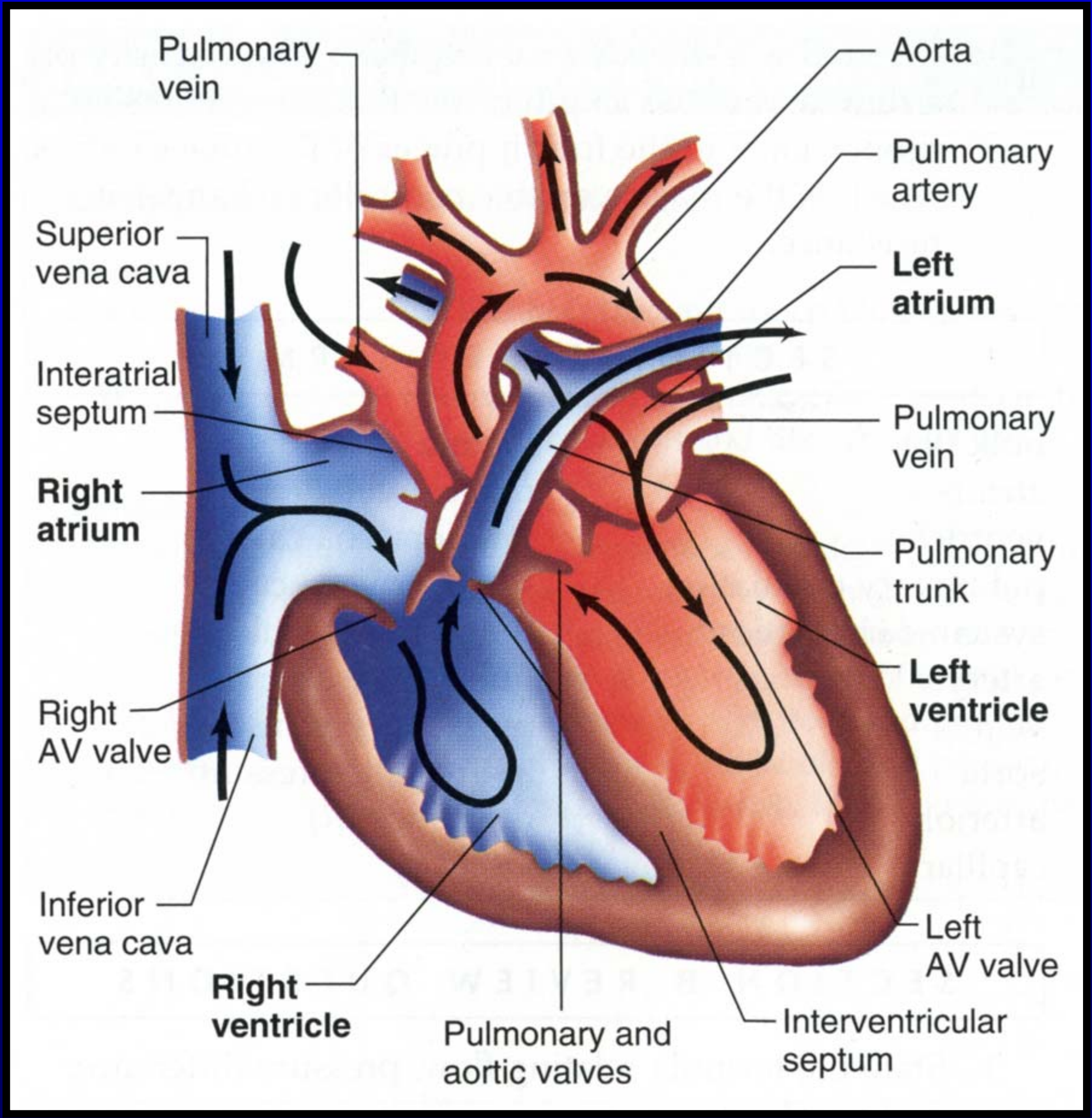
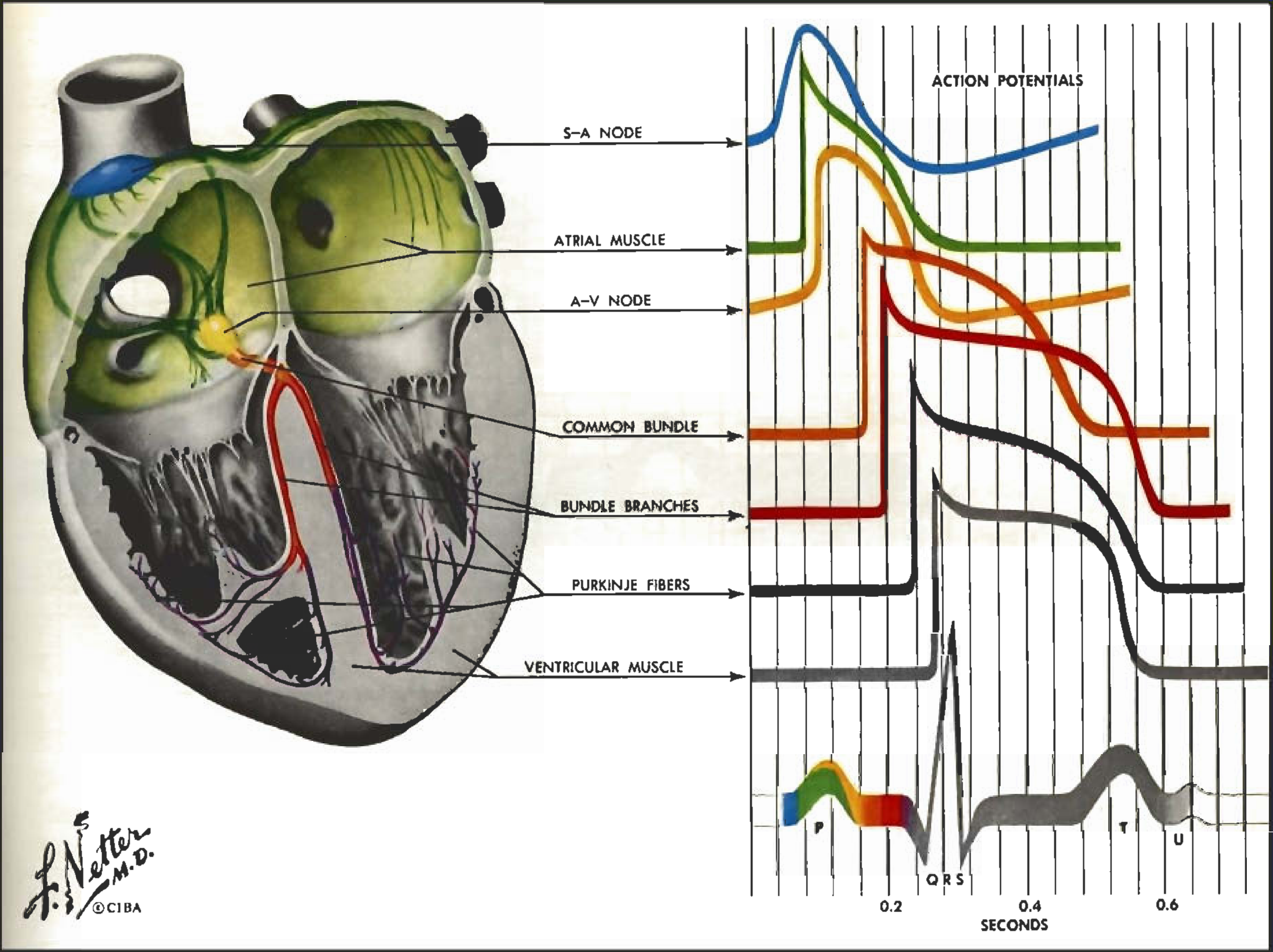
The Heart as a Pump

