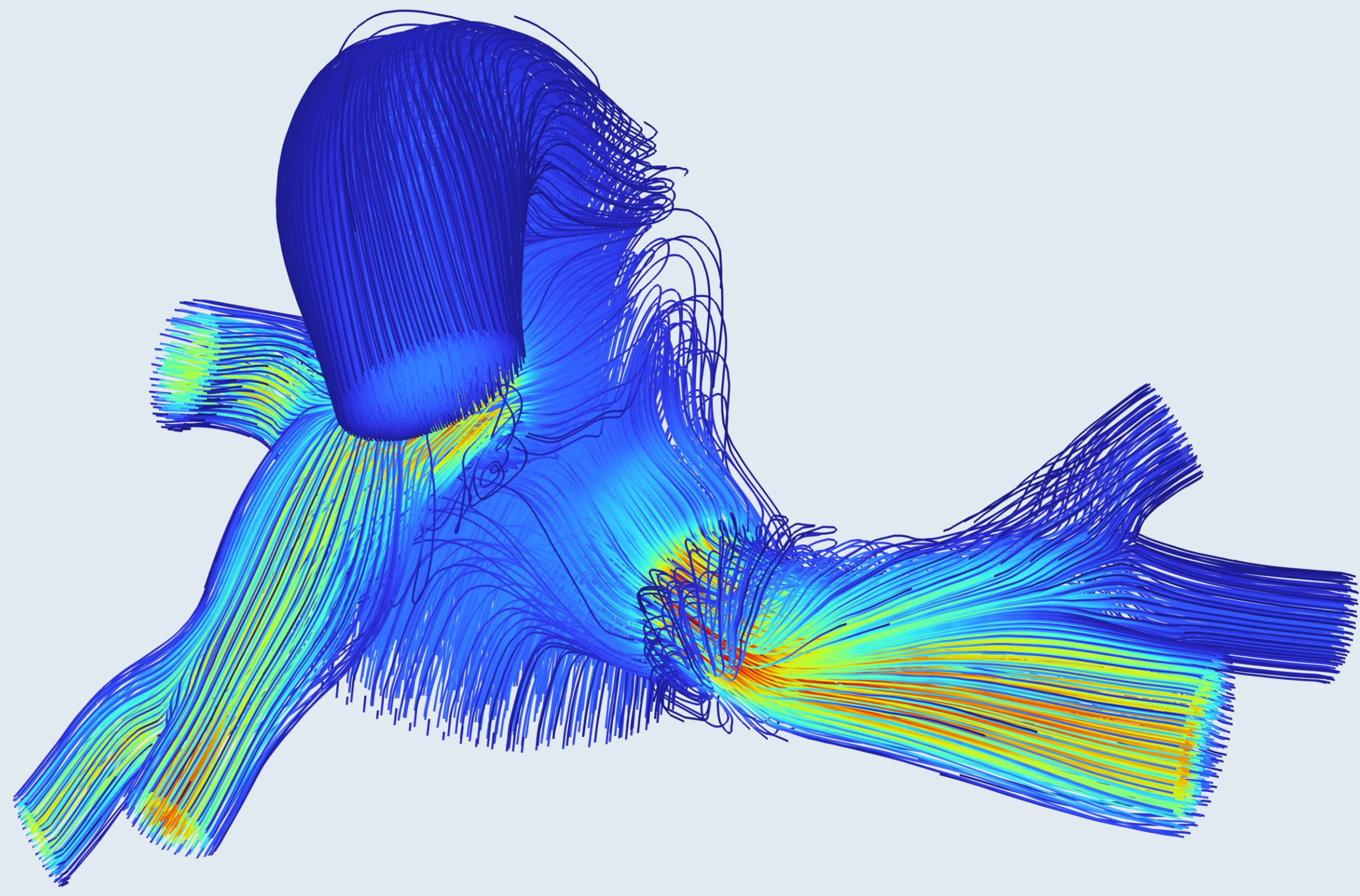




Computational Modeling of Pulmonary Flow Restriction Devices for Hypoplastic Left Heart Syndrome

A Patient-specific CFD framework is developed to evaluate the hemodynamic effects of the fenestration design in microvascular plugs for pulmonary flow restriction in hypoplastic left heart syndrome.

Jayran Khodadad¹, Damien Bonnet², Sophie Guiti Malekzadeh-Milani^{1,2}, Abdul I. Barakat¹

1. LadHyX, CNRS, École Polytechnique, Institut Polytechnique de Paris, Palaiseau, France.

2. M3C-Necker, Hôpital Universitaire Necker-Enfants Malades, Assistance Publique-Hôpitaux de Paris (AP-HP), Université Paris Cité, Paris, France.

Introduction & Goals

Hypoplastic left heart syndrome (HLHS) is a severe congenital heart defect characterized by underdevelopment of the left-sided cardiac structures. A novel transcatheter approach using fenestrated microvascular plugs (MVPs) aims to control pulmonary blood flow without open-chest surgery [1].

