課程名稱： 醫學工程概論

（Introduction to biomedical engineering）

心血管系統工程簡介

Cardiovascular Engineering

授課教師： 潘力誠副教授

開課單位 ： 通識教育中心

開課學期 ： 102學年度上學期

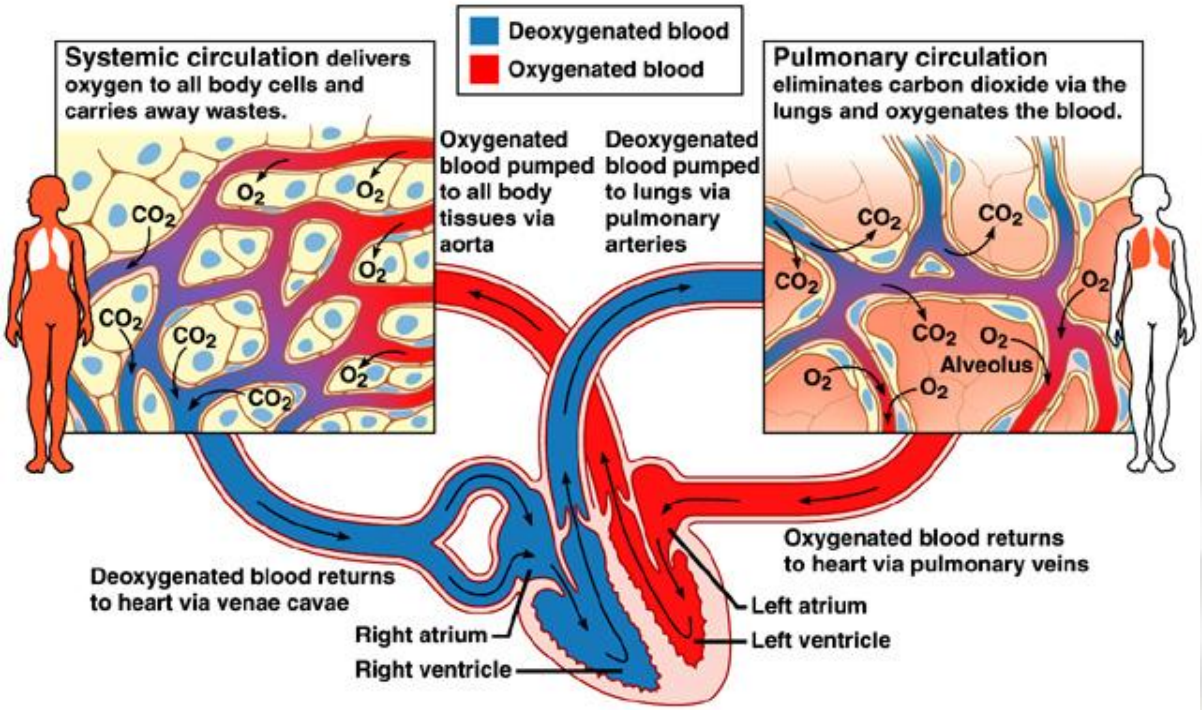
上課地點 ： 2202 上課時間 ： 星期一3, 4

學 習 目 標：

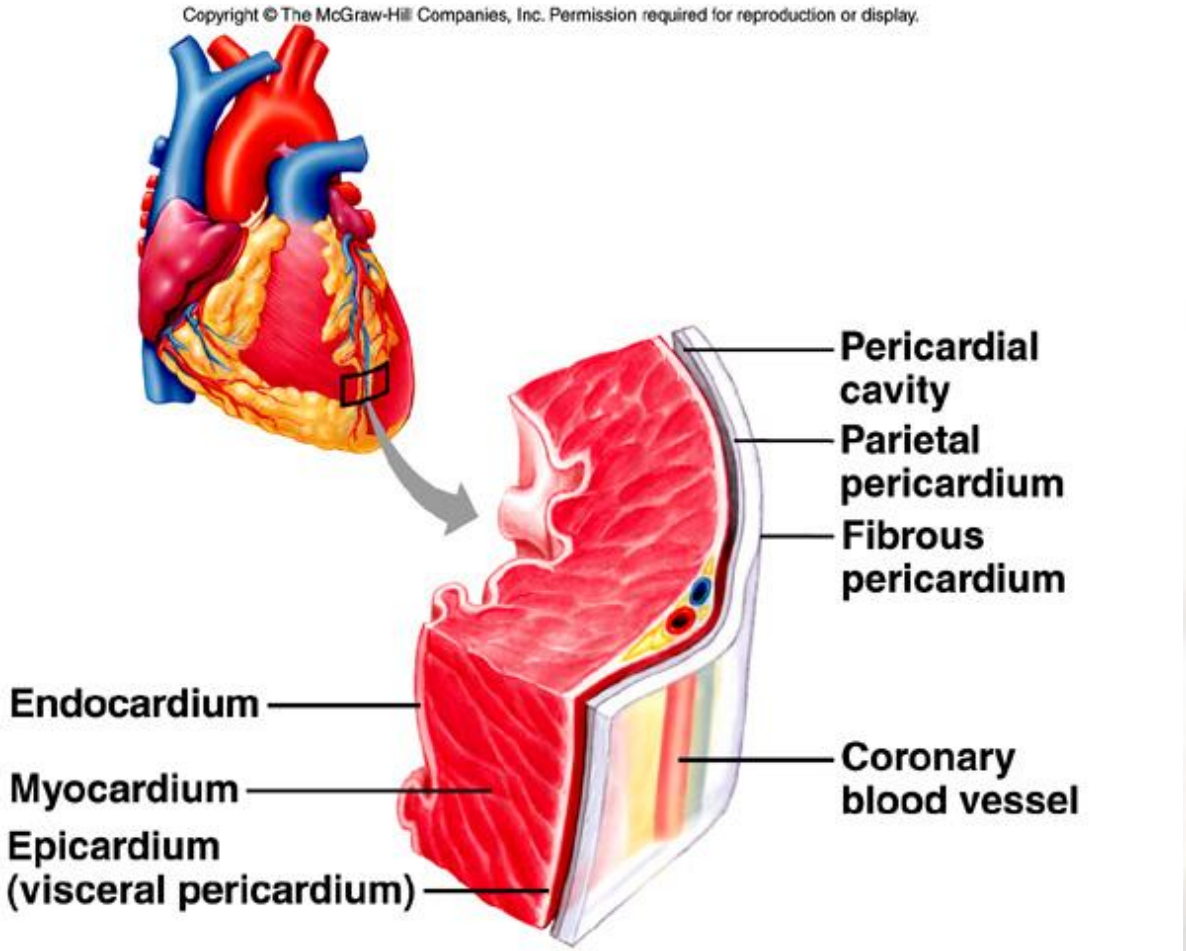
- 心血管系統簡介
- 心臟的構造
- 心臟的週期,
- 血管組成及功能
- 心血管的數學模型及其數值模擬

心血管系統簡介

The double pump：



心臟的構造簡介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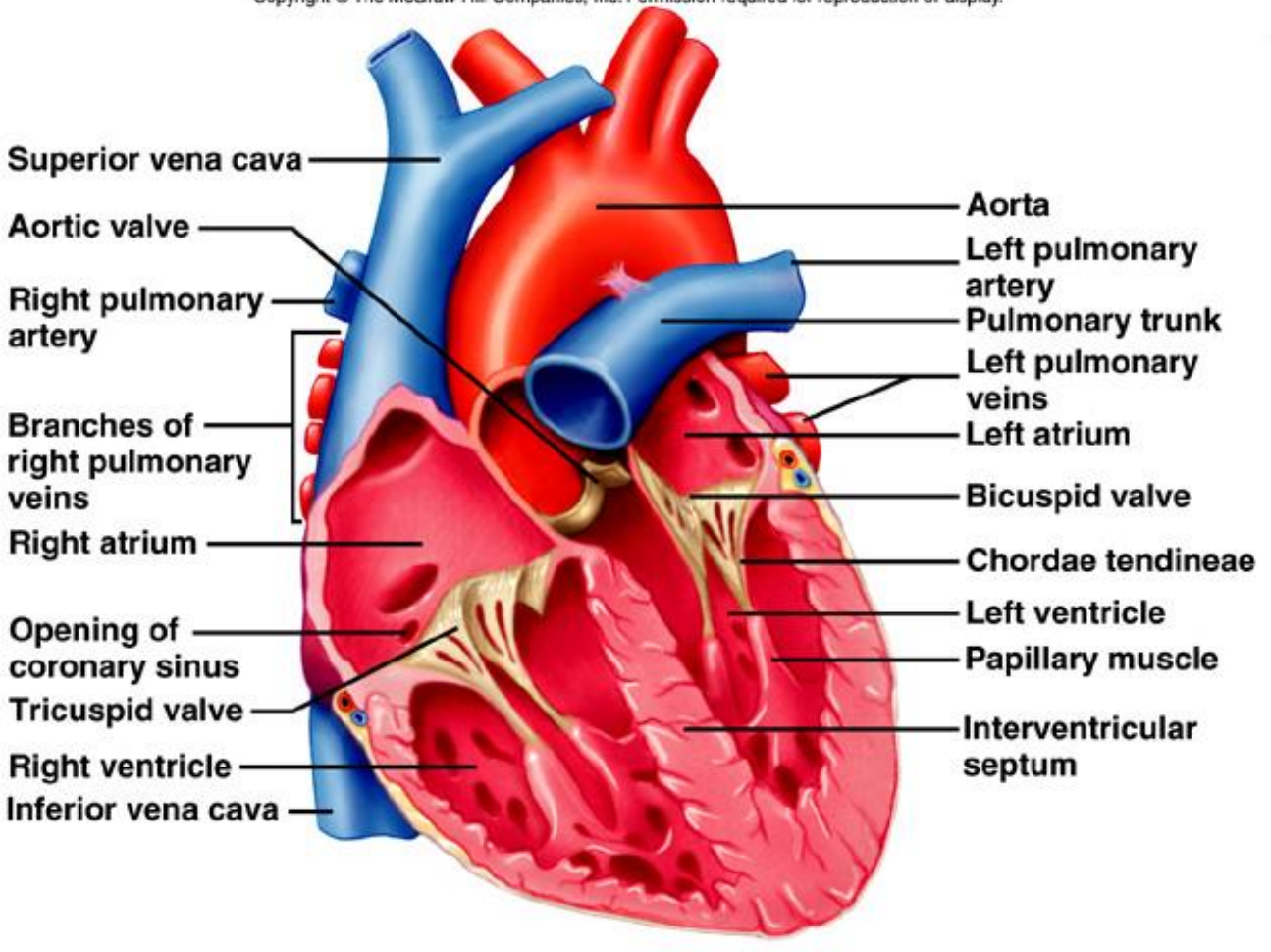
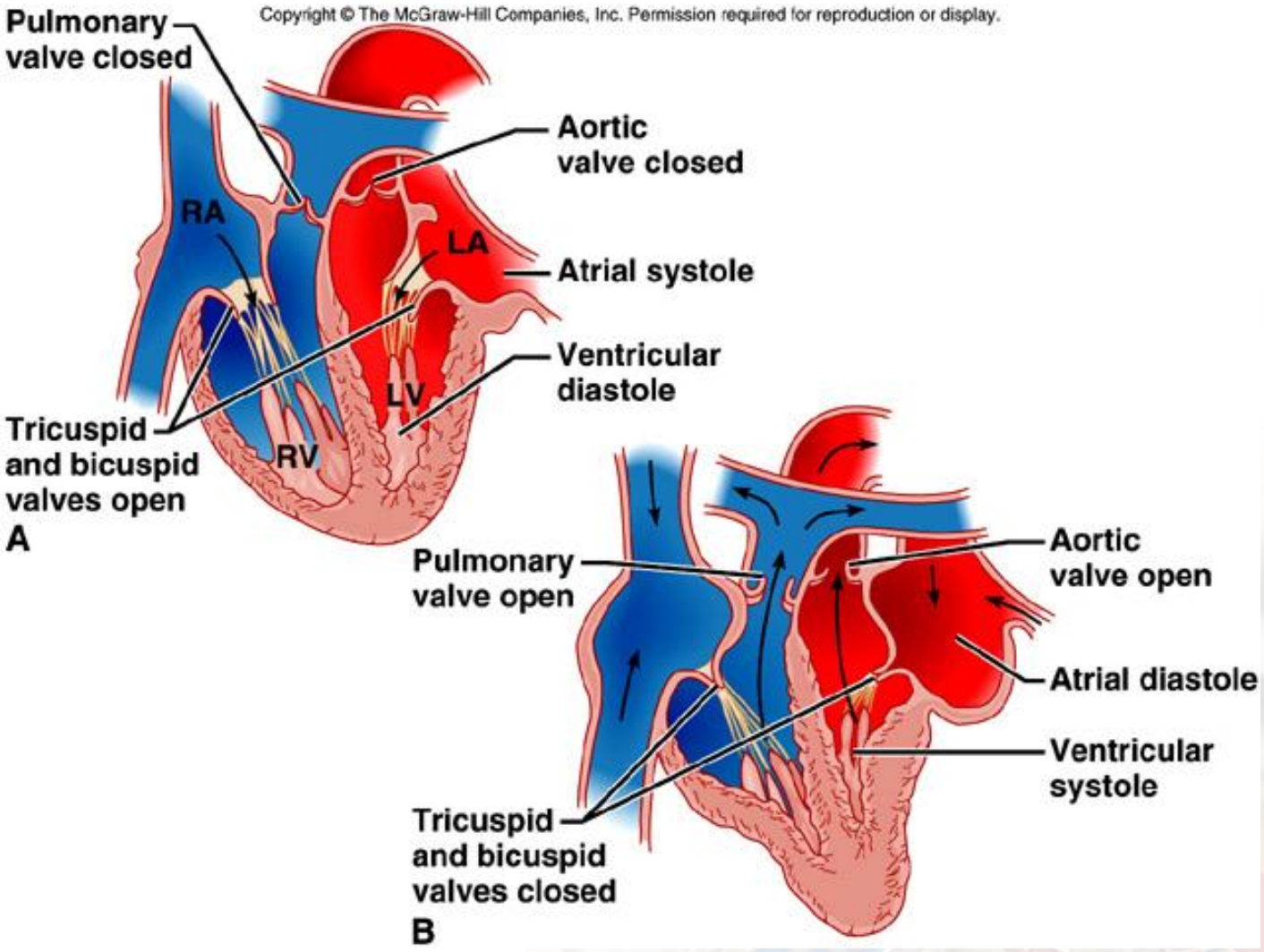
Pericardial cavity
Parietal pericardium
Fibrous pericardium
Endocardium
Myocardium
Epicardium (visceral pericardium)
Coronary blood vessel