Prof. Roger Mark

Blood Flow in the Heart



From Vander


ACTION POTENTIALS
S-A NODE
ATRIAL MUSCLE
A-V NODE
COMMON BUNDLE
BUNDLE BRANCHES
PURKINJE FIBERS
VENTRICULAR MUSCLE
P
Q R S
T
U
0.2
0.4
0.6
SECONDS
F. Netter M.D.
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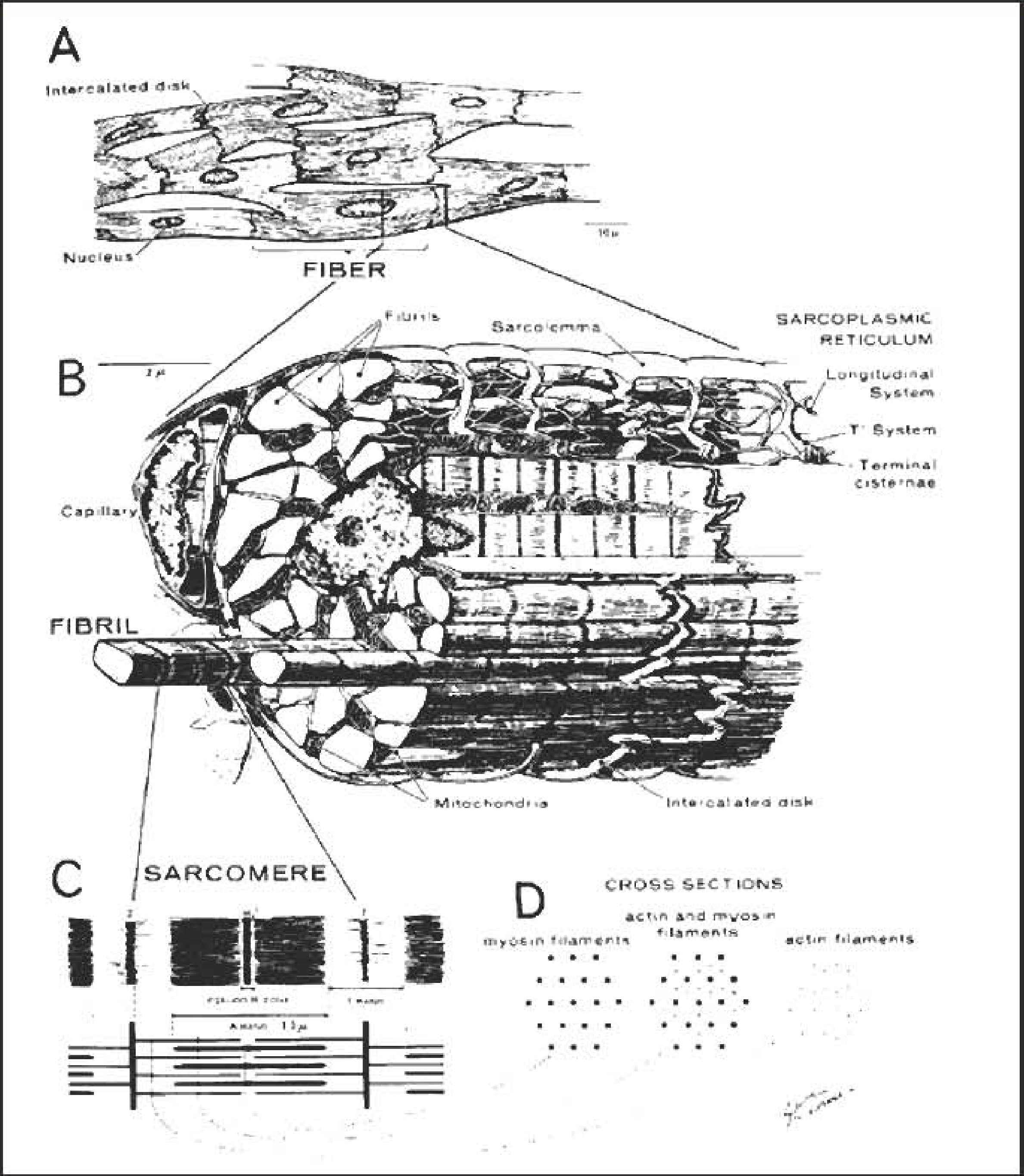

A
Intercalated disk
Nucleus
10 μ
FIBER
B
2 μ
Fibrils
Sarcolemma
SARCOPLASMIC
RETICULUM
Longitudinal System
T System
Terminal cisternae
Capillary
N
FIBRIL
Mitochondria
Intercalated disk
C
SARCOMERE
A band 1.5 μ
D
CROSS SECTIONS
myosin filaments
actin and myosin filaments
actin filaments

Filament Arrangement in Skeletal Muscle

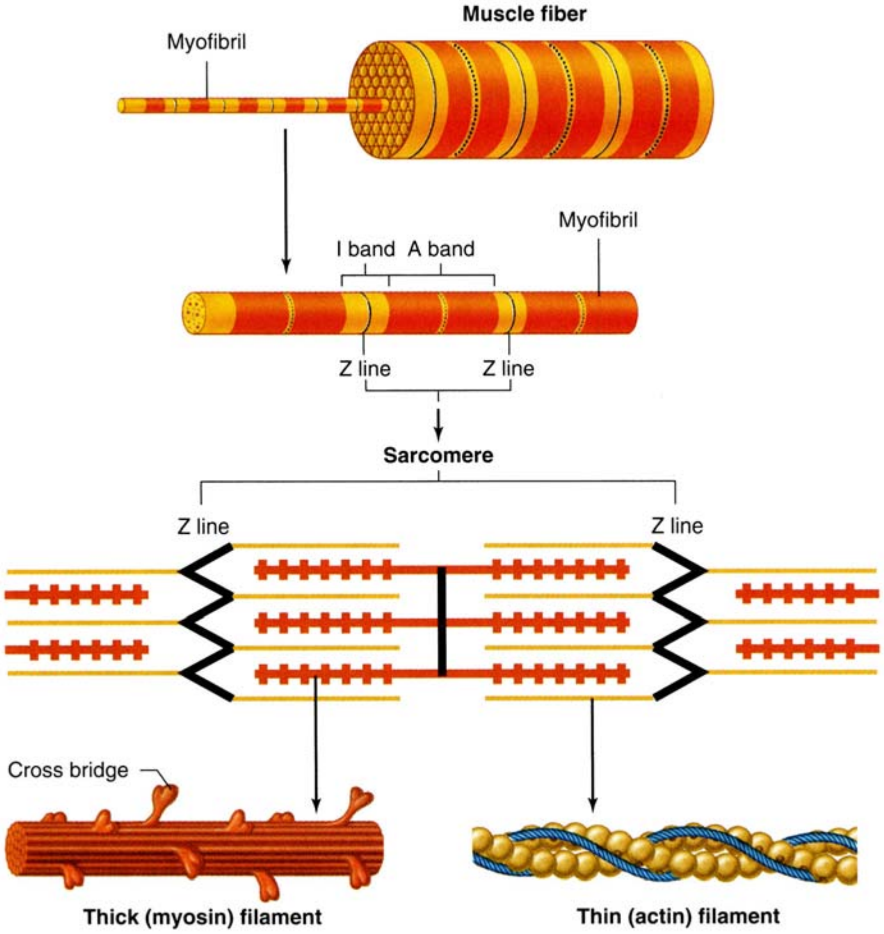


FIGURE 11–4

Arrangement of filaments in a skeletal-muscle fiber that produces the striated banding pattern.

