MODEL-BASED COMPUTATION OF TOTAL STRESSED BLOOD VOLUME FROM A PRELOAD REDUCTION EXPERIMENT

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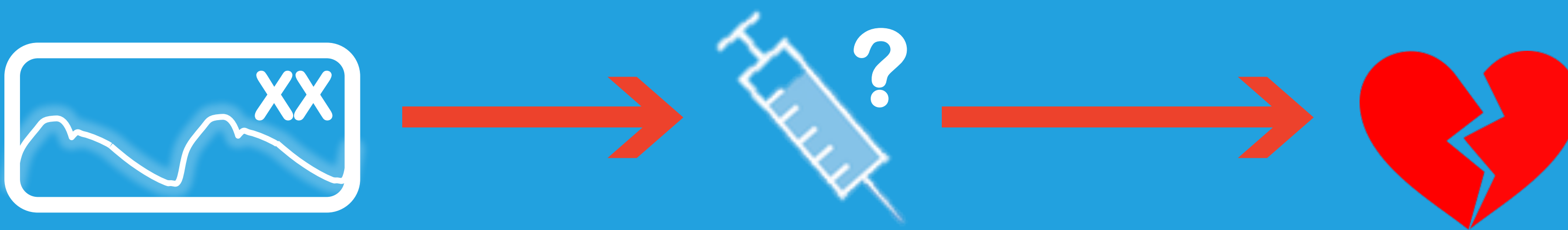
19TH IFAC WORLD CONGRESS
AUGUST 24-29, 2014, CAPE TOWN, SOUTH AFRICA

1 INTRODUCTION

1 LUMPED-PARAMETER CVS MODELS



Limited amount of data in the ICU

Difficult treatment

Cardiovascular diseases

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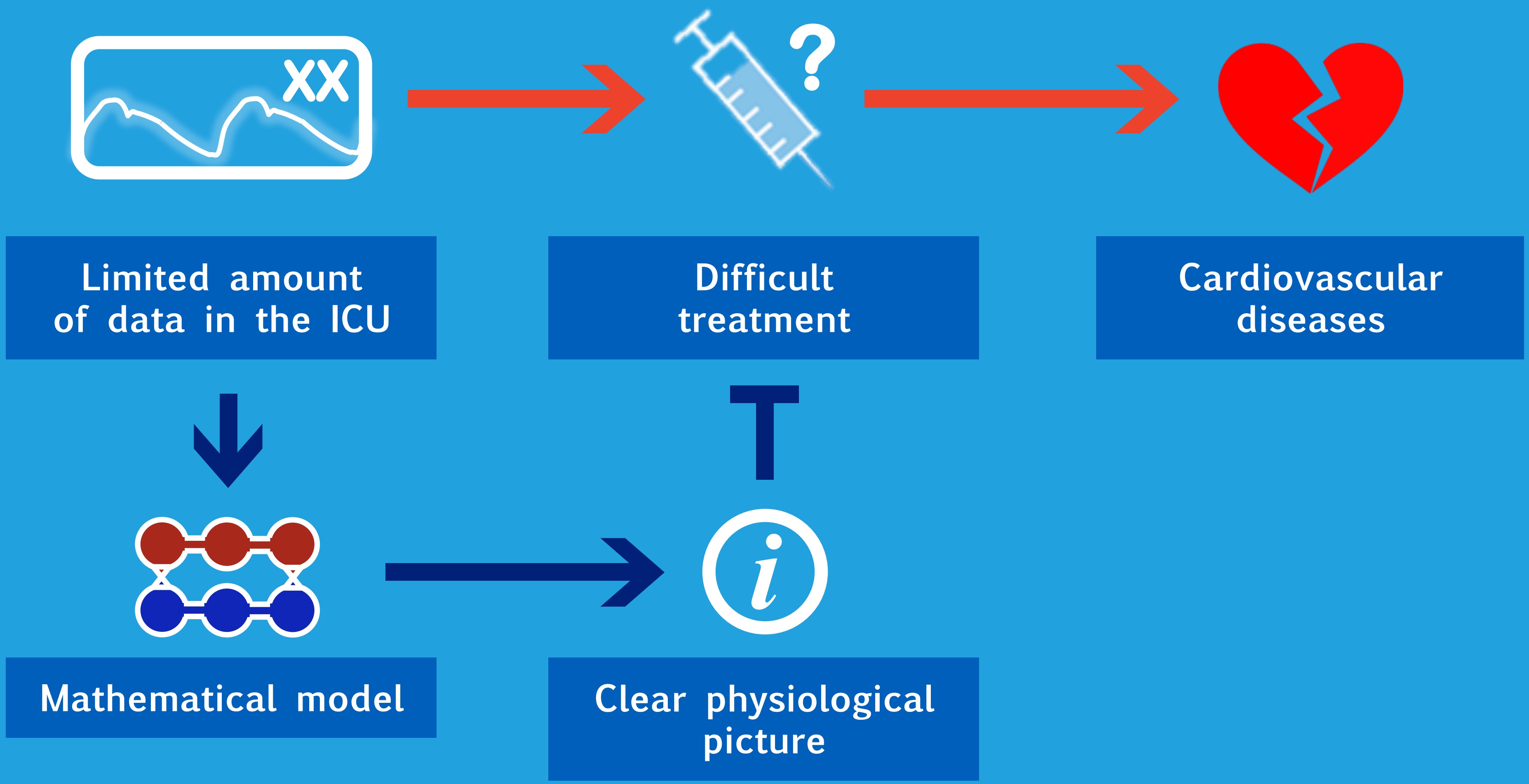

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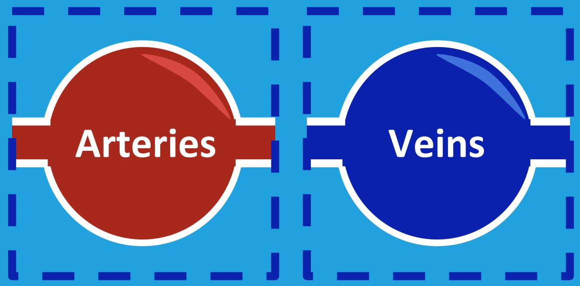
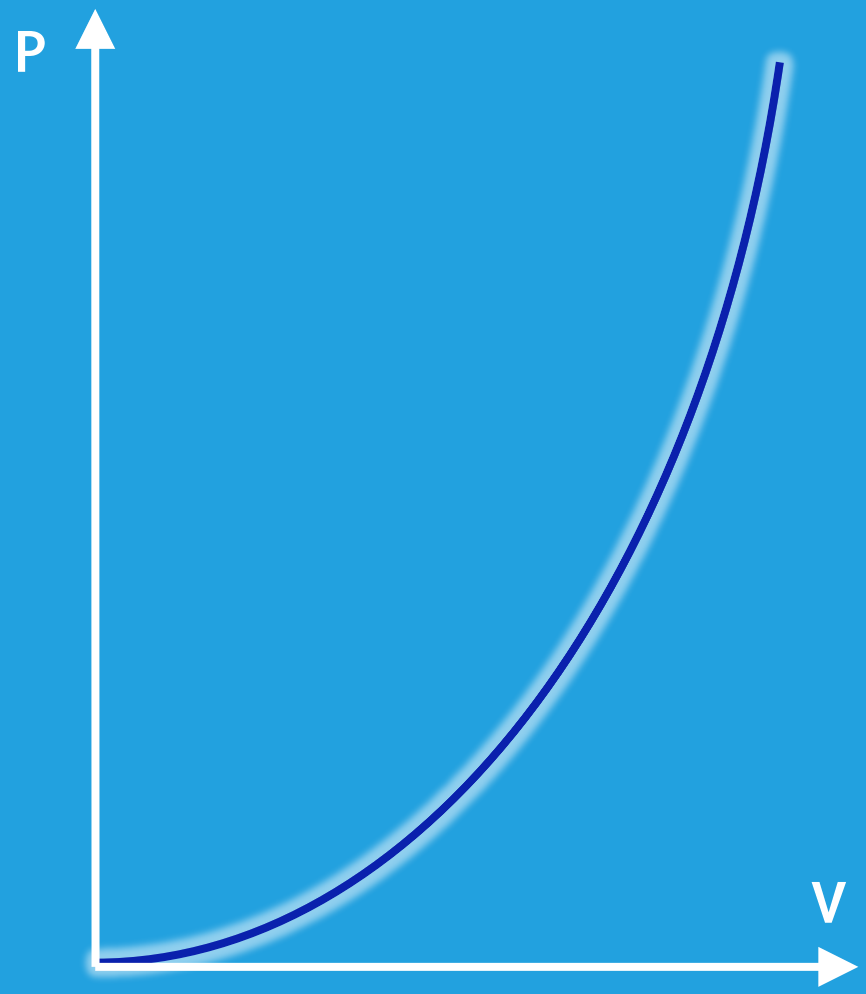
Passive vessels:



$$P = f(V)$$



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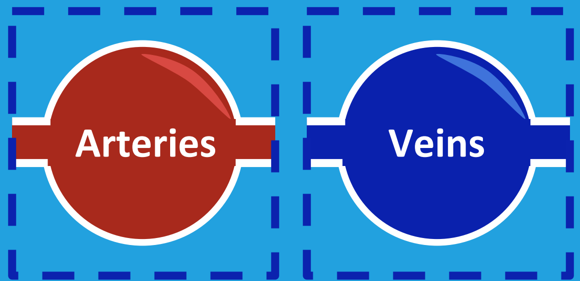

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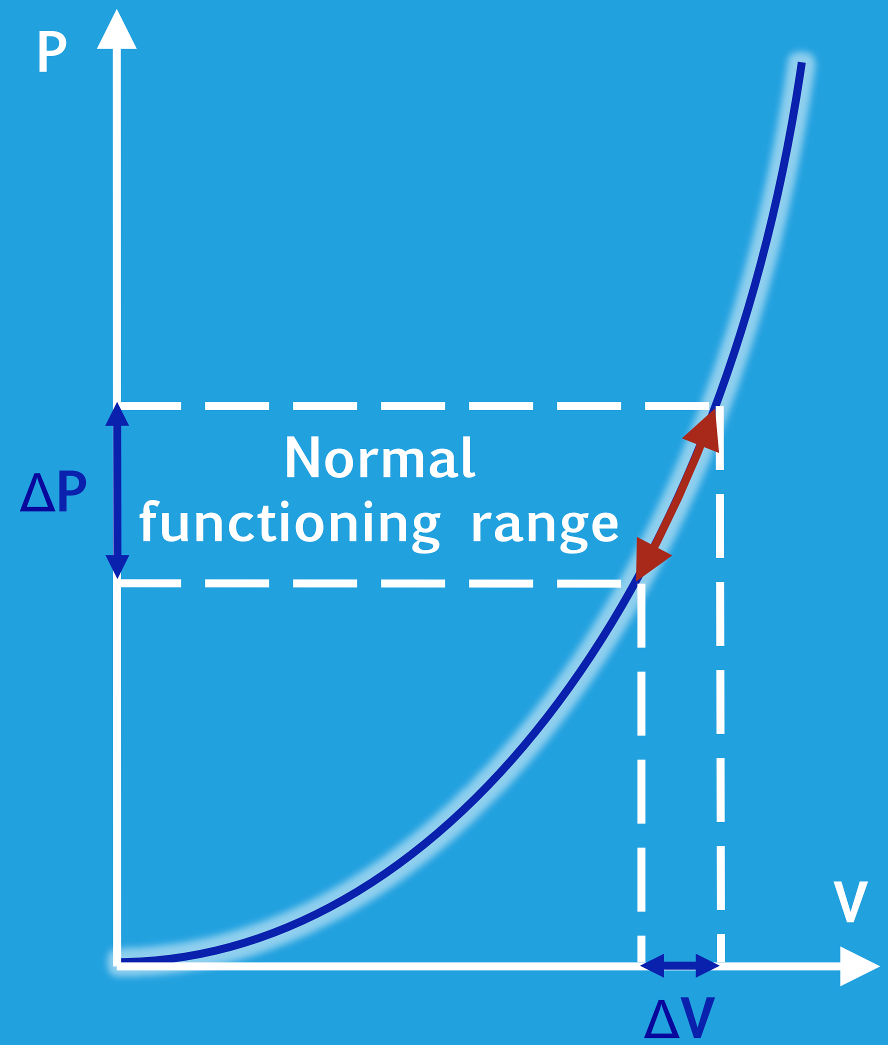