心房、心室及心臟瓣膜的構造



心臟的機能簡介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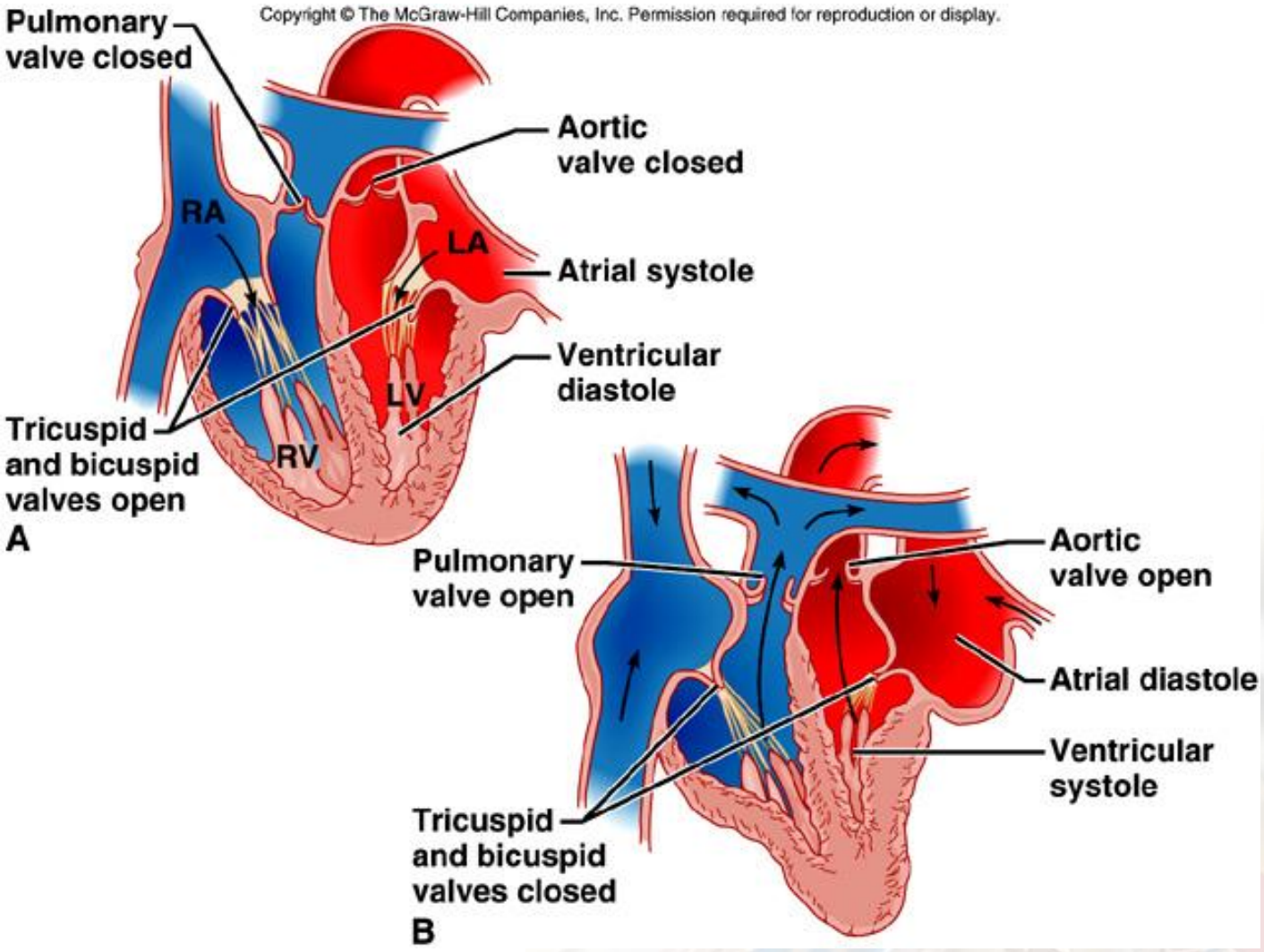
Pulmonary valve closed
Aortic valve closed
RA
LA
Atrial systole
Ventricular diastole
LV
Tricuspid and bicuspid valves open
RV
A
Pulmonary valve open
Aortic valve open
Atrial diastole
Ventricular systole
Tricuspid and bicuspid valves closed
B

心臟的機能簡介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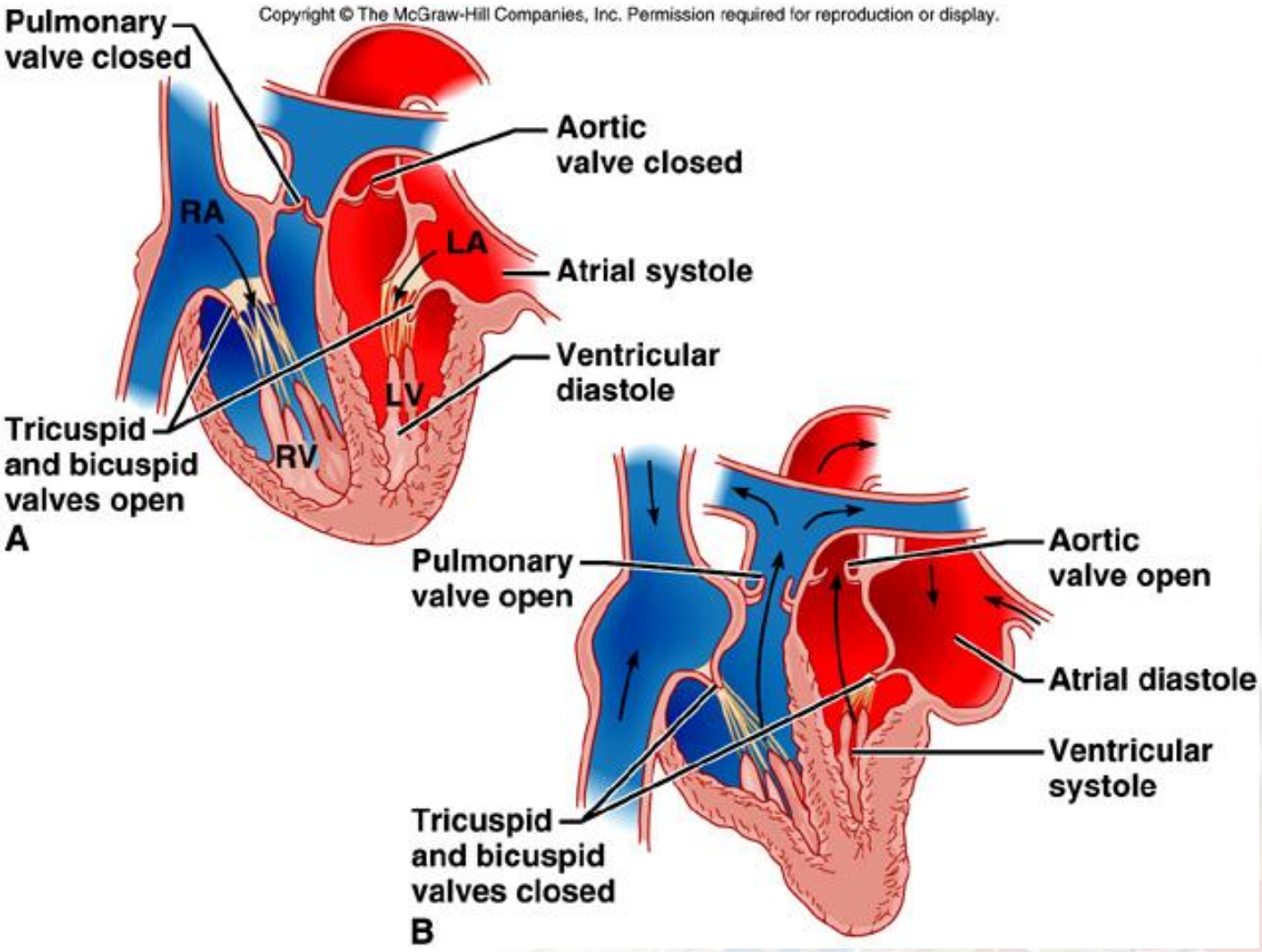
Pulmonary valve closed
Aortic valve closed
RA
LA
Atrial systole
Ventricular diastole
LV
Tricuspid and bicuspid valves open
RV
A
Pulmonary valve open
Aortic valve open
Atrial diastole
Ventricular systole
Tricuspid and bicuspid valves closed
B

