DEVELOPMENT AND IDENTIFICATION OF A CLOSED-LOOP MODEL OF THE CARDIOVASCULAR SYSTEM INCLUDING THE ATRIA

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8TH IFAC SYMPOSIUM ON BIOLOGICAL AND MEDICAL SYSTEMS
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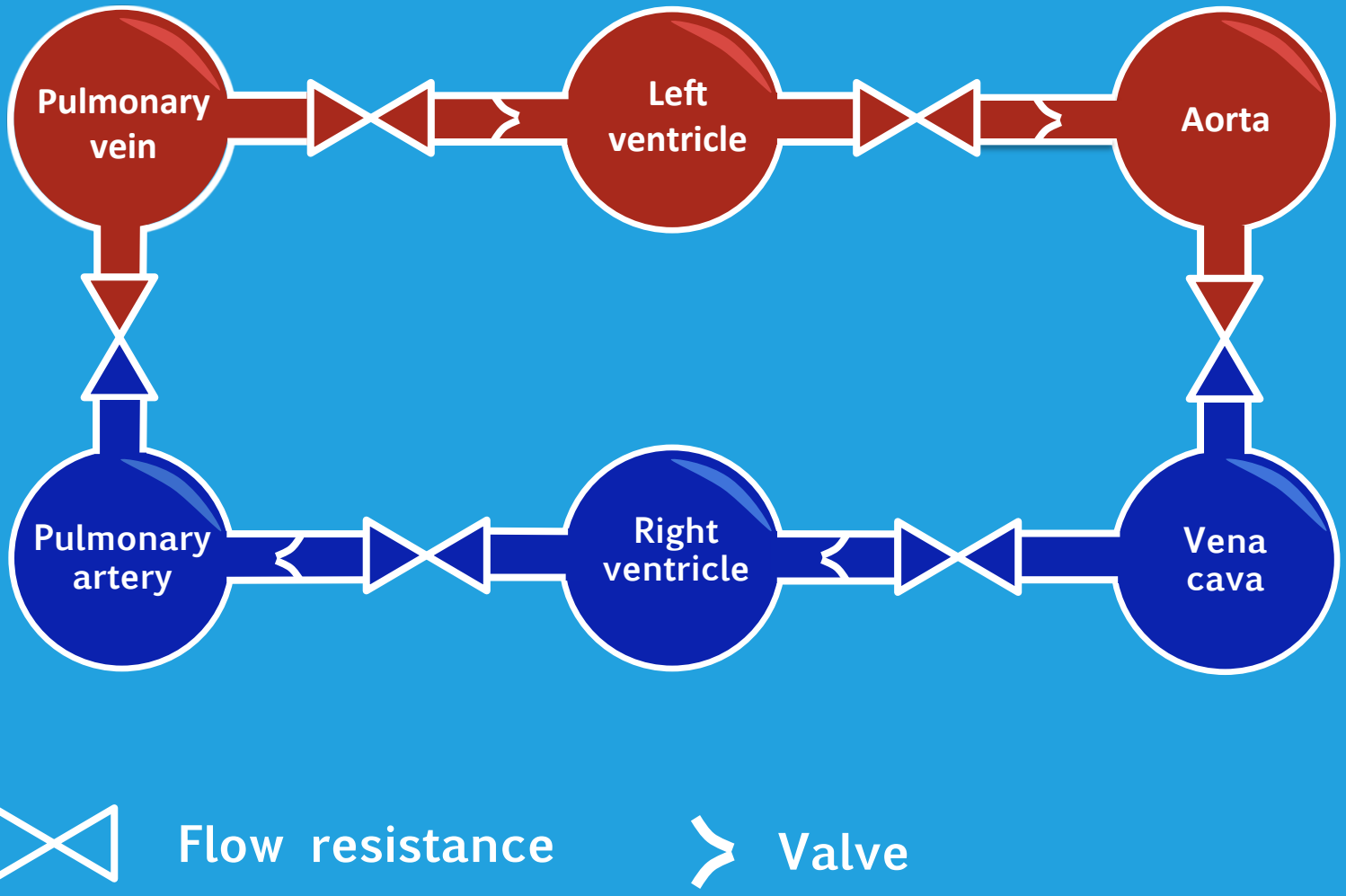
1 CONTENTS

- Initial CVS model
- Introduction of the atria
- Parameter identification
- Results

2 METHODS

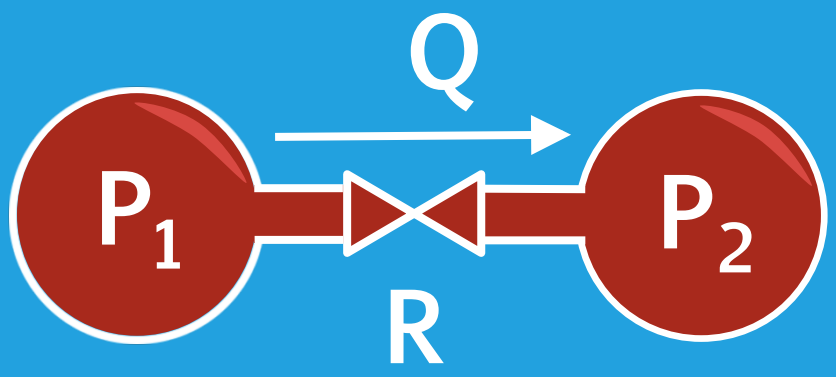
1 ORIGINAL CVS MODEL



2 METHODS

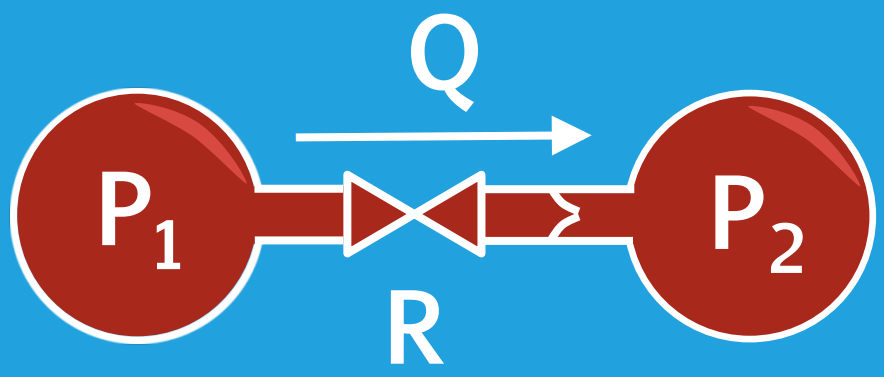
1 ORIGINAL CVS MODEL

No valve:



$$Q = \frac{P_1 - P_2}{R}$$

Valve:

