BENCHTOP CIRCULATORY FLOW LOOP OF THE LEFT ATRIUM THAT CAN ACHIEVE TUNABLE, CLINICALLY RELEVANT PRESSURE AND FLOW WAVEFORMS

Keegan Mendez,[1], Manisha Singh,1, Aileen Liao,[1], Susan Su,[1], Ellen Roche,[1]

[1] Massachusetts Institute of Technology

Correspondence: Ellen Roche, etr@mit.edu

Background:

Patient-specific 3D printed models of the left atrial appendage (LAA) have recently been used to improve precision in occlusion device sizing and placement. While these models have led to improved outcomes, they fail to emulate the dynamic physical and physiological principles that govern cardiac function and subsequently affect intracardiac device performance. There is a significant need for high-fidelity, dynamic benchtop models that also incorporate patient heterogeneity, or even patient-specificity, to enable procedural planning and device development in a more accurate, physiologically relevant, and diverse patient population.

Objective:

We aim to develop and validate a benchtop circulatory model of the left atrium (LA) and left atrial appendage (LAA) with interchangeable, patient-derived left atrial appendages. This model will replicate physiological structure (e.g., geometry, mechanical properties) and hemodynamics (e.g., healthy and pathological pressure and flow waveforms). This model will support repeatable and reliable device deployment for occlusion testing and procedural planning, offering a unique insight into the optimal device size and placement for a patient's appendage anatomy. This model will support the development of new methods for occlusion, in which model versatility will enable the development of occlusion techniques for a more diverse patient population, expanding the total treatable population.

Methods:

An open-source database of 100 CT scans from patients with AF (Roney et al., 2022) was used to select an LA for modification. The LA was modified in CAD software to remove the existing LAA and replace it with a custom fitting that allows for interchangeable attachment of multiple LAAs with ostium sizes from 14-31.5mm. The modified LA model was 3D printed in a rigid material (VeroBlue, Object Connex). Patient-specific CT scans were segmented in 3DSlicer, isolating the LAA. Each LAA geometry was 3D printed and used to make a silicone casting

(Ecoflex00-35 FAST) that was integrated onto the LA model using the custom fitting. The model was connected to a circulatory flow loop with a pulsatile pump (HEARTROID), an artificial mechanical valve in the mitral position (Masters Series Mechanical Heart Valve, Abbott), and resistance valves and compliance chambers to mimic pulmonary and systemic vasculature. Pressure and flow were measured at the four pulmonary vein inlets, the left atrium, and the mitral valve (PendoTech Pressure Sensors; Transonic Flow Probes).

Results:

We develop a benchtop circulatory flow loop of the LA that can achieve tunable, clinically relevant pressure and flow waveforms (Figure 1f). The flow loop consists of a custom rigid model of the LA (Figure1a) that allows for attachment of compliant, patient-specific LAAs in a range of ostium sizes (14-31.5mm) (Figure1d), coupled to a pulsatile pump and resistance/compliance elements that can be tuned to mimic the hemodynamics of the pulmonary and systemic vasculature (Figure1f). We demonstrate dynamic contraction of soft, patient-specific silicone castings that can be incorporated onto the atrial model (Figure1e). We demonstrate physiological pressure and flow waveforms (Figure2). Further, we demonstrate the ability to tune pressure and flow waveforms according to the desired pathophysiology (Figure2c-e).

Conclusions:

We present the design and development of a benchtop circulatory flow loop of the LA with interchangeable, patient-derived LAA geometries that can achieve tunable, clinically relevant pressure and flow waveforms. We can tune the pressure and flow waveforms by varying the pulse rate, resistance, and compliance of the circuit according to the desired pathophysiology. By developing an LA model that allows for the incorporation of a wide range of LAA geometries and is capable of recreating physiological pressures and flows, we believe our model can be used for more robust, physiologically relevant, patient-centric device testing and validation.

