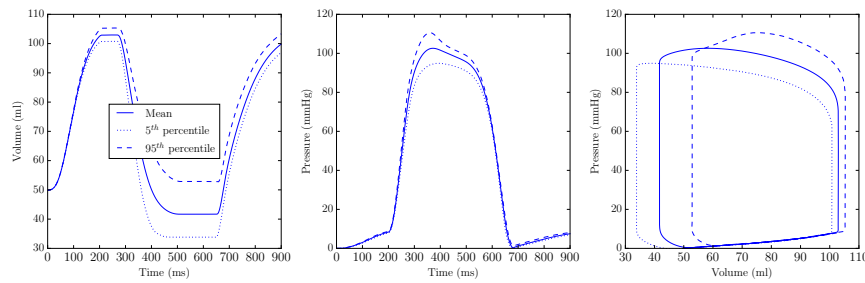


Figure 1: Experiment 1: Pressure-volume loop.

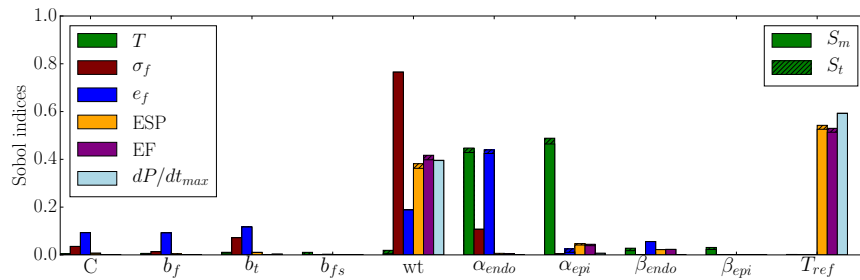


Figure 2: Experiment 1: Sensitivity analysis at early ejection.

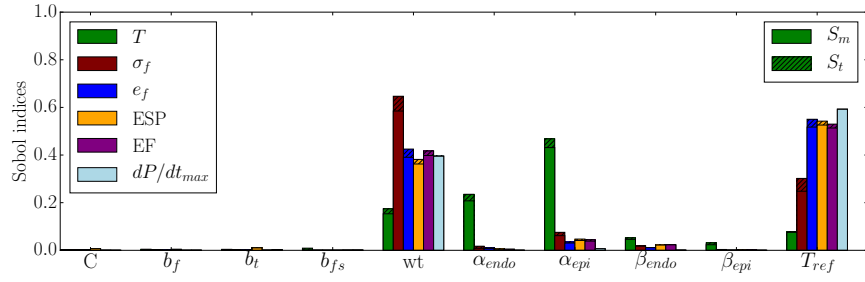


Figure 3: Experiment 1: Sensitivity analysis at end-systole.

1.2. Experiment 2

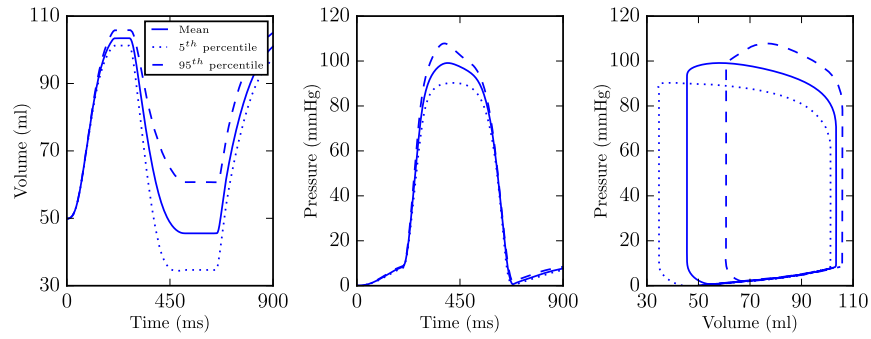


Figure 4: Experiment 2: Pressure-volume loop.