From Vander

Myosin Molecule

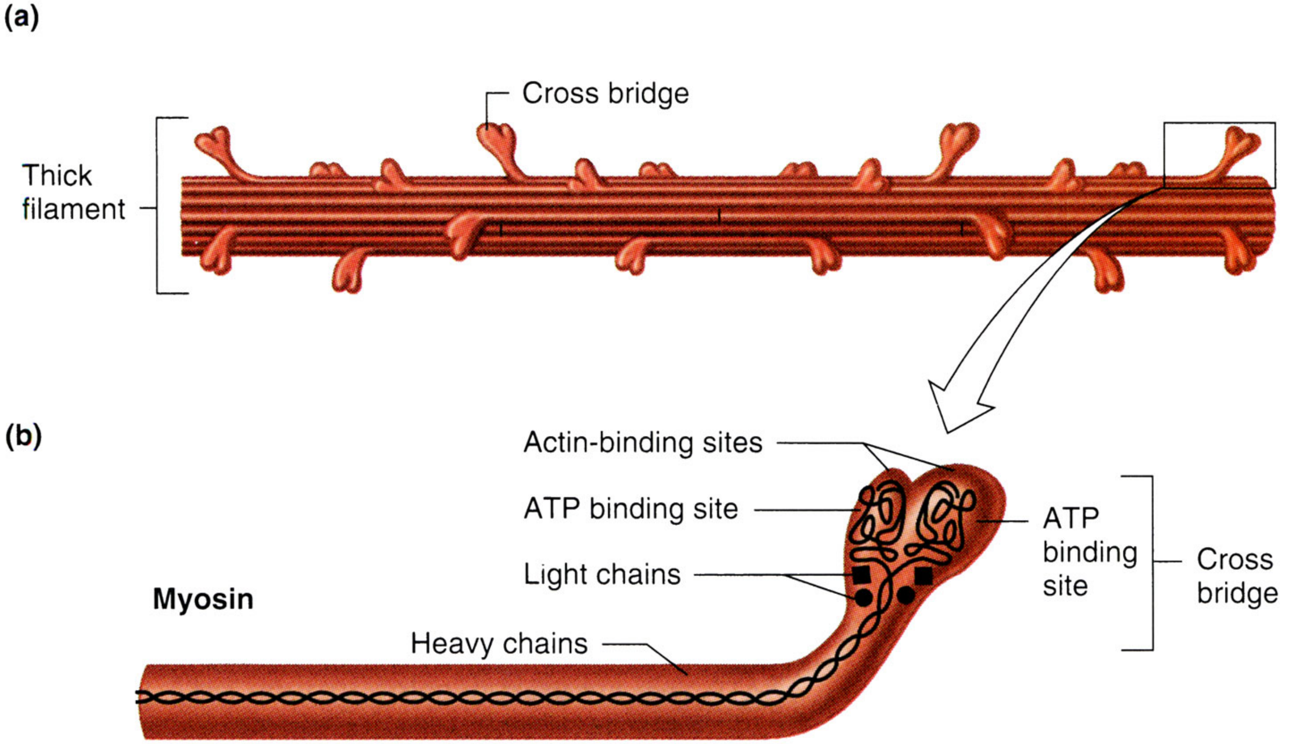


FIGURE 11–11

(a) The heavy chains of myosin molecules form the core of a thick filament. The myosin molecules are oriented in opposite directions in either half of a thick filament. (b) Structure of a myosin molecule. The two globular heads of each myosin molecule extend from the sides of a thick filament forming a cross bridge.

From Vander

Troponin and Tropomyosin

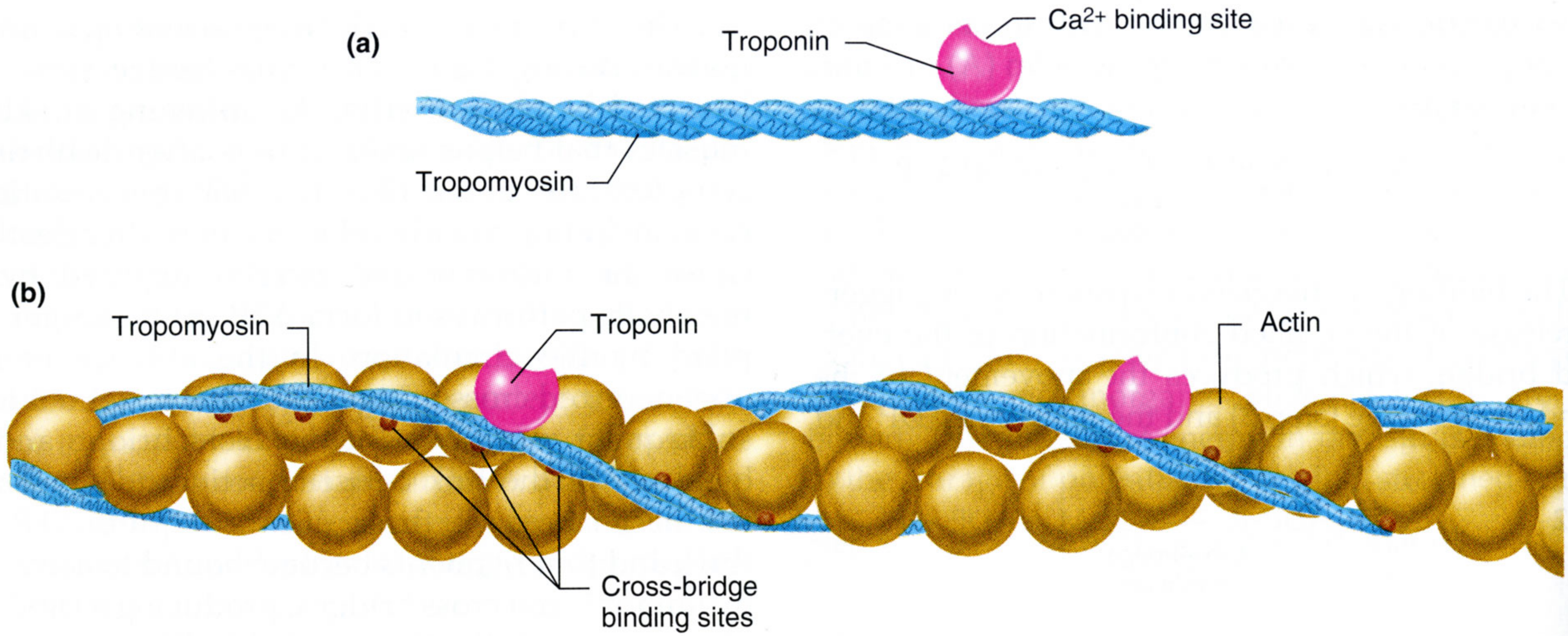


FIGURE 11–13

(a) Molecule of troponin bound to a molecule of tropomyosin. (b) Two chains of tropomyosin on a thin filament regulate access of cross bridges to binding sites on actin.