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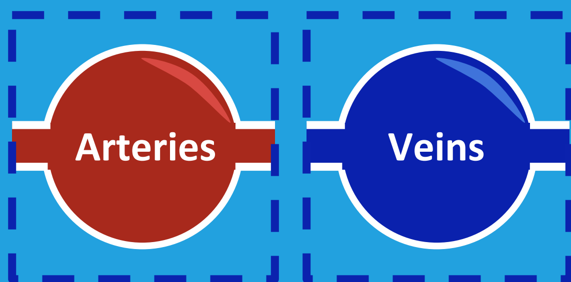
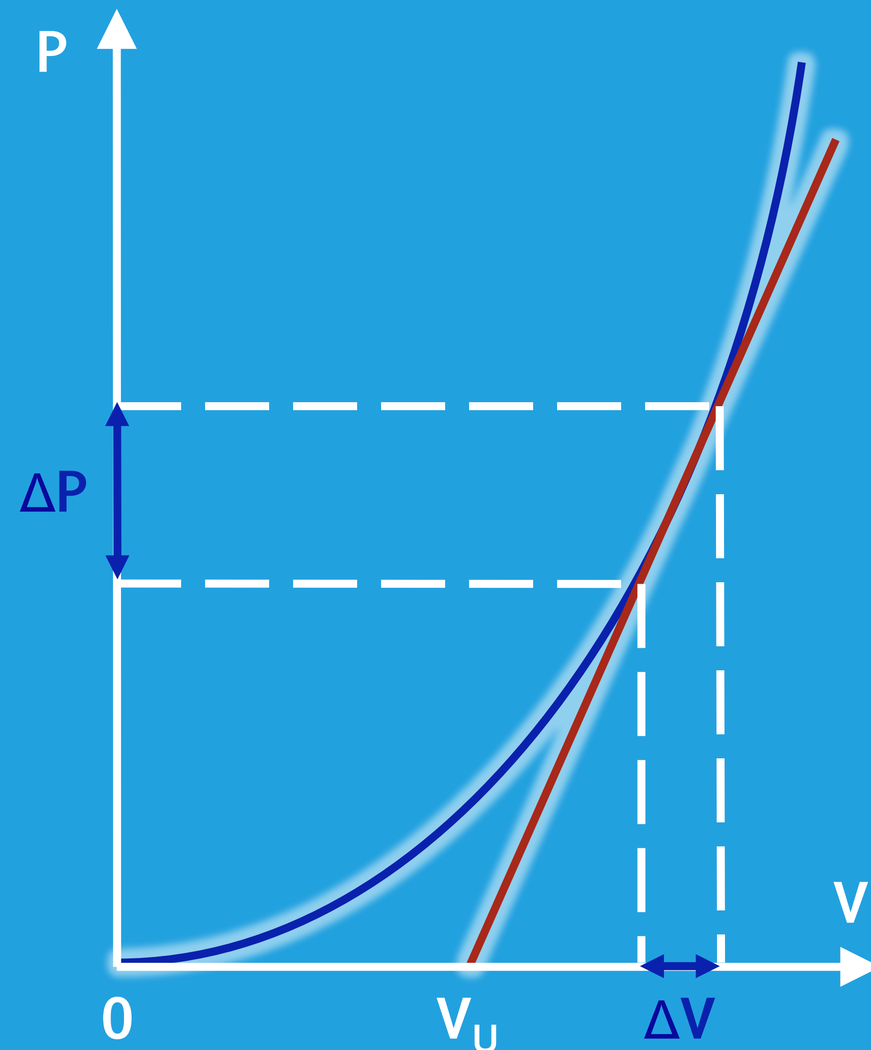


$$E = \Delta P / \Delta V$$

$$P = E\,(V - V_U)$$



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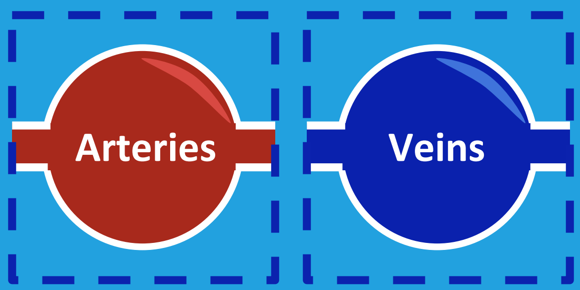
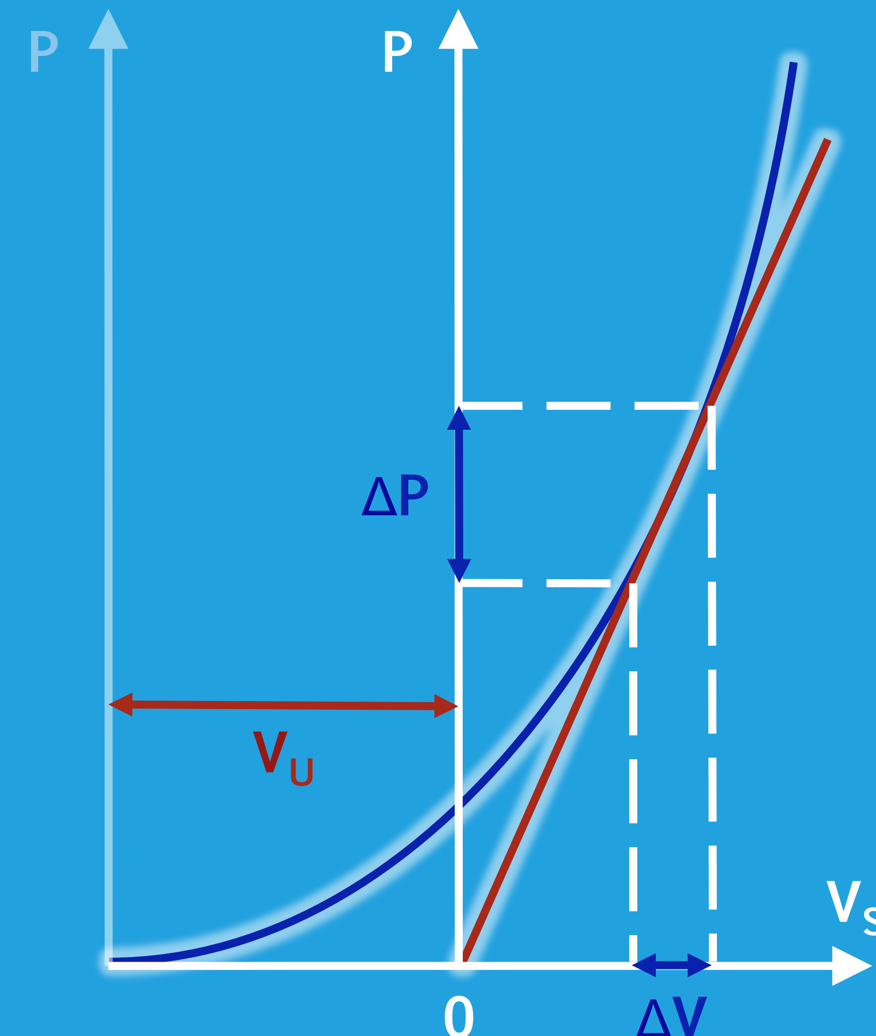


$$V_S = V - V_U$$

$$P = E\,V_S$$



V	$V_S = V - V_U$

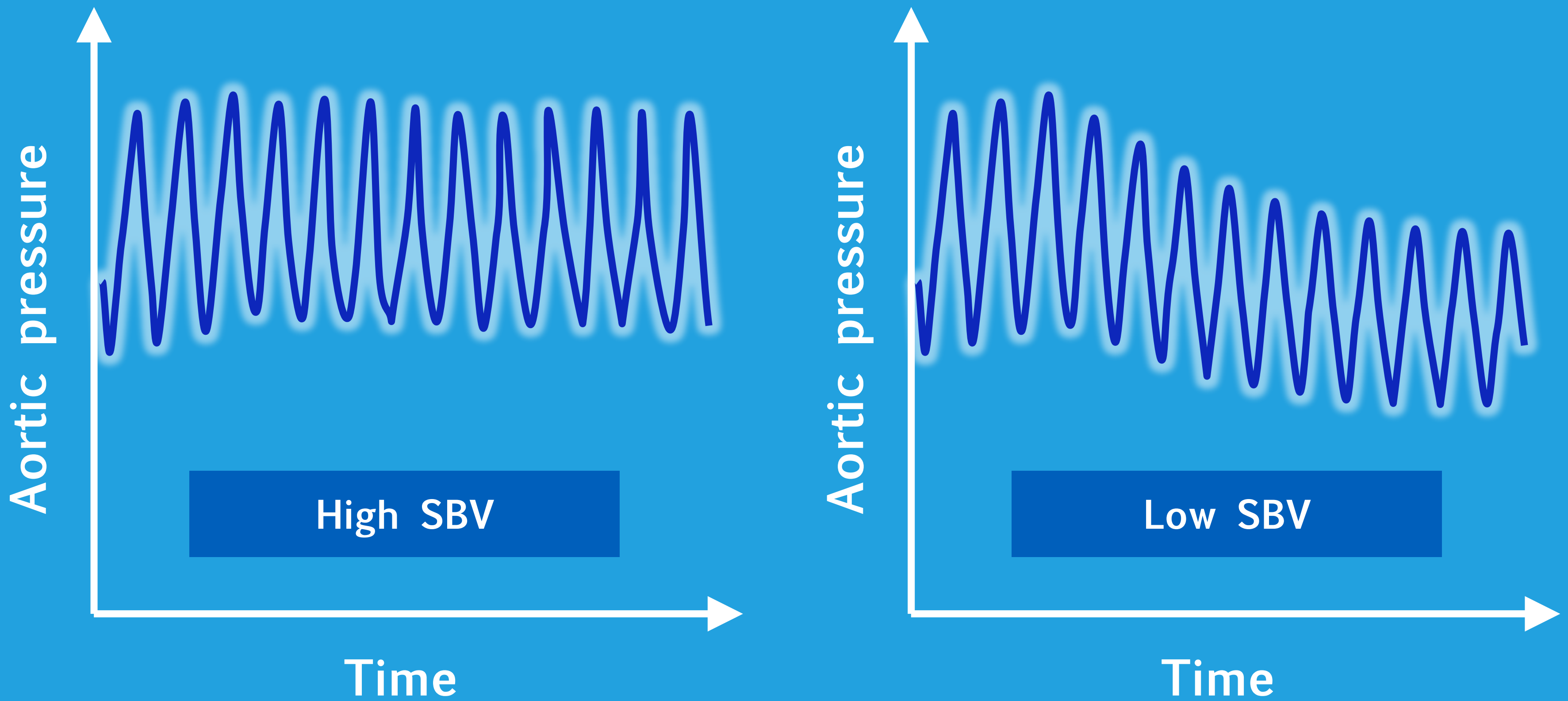
- Total blood volume: $TBV = \sum_i V_i$
- Unstressed volumes: $V_{U,i}$