The hemodynamic effects of an MVP depend on its fenestration design and the patient-specific pulmonary artery anatomy. This study aims to computationally investigate how fenestration geometry affects pulmonary-to-systemic flow distribution and to identify suitable fenestration sizes for patient-specific anatomies.

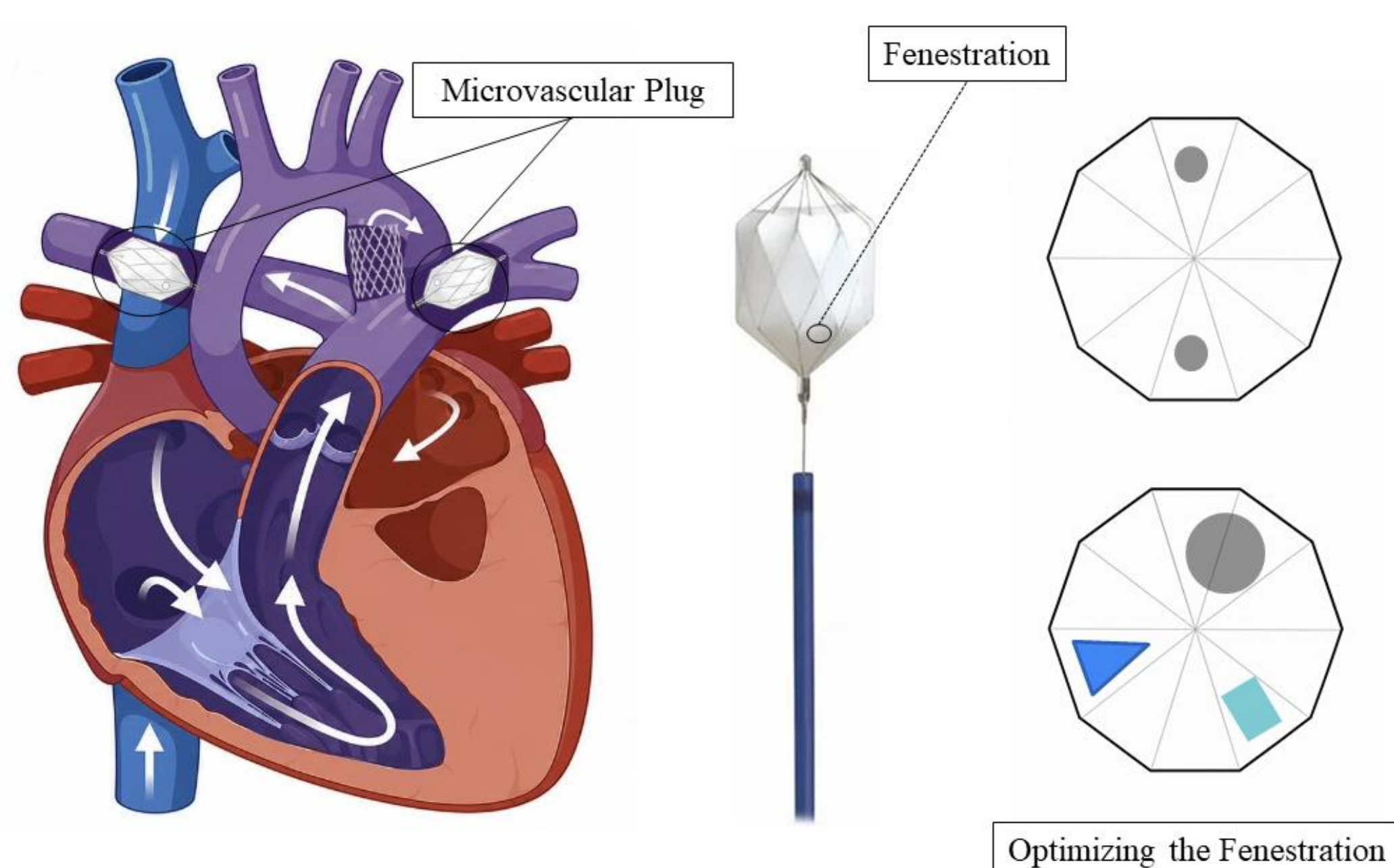


FIGURE 1. Transcatheter pulmonary flow restriction using a fenestrated MVP and optimization of fenestration geometry.

Methodology

A three-dimensional patient-specific pulmonary artery model, including the main pulmonary artery (MPA), right pulmonary artery (RPA), left pulmonary artery (LPA), and patent ductus arteriosus (PDA), was reconstructed from CT data. A simplified MVP was incorporated into the reconstructed anatomy. Circular and elliptical fenestrations of different sizes were investigated, including configurations with one and two fenestrations having the same total area. Time-dependent flow simulations were performed using velocity waveforms extracted from echocardiography at the inlet and literature-based resistance boundary conditions at the outlets to reproduce pulsatile pulmonary flow. All simulations were conducted using the CFD Module of COMSOL Multiphysics® 6.3.