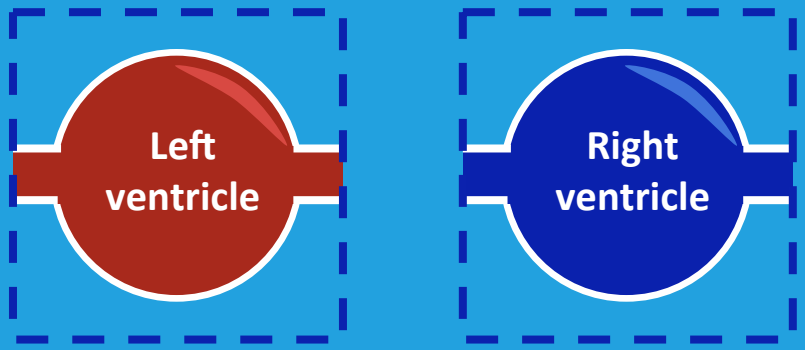


$$Q = \begin{cases} \dfrac{P_1 - P_2}{R} & \text{if } P_1 > P_2 \\ 0 & \text{otherwise} \end{cases}$$

2 METHODS

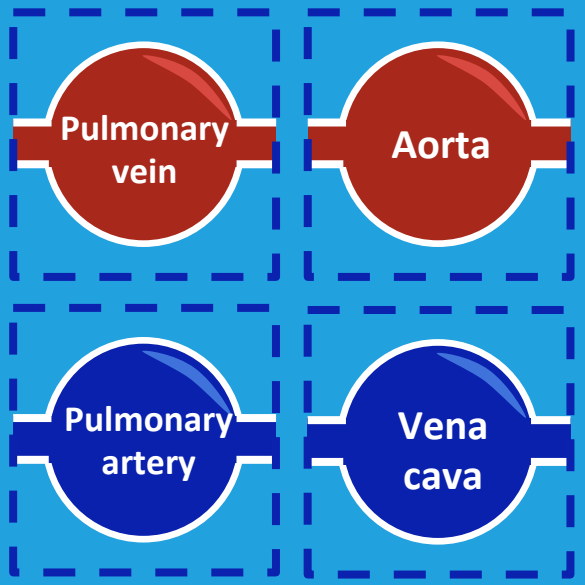
1 ORIGINAL CVS MODEL

Cardiac chambers:



$$P = E(t)\, V$$

Other chambers:



$$P = E\, V$$

2 METHODS

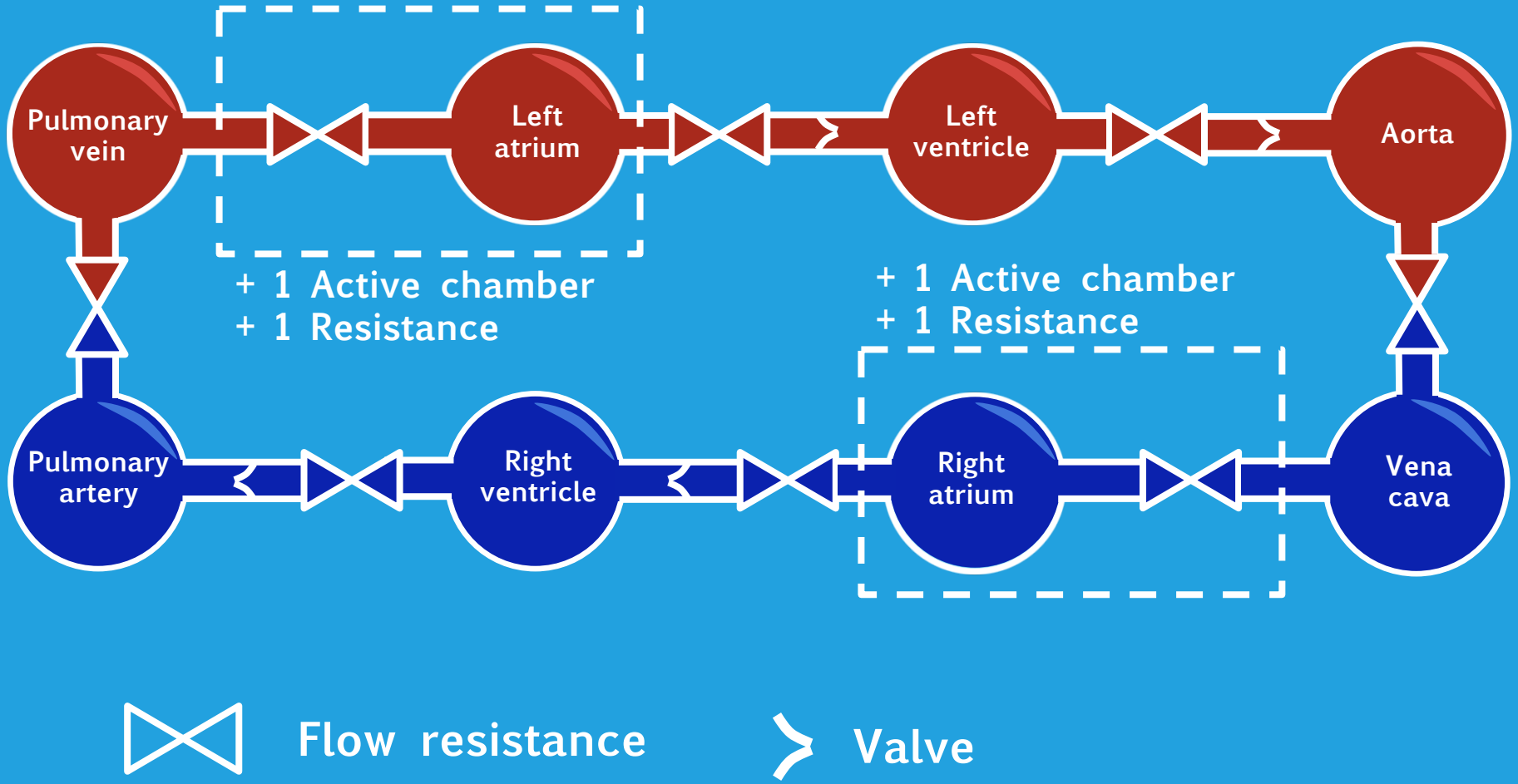
1 ORIGINAL CVS MODEL

Continuity equation:

$$\dot{V} = Q_{in} - Q_{out}$$

2 METHODS

2 INTRODUCTION OF THE ATRIA



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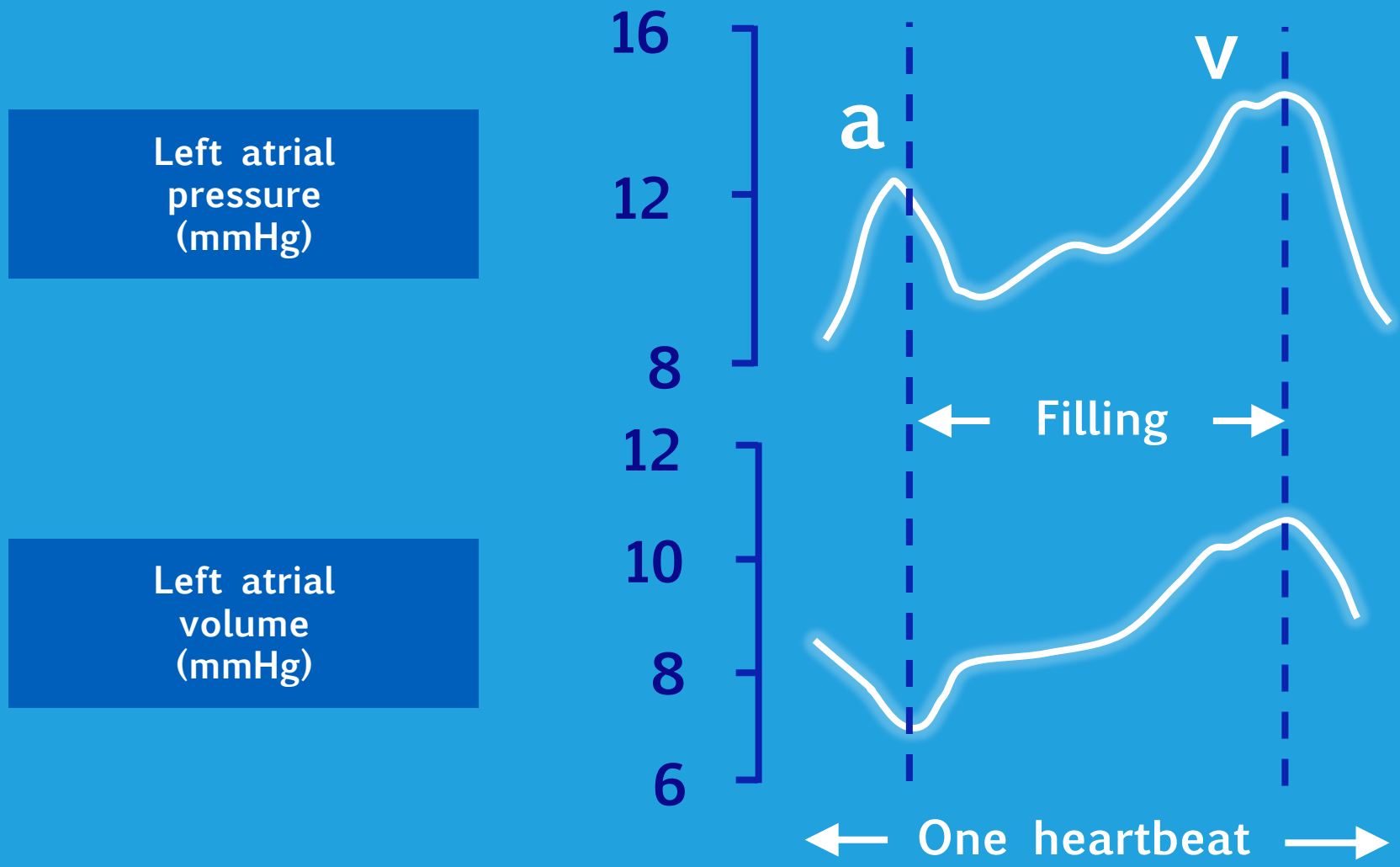

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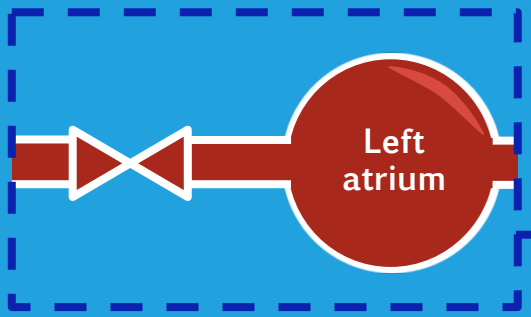
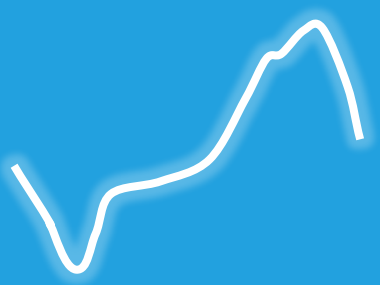
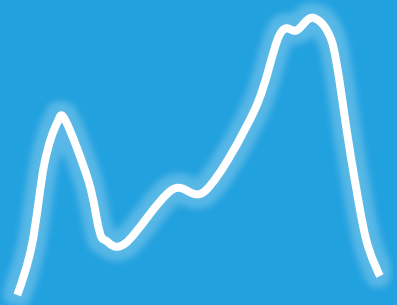


$$P(V,t) = P_a\, e(t) + EV(1 - e(t))$$



Atrial volume



Atrial pressure

2 METHODS

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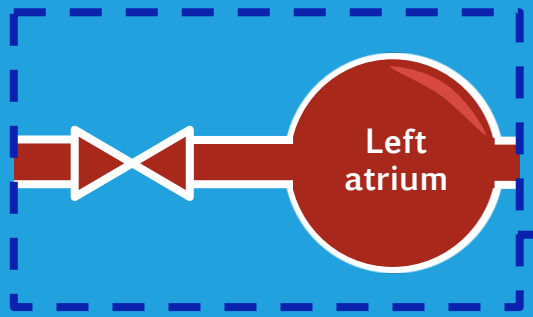
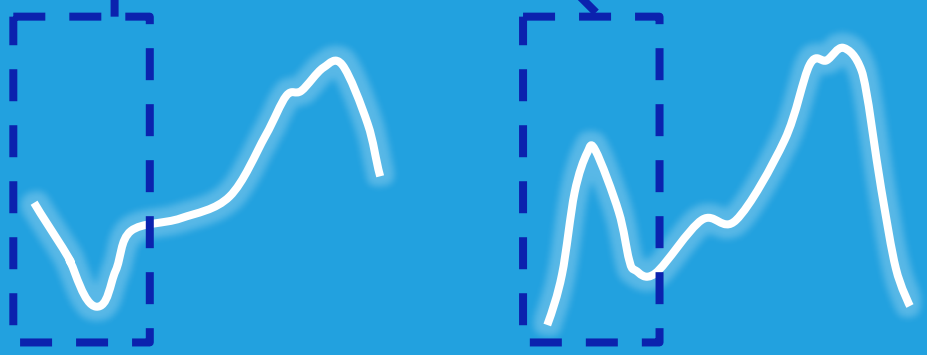