- Total stressed blood volume: $SBV = \sum_i V_{S,i}$

1 INTRODUCTION

2 TOTAL STRESSED BLOOD VOLUME

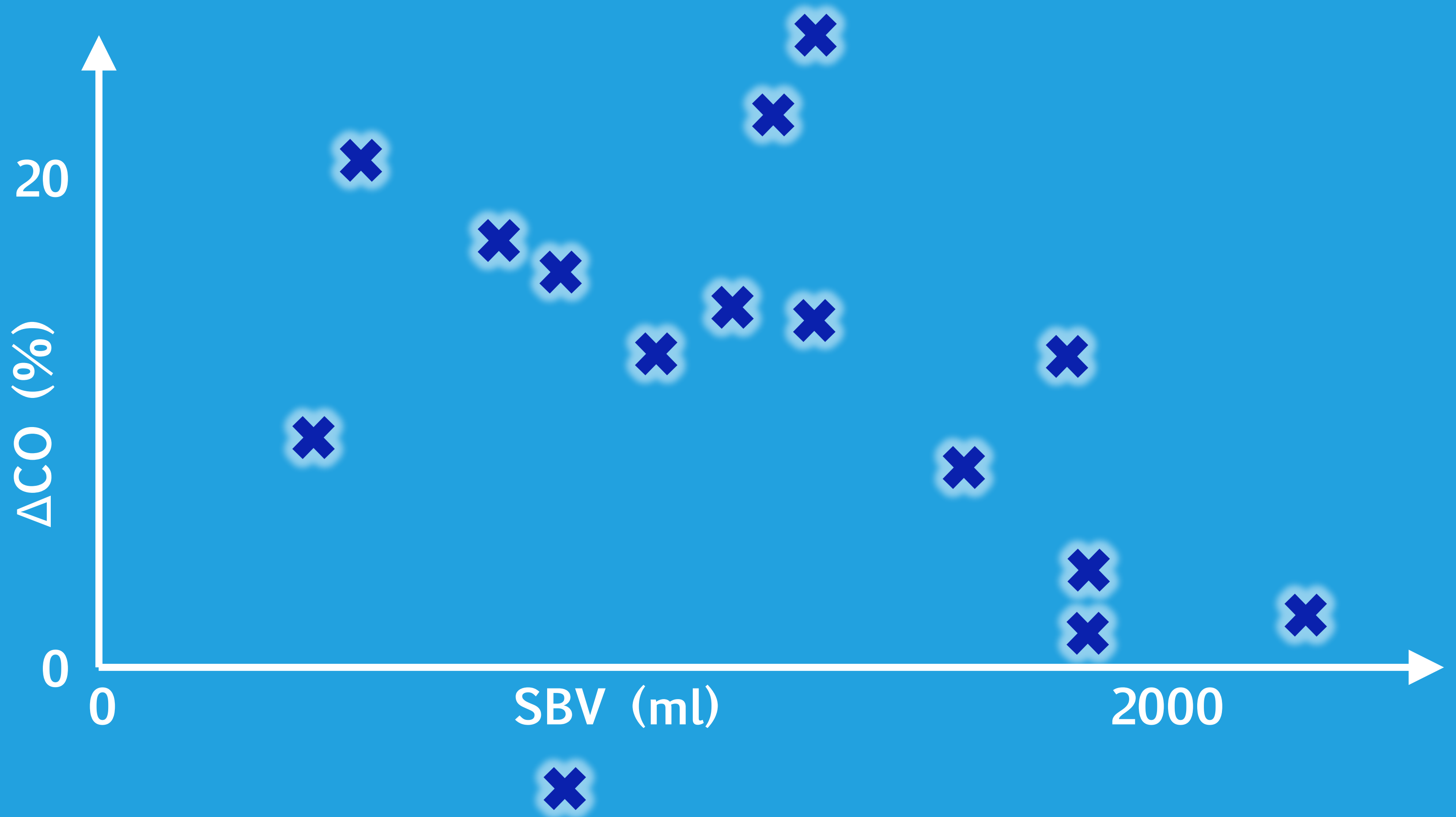
- In engineering



1 INTRODUCTION

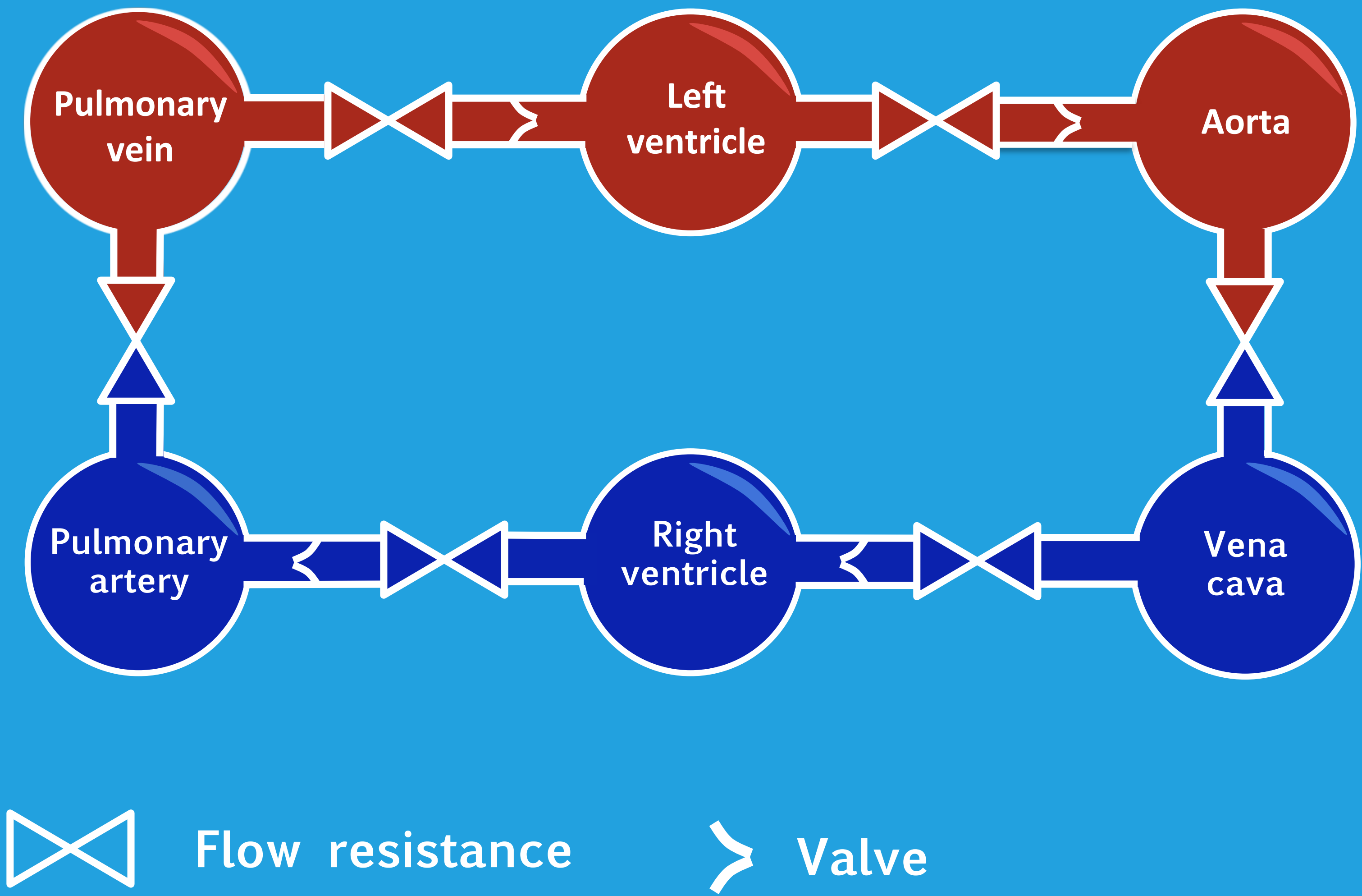
2 TOTAL STRESSED BLOOD VOLUME

- In medicine (Maas *et al.*, 2012)



2 METHODS

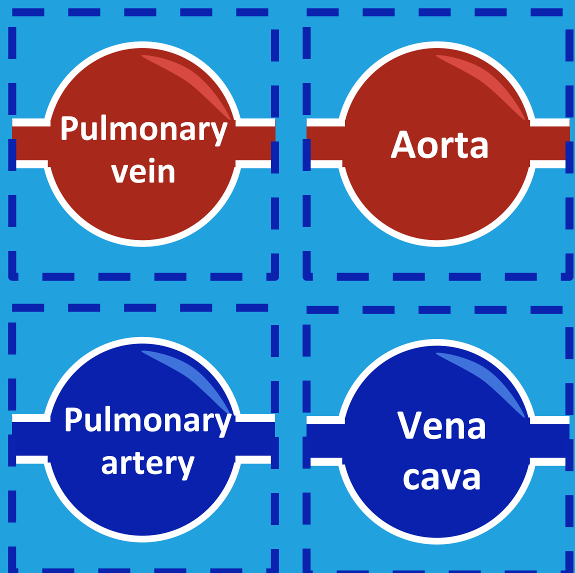
1 CVS MODEL



2 METHODS

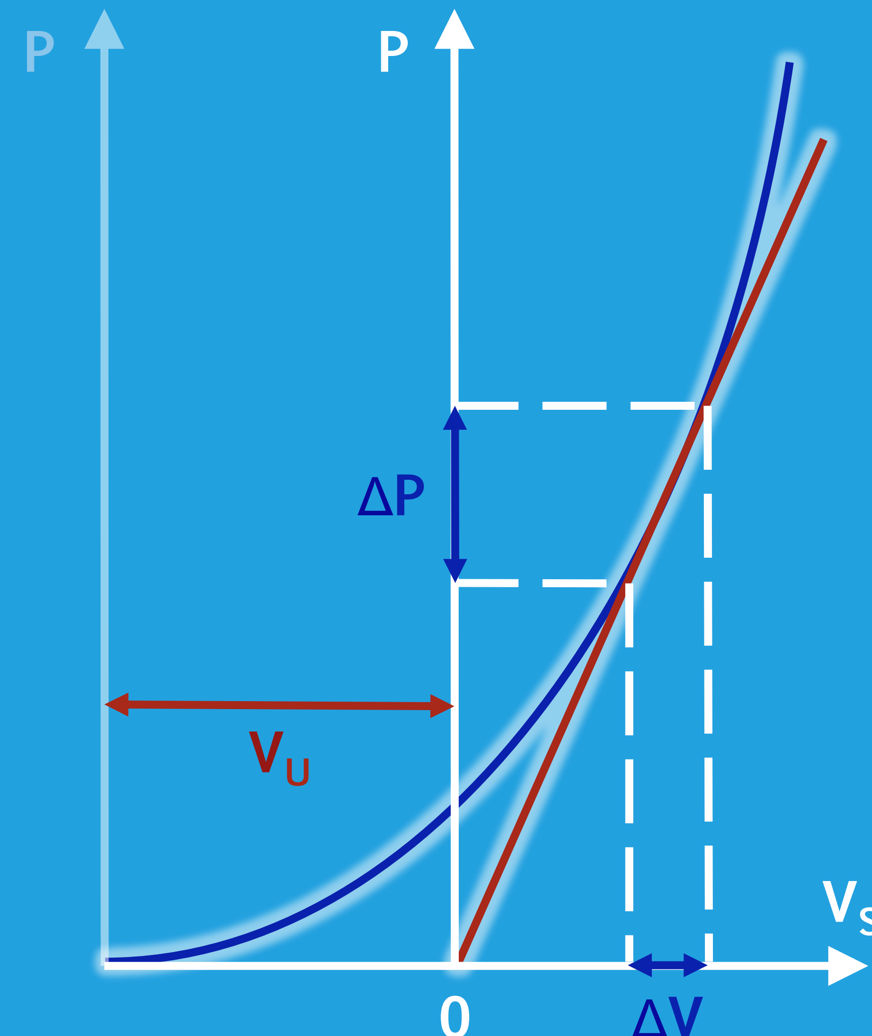
1 CVS MODELS

Passive chambers:



$$V_S = V - V_U$$

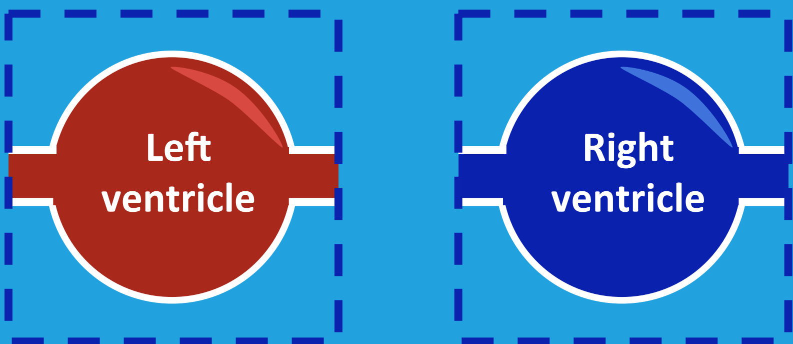
$$P = E\,V_S$$



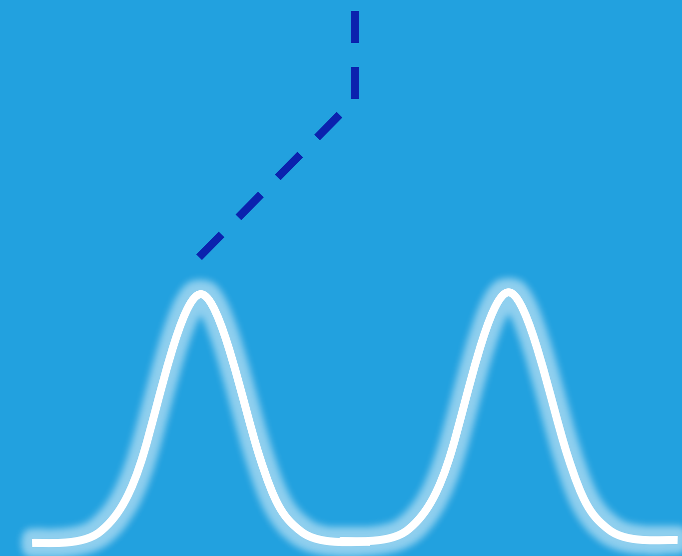
2 METHODS

1 CVS MODEL

Cardiac chambers:



$$P = E\ e(t)\ V_S$$

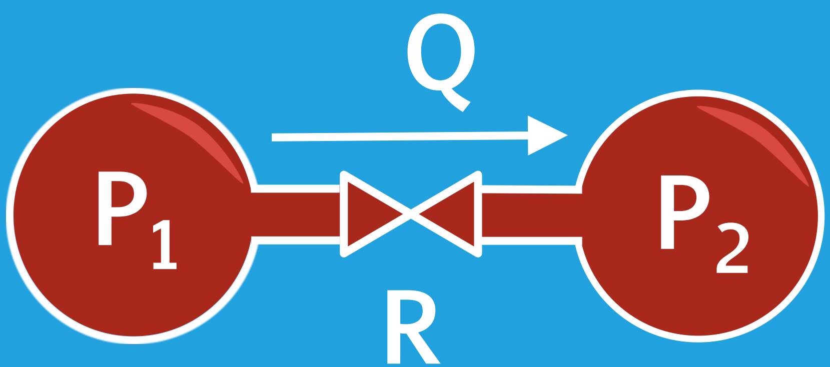


Driver function
e(t) in [0, 1]

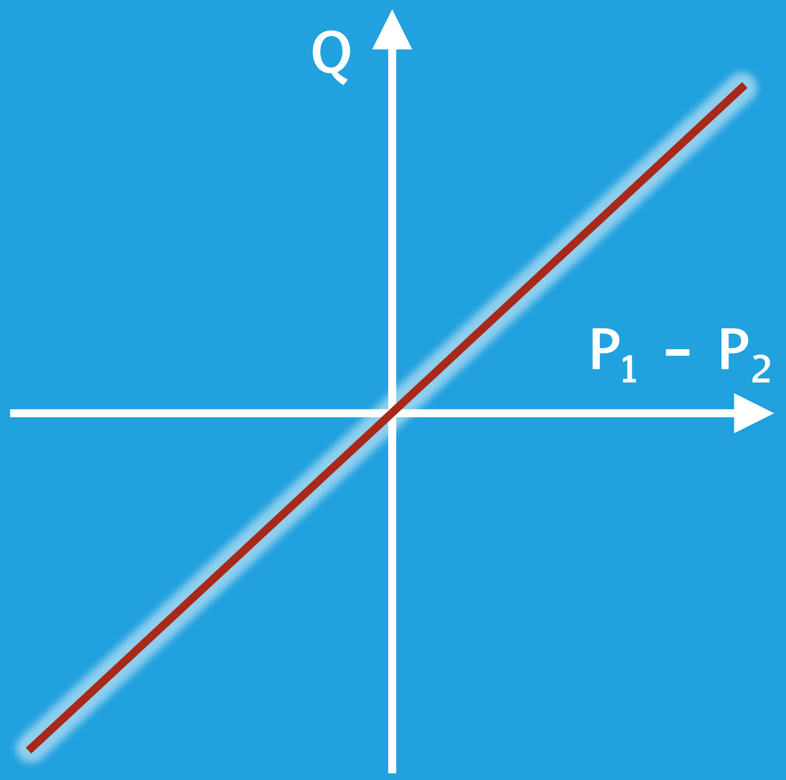
2 METHODS

1 CVS MODEL

No valve:



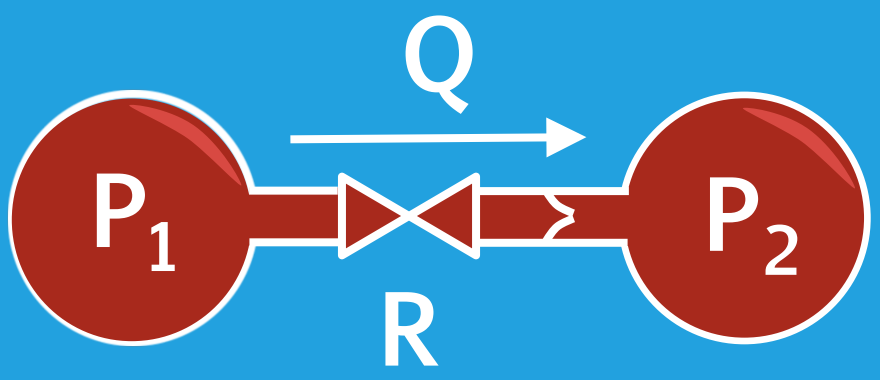
$$Q = \frac{P_1 - P_2}{R}$$

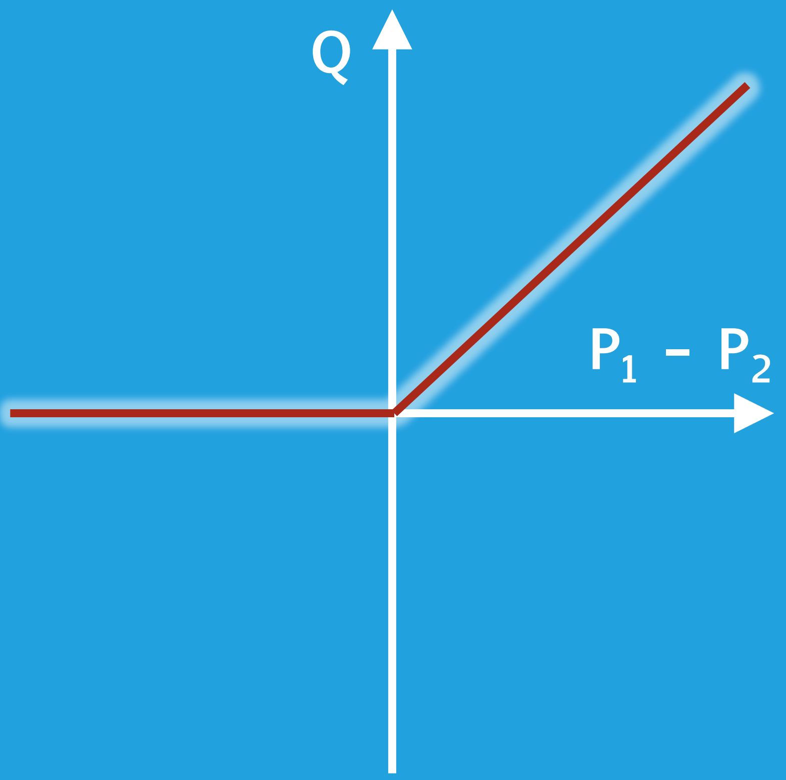


2 METHODS

1 CVS MODEL

Valve:





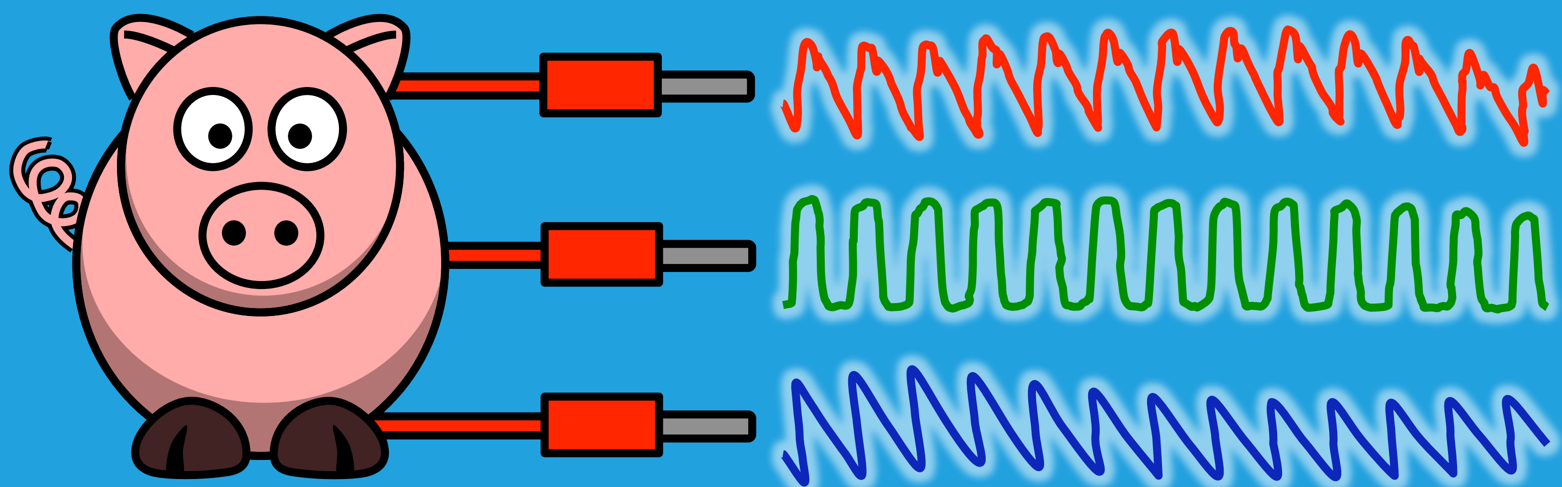
$$Q = \begin{cases} \dfrac{P_1 - P_2}{R} & \text{if } P_1 > P_2 \\ 0 & \text{otherwise} \end{cases}$$

Continuity equation:

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

2 EXPERIMENTAL DATA

Pig data:
- Aortic and pulmonary artery pressures
- Ventricular pressures
- Ventricular volumes



2 METHODS

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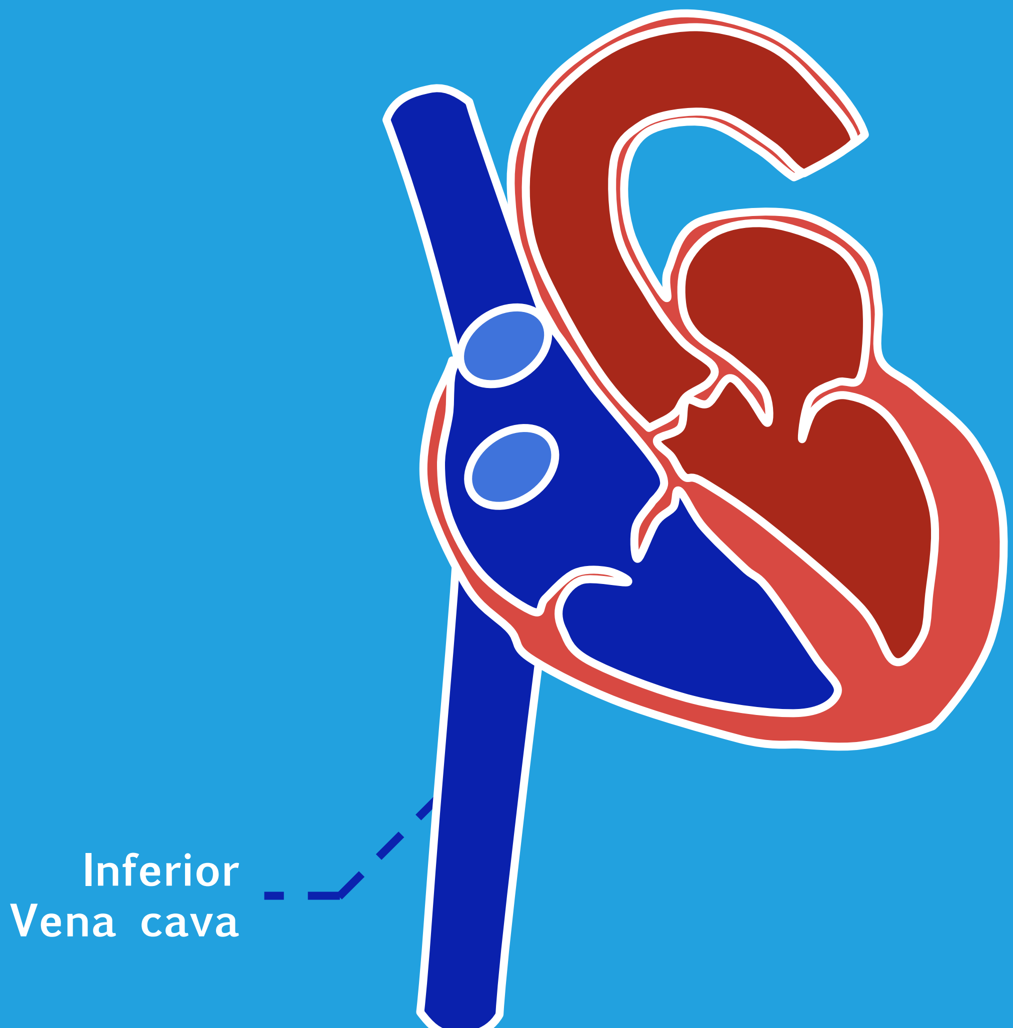

2 METHODS

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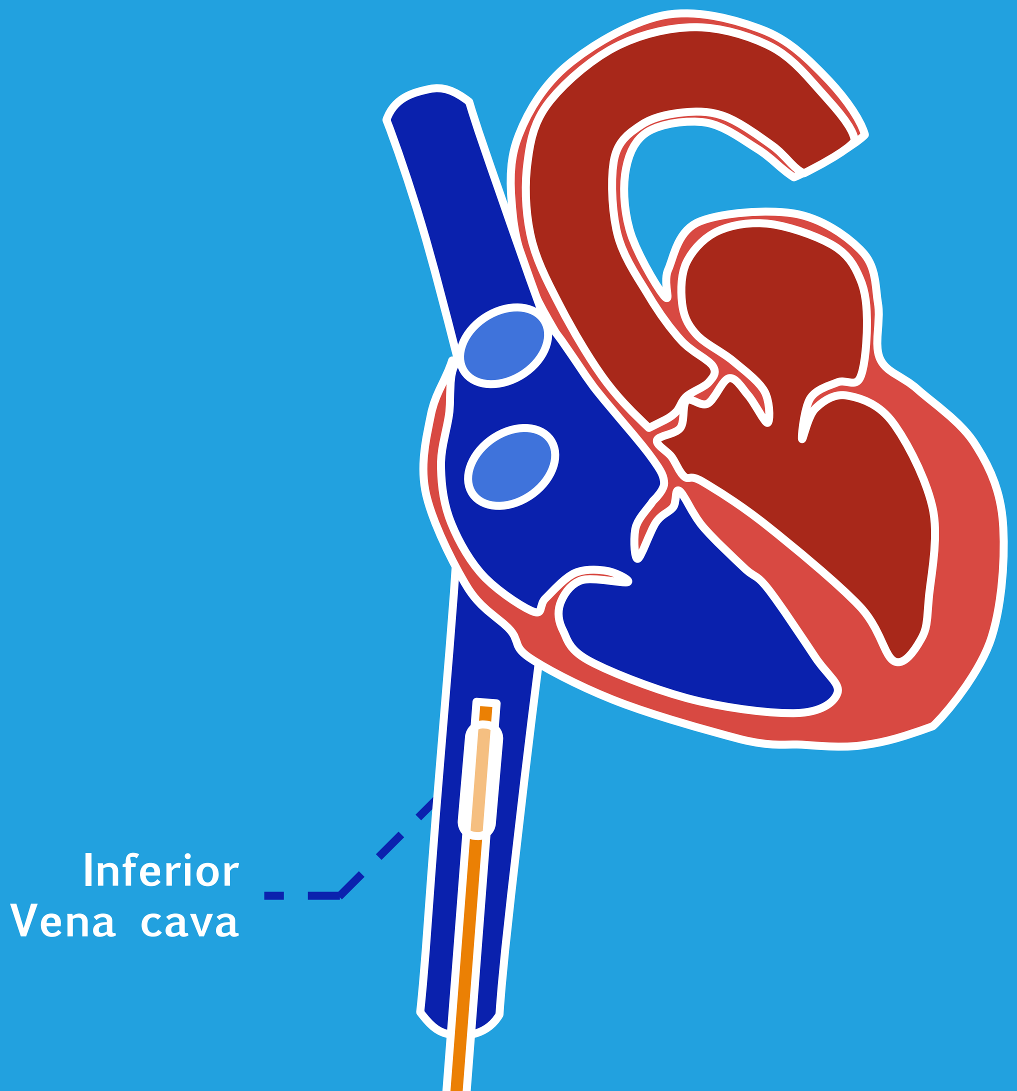