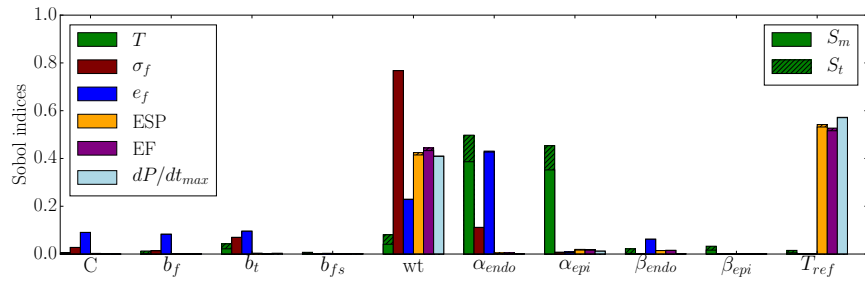


Figure 5: Experiment 2: Sensitivity analysis at early ejection.

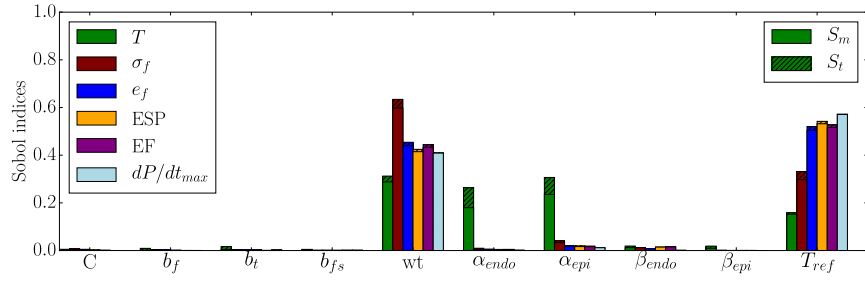


Figure 6: Experiment 2: Sensitivity analysis at end-systole.

1.3. Experiment 3

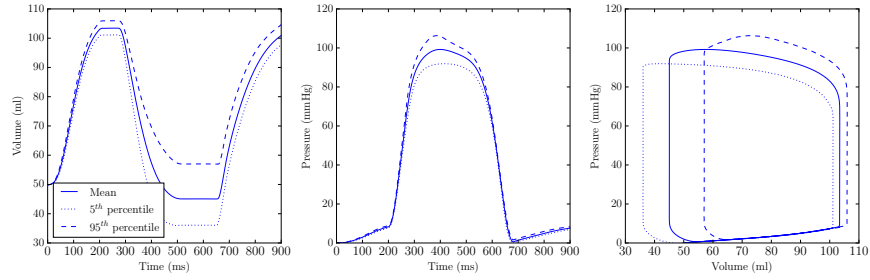


Figure 7: Experiment 3: Pressure-volume loop.

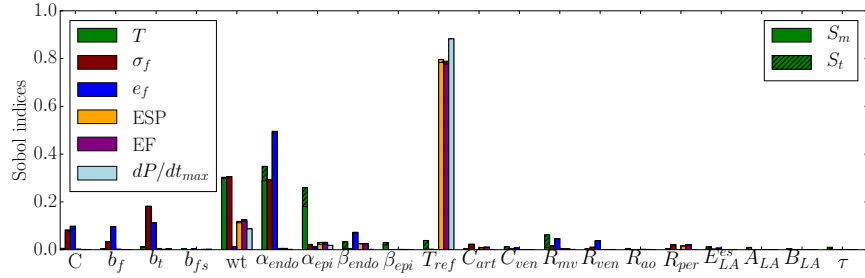


Figure 8: Experiment 3: Sensitivity analysis at early ejection.