REFERENCES:

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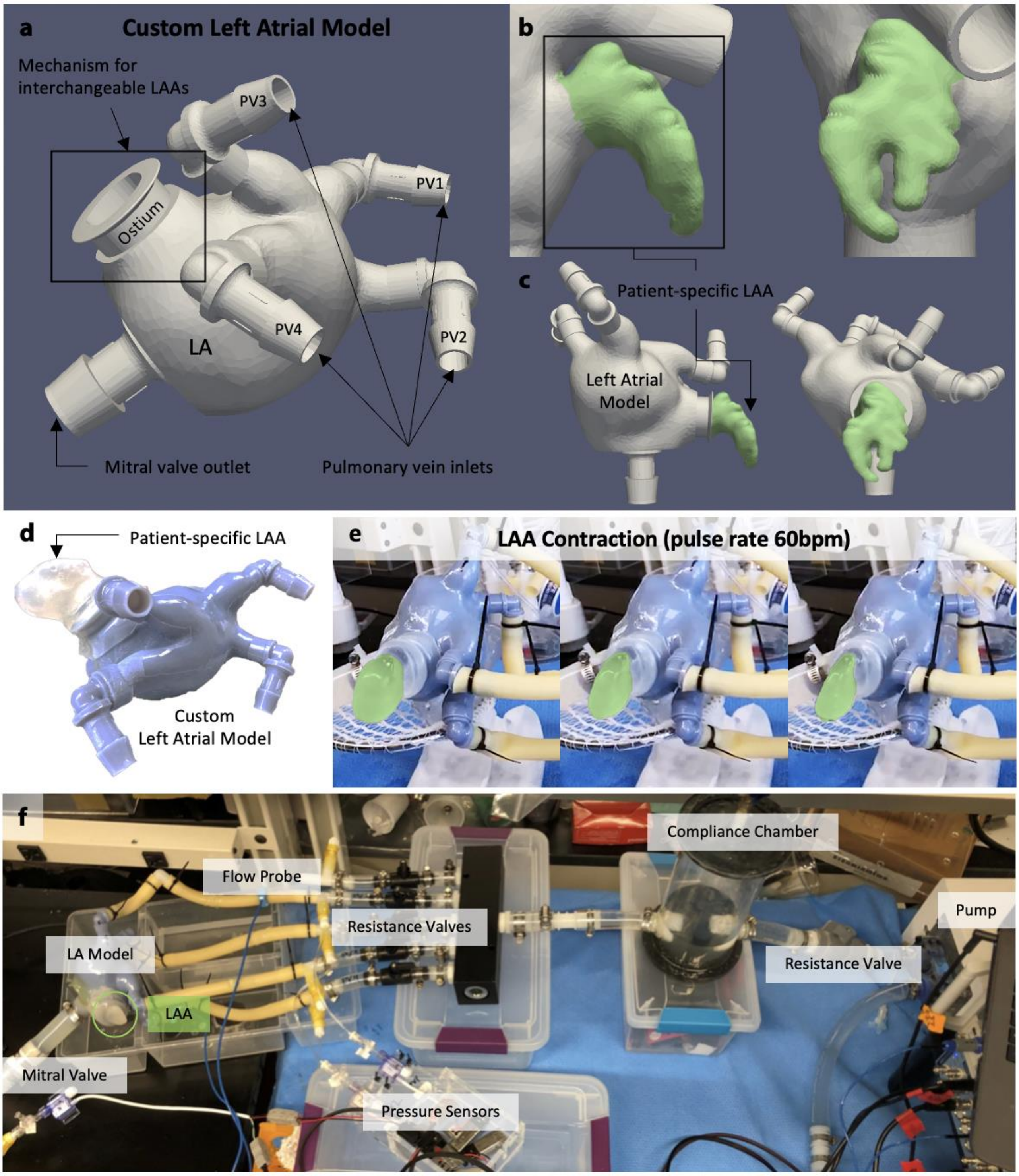

Figure 1. (a) Custom, patient-derived LA model with the mechanism for interchangeable LAAs. Barbed fittings at inlets and outlet for incorporation into circulatory flow loop. (b) Patient-specific LA and LAA segmented from CT imaging. (c) Patient-specific LAA from (b) shown on custom LA model from (a). (d) 3DP custom LA with patient-specific silicone LAA attached. (e) Contraction of LAA using a pulsatile pump (pulse rate 60bpm). (f) Benchtop circulatory flow loop with LA model, LAA (inside green circle), mitral valve, pulsatile pump, tunable resistance/compliance elements, pressure sensors, and flow probes.