2 METHODS

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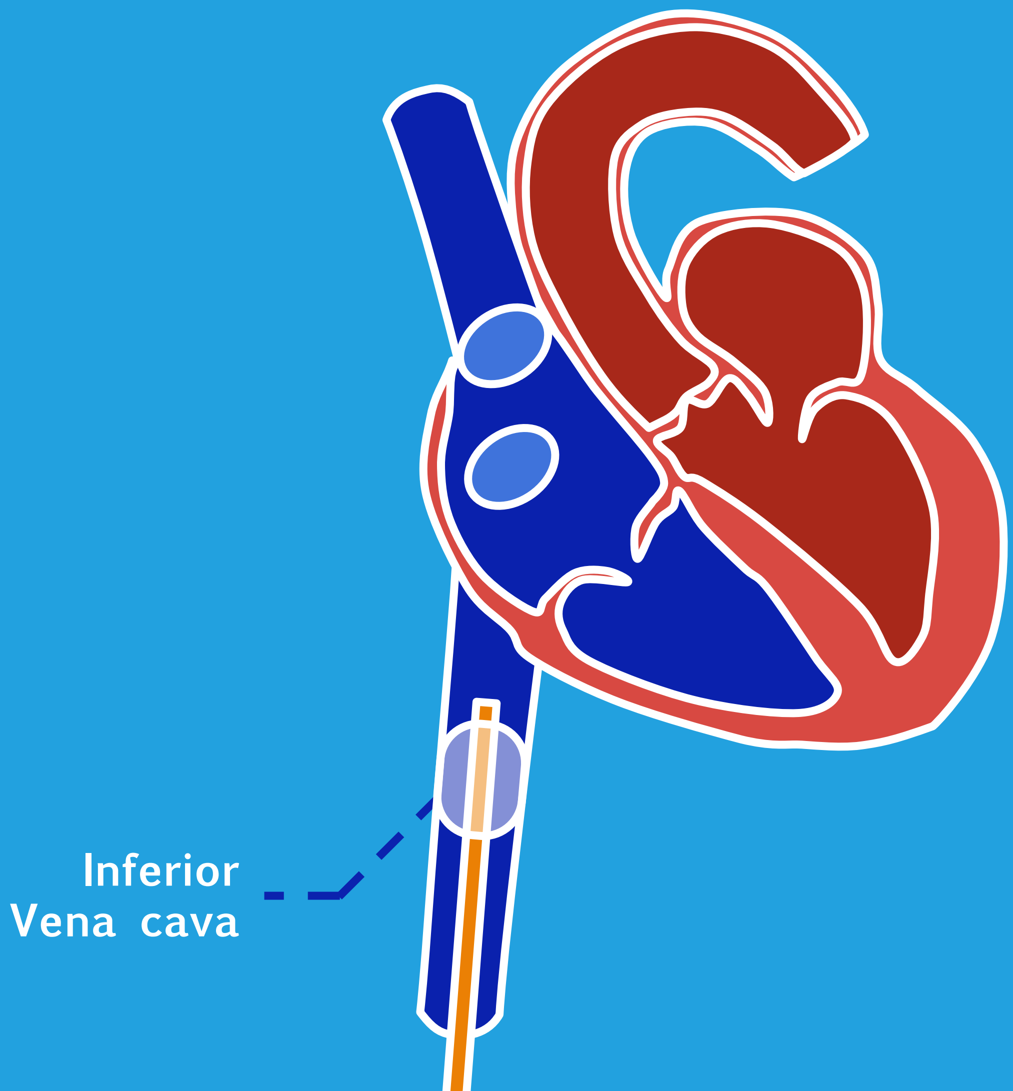
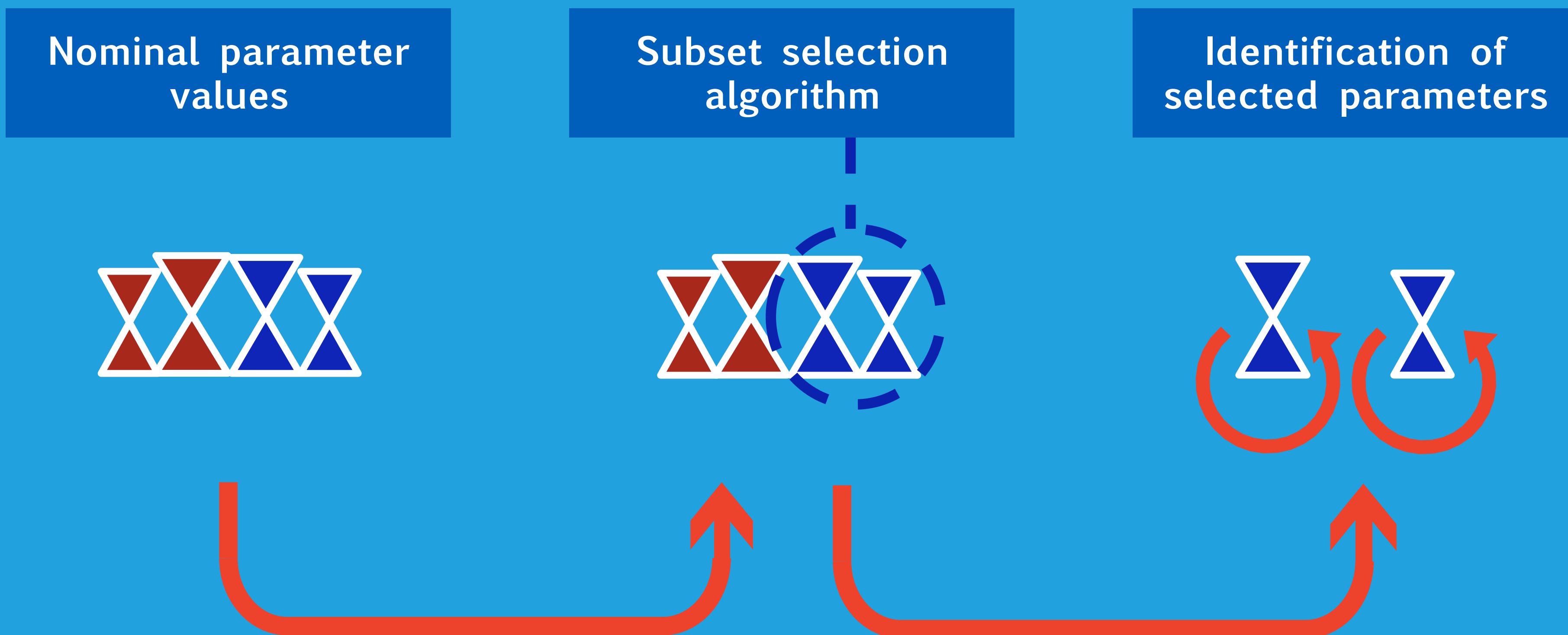


2 METHODS

3 PARAMETER IDENTIFICATION



2 METHODS

3 PARAMETER IDENTIFICATION: STEP 1

Nominal parameter values

- From the literature
- Directly from data, e.g.:

$$SVR = \frac{MAP}{CO}$$

2 METHODS

3 PARAMETER IDENTIFICATION: STEP 2

Nominal parameter values → Subset selection algorithm

- e = simulations − measurements
- Jacobian matrix $J = \partial e / \partial p$
- Hessian matrix $H \approx J^T J$
- Compute the eigenvalues of H

2 METHODS

3 PARAMETER IDENTIFICATION: STEP 2

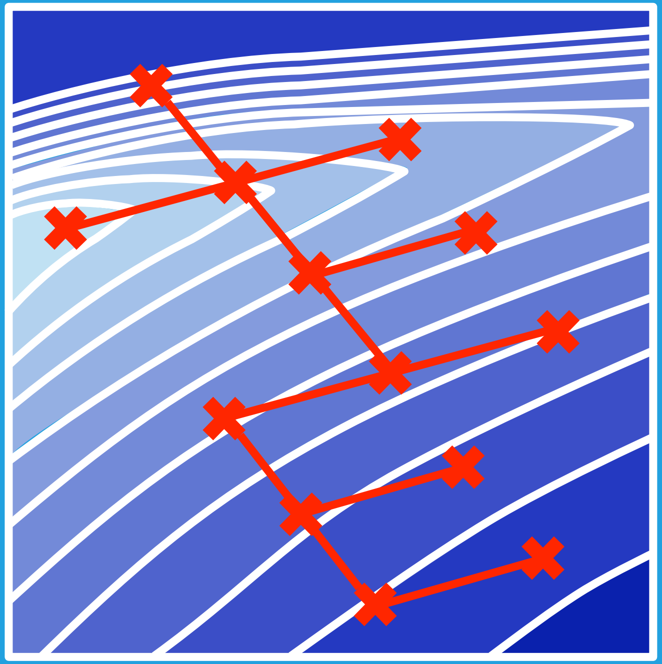
Nominal parameter values → Subset selection algorithm

- Select the r largest eigenvalues of H
- Find the corresponding parameters through a QR decomposition
- Select these r parameters for optimization

2 METHODS

3 PARAMETER IDENTIFICATION: STEP 3

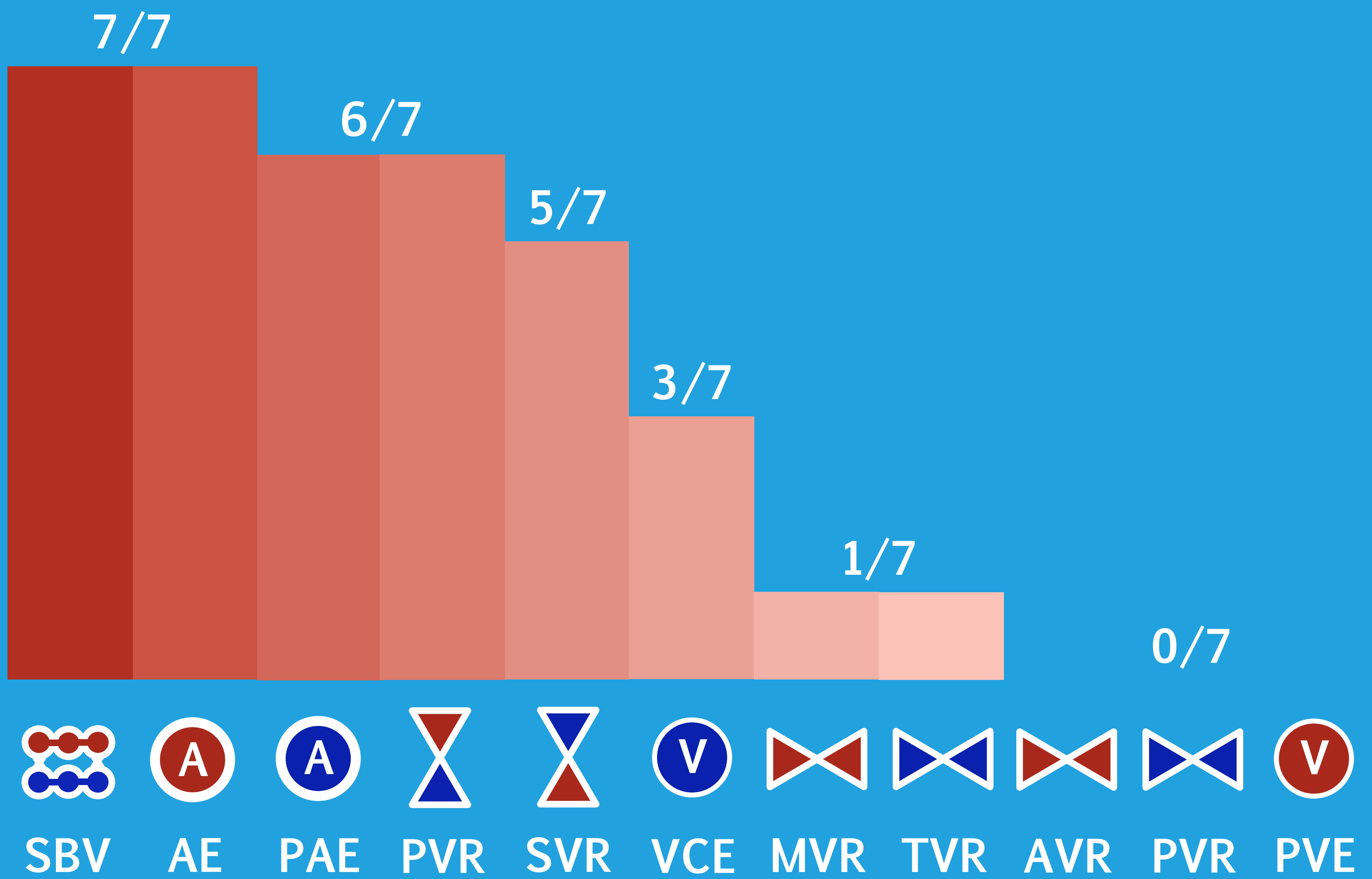
Nominal parameter values → Subset selection algorithm → Identification of selected parameters



Using the direct search method and the initial values computed at step 1.