From Vander

The Cross-bridge Cycle

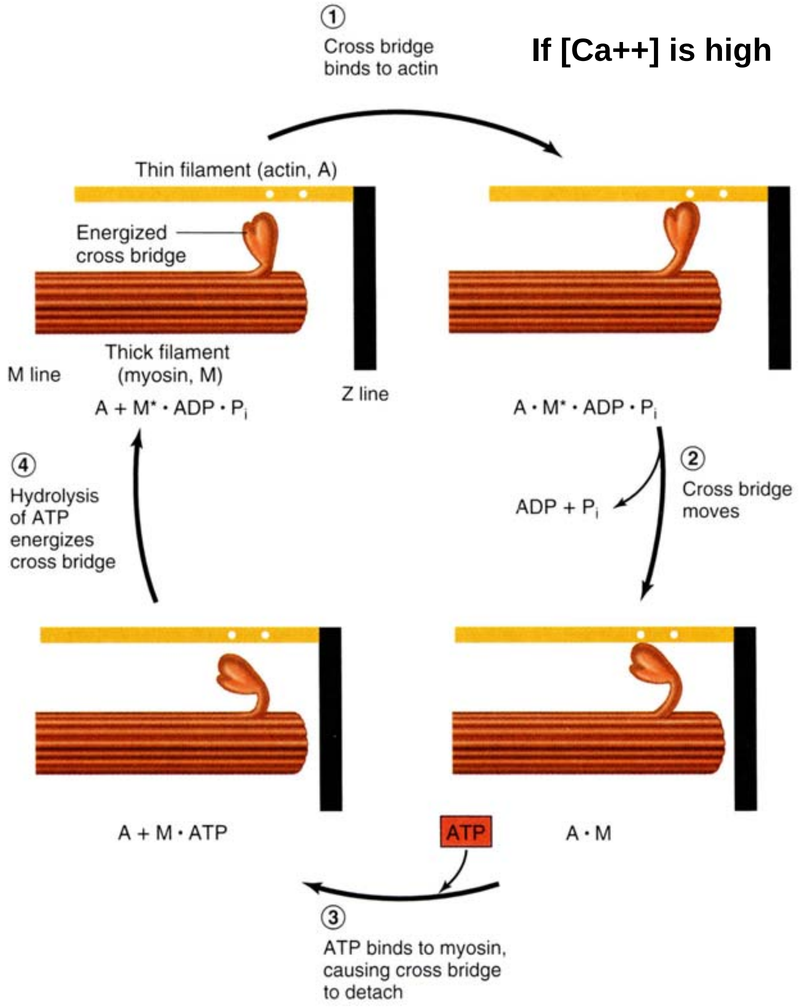


FIGURE 11–12

Chemical and mechanical changes during the four stages of a cross-bridge cycle. In a resting muscle fiber, contraction begins with the binding of a cross bridge to actin in a thin filament—step 1. (M* represents an energized myosin cross bridge.)

From Vander

Skeletal Muscle Anatomy

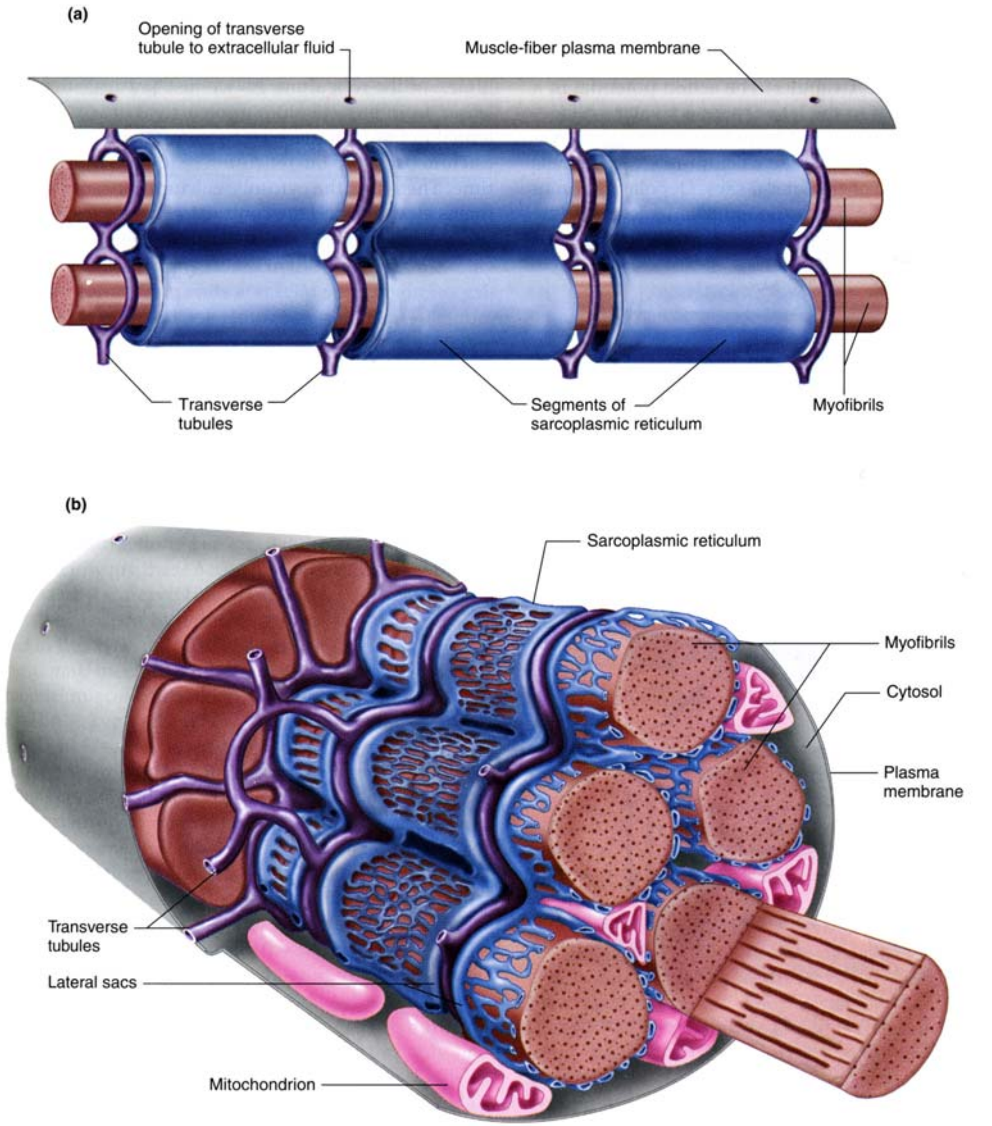


FIGURE 11–15

(a) Diagrammatic representation of the sarcoplasmic reticulum, the transverse tubules, and the myofibrils. (b) Anatomical structure of transverse tubules and sarcoplasmic reticulum in a single skeletal-muscle fiber.