心肌收縮與心電信號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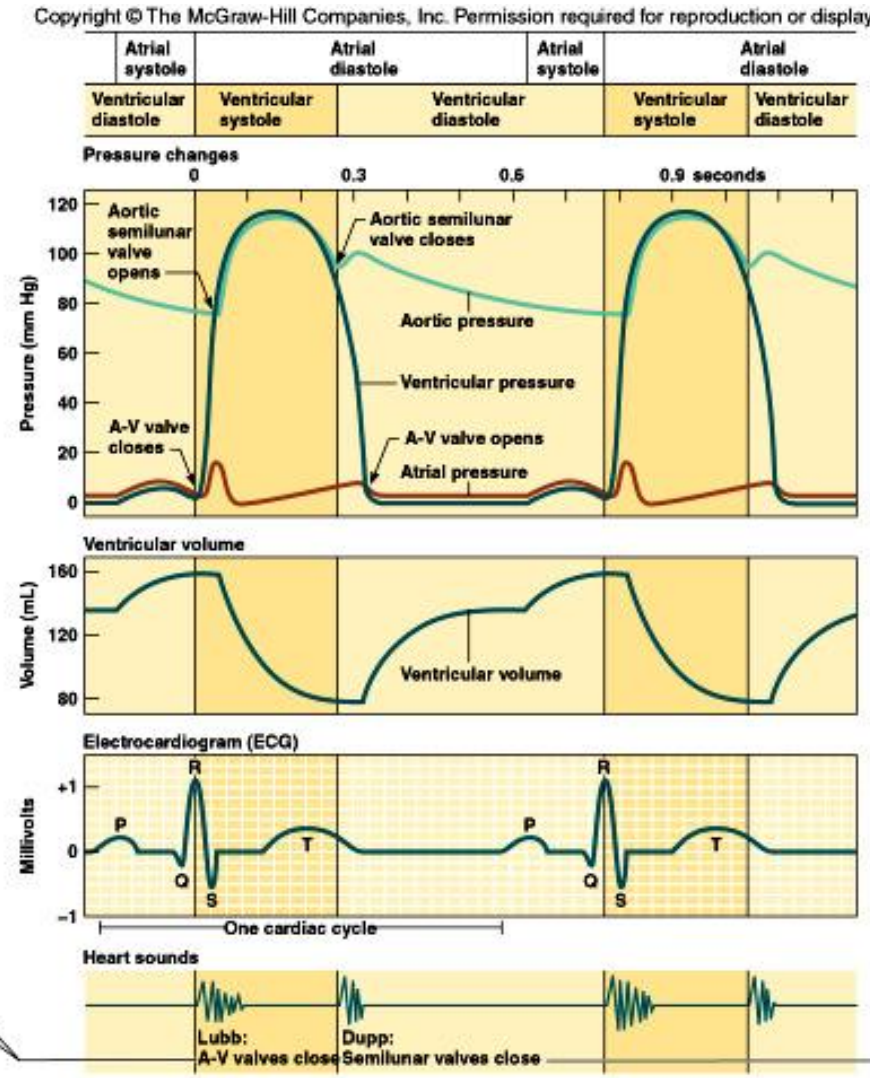
Pulmonary valve closed
Aortic valve closed
RA
LA
Atrial systole
Ventricular diastole
LV
Tricuspid and bicuspid valves open
RV
A
Pulmonary valve open
Aortic valve open
Atrial diastole
Ventricular systole
Tricuspid and bicuspid valves closed
B

心肌收縮與心電圖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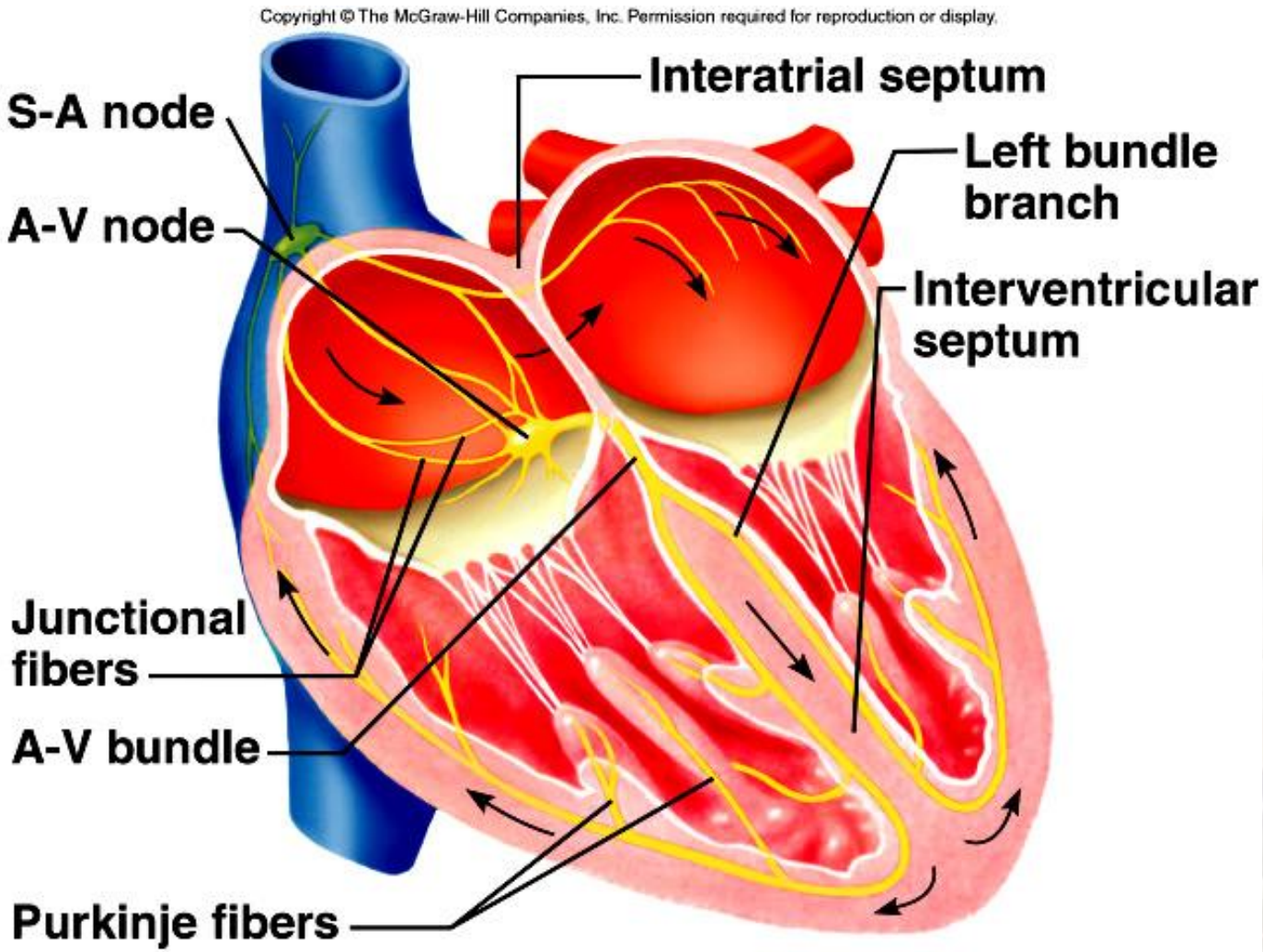
Atrial systole
Atrial diastole
Atrial systole
Atrial diastole
Ventricular diastole
Ventricular systole
Ventricular diastole
Ventricular systole
Ventricular diastole
Pressure changes
0
0.3
0.5
0.9 seconds
Pressure (mm Hg)
120
100
80
60
40
20
0
Aortic semilunar valve opens
Aortic semilunar valve closes
Aortic pressure
Ventricular pressure
A-V valve closes
A-V valve opens
Atrial pressure
Ventricular volume
Volume (mL)
160
120
80
Ventricular volume
Electrocardiogram (ECG)
Millivolts
+1
0
−1
R
P
Q
S
T
One cardiac cycle
Heart sounds
Lubb:
A-V valves close
Dupp:
Semilunar valves close

心電信號傳遞簡介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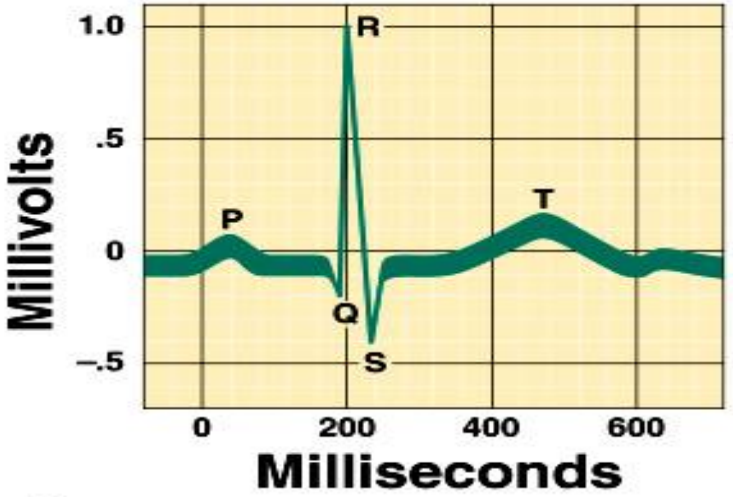
S-A node
A-V node
Interatrial septum
Left bundle branch
Interventricular septum
Junctional fibers
A-V bundle
Purkinje fibers