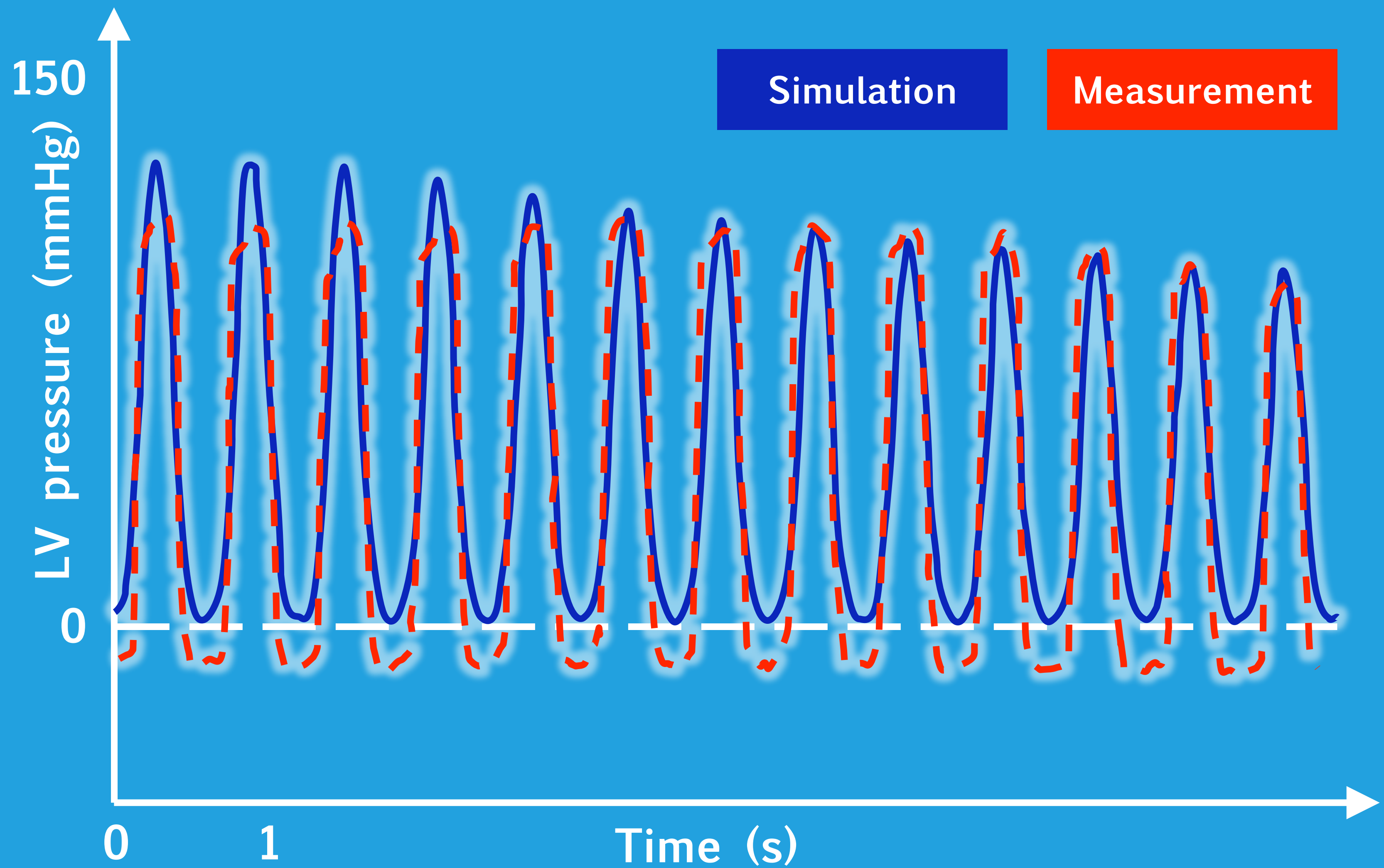
3 RESULTS

1 NUMBER OF PARAMETER SELECTIONS



3 RESULTS

2 PARAMETER ADJUSTMENT



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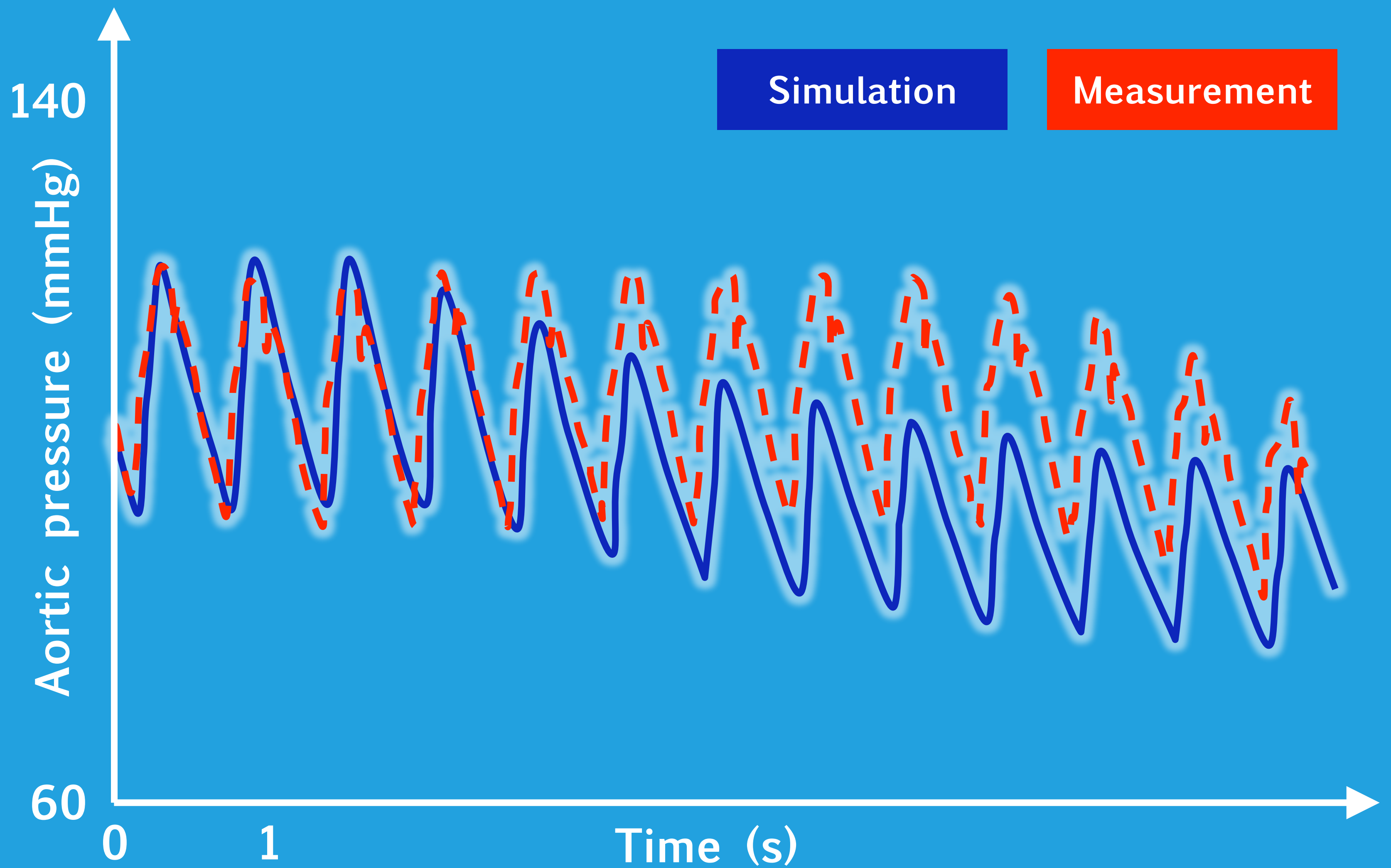

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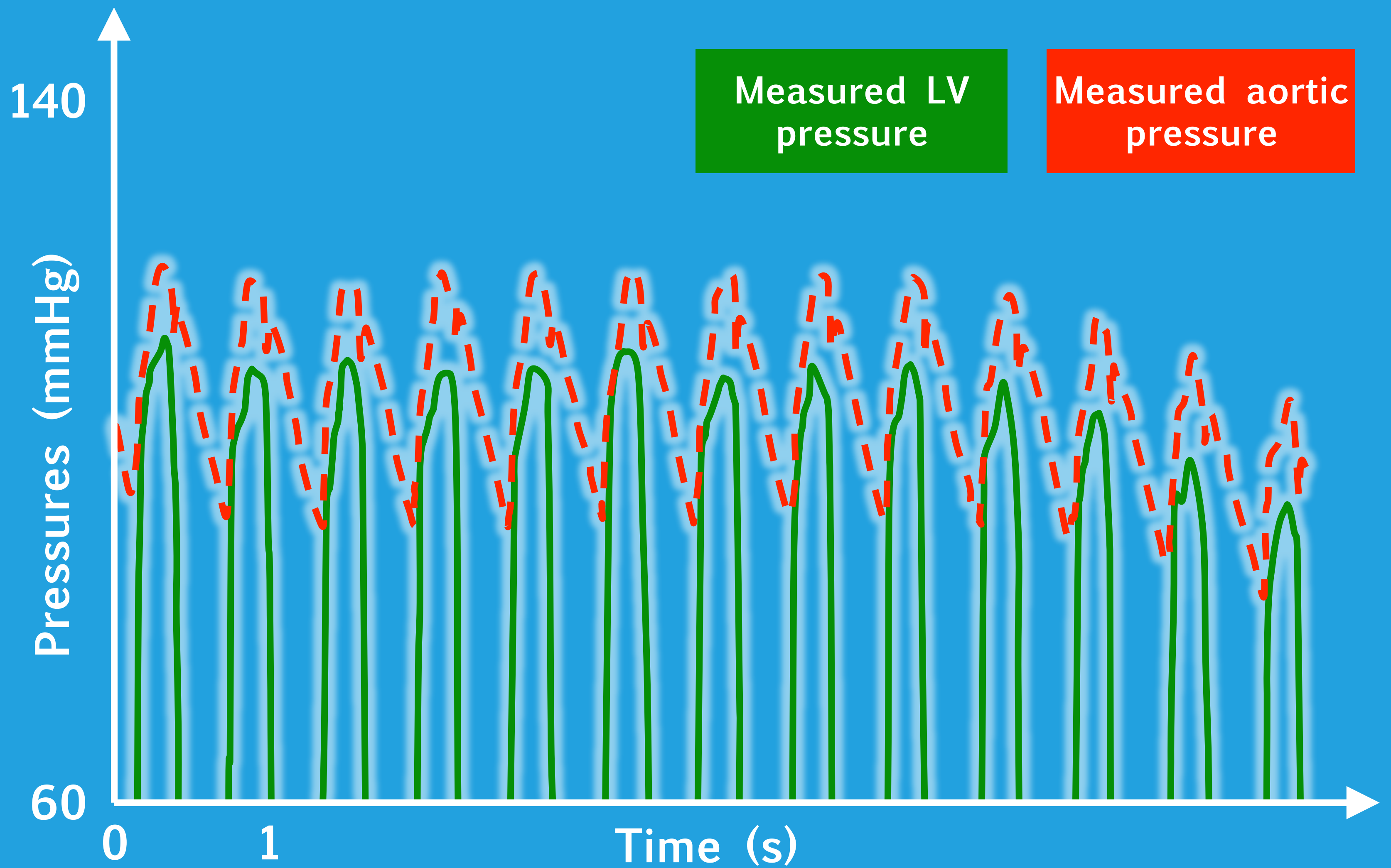
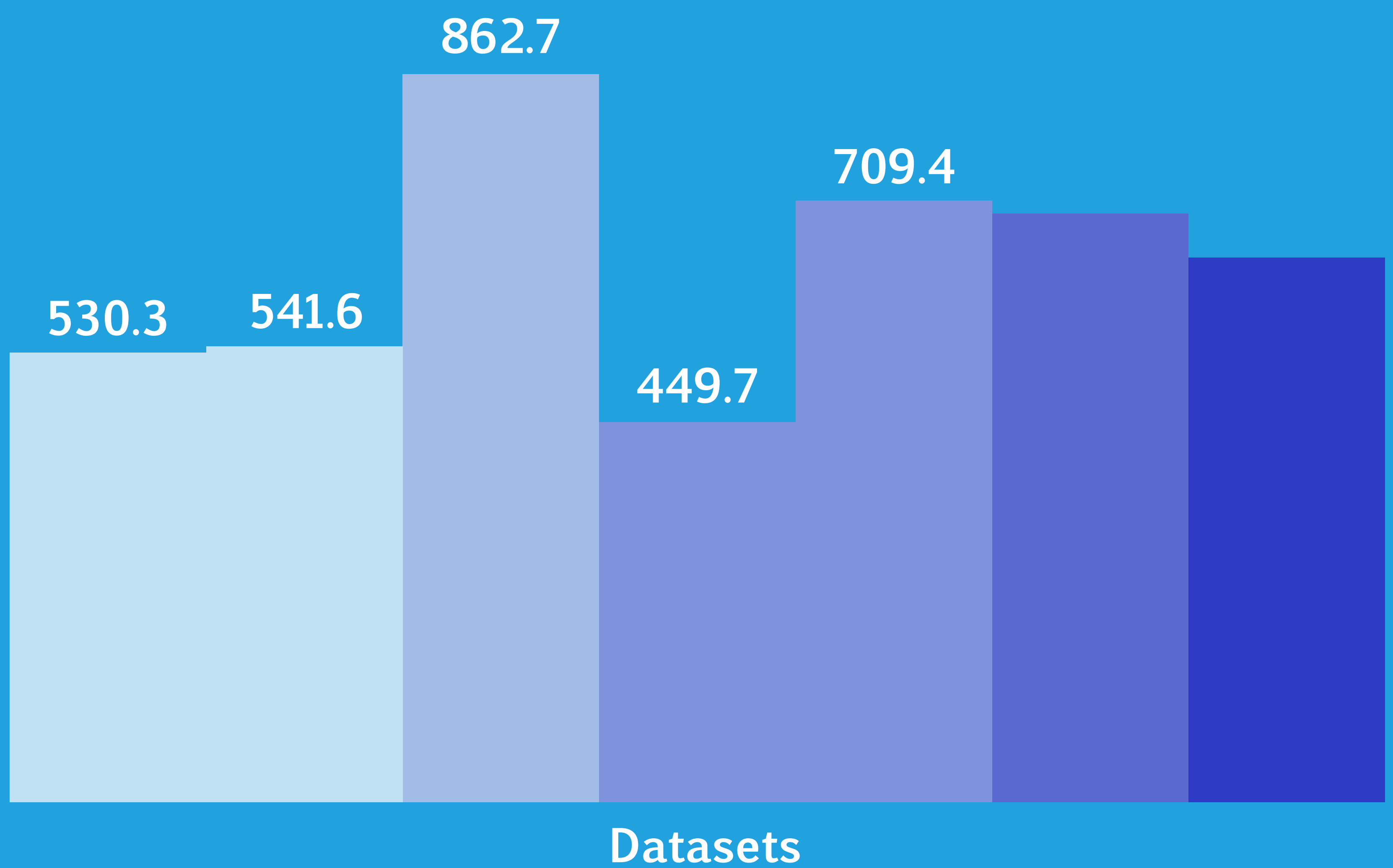