From Vander

Calcium Dynamics in Contraction and Relaxation

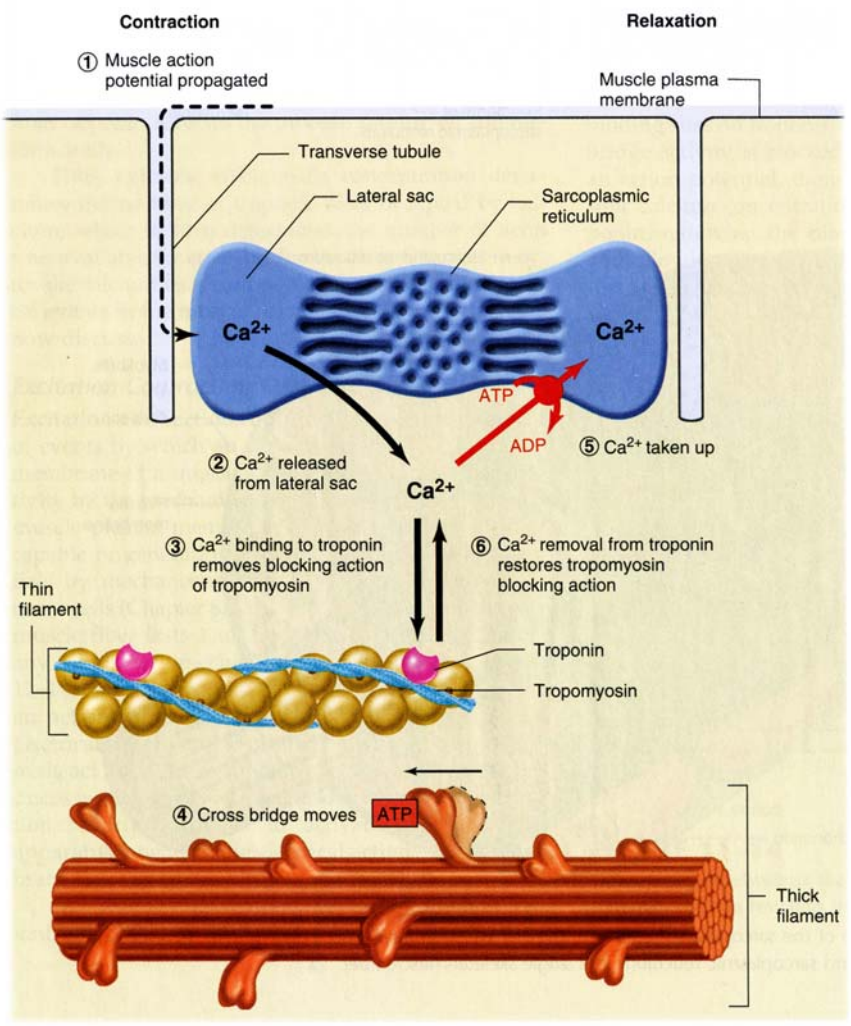
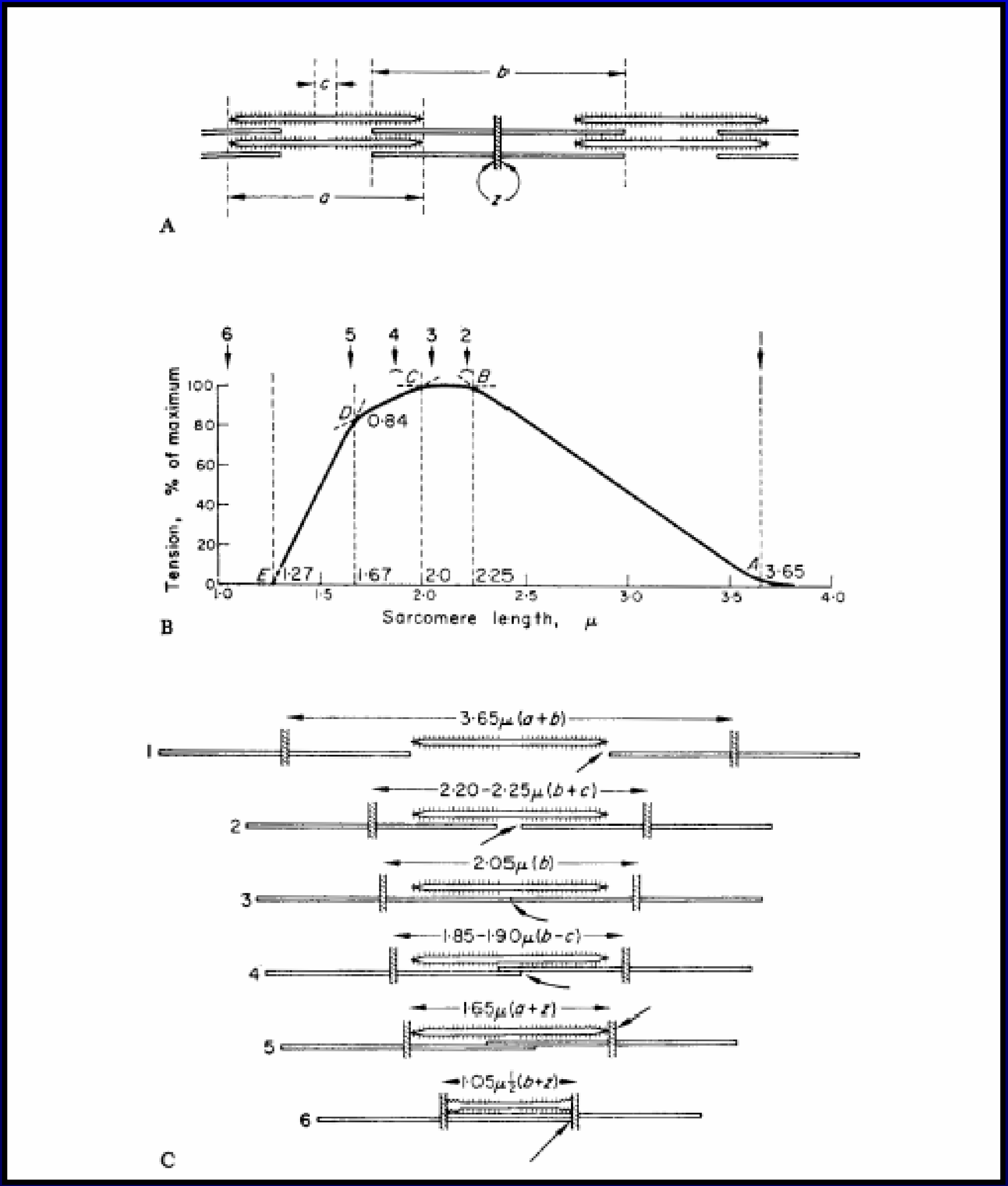


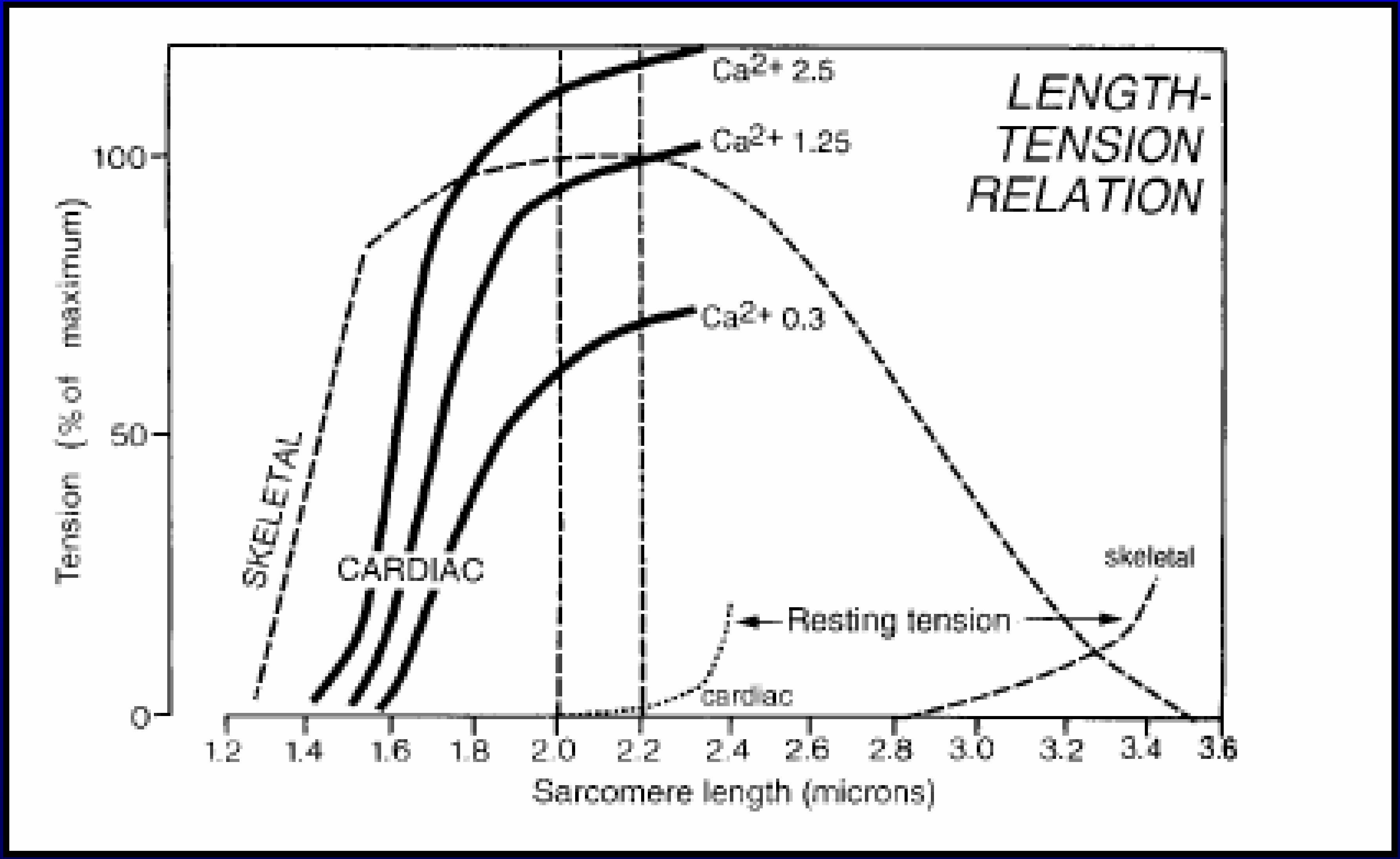
FIGURE 11–16
Release and uptake of calcium by the sarcoplasmic reticulum during contraction and relaxation of a skeletal-muscle fiber.

