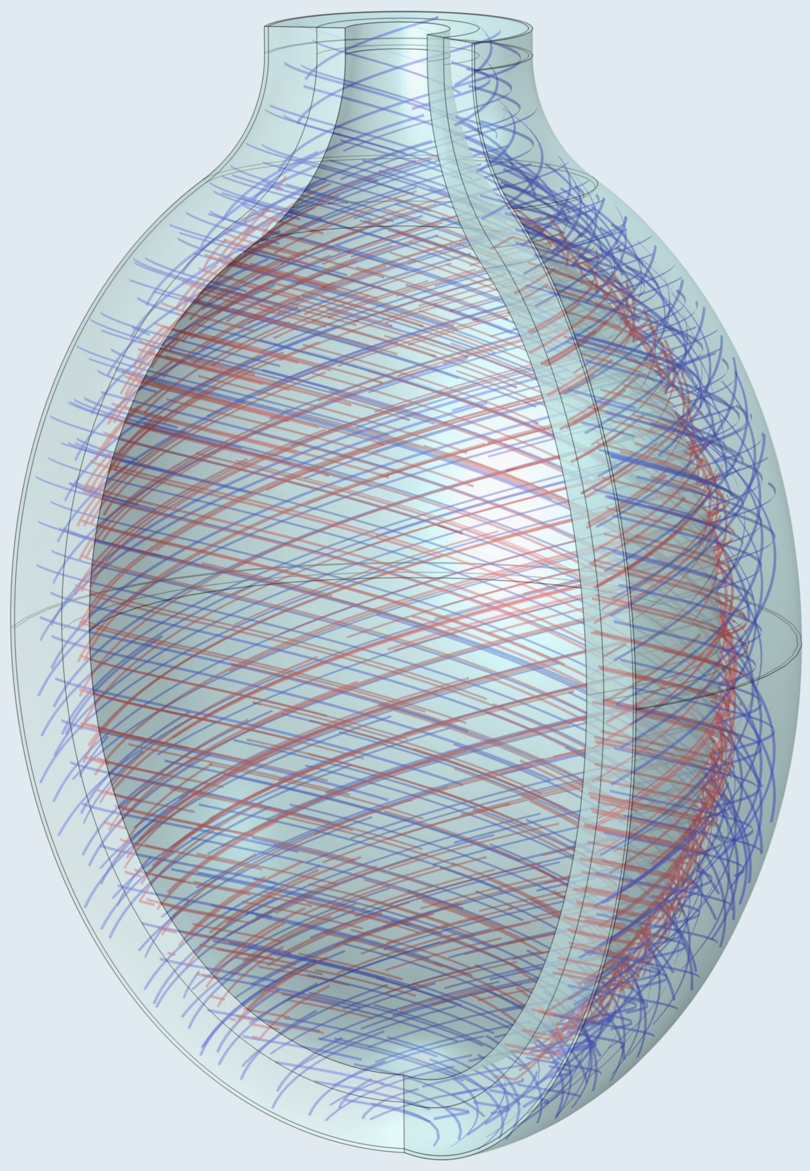

BOOM: Towards a Digital Twin of the Bladder

Biomechanical models of the bladder wall can help better our understanding of the mechanobiological changes that occur due to bladder outlet obstruction.

Kieran Boniface[1], Shaghayegh Zamani Ashtiani[3], Naoki Yoshimira[2], Anne Robertson[3], Paul Watton[1,3]
[1]Department of Computer Science & Insigneo Institute for in silico Medicine, University of Sheffield, Sheffield, UK.
[2]Department of Urology, University of Pittsburgh, US.
[3]Department of Mechanical Engineering and Materials Science, University of Pittsburgh, US.

Introduction & Goals

Bladder outlet obstruction (BOO) is a prevalent condition that is characterized by increased urethral resistance which gives rise to a myriad of lower urinary tract symptoms (LUTs). Over time, the BOO can significantly impact bladder functionality and quality of life.

The bladder can alter its constituents through a growth and remodelling (G&R) process. BOO bladders trigger a G&R response to overcome the increased urethral resistance (Ref. 1). In-silico models of the bladder can help our understanding of what drives bladder remodelling and how this can affect bladder function.

Building on previous work that assumes the bladder to be a spherical membrane (Ref. 2), we develop a micturition model of an ellipsoidal bladder using COMSOL Multiphysics®.