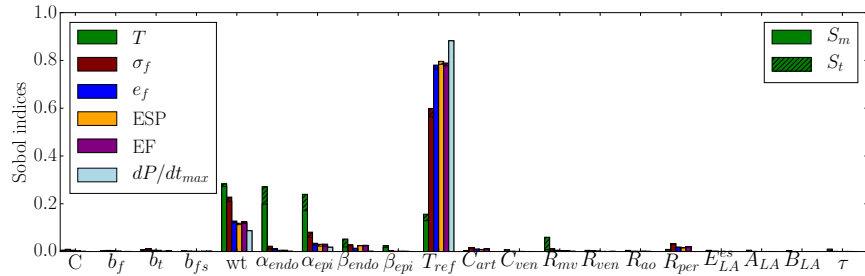


Figure 9: Experiment 3: Sensitivity analysis at end-systole.

1.4. Experiment 4

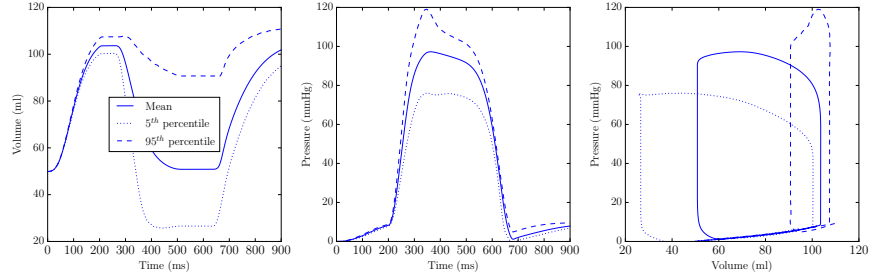


Figure 10: Experiment 4: Pressure-volume loop.

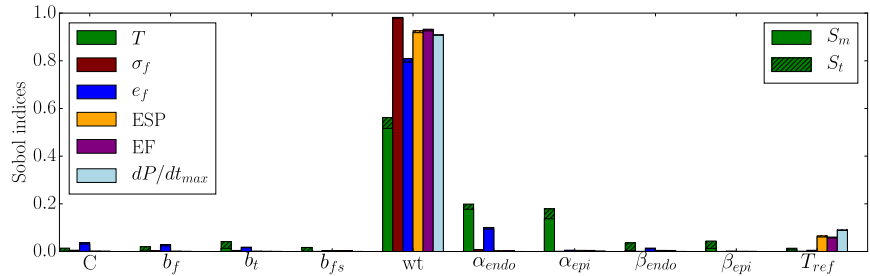


Figure 11: Experiment 4: Sensitivity analysis at early ejection.

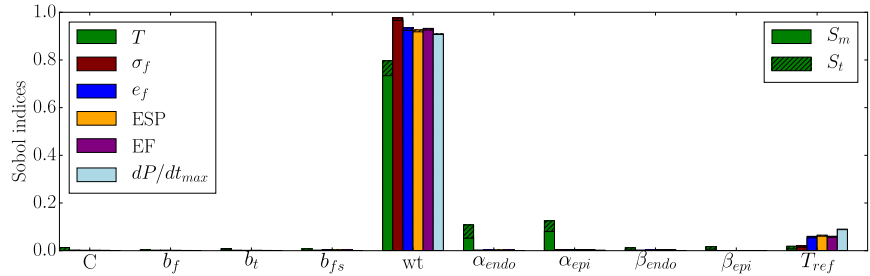


Figure 12: Experiment 4: Sensitivity analysis at end-systole.

2. Variability of the parameters in the experiments

In this section we report on the choice of using COV as 5%, 10% or 20% for all uncertain parameters in experiment 2. We report next the number of failed samples for each case from a total of 198 samples:

- COV=5%, Failed samples 16/198
- COV=10%, Failed samples 40/198
- COV=20%, Failed samples 99/198

The failed samples were rejected and the surrogate model to perform UQ and SA was constructed without considering them. The results of sensitivity analysis for each case are presented next.