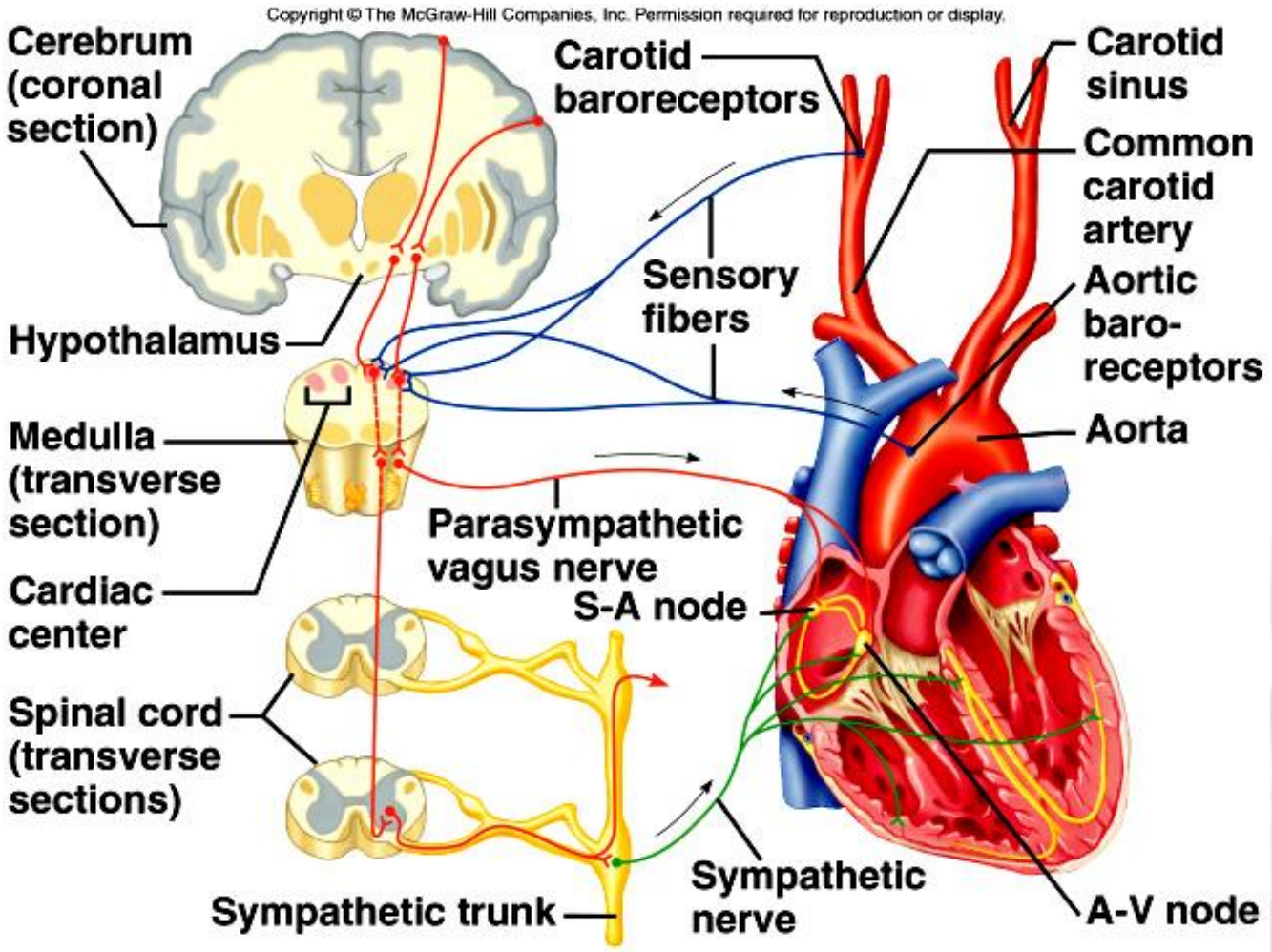
心電圖簡介

A



B

自律神經心臟調控機轉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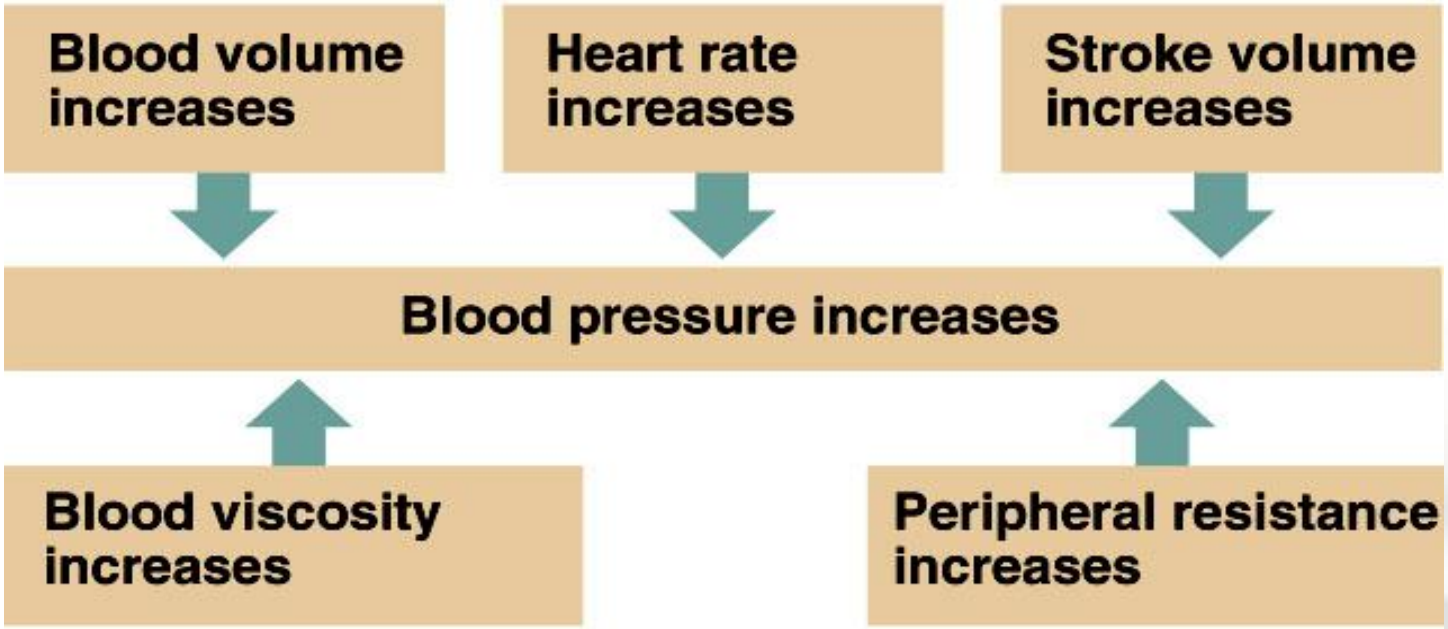
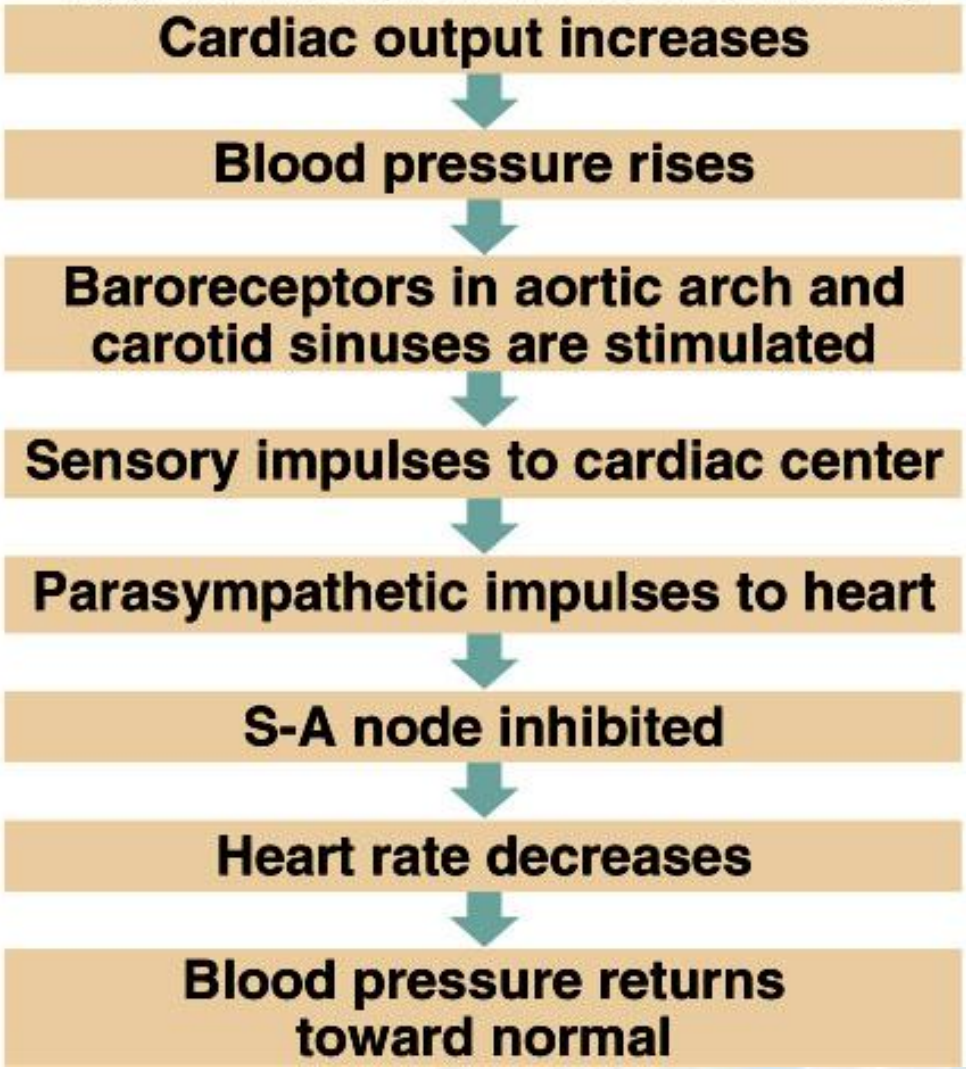
Cerebrum (coronal section)
Carotid baroreceptors
Carotid sinus
Common carotid artery
Sensory fibers
Aortic baro-receptors
Hypothalamus
Aorta
Medulla (transverse section)
Parasympathetic vagus nerve
S-A node
Cardiac center
Spinal cord (transverse sections)
Sympathetic nerve
Sympathetic trunk
A-V node