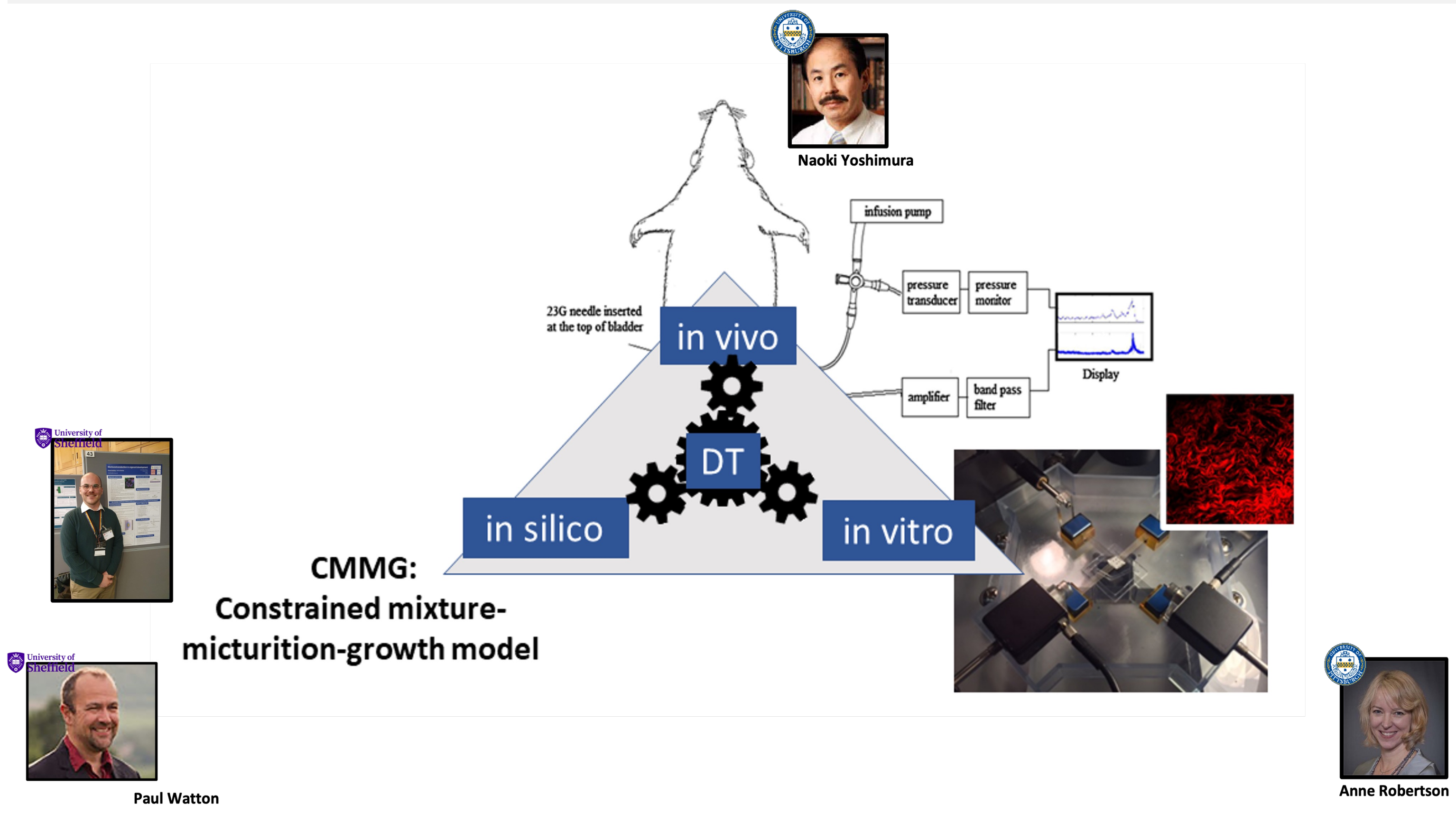

FIGURE 1. Integrative in vivo, in vitro, in silico modelling approach.

Methodology

Integrative modelling approach to help inform rate-based constrained mixture model of the bladder. We model the bladder as a multi-layered, fibre reinforced hyperelastic material. Axial symmetry was utilized to reduce computational cost.

The total stress, $\boldsymbol{\sigma}$, in the bladder wall is given as the sum of the stress from each constituent

$$\boldsymbol{\sigma} = \boldsymbol{\sigma}_E(\lambda_E) + \boldsymbol{\sigma}_{LP}^c(\lambda_c) + \boldsymbol{\sigma}_{DSM}^c(\lambda_c) + \boldsymbol{\sigma}_{SMC}^A(\lambda_m)$$

where the stresses are functions of the stretches of each constituent/cell.

Results

With a model for micturition, we can produce characteristic pressure-volume loops for the bladder. We observe filling at relatively low-pressures, before a steep increase in pressure due to the active contraction of the smooth muscle cells. The pressure inside the bladder decreases until voiding stops, at which point the bladder can begin to fill again.

