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Combining image analysis with dynamic models to improve understanding of vascular disease

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The incorporation of mathematical models in data analysis is essential for understanding physiological processes and developing better diagnosis and treatment strategies. This presentation will focus on cardiovascular diseases, particularly pulmonary hypertension, which is characterized by high blood pressure in the pulmonary vasculature, and effects of aortic remodeling in Fontan patients. Diagnosing the hemodynamic effects of such vascular changes can be challenging, and successful treatment requires early and accurate diagnosis of the disease subtype. To enhance our understanding, we study the features of the vascular network, methods for generating networks for fluid dynamics models, and strategies for designing optimal treatments tailored to individual patients.

For both applications, we employ a multiscale approach to examine the vasculature at both vessel and network levels, constructing models that include large arteries and veins, arterioles and venules, as well as capillaries. We represent the large arteries and veins using a directed graph derived from computed tomography images.

The network of arterioles and venules is modeled as structured trees, with parameters informed by data. The capillary network is depicted as a sheet connected to arterioles and venules in a ladder-like arrangement. In the large vessels, we solve the one-dimensional Navier-Stokes equations, while in the network of smaller vessels and capillaries, we solve linearized equations. These smaller-scale equations are connected to the larger vessels through outflow boundary conditions. The model is calibrated to patient data through simulations and data emulation.

We emphasize the significance of sensitivity analysis and parameter inference in customizing the model for individual patients and demonstrate how the calibrated models can predict treatment effects effectively.