Fluid-Structure Interaction analysis of the PennState 12cc pediatric Ventricular Assist Device

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Background and Aims of the Study

Cardiovascular Disease (CVD) ------- lacking fresh organs --------->

> **10,000** USA babies with congenital CVDs.
Nearly **1,800** infants die each year due to CVDs [1].

Heart transplantation
Gold standard therapy for patients with CVDs.
High mortality of infants, waiting for a new heart [2].

waiting for surgery

Pediatric ventricular assist device (pVAD)
Valuable bridge to transplantation, showing a decrease in mortality [3].
Low mortality rate during teraphy.

PennState 12cc pVAD

device optimization

Fluid structure interaction (FSI)
Computational strategy to assess the pVAD 12cc performances and improve optimization procedures:
- ❑ Capture the complex interaction between air, blood and the polymeric pVAD diaphragm.
- ❑ Assess the diaphragm kinematics (buckling motion) and the pVAD fluid dynamics.
- ❑ Provide adequate validation of the device and complement experimental data.

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Materials and Methods

FSI simulations performed in **LS-DYNA R6** [4] (Livermore software Inc, Livermore, CA, USA).
CAD-model derived from PennState original molds for mock-loop *in vitro* testing device (Fig.1).

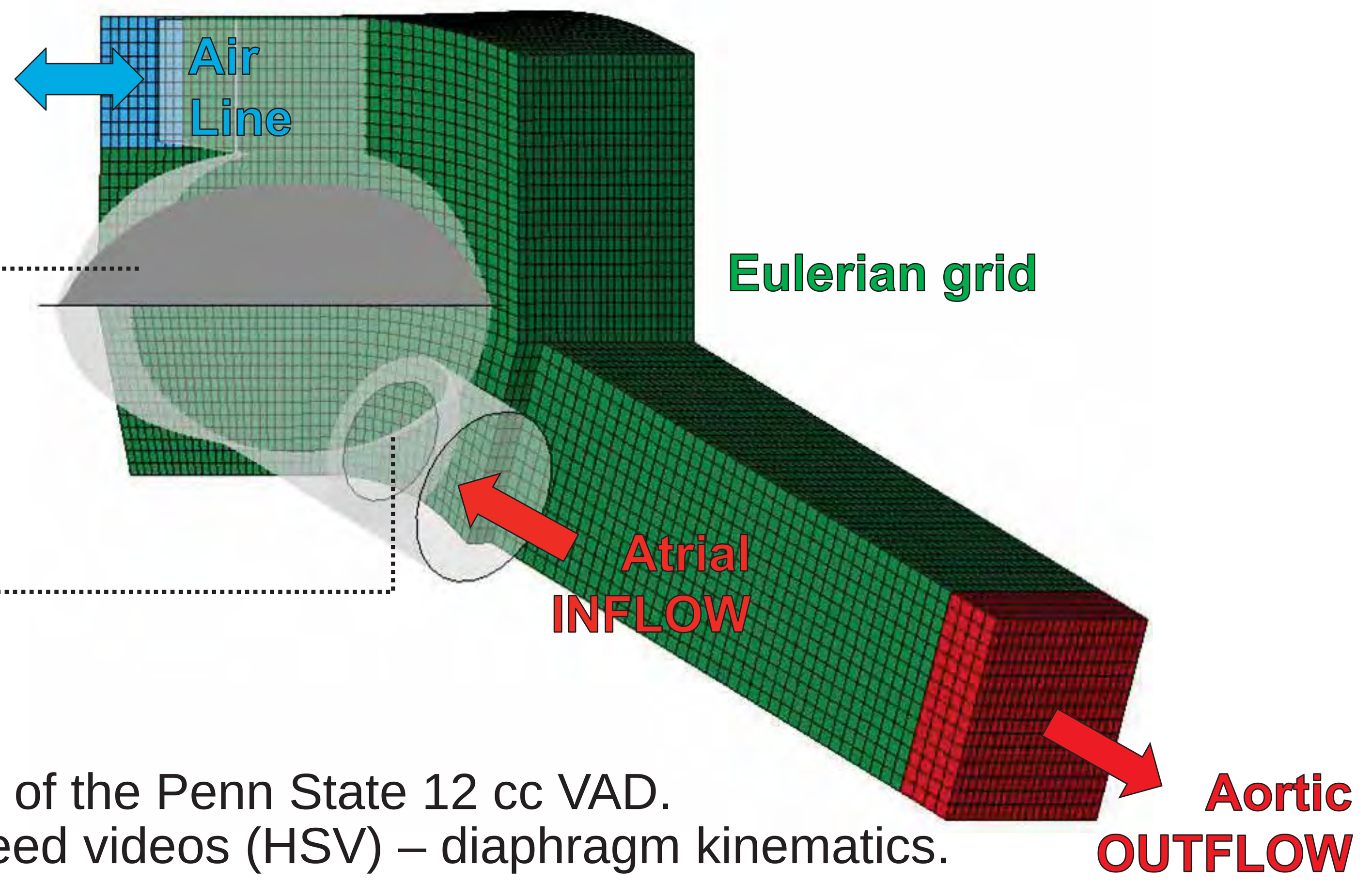
Blood: Newtonian incompressible fluid
- $\rho = 1.06\ g\cdot cm^{-3}$
- $\mu = 4$ cP, Ht=40%