Future work: we will couple the micturition model with a growth and remodelling process to understand how changes in the wall microstructure (due to BOO) can influence bladder functionality.

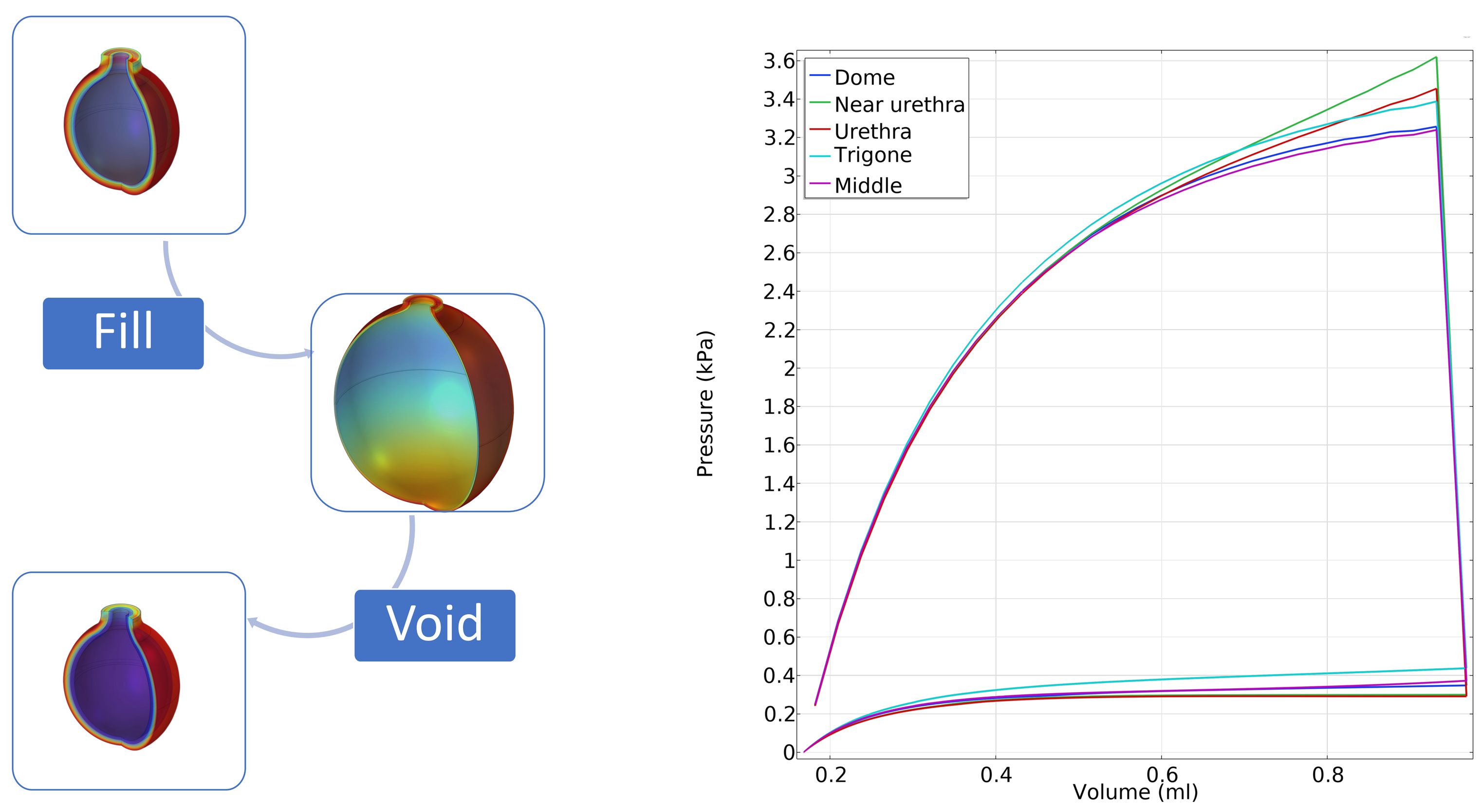

FIGURE 2. Left: Stress in bladder wall during micturition. Right: Pressure-volume loops during a fill-void cycle.

REFERENCES

1. Fusco, Ferdinando, et al. "Progressive bladder remodeling due to bladder outlet obstruction: a systematic review of morphological and molecular evidences in humans." BMC Urol., vol. 18, no. 1, 9 Mar. 2018, p. 15., doi:10.1186/s12894-018-0329-4.
2. Cheng, Fangzhou, et al. "A constrained mixture-micturition-growth (CMMG) model of the urinary bladder: Application to partial bladder outlet obstruction (BOO)." J. Mech. Behav. Biomed. Mater., vol. 134:105337., Oct. 2022, doi:10.1016/j.jmbbm.2022.105337.