3 RESULTS

3 VALUE OF SBV (ml)



4 LIMITATIONS

The method needs validation.

- With the usual way to compute SBV.
- Track SBV during vascular filling.
- Using simulated data.

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5 EXTENSIONS

The method could be made fully non-invasive:

- SBV is an important parameter.

→ No need for ventricular pressures.

- Change load by raising the legs.

→ No need for vena cava occlusion.

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6 CONCLUSION

- Model-based method to compute SBV from preload reduction data.
- SBV is an important parameter

➔ If validated, the method could provide a non-invasive way to track SBV.

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Thanks for your attention!
Questions?

2 METHODS

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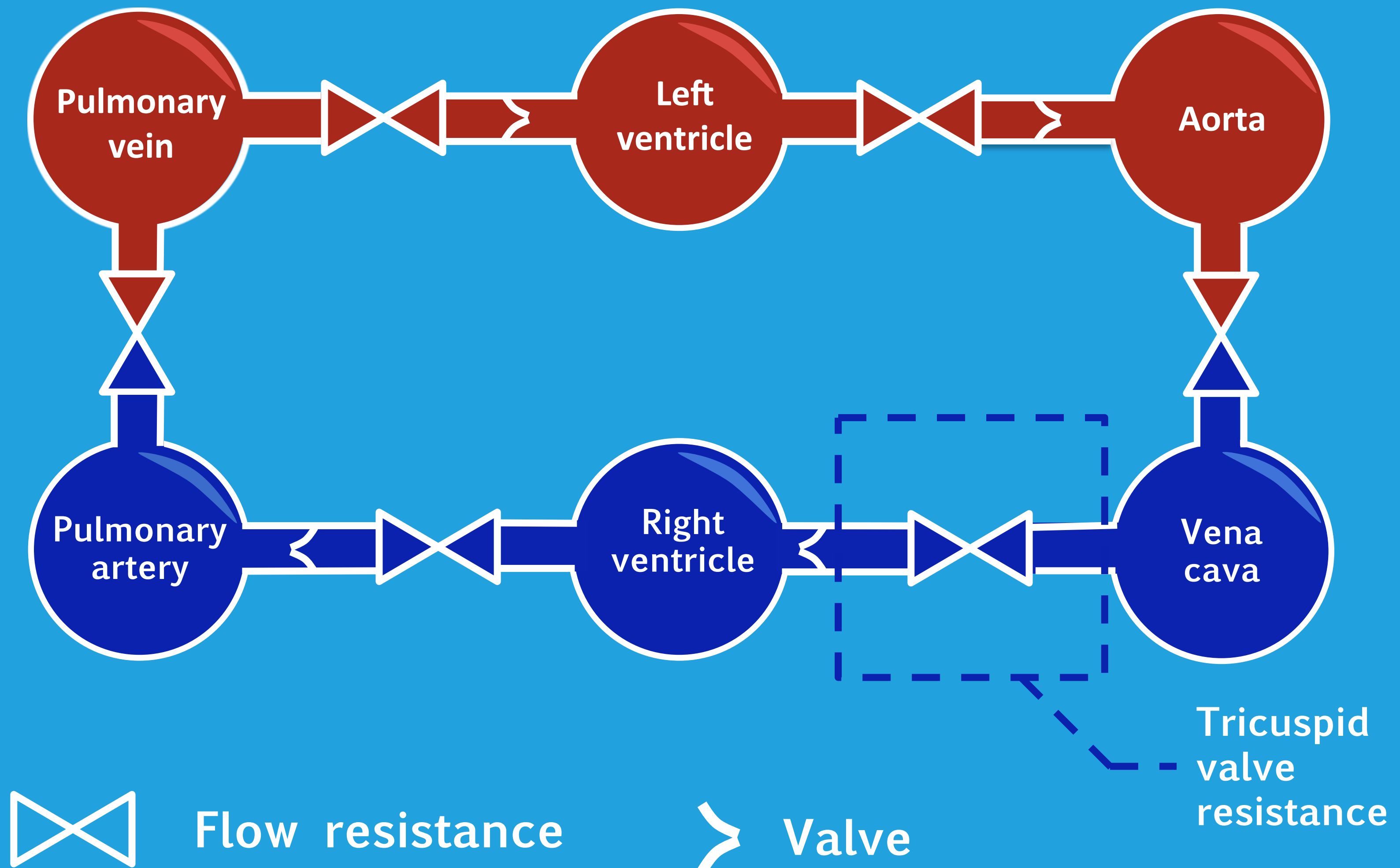

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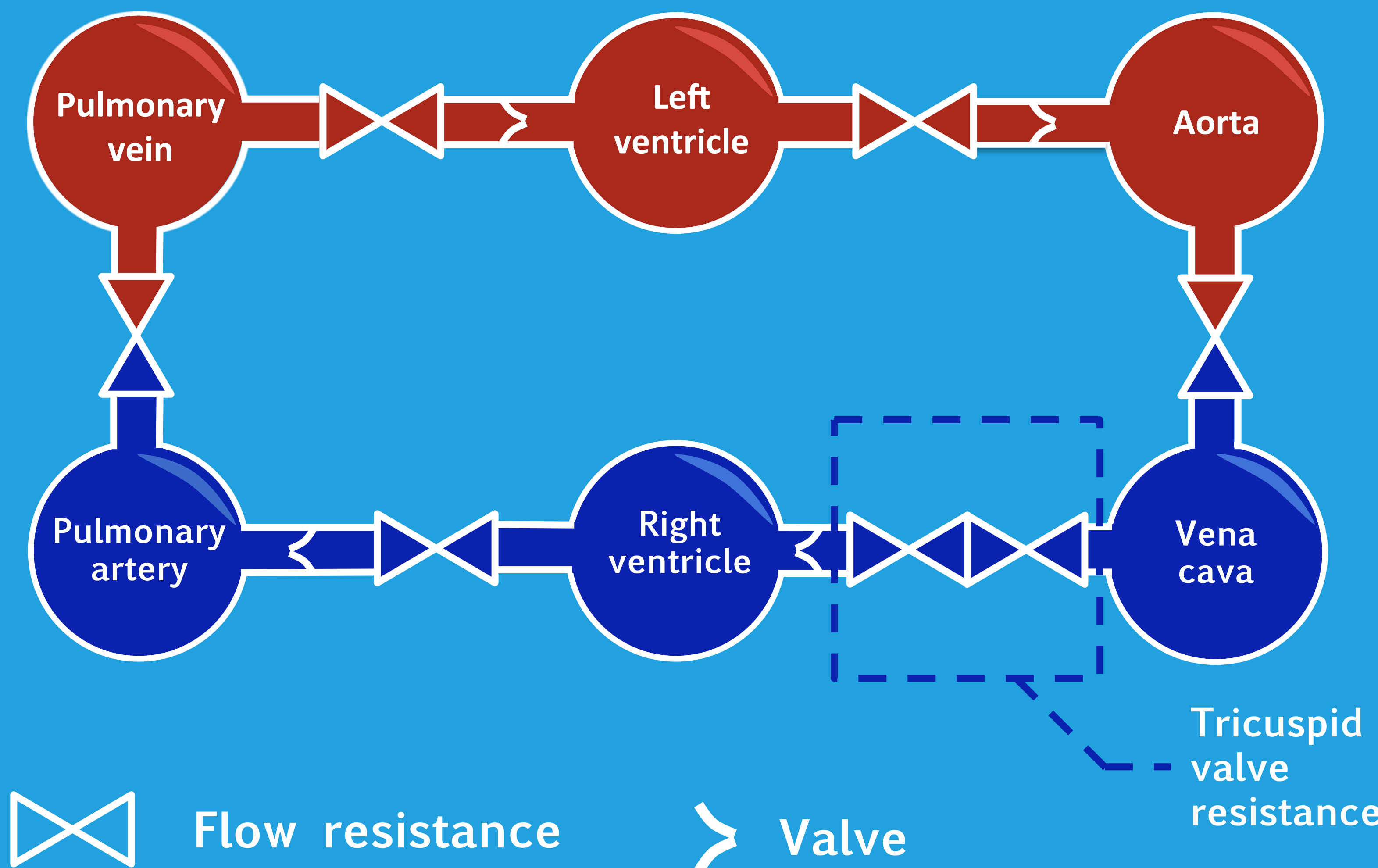

3 RESULTS

4 SBV VERSUS WEIGHT