Diaphragm
- Isotropic linear elastic
- E = 7.0 Mpa ($\sigma_{UTS} = 38.6$ MPa)

Air: Ideal gas
- $\rho = 0.0128\ g\cdot cm^{-3}$
- $\mu = 0.00004$ Pa·s

Mitral and Aortic Valves
- Rotating rigid disks
- *on-off* behavior.

Fig. 1 pVAD computational FSI model



Reliable FSI boundary conditions reproduced through experimental operative *in vitro* conditions of the Penn State 12 cc VAD.
Preliminary **comparison with experimental measurements** (Fig. 4):
- Pre-recorded high-speed videos (HSV) – diaphragm kinematics.
- particle image velocimetry (PIV) – fluid dynamics field.

Results and Discussion

Diaphragm kinematics. Three dimensional time-dependent asymmetry induced by the internal pVAD hemodynamics (Fig. 2).

pVAD fluid dynamics. Three-dimensional and time-dependent velocity field.
- Complex fluid dynamics: circular washing pattern, in particular during diastole (Fig. 3).
- Velocity range equal to 0.0÷1.0 $m\cdot s^{-1}$ (peak value = 1.4 $m\cdot s^{-1}$).
- Blood pressure range computed throughout a cardiac cycle: 85÷170 mmHg.