2.1. Sensitivity analysis for the 5%, 10% and 20% of COV for all parameters

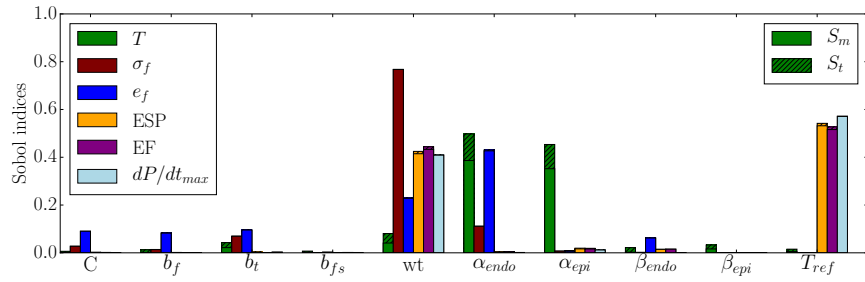


Figure 13: Sensitivity analysis at early ejection for the case COV=5% (Experiment 2).

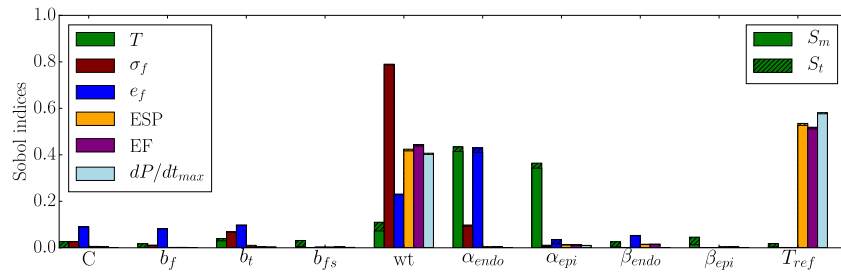


Figure 14: Sensitivity analysis at early ejection for the case COV=10%.

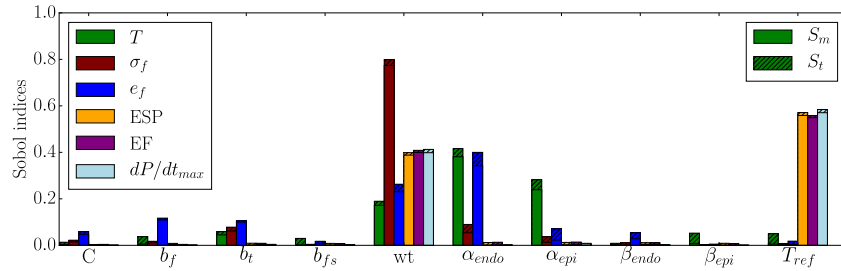


Figure 15: Sensitivity analysis at early ejection for the case COV=20%.

2.2. Scatterplots of the sample for the 5%, 10% and 20% of COV for all parameters

To investigate the failed samples we present next two-by-two scatterplots of all input parameters. Red dots denotes the failed samples, whereas blue dots corresponds to samples which the simulation did not fail.