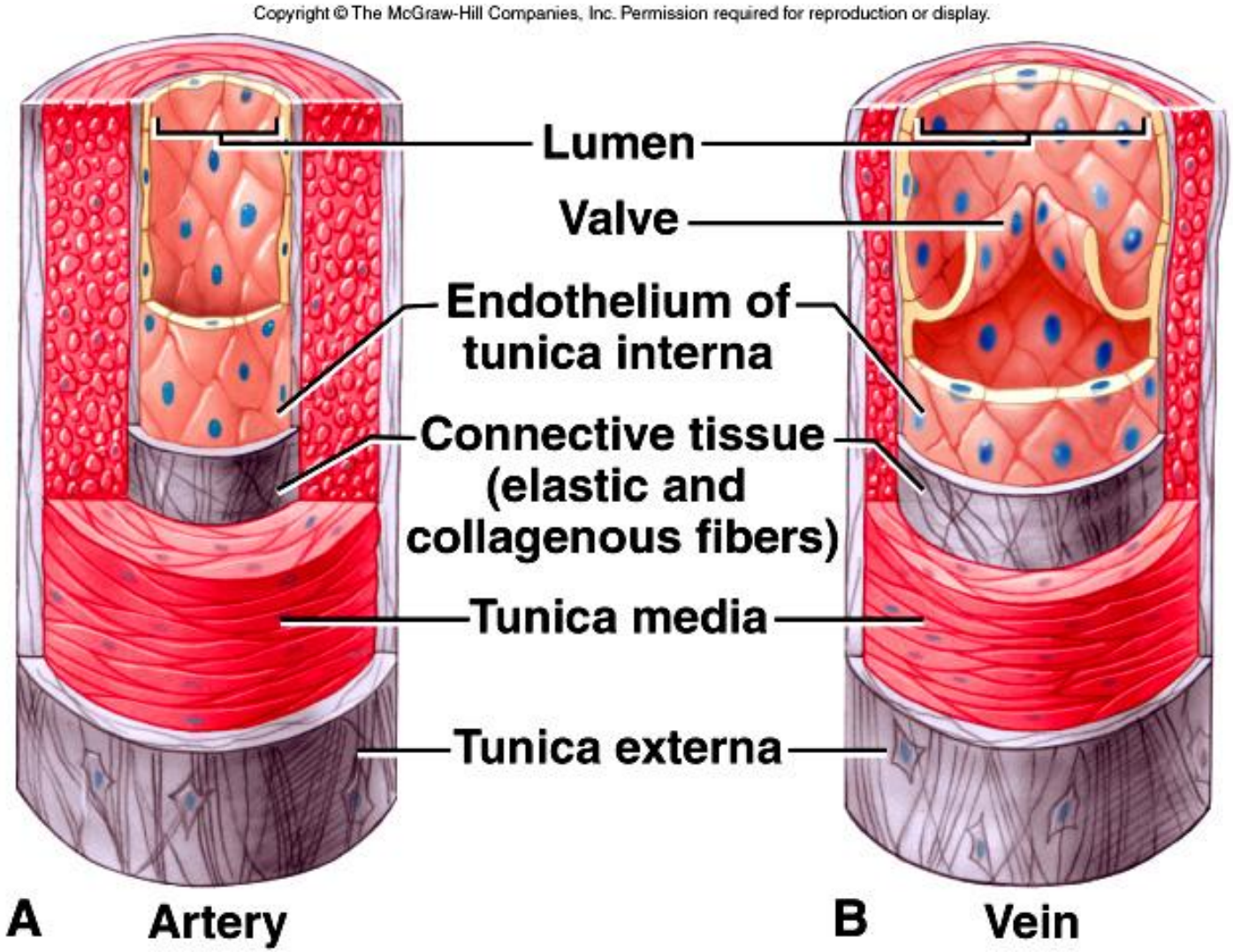
血壓的調控機轉



心博率的調控機轉



血管的構造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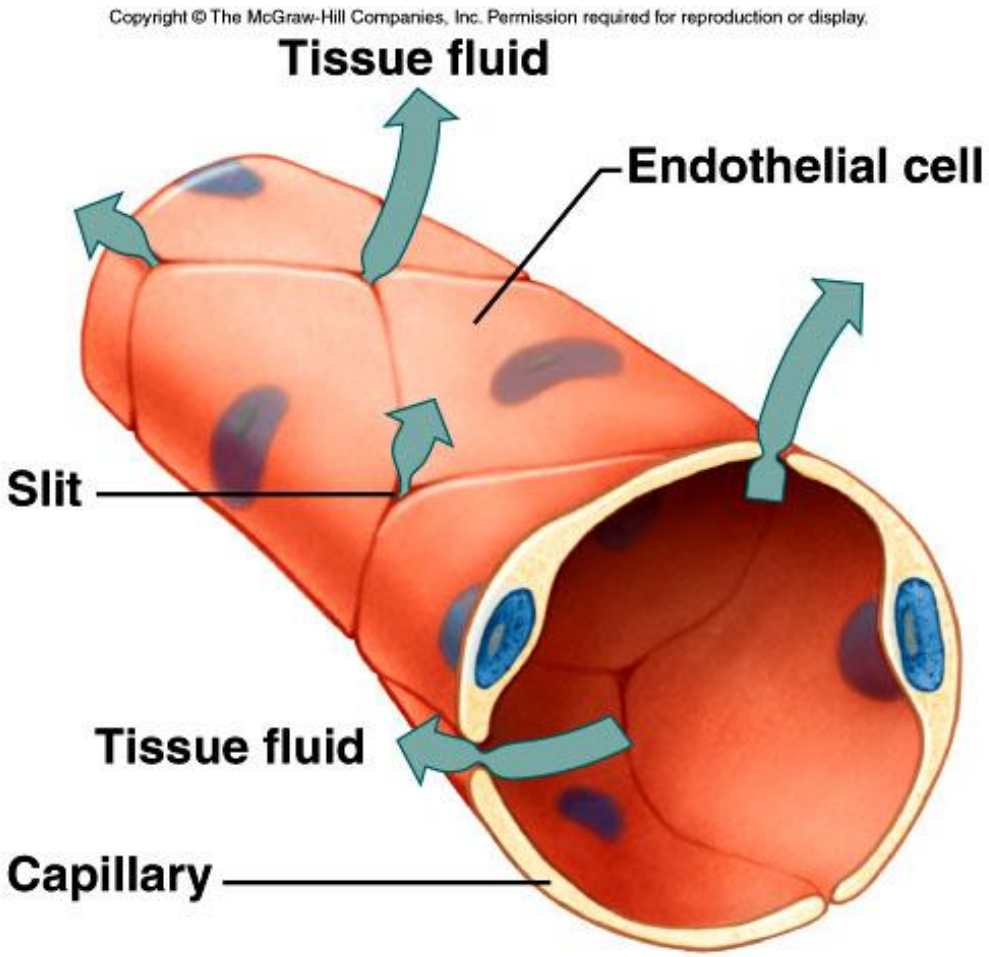
Lumen
Valve
Endothelium of tunica interna
Connective tissue (elastic and collagenous fibers)
Tunica media
Tunica externa
A
Artery
B
Vein

微血管的構造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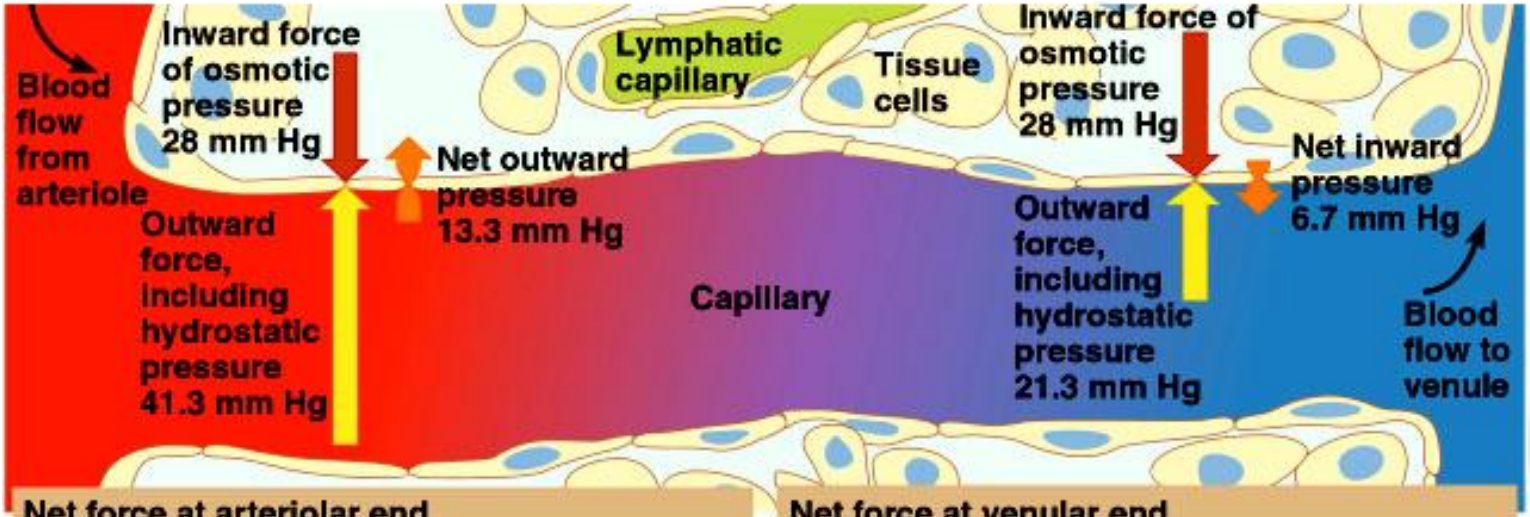
Tissue fluid
Endothelial cell
Slit
Tissue fluid
Capillary