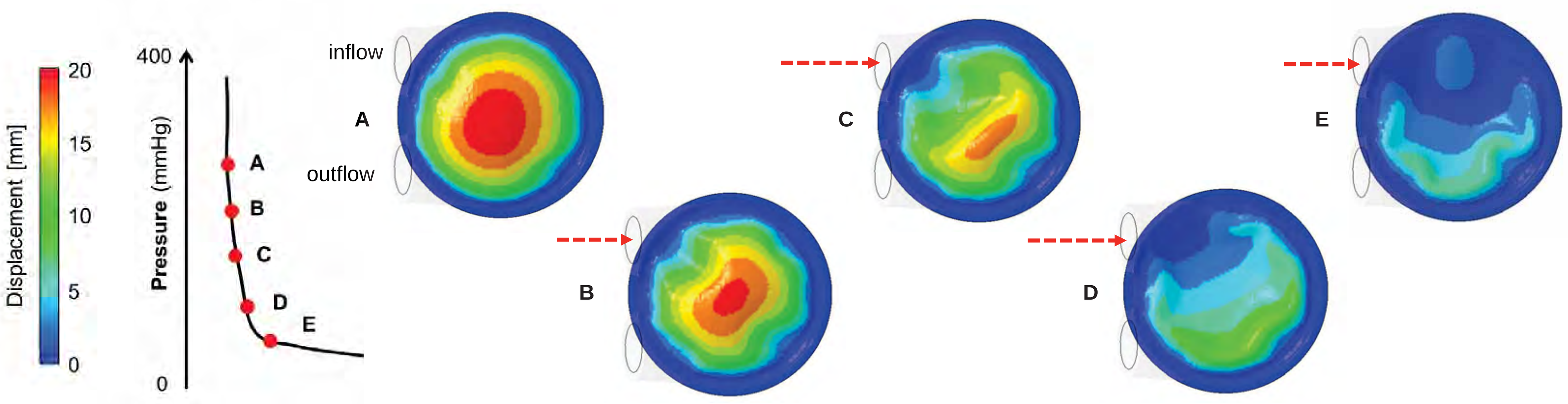


Fig. 2 Diastolic contour maps of pVAD nodal displacement along the normal direction to the diaphragm plane.