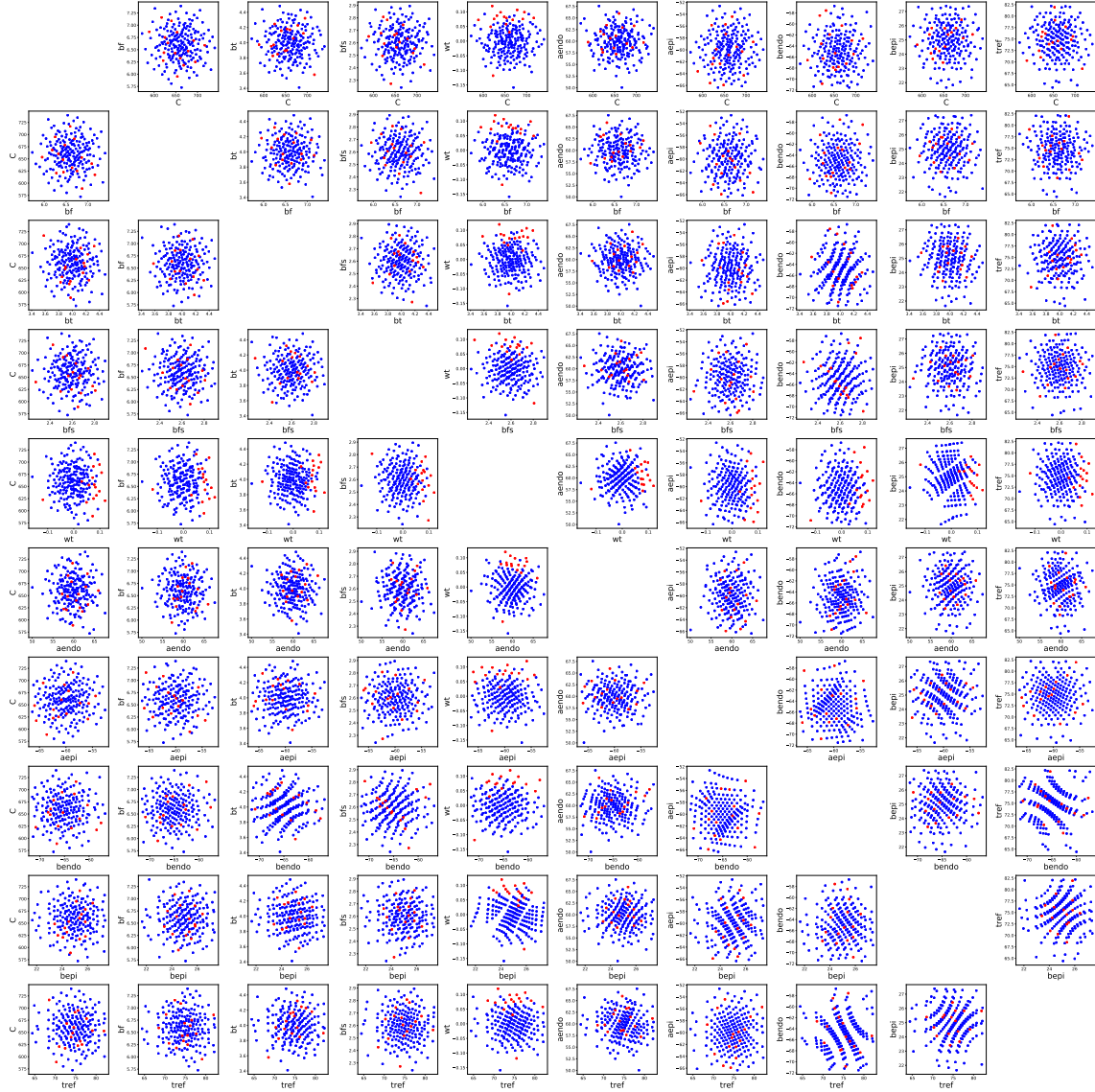


Figure 16: Scatterplots of the samples for the case COV=5%.