From Vander

Length-Tension Relationship in Skeletal Muscle

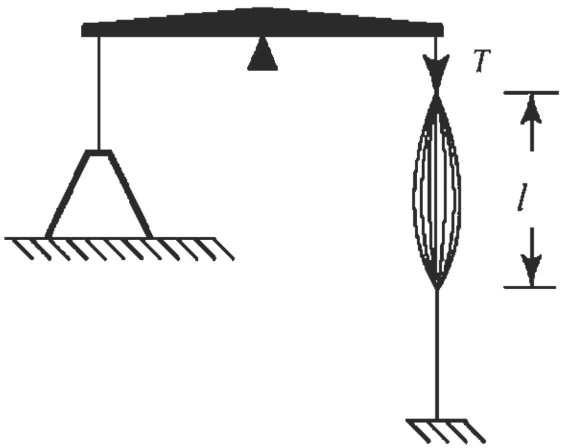


Cardiac vs. Skeletal Muscle

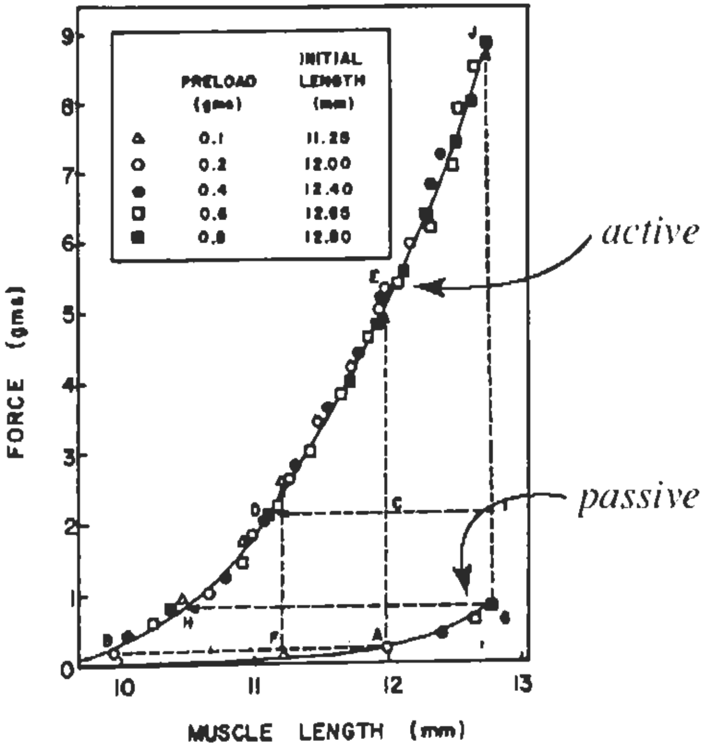


Pump Function: Toward a Model

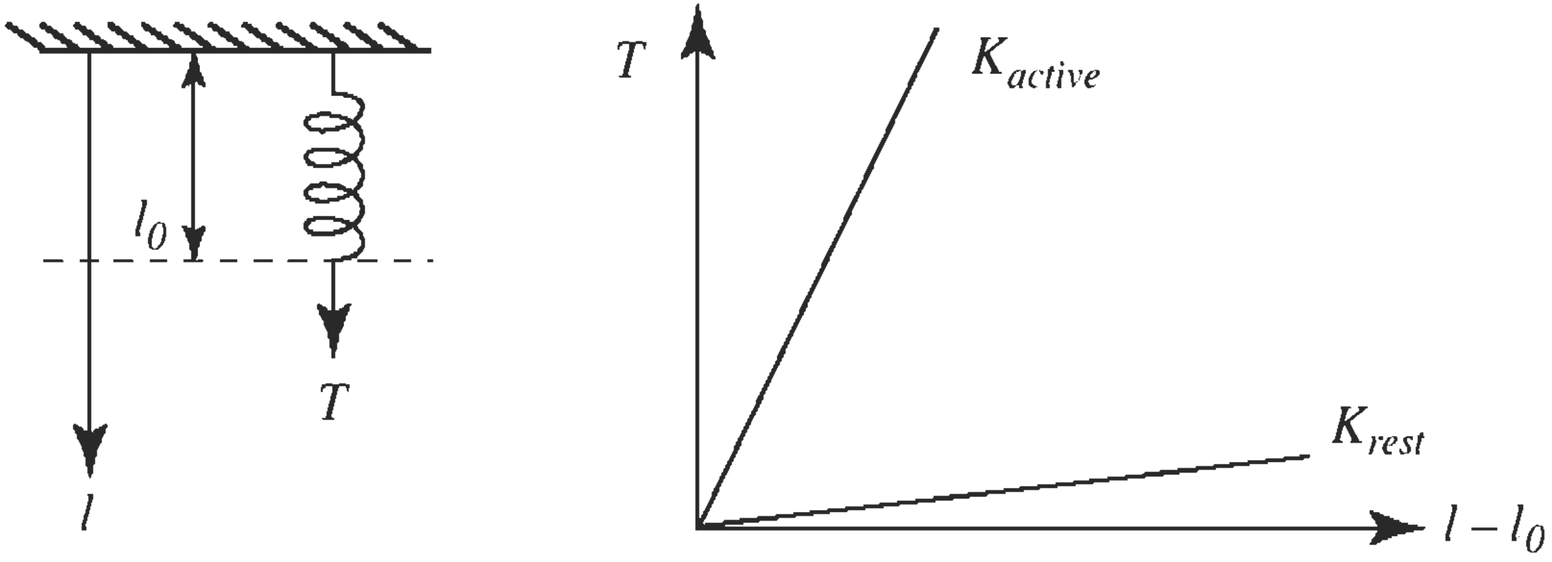
Isolated Cardiac Muscle Experiments



a. Experimental Apparatus

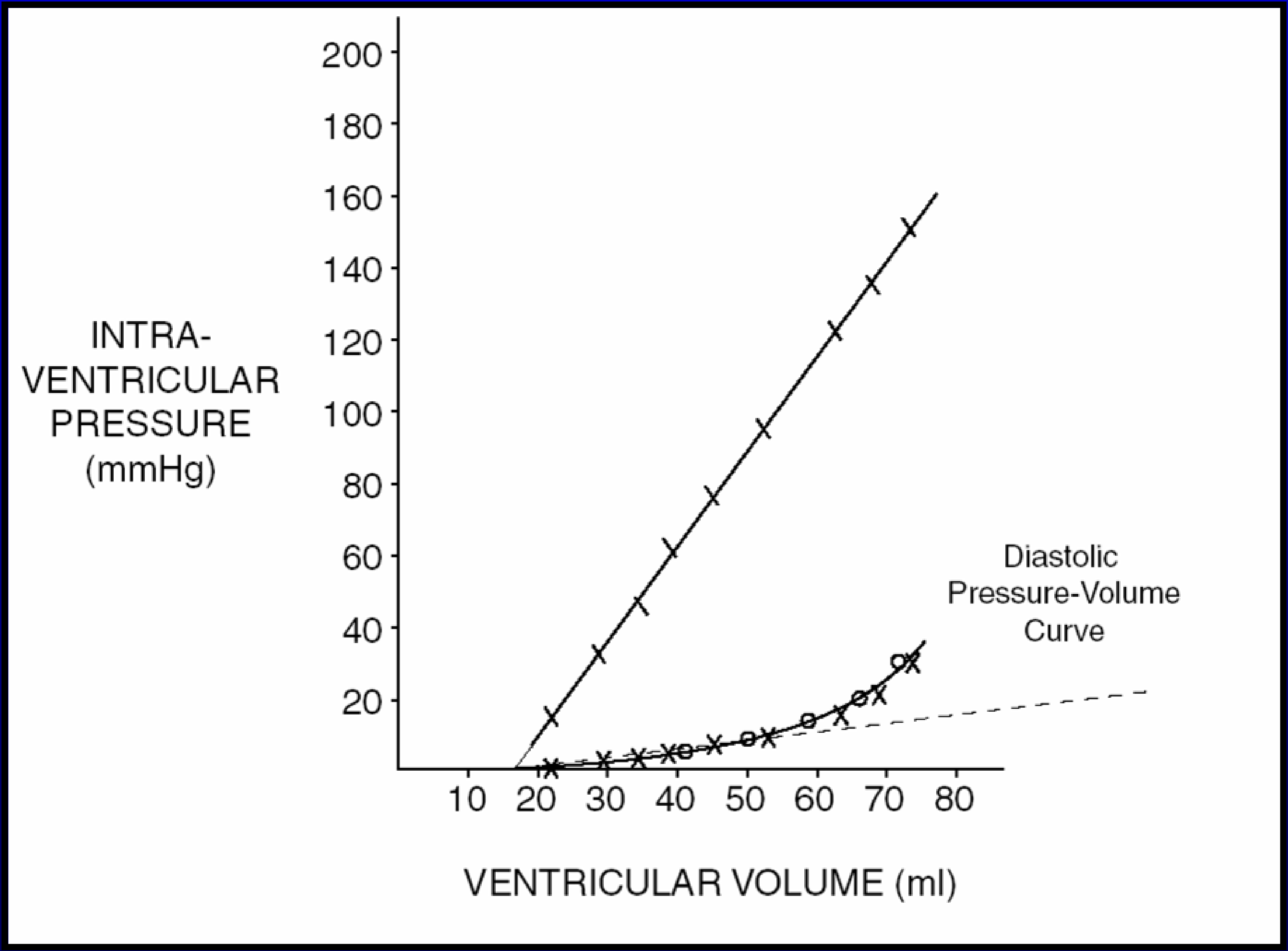


b. *Relation between Force (Tension) and Length for ıe Cat Papillary Muscle (Reproduced from Downing and Sonnenblick*[95] *with the Permission of the Publisher).*