Results

The simulations show that fenestration shape and hole orientation have limited effects on the pulmonary-to-systemic flow ratio (Q_p/Q_s) when the total fenestration area is maintained constant. Similarly, using one or two fenestrations with the same total area does not substantially affect Q_p/Q_s .

In contrast, the required fenestration area depends on the patient-specific pulmonary artery geometry. Post-intervention simulations show flow acceleration through the MVP device, increased flow through the PDA, and reduced flow through the RPA and LPA. These results support the use of patient-specific CFD to guide MVP fenestration sizing.

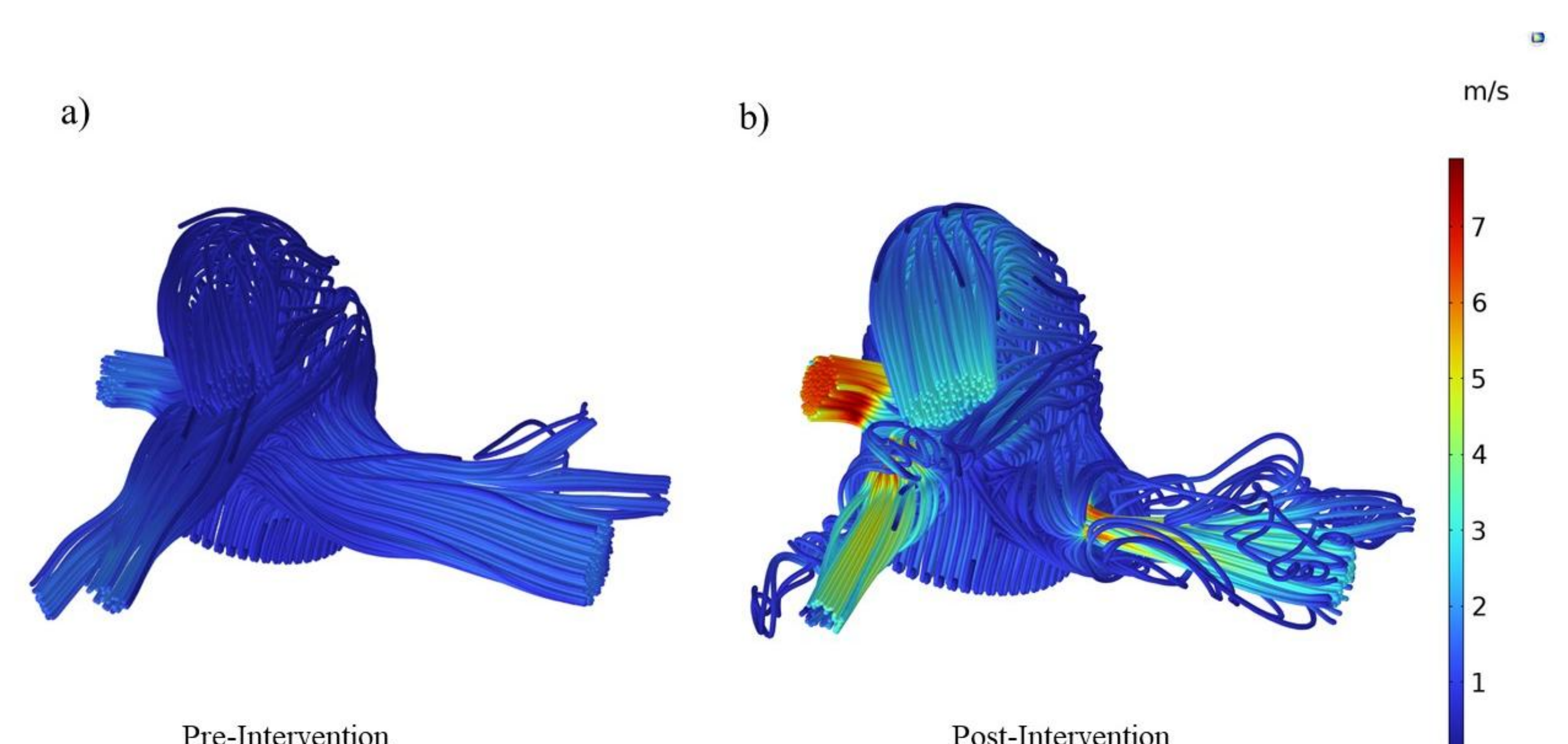


FIGURE 2. Comparison of hemodynamic results before and after MVP deployment. Blood flow is represented by flow streamlines.

REFERENCES

1. Sperotto F, Lang N, Nathan M, et al. Transcatheter Palliation With Pulmonary Artery Flow Restrictors in Neonates With Congenital Heart Disease. *Circ Cardiovasc Interv.* 2023;16(12):e013383. doi:10.1161/CIRCINTERVENTIONS.123.013383.



LadHyX



Hôpital Necker
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AP-HP