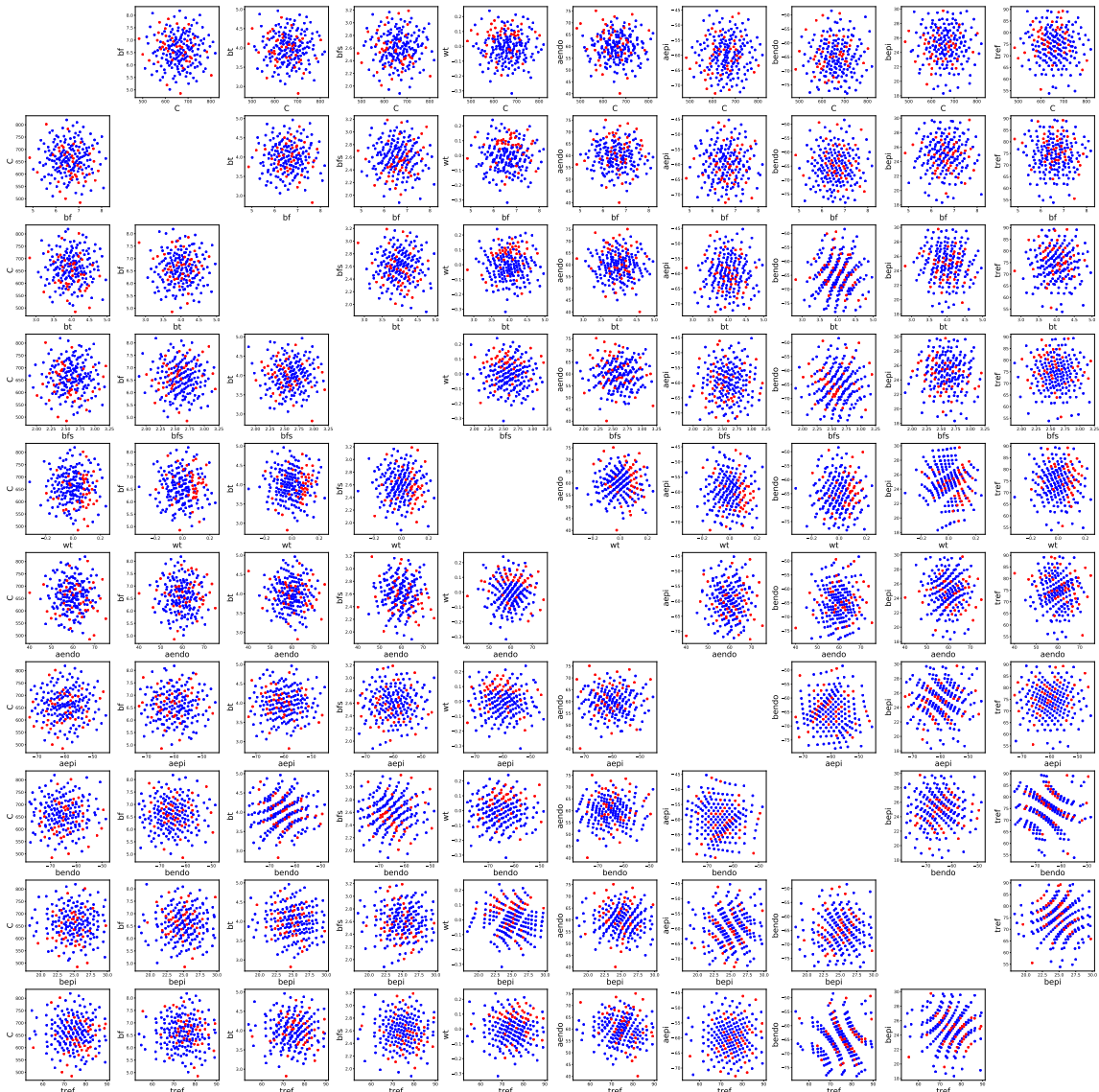


Figure 17: Scatterplots of the samples for the case $COV=10\%$.