$$P(V,t) = P_a\, e(t) + E\,V(1 - e(t))$$

Active component
$e(t) \approx 1$



Atrial volume

Atrial pressure

2 METHODS

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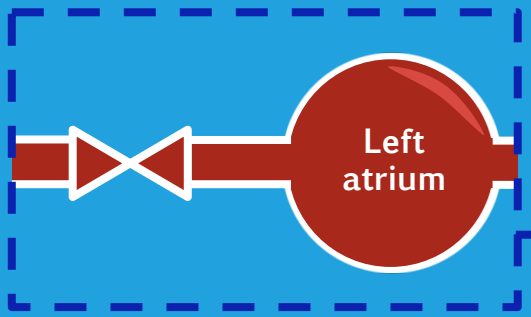
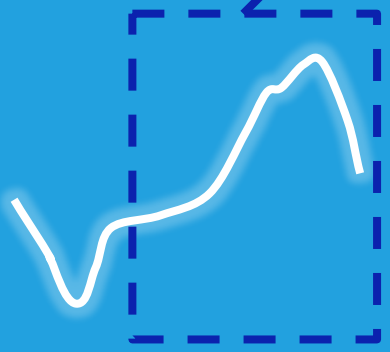
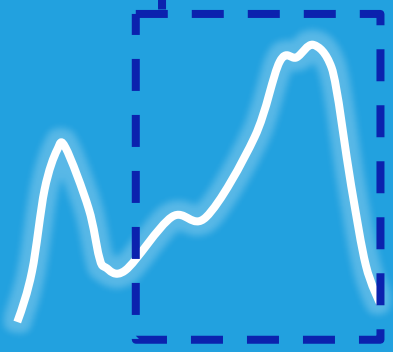


$$P(V,t) = P_a\, e(t) + E\,V(1 - e(t))$$

Passive component
$e(t) \approx 0$



Atrial volume



Atrial pressure

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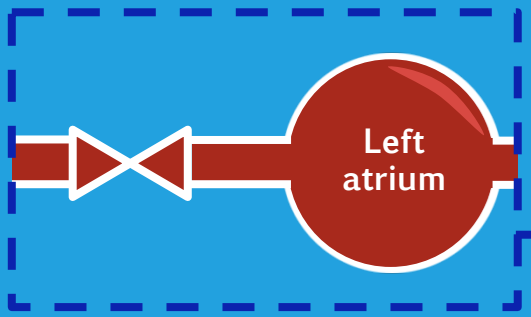
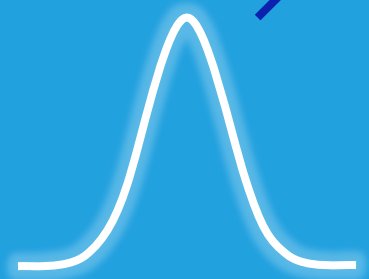
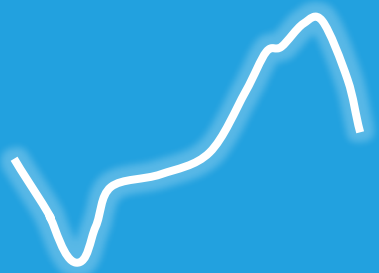


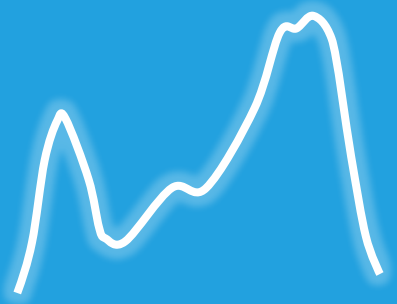
$$P(V,t) = P_a\, e(t) + EV(1 - e(t))$$



Driver function
e(t) in [0, 1]



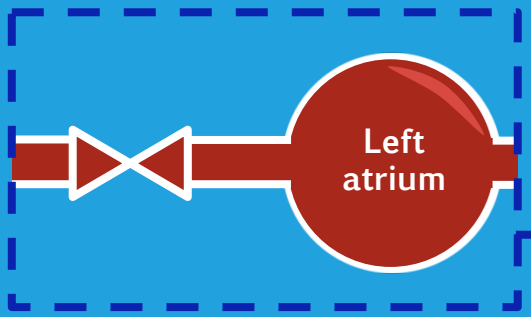
Atrial
volume



Atrial
pressure

2 METHODS

2 INTRODUCTION OF THE ATRIA

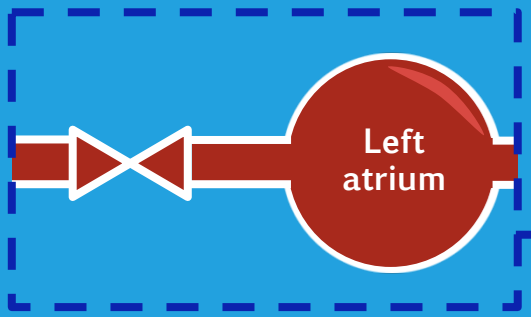


$$P(V,t) = P_a\, e(t) + EV(1 - e(t))$$

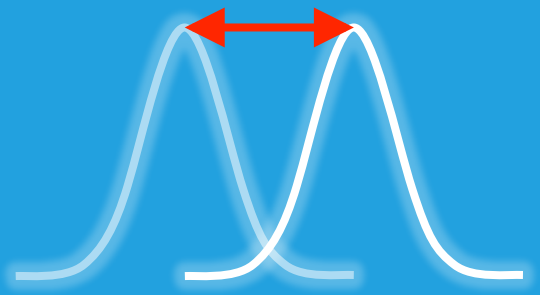
P_a A-wave peak pressure	=	Maximum diastolic ventricular pressure	+	Offset (atrio-ventricular pressure gradient)

2 METHODS

2 INTRODUCTION OF THE ATRIA



$$P(V,t) = P_a\, e(t) + EV(1 - e(t))$$



Driver function
e(t) in [0, 1]