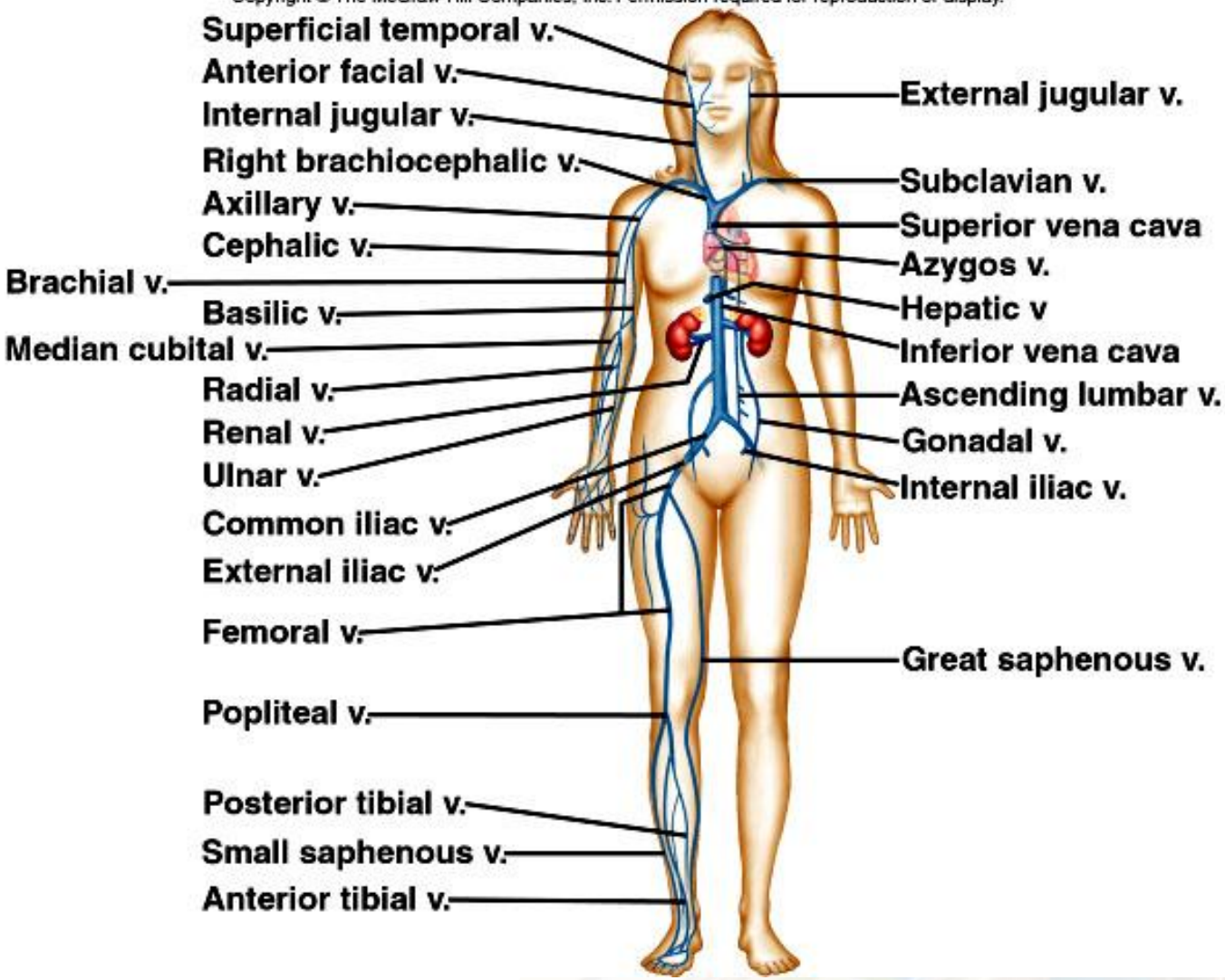
微血管的功能



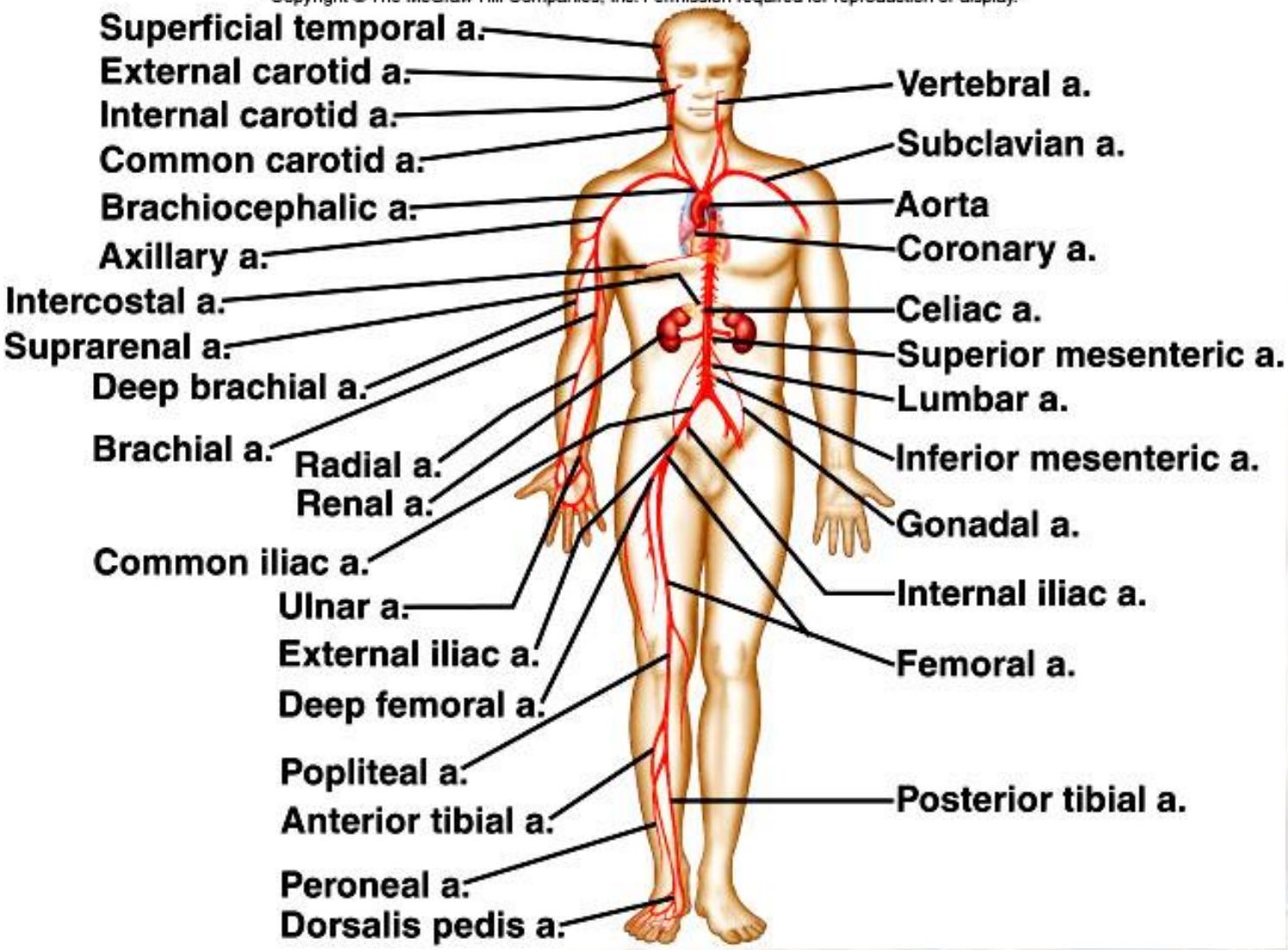
Net force at arteriolar end	
Outward force, including hydrostatic pressure	= 41.3 mm Hg
Inward force of osmotic pressure	= 28 mm Hg
Net outward pressure	= 13.3 mm Hg

Net force at venular end	
Outward force, including hydrostatic pressure	= 21.3 mm Hg
Inward force of osmotic pressure	= 28 mm Hg
Net inward pressure	= 6.7 mm Hg