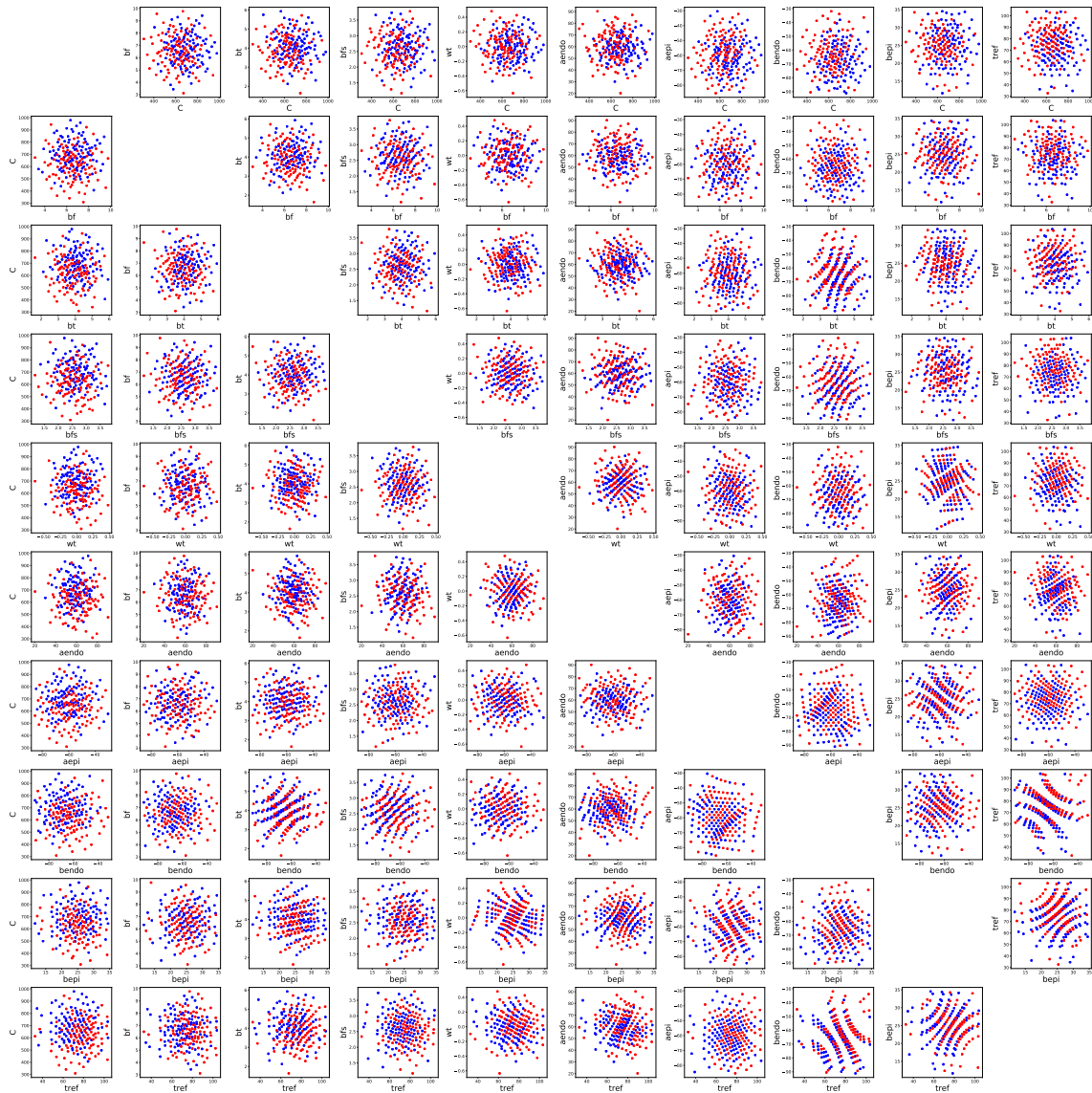


Figure 18: Scatterplots of the samples for the case $COV=20\%$.

3. Sensitivity analysis including the active stress model

In this section we report on a study which was performed considering Experiment 2 as a basis and then included the parameters from the active stress model by Bovendeerd *et al.* [17] as uncertain parameters.

