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Sensitivity analysis of a venous valve model

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INTRODUCTION

Patients suffering from chronic venous disease show symptoms as varicose (dilated) veins, edema, and even venous ulcers in the legs. An important cause is the increased venous pressure during exercise due to leaking venous valves sometimes combined with obstructed venous outflow. Venous refilling time is amongst others a diagnostic parameter to determine the severity of the disease.

AIM: Examine the dynamics of a healthy venous valve under head up tilt with a lumped venous valve model using a sensitivity analysis to assess the most important parameters.

METHODS

VARY INPUT PARAMETERS

- Valve pressure drop at which opening and closing is initiated: \( \Delta p_{\text{valve}} \)
- Venous radius: \( r_\text{vein} \)
- Area ratio: \( \beta = A_\text{prox}/A_\text{dist} \)
- 8 extra valve and filling parameters

SIMULATE HEAD UP TILT

1D collapsible vein (Keijsers2015)

DIFFERENT VENOUS VALVE DYNAMICS

MODEL

OD dynamic valve (Mynard2012)

OUTPUT OF INTEREST

Valve dynamic timings

SENSITIVITY ANALYSIS

Generalized polynomial chaos expansion is used to assess the contribution of input parameters to output variance, including interactions.

The venous valve dynamics under head up tilt is examined within a 1D venous model including a single 0D dynamic valve. Varying the input parameters within their uncertainty range provides the output variance (valve dynamics timings). Finally, using generalized polynomial chaos expansion [Huberts2014] the contribution of each input parameter, and their interactions, to the output variance is computed.

RESULTS

The sensitivity indices show how the output variance is attributed to each individual input parameter \((S_i)\) and their second \((S_{ij})\) and third order \((S_{ijk})\) interactions.

- For the time at which the valve starts to close \(t_{\text{close}}\), the time needed for the valve to close \(dt_{\text{closing}}\) and to open \(dt_{\text{opening}}\), the valve pressure drop \(\Delta p_{\text{valve}}(o)\) is the main parameter determining the variance.
- The variance in the time the valve remains closed \(dt_{\text{fully closed}}\) is almost solely determined by the venous radius \(r_{\text{vein}}(o)\).
- The baseline valve state \(\beta_{bl}\) is mainly determined by the valve pressure drop \(\Delta p_{\text{valve}}(o)\) and its interaction with the venous radius \(r_{\text{vein}}(x)\) and the area ratio \(\beta_A(x)\).

DISCUSSION & CONCLUSION

This study suggests that the most important input parameters for the valve dynamics under head up tilt are the valve pressure drop (related to valve dynamics) and the venous radius (related to venous filling). In the future, a better estimate of venous filling can be obtained by measuring venous radius using ultrasound and more insight into the valve dynamics can be obtained from 3D simulations.

References