Time of atrial contraction

=

Time of maximum diastolic ventricular pressure

2 METHODS

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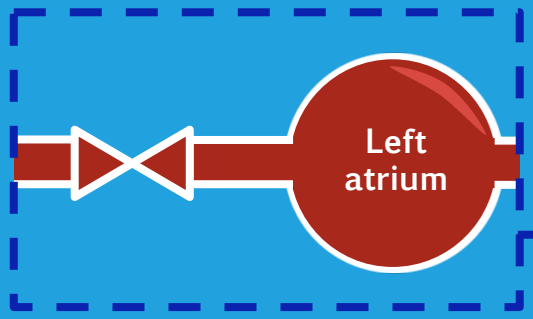
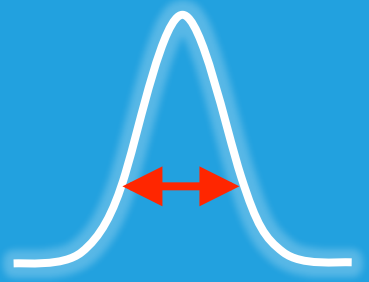


$$P(V,t) = P_a\, e(t) + E\, V(1 - e(t))$$



Driver function
e(t) in [0, 1]

Width of driver function = Fixed

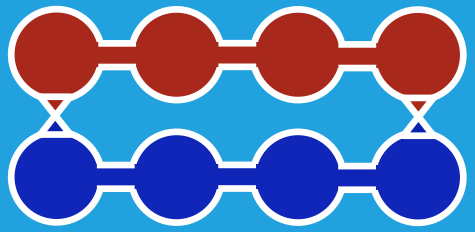
Atrial passive elastance (E) = Fixed

2 METHODS

3 PARAMETER IDENTIFICATION

Reference measurement

Model simulation



2 METHODS

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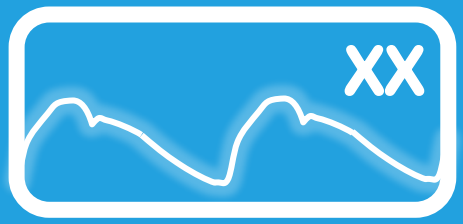