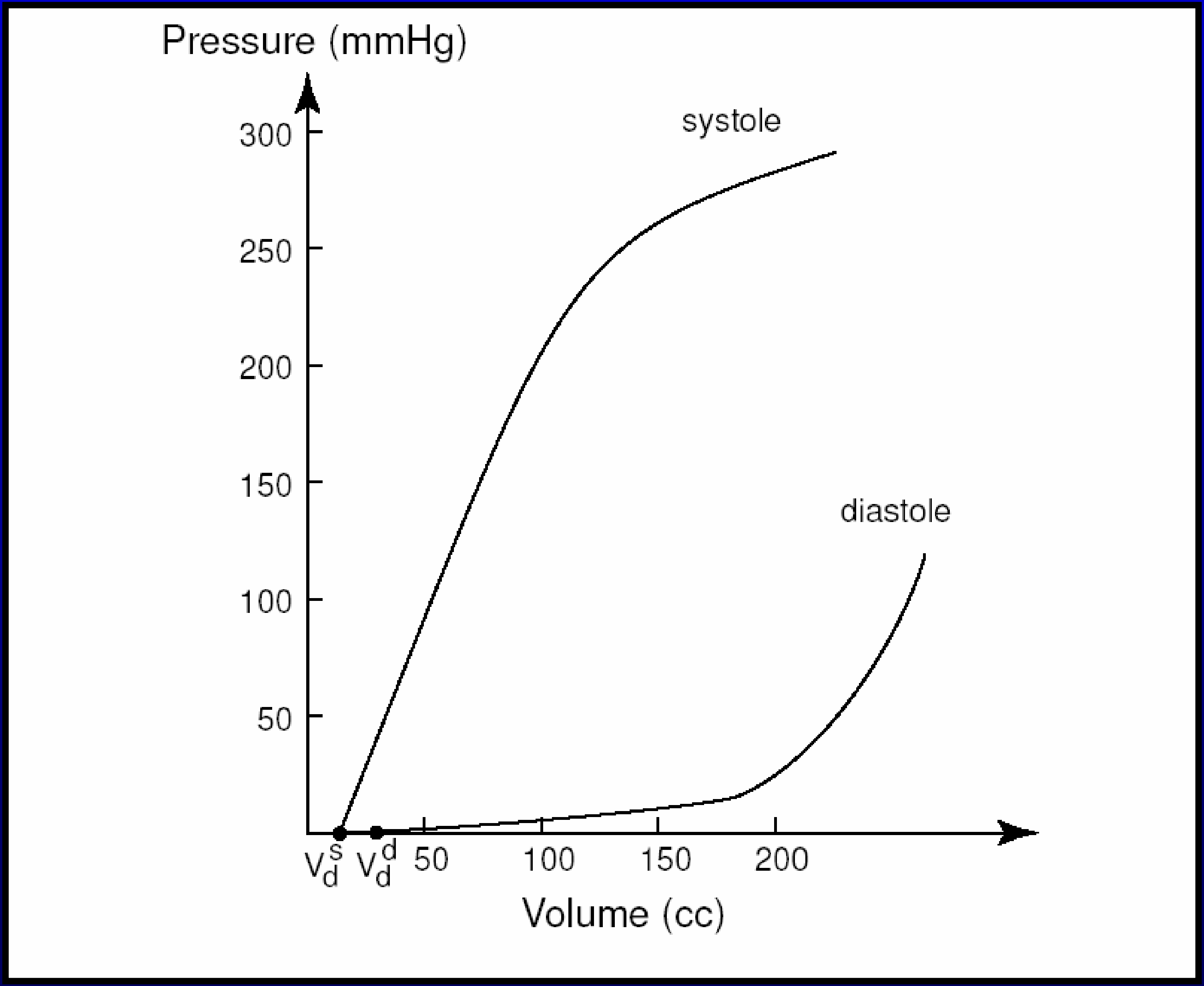


The Two-State Spring Model

Isovolumetric Contraction: Dog Ventricle

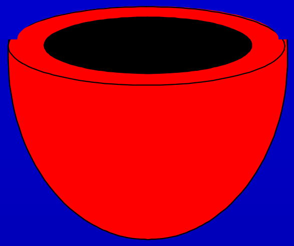


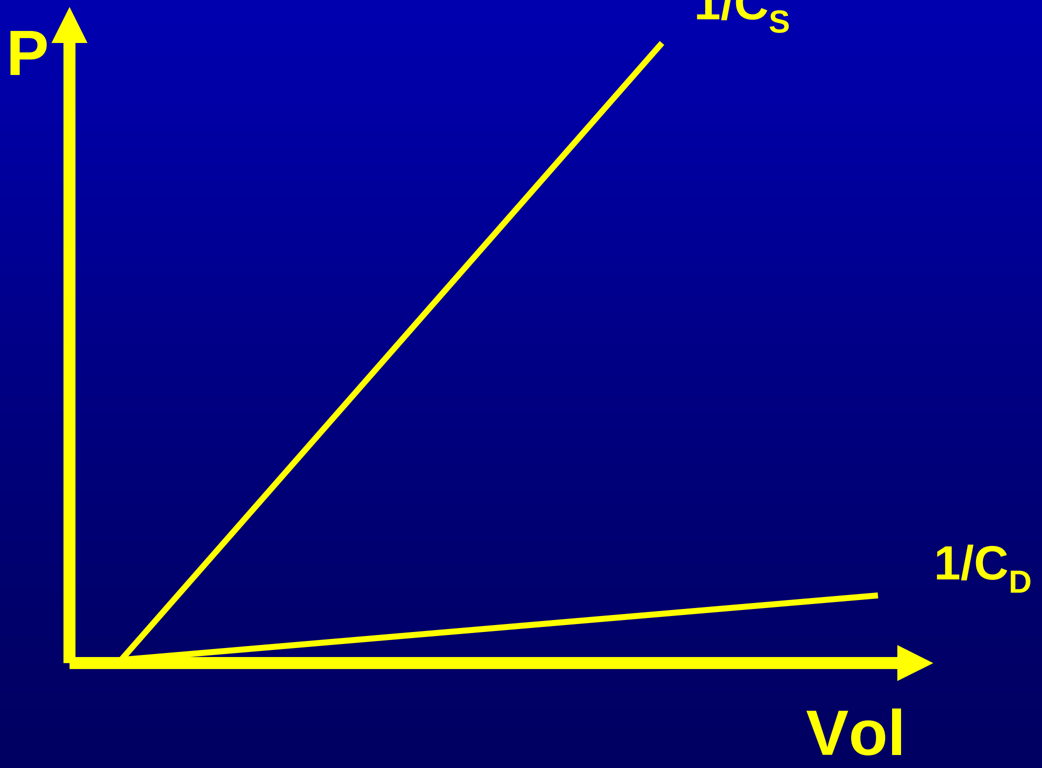