靜脈循環系統簡介

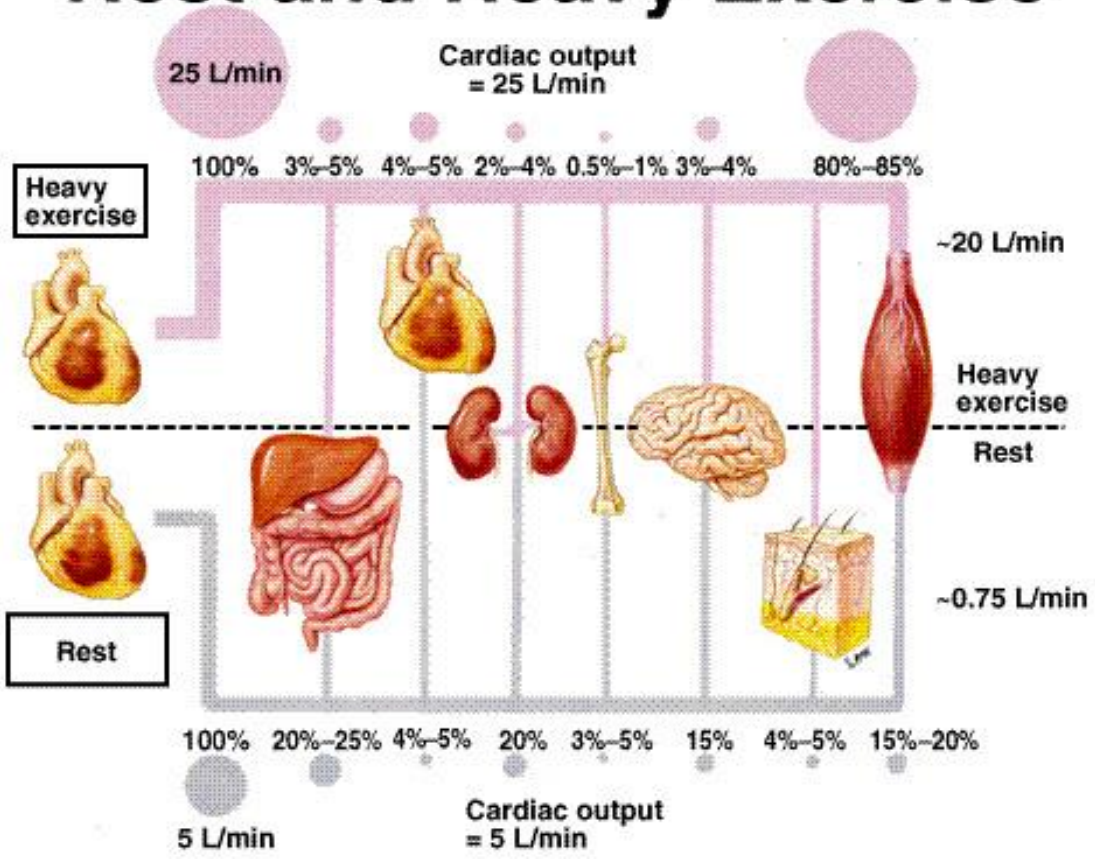


動脈循環系統簡介



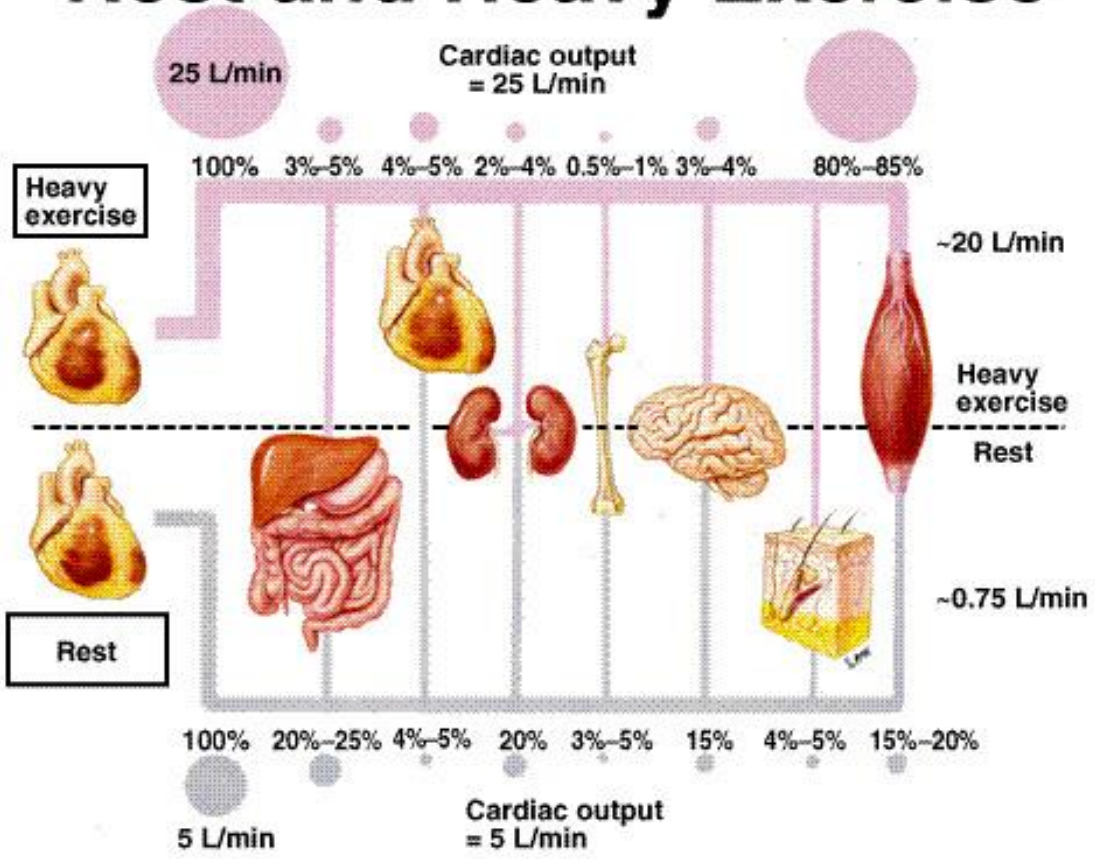
心輸出量的調控與分配

Distribution of Blood Flow (Cardiac Output) During Rest and Heavy Exercise



心輸出量的調控與分配

Distribution of Blood Flow (Cardiac Output) During Rest and Heavy Exercise



心血管系統的數學模型

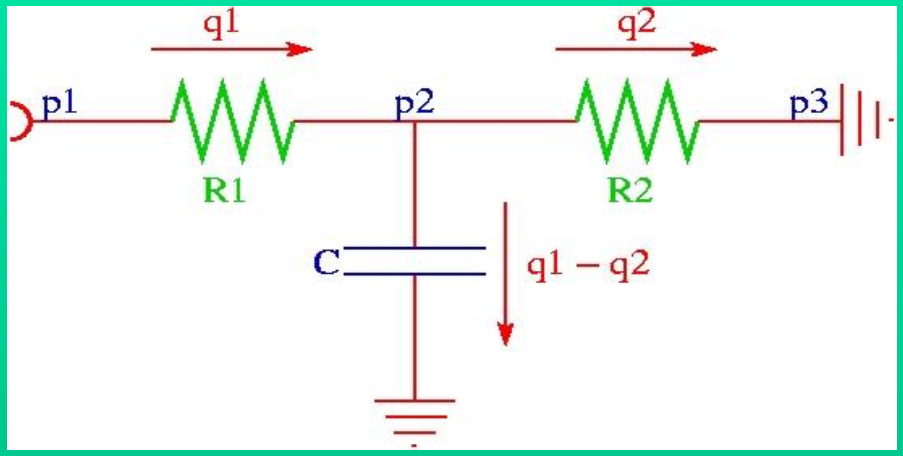
- **Equations for blood flow and pressure**

$$q_1 = \frac{p_1 - p_2}{R_1}$$

$$q_2 = \frac{p_2 - p_3}{R_2} = \frac{p_2}{R_2}$$

$$C\frac{dp_2}{dt} = q_1 - q_2$$

Windkessel model

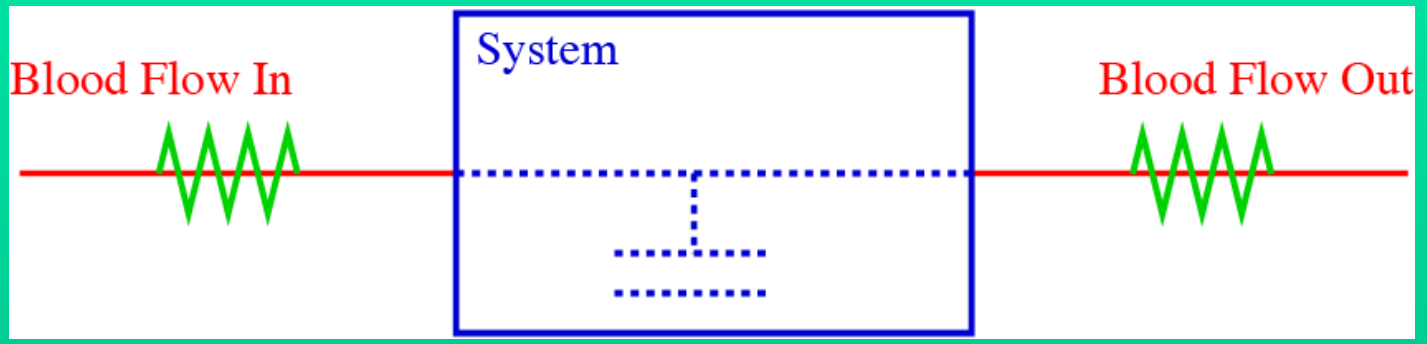


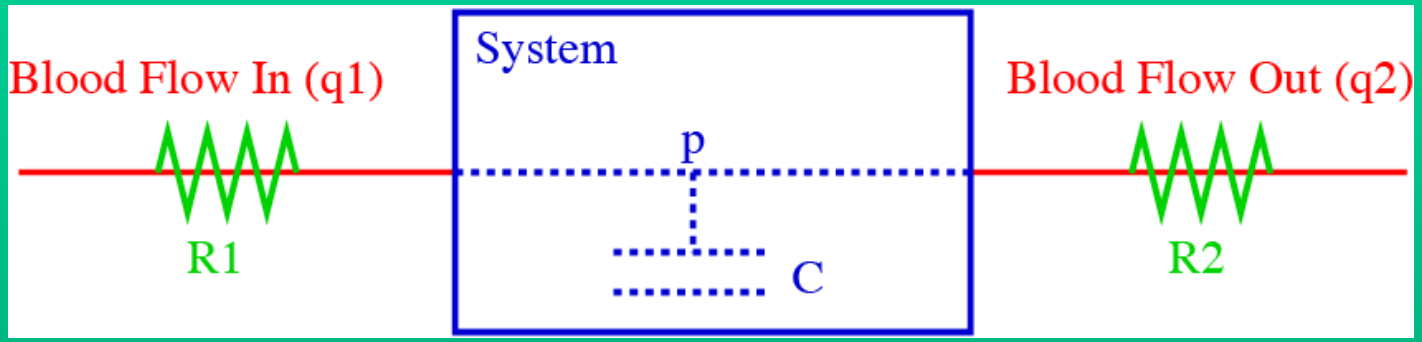
- **Solving equations for q_1 as a function of p_1**

$$R_1\left[\frac{dq_1}{dt} + \frac{(R_1 + R_2)q_1}{CR_1R_2}\right] = \frac{dp_1}{dt} + \frac{p_1}{CR_2}$$

心血管系統的數學模型

Compartment Model





心血管系統的數學模型

- **Fitting the model to data**

$$Z(w) = \frac{R_1 + R_2 + iwCR_1R_2}{1 + iwCR_2}$$

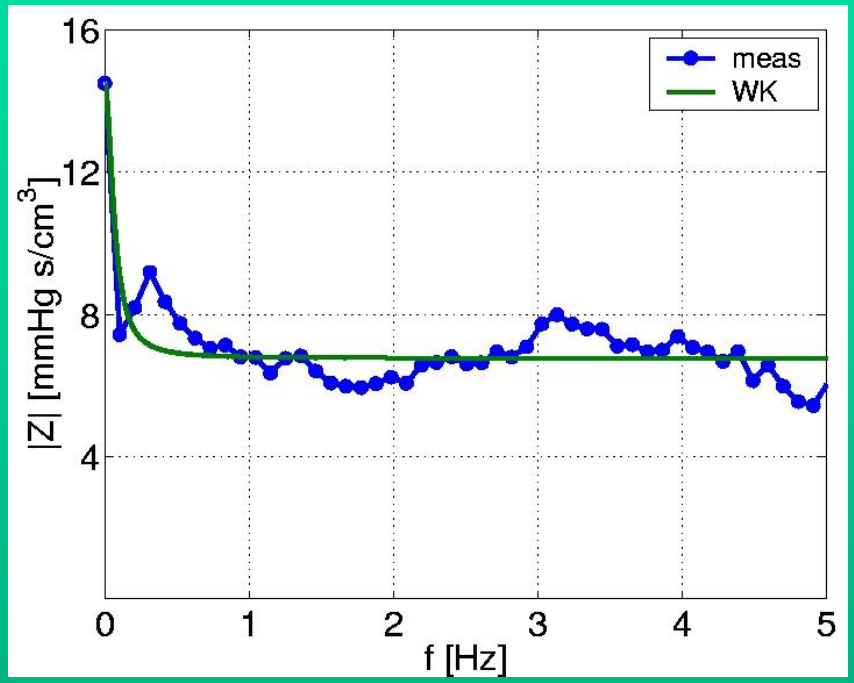
- **Estimating parameters**

$Z(0) = R_1 + R_2$,

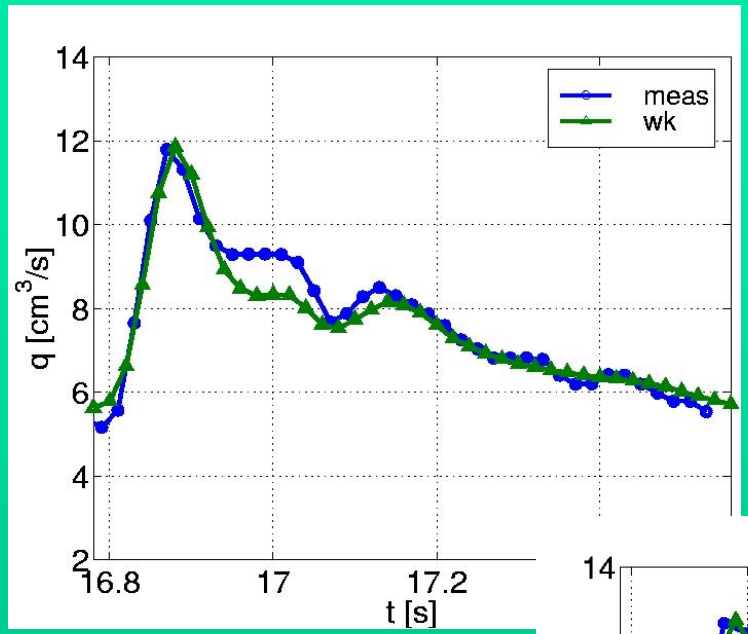
$\lim_{w \to \infty} Z(w) = R_1$, and

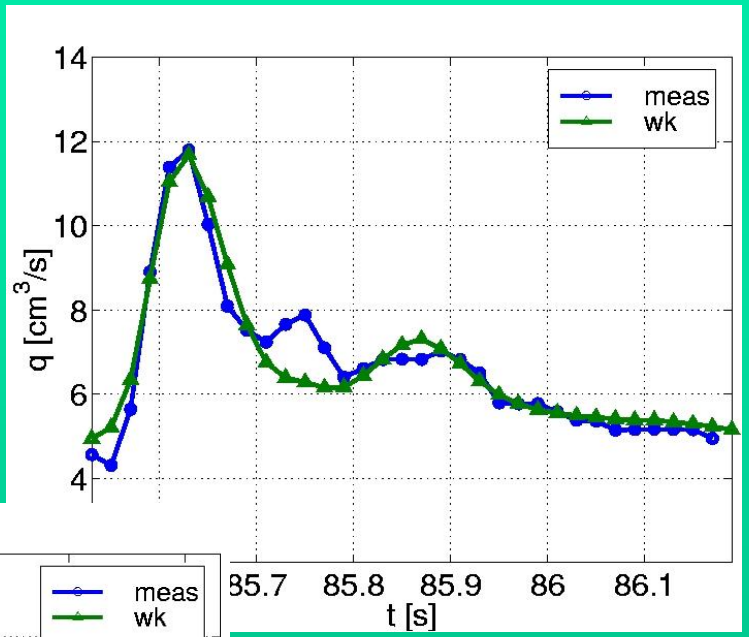
C is found by a least squares fit between the model and the data