Reference measurement

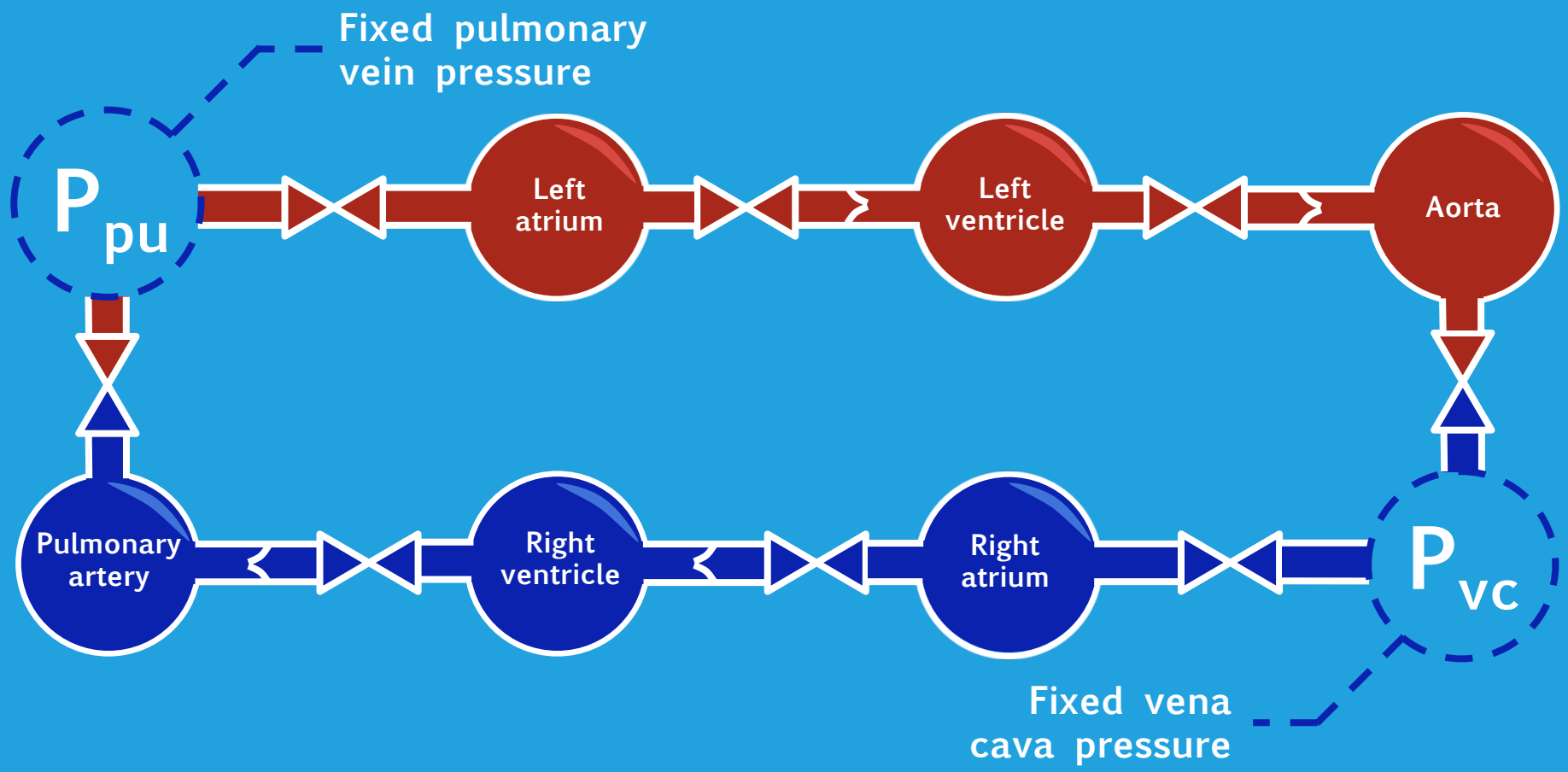
Initial parameter value

Model simulation

New parameter value

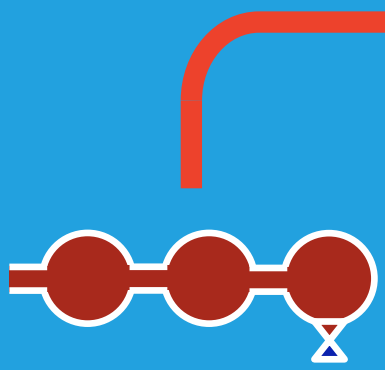
2 METHODS

3 PARAMETER IDENTIFICATION

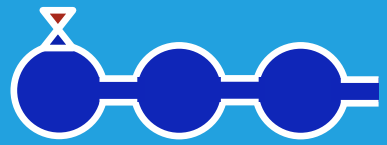


2 METHODS

3 PARAMETER IDENTIFICATION: STEP 1



Identification of the systemic model



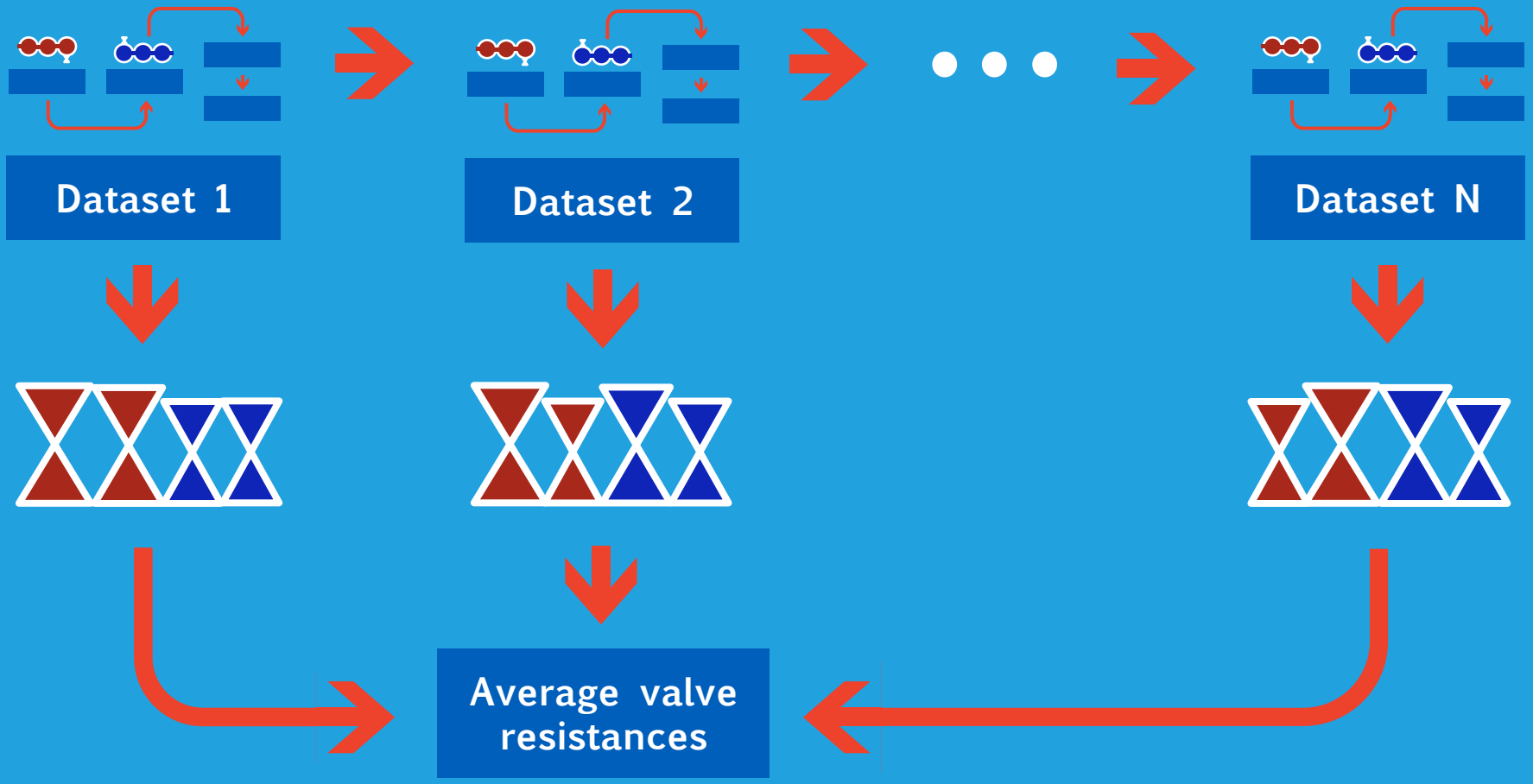
Identification of the pulmonary model

Identification of ventricular elastances

Computation of ventricular interaction

2 METHODS

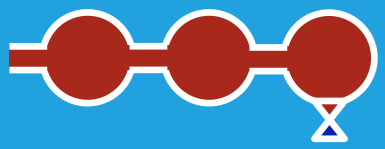
3 PARAMETER IDENTIFICATION: STEP 2



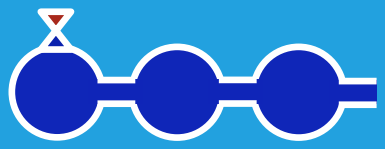
2 METHODS

3 PARAMETER IDENTIFICATION: STEP 3

Fixed valve resistances



Identification of the systemic model



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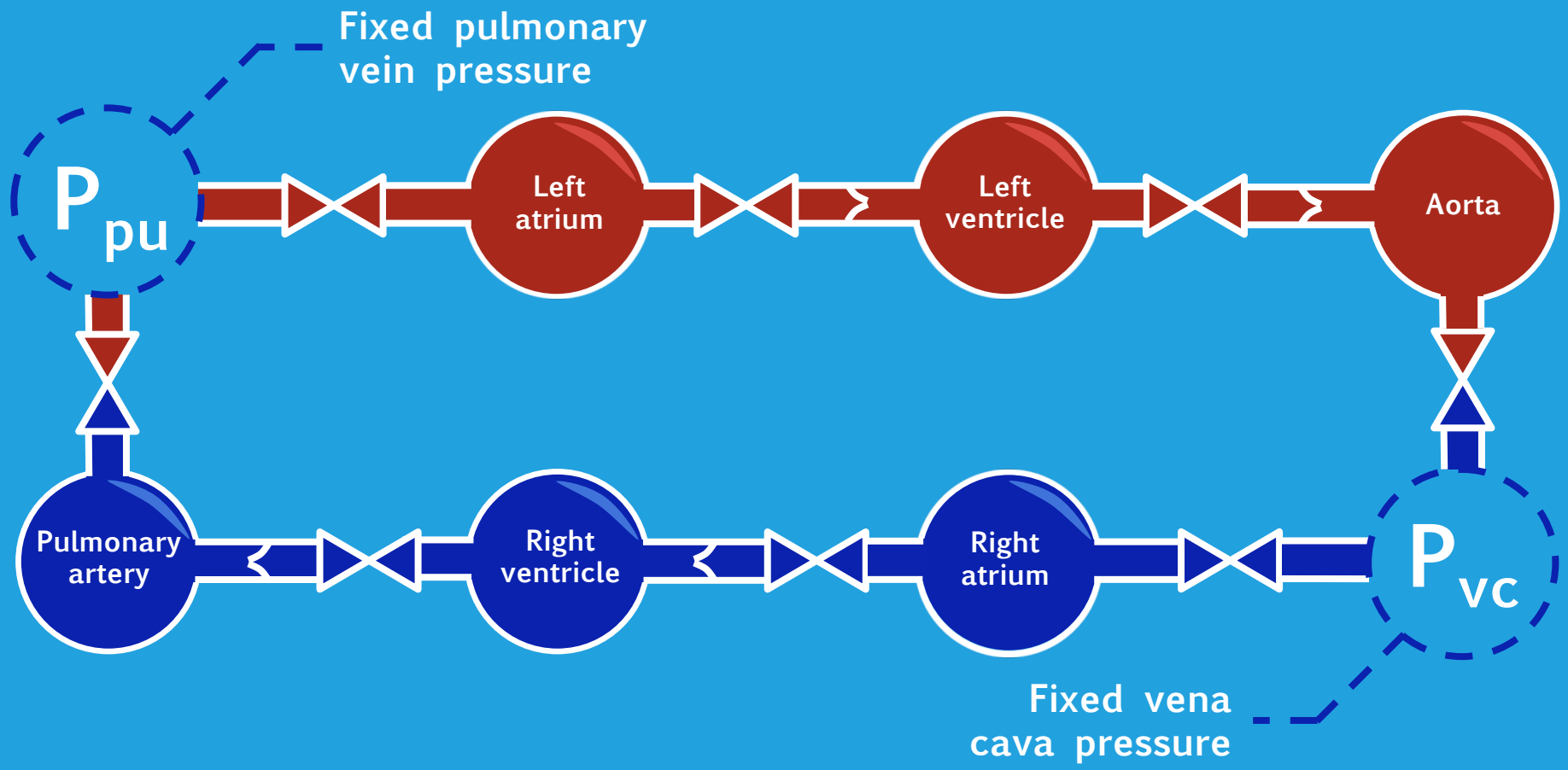
2 METHODS