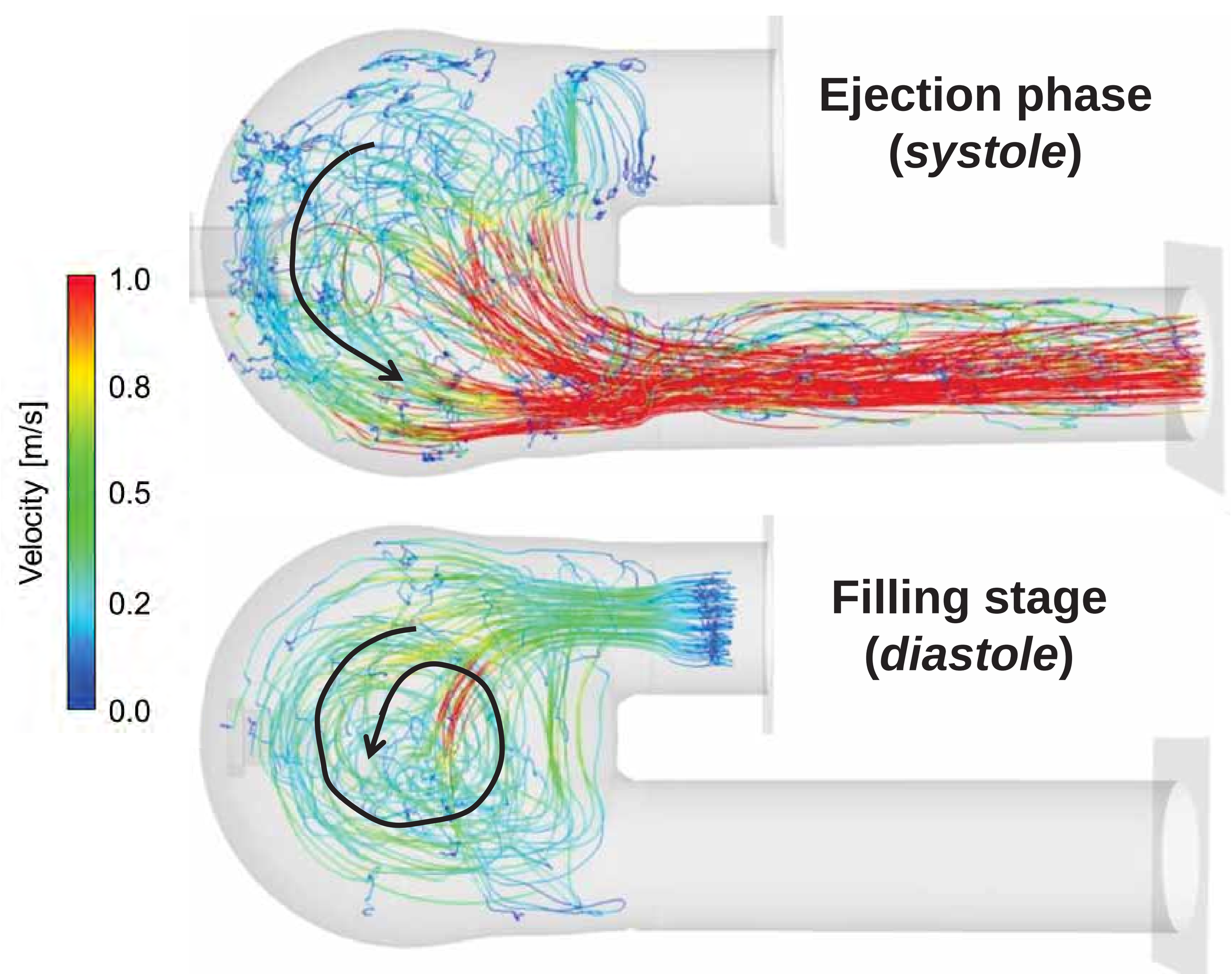


Fig. 3 Blood pVAD pathlines.

Experimental proofs. Range of blood velocity comparable to PIV (Fig. 4a) and realistic diaphragm kinematics, as visible from HSV (Fig. 4b).

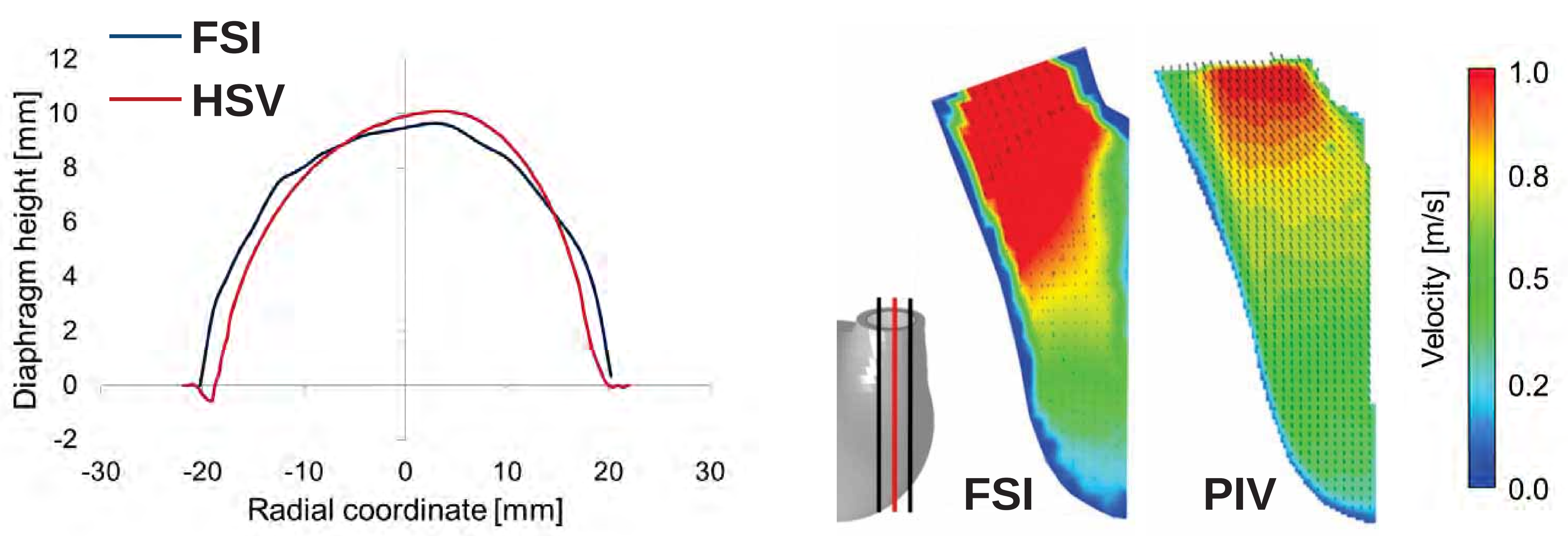


Fig. 4 – a) FSI diaphragm kinematics vs. HSV **b)** FSI and PIV velocity contour maps.

Conclusions. The developed FSI model can elucidate the continuous, time-dependent and three-dimensional pVAD fluid dynamics as well as the three-dimensional and asymmetric kinematics of the pVAD diaphragm. This approach may be pivotal in the optimization of the device, complementing ground truth data from PIV and HSV mock-loop *in-vitro* tests.

References

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