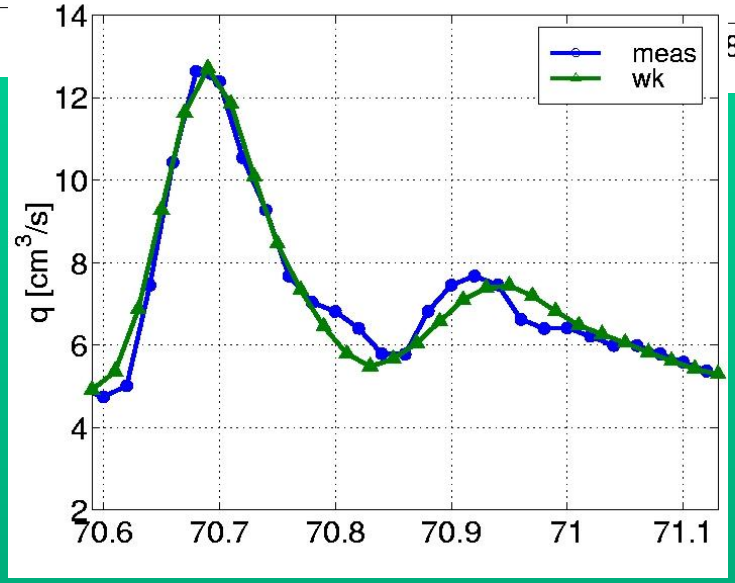
Windkessel model



心血管系統的數學模型
Windkessel model

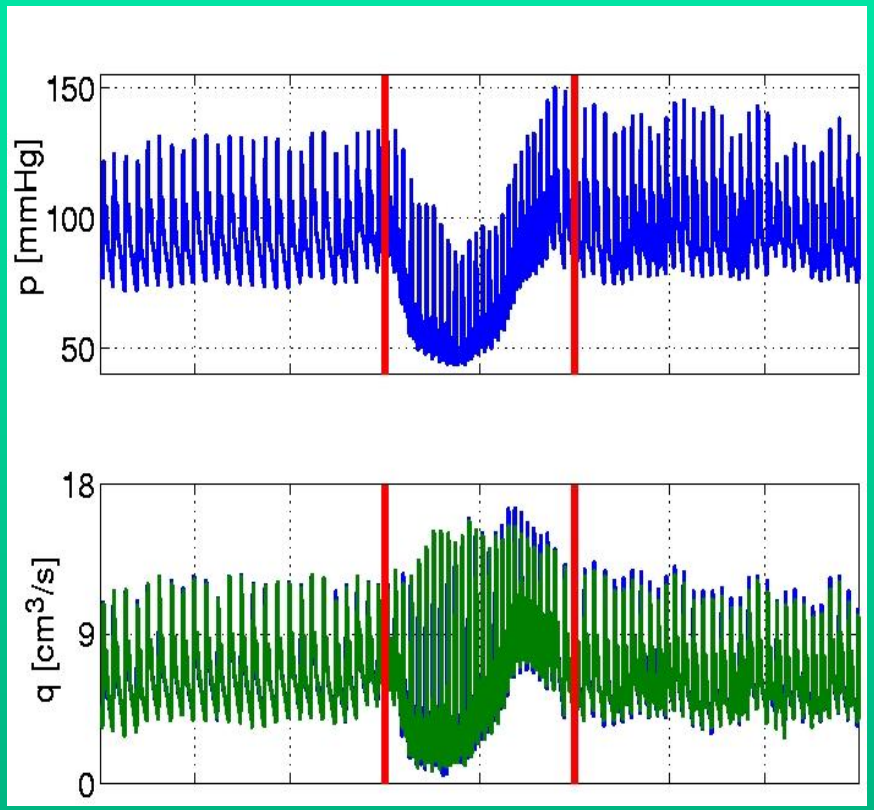




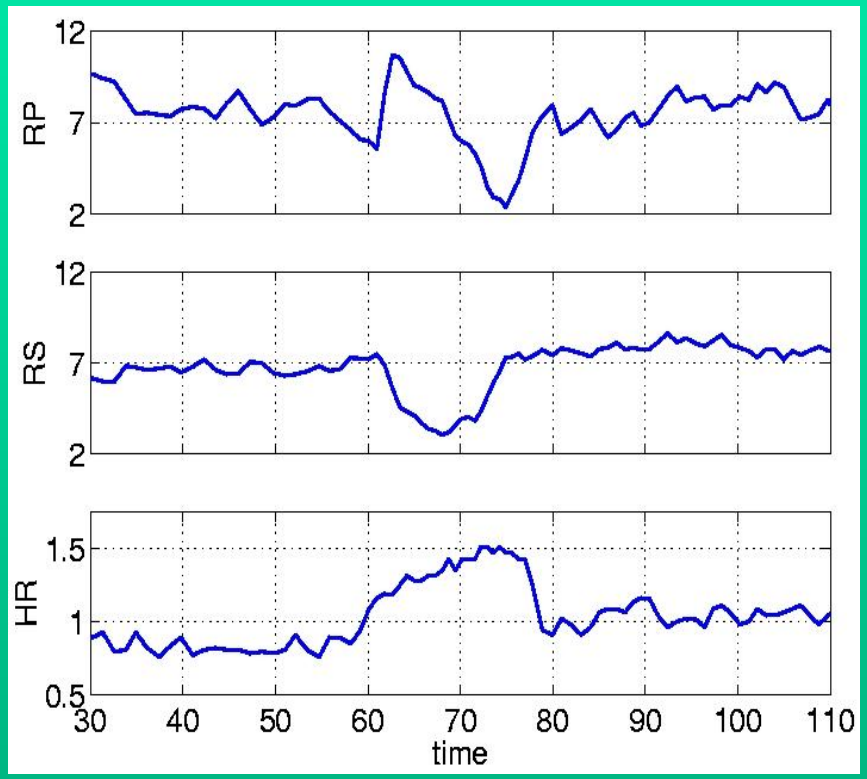


心血管系統的數學模型
Windkessel model

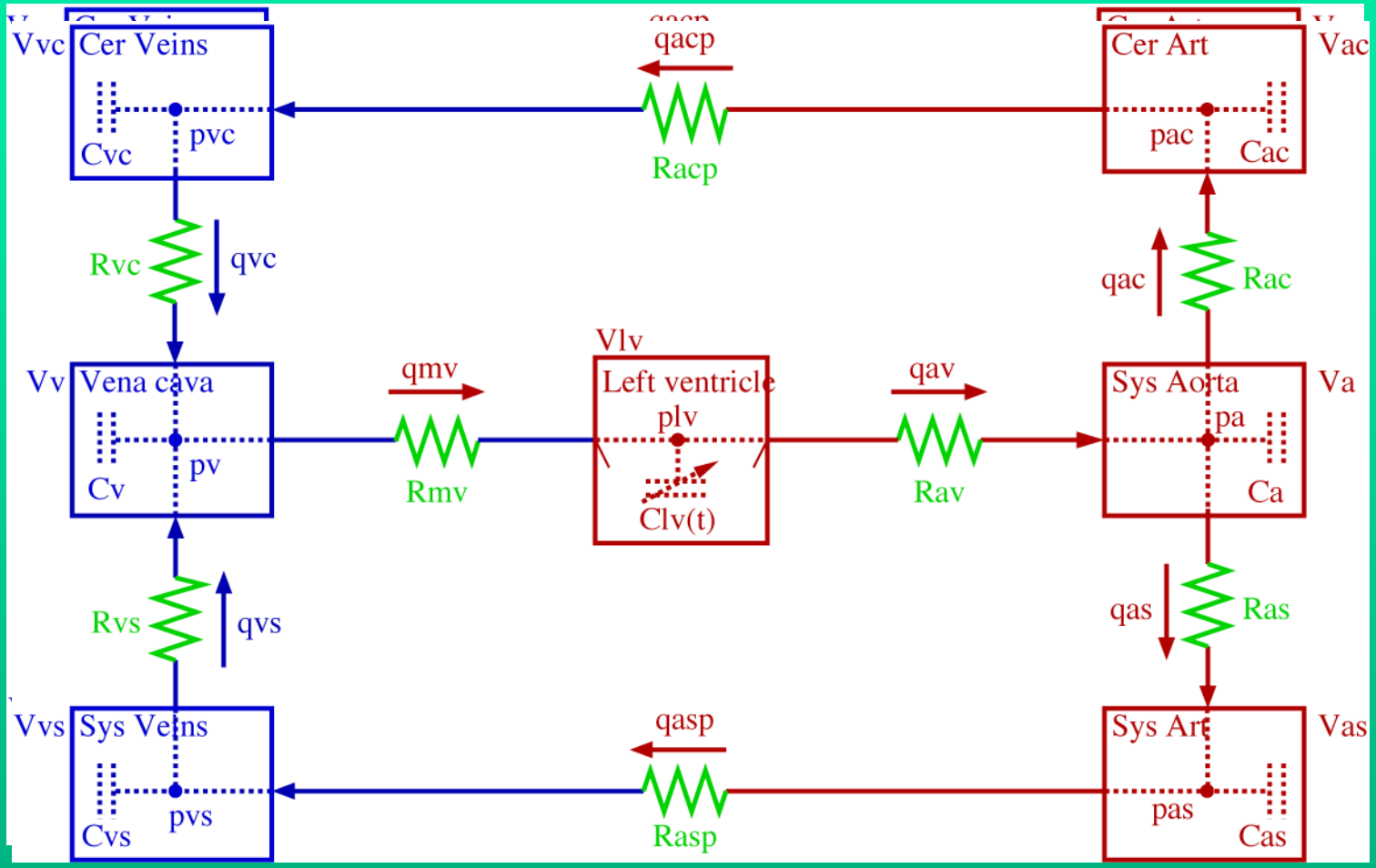
Pressure and flow time series



Parameters



心血管系統的數學模型
Simple circuit model



心血管系統的數學模型
Simple circuit model

Basic components:

- Pressure (p, mmHg)
- Flow (q, cm^3/sec)
- Volume (V, cm^3)
- Resistance (R, mmHg sec/$cm^{3)}$
- Capacitance (C, cm^3/mmHg)

Abbreviations:

- Aorta (a)
- Systemic arteries (as)
- Cerebral (brain) arteries(ac)
- Systemic veins (vs)
- Cerebral (brain) veins (vc)
- Vena cava (v)
- Left ventricle (lv)
- Aotric valve (av)
- Mitral valve (mv)

心血管系統的數學模型
Mathematical model

- **Change in volume:**

$$\frac{dV_i}{dt} = q_{in} - q_{out}$$

- **Kirchhoff's current law:**

$$q_i = \frac{p_{in} - p_{out}}{R_i}$$

- **Pressure volume relation:**

$$V_i = C_i p_i \quad \Leftrightarrow \quad C_i \frac{dp_i}{dt} + p_i \frac{dC_i}{dt} = q_{in} - q_{out}$$