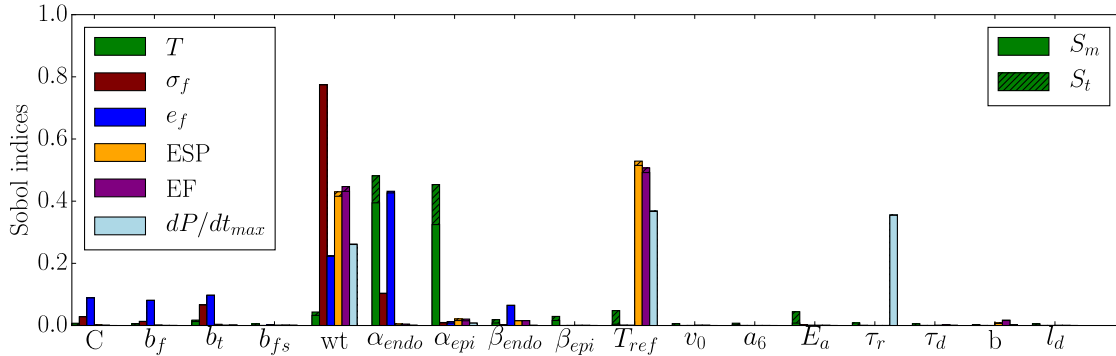


Figure 19: Sensitivity analysis at early ejection for a case with parameters from the active stress model.

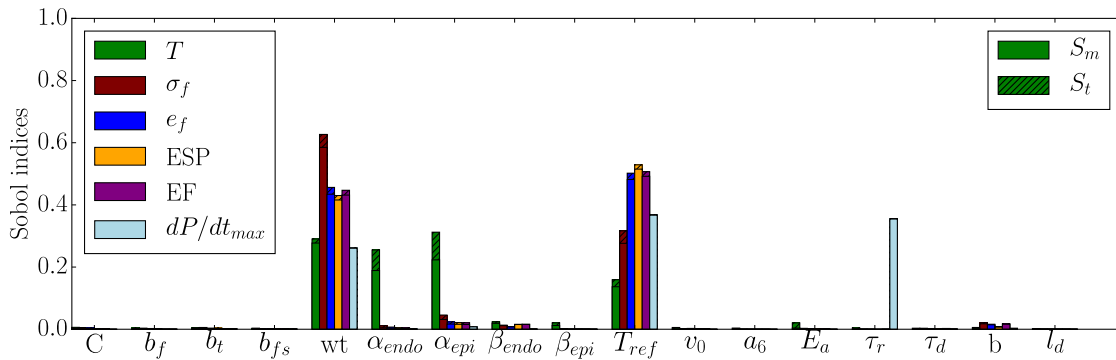


Figure 20: Sensitivity analysis at end-systole for a case with parameters from the active stress model.

The sensitivity indices shown in Figures 19 and 20 reveal that the parameters from the active stress model that most impact the QoIs analyzed are T_{ref} and τ_r , which control the maximum value of the active stress and time to rise, respectively. In particular T_{ref} impacts all quantities, whereas τ_r impacts only on dP/dt_{max} .

4. Example of geometrical sample of the Left Ventricle

A detailed description of the algorithm used for generating geometrical samples of the LV is present in our previous work (Appendix A of reference [15]). Figure 21 shows an example of an LV sample generated in Experiment 4 where a COV=20% was used for wt in the lateral region.

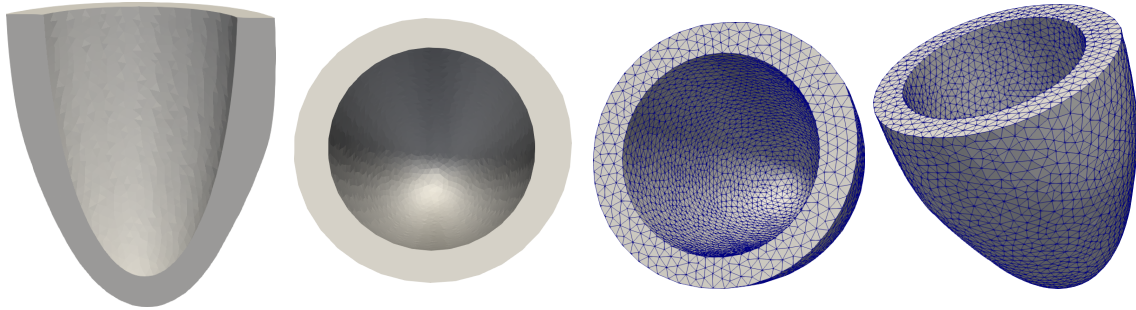


Figure 21: Different views from a geometrical LV sample from experiment 4 and its FE mesh.