Cardiac Output & Coronary flow

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Sherwood Fig 9-1
Cardiac Output = Heart Rate \times \text{Stroke Volume}

\begin{align*}
\text{CO} & = \text{HR} \times \text{SV} \\
\text{At rest} & : \text{CO} = 70 \text{ bpm} \times 70 \text{ ml/beat} \\
& = 4,900 \text{ ml/min} \sim 5 \text{ L/min} \\
\text{Exercise} & : \text{CO} \sim 20-25 \text{ L/min}
\end{align*}

How do you get a 4-5 fold increase in cardiac output?
Do the math
Sympathetic regulation of cardiac output

- ↑ Stroke volume
- +
- +
- +
- +
- +
- +

↑ Strength of cardiac contraction
↑ End-diastolic volume
↑ Venous return

- ↑ Sympathetic activity (and epinephrine)
  - Extrinsic control
  - Intrinsic control

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Sherwood Fig 9-25
How does increased venous return increase SV?
Passive Filling

Active Contraction

Ganong Fig 3-16
Intrinsic control of stroke volume

Frank-Starling Law of the Heart

Sherwood Fig 9-26
Extrinsic control

↑ Sympathetic activity (and epinephrine)

Intrinsic control

↑ Stroke volume

↑ Strength of cardiac contraction

Intrinsic control

↑ End-diastolic volume

Intrinsic control

↑ Venous return

Sherwood Fig 9-25
Extrinsic control of stroke volume

Left Ventricular Pressure (mmHg)

+ Inotropic

Control

Time, seconds

a, b, c, d, e, f, g, h
Increased contractility results in increased stroke volume (for the same end-diastolic volume)

Frank-Starling curve on sympathetic stimulation

Normal Frank-Starling curve

Increase in stroke volume at same end-diastolic volume

Sherwood Fig 9-28
End-diastolic volume 135 ml

↑ Force of contraction
- Force of contraction
- Venous return

End-diastolic volume 175 ml

Stroke volume 70 ml

End-systolic volume 65 ml

End-diastolic volume 135 ml

Stroke volume 100 ml

End-systolic volume 35 ml

End-diastolic volume 135 ml

Stroke volume 140 ml

End-systolic volume 35 ml

Ejection Fraction = \frac{SV}{EDV}

Do the math

Sherwood Fig 9-27
Pressure-volume loop

What is happening between C&D?

What is happening between A&B?

Netter Fig. 4.10
Cardiac output = Heart rate $\times$ stroke volume

Stroke volume = end-diastolic volume - end-systolic volume

Netter Fig. 4.10
As heart rate increases, duration of diastole decreases

Does this lead to reduced EDV (i.e., ventricular filling)?

No! Why?

Sherwood Fig 9-22
Extrinsic control of stroke volume

Why is relaxation faster with $\beta$-AR stimulation?
Sympathetic stimulation $\uparrow$ force of contraction

\[ \beta \text{AR} = \text{beta adrenergic receptor} \]
\[ \text{Gx} = \text{G-proteins} \]
\[ \text{AC} = \text{adenylate cyclase} \]
\[ \text{cAMP} = \text{cyclic adenosine monophosphate} \]
\[ \text{PKA} = \text{protein kinase A} \]
\[ \text{SR} = \text{sarcoplasmic reticulum} \]
\[ \text{PLB} = \text{phospholamban} \]

And $\uparrow$ rate of relaxation
What happens if HR is too fast?

Martini Fig 20-17
Coronary Blood Flow

Netter
Would you expect coronary flow to be different in endocardium vs epicardium?

Why does left side drop to no flow?

Right coronary flow follows aortic pressure (i.e. does not drop to 0)
Oxygen extraction is near maximal even at rest
How does heart increase oxygen to meet metabolic need?

1. Metabolic activity of cardiac muscle cells (↑ oxygen need)
2. ↑ Adenosine
3. Vasodilation of coronary vessels
4. ↑ Blood flow to cardiac muscle cells
5. ↑ Oxygen available to meet ↓ oxygen need

*Sherwood Fig 9-32*
Atherosclerosis compromises blood flow

Collagen-rich smooth muscle cap of plaque

Plaque

Lipid-rich core of plaque

Endothelium

Sherwood Fig 9-33
Inappropriate clotting

Sherwood Fig 9-33
Normal

Restricted circulation

Martini Fig 20-10
Depressed contractility during heart failure

HF defined when EF $\leq$ 35%

Sherwood Fig 9-30
↑ Sympathetic activity to compensate for ↓ CO
Thought Case

A 69-year old man sees you in the office for follow-up of his chronic congestive heart failure. He has a marked reduction in his ejection fraction following a series of myocardial infarctions. He also has hypertension and type 2 diabetes mellitus. His symptoms include dyspnea on exertion, orthopnea, paroxysmal nocturnal dyspnea, and peripheral edema. He has normal renal function.

Why is this patient experiencing difficulty in breathing?
Why does he have peripheral edema?

From Toy, Rosenfeld, Loose, Briscoe: Case Files; Pharmacology (Lange) 2005