3 PARAMETER IDENTIFICATION: STEP 4



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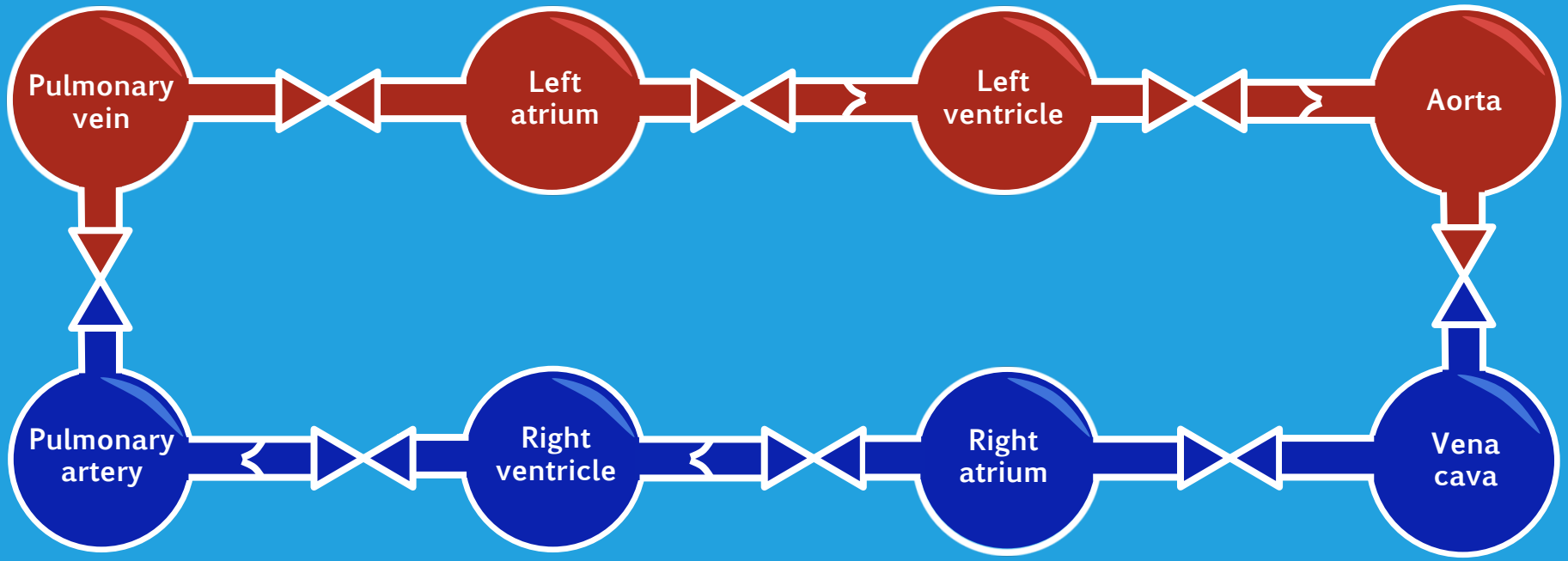
3 PARAMETER IDENTIFICATION: STEP 4



2 METHODS

4 PORCINE EXPERIMENTS AND DATA

- Pig with induced pulmonary embolism
- Measurements: ventricular pressures and volumes, aortic and pulmonary artery pressure
- Taken every 30 minutes, providing 10 data sets for identification