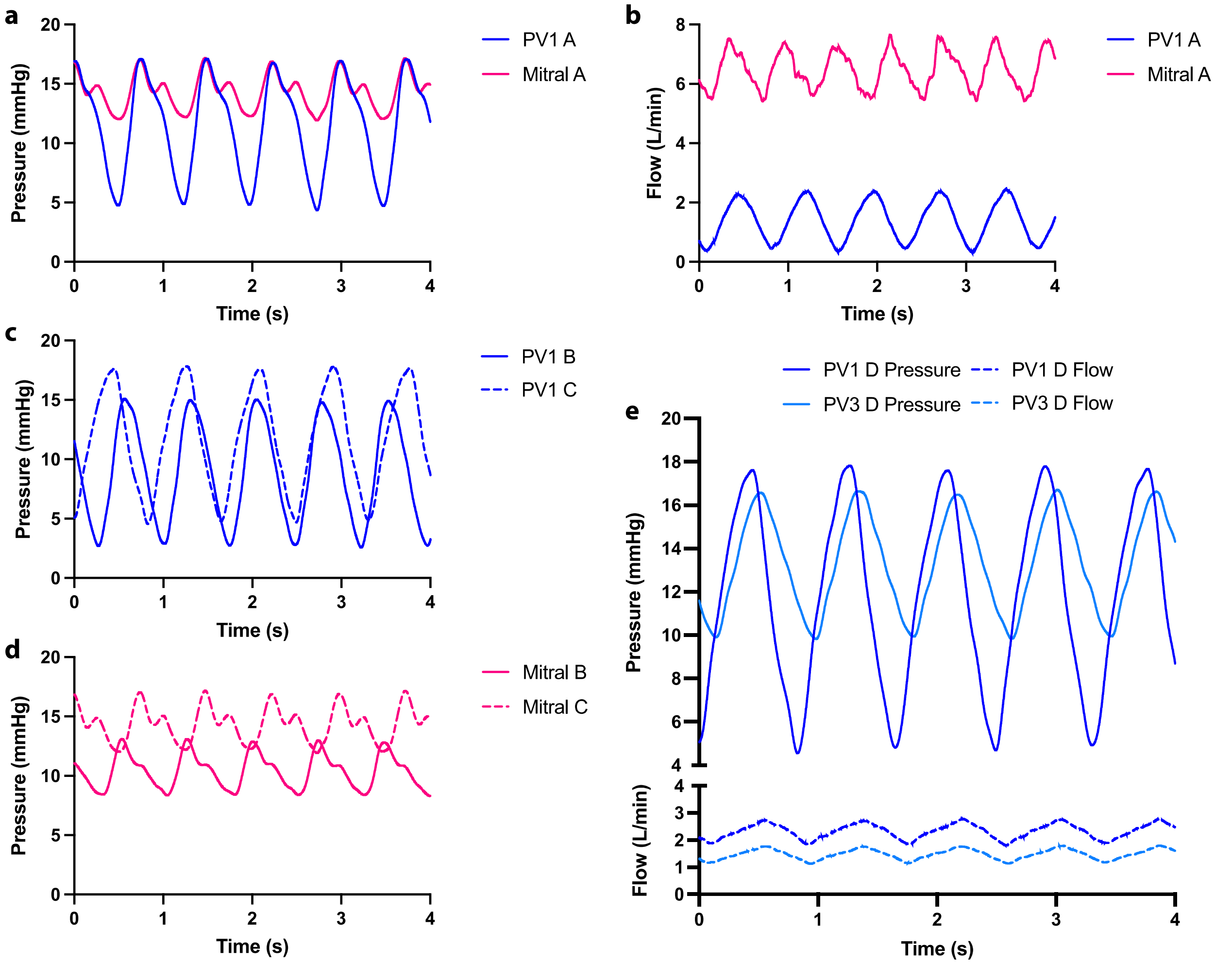

Figure 2. (a) Pulmonary Vein 1 (PV1 A) and Mitral Valve (Mitral A) pressure during ventricular diastole. Data collected during loop setting A. (b) Pulmonary Vein 1 (PV1 A) and Mitral Valve (Mitral A) flow rate. Data collected during loop setting A. (c) Tunable pressures at Pulmonary Vein 1 (PV1 B, PV1 C). PV1 B collected during loop setting B. PV1 C collected during loop setting C. (d) Tunable pressures at Mitral Valve (Mitral B, Mitral C). Mitral B collected during loop setting B. Mitral C collected during loop setting C. (e) Tunable pressures and flow rates at pulmonary vein inlets (Pulmonary Vein 1, PV1 D; Pulmonary Vein 3, PV3 D). Data collected during loop setting D.