LV Pressure Volume Curves: Human

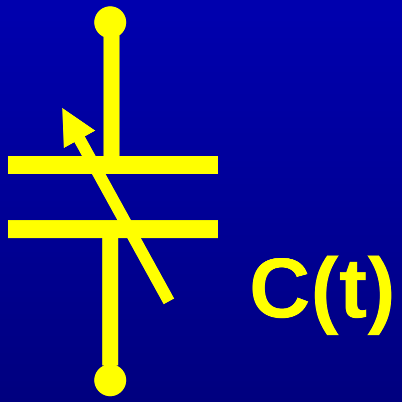


Model of Ventricle

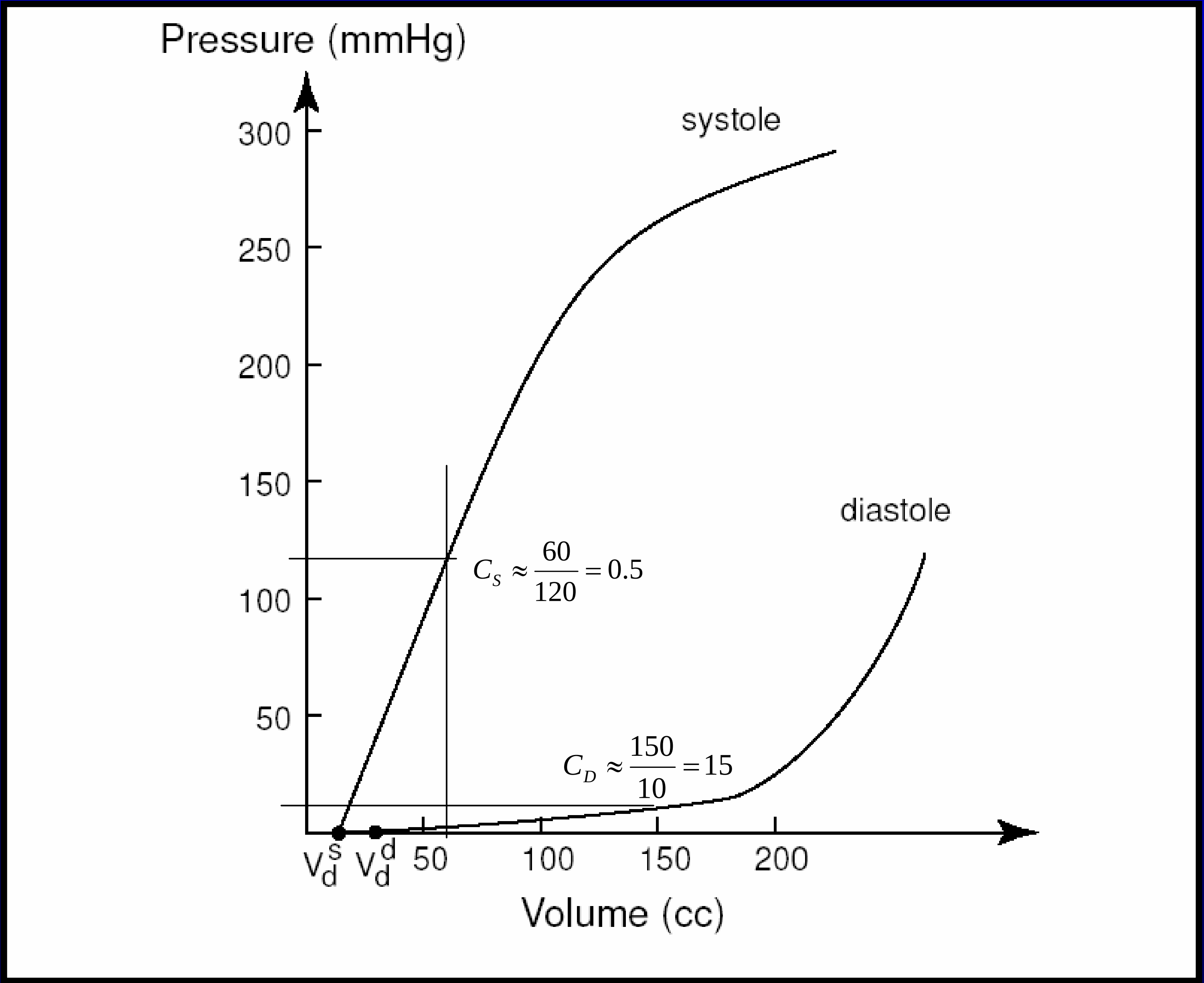
$C = \Delta V / \Delta P$