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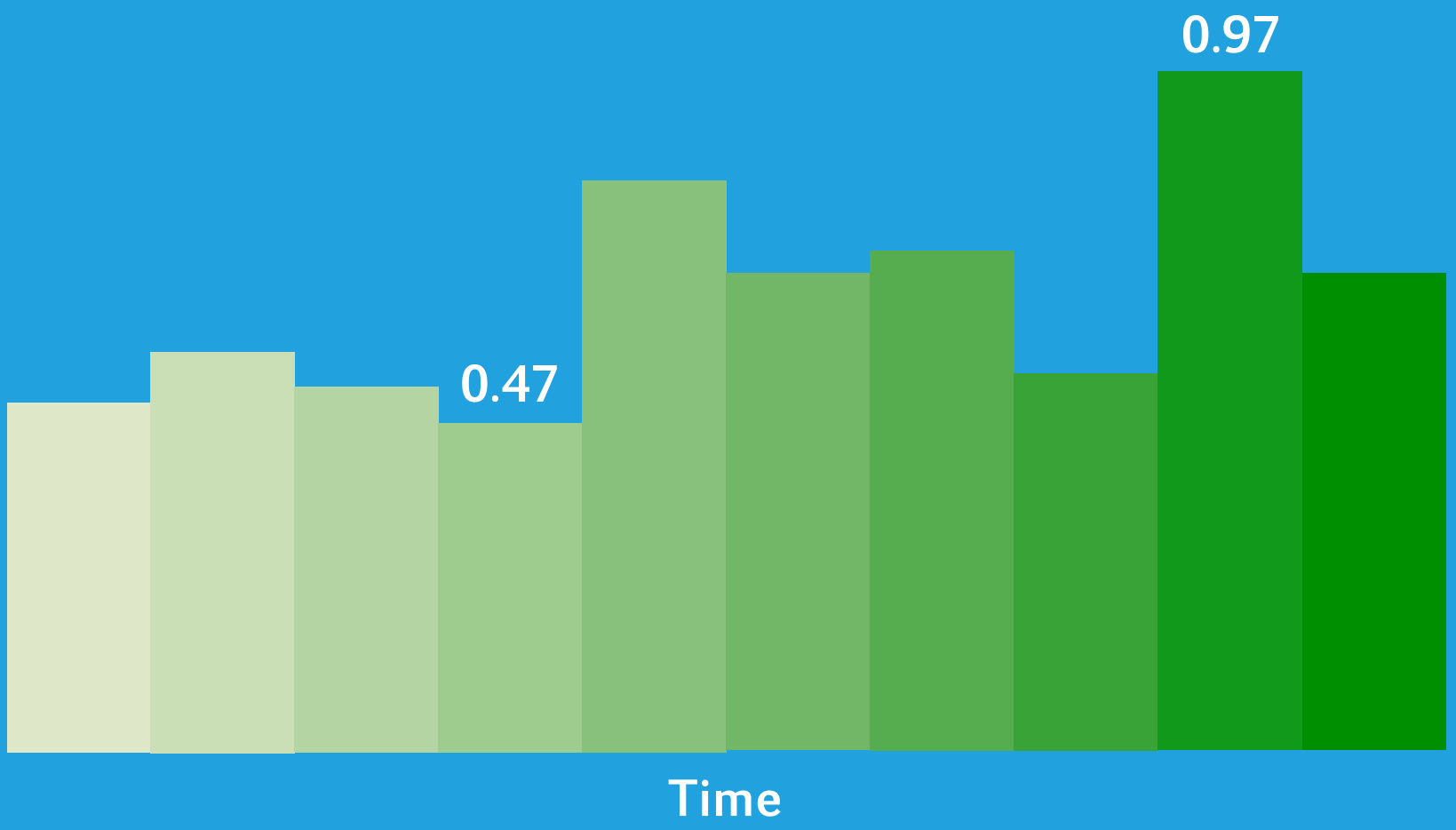
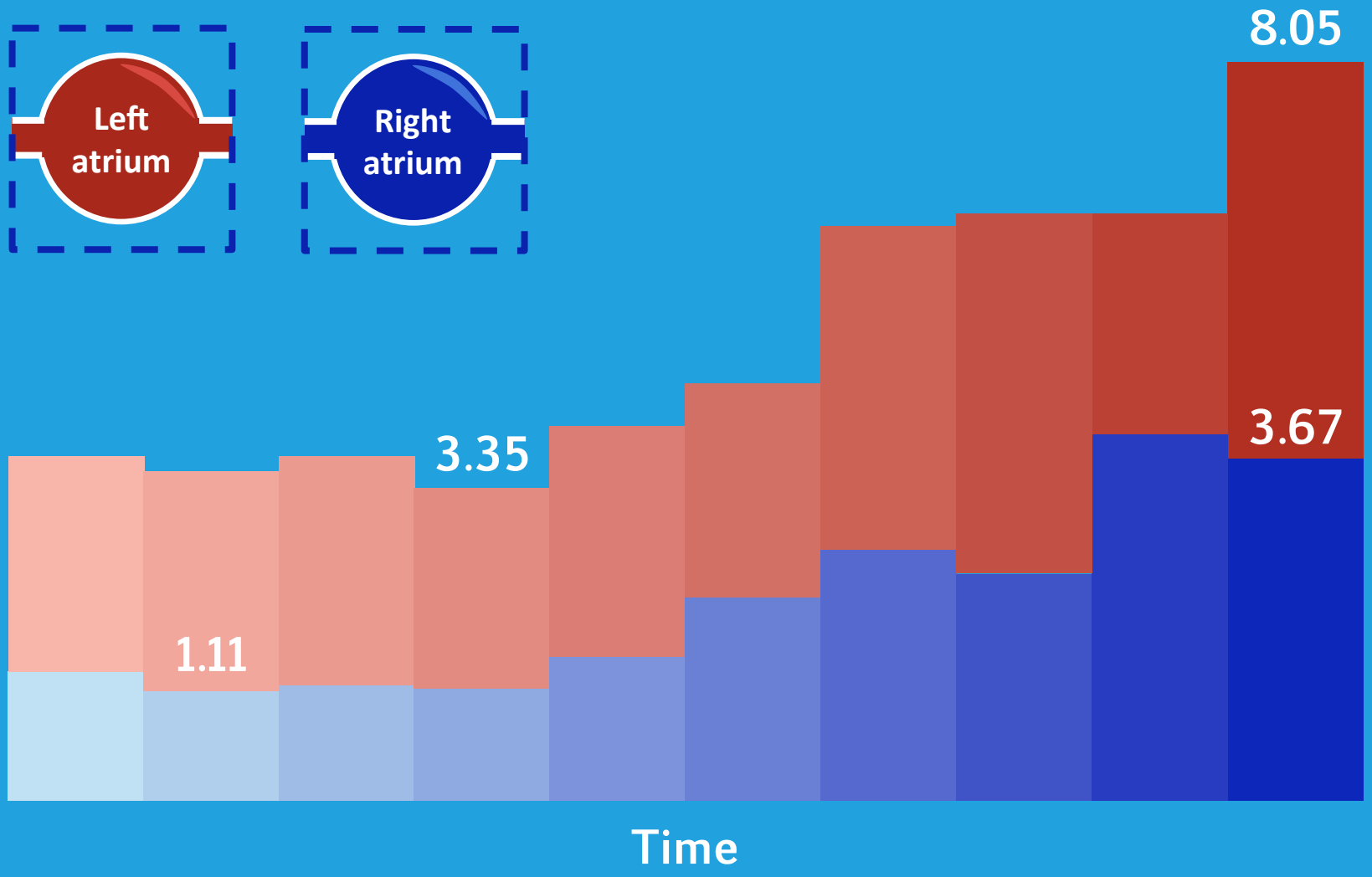
3 RESULTS

1 PULMONARY RESISTANCE (PRU)



3 RESULTS

2 ATRIAL PRESSURES (mmHg)



4 DISCUSSION

- Lumped models have well-known limitations
- Atrial model is load-dependent
- Hypotheses formulated for the atria have to be further validated

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5 CONCLUSION

- Atria are inserted in a model of the CVS
- Identification method is extended to the atria

→ First step to real-time atrial monitoring inside a full cardiovascular system model

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Thanks for your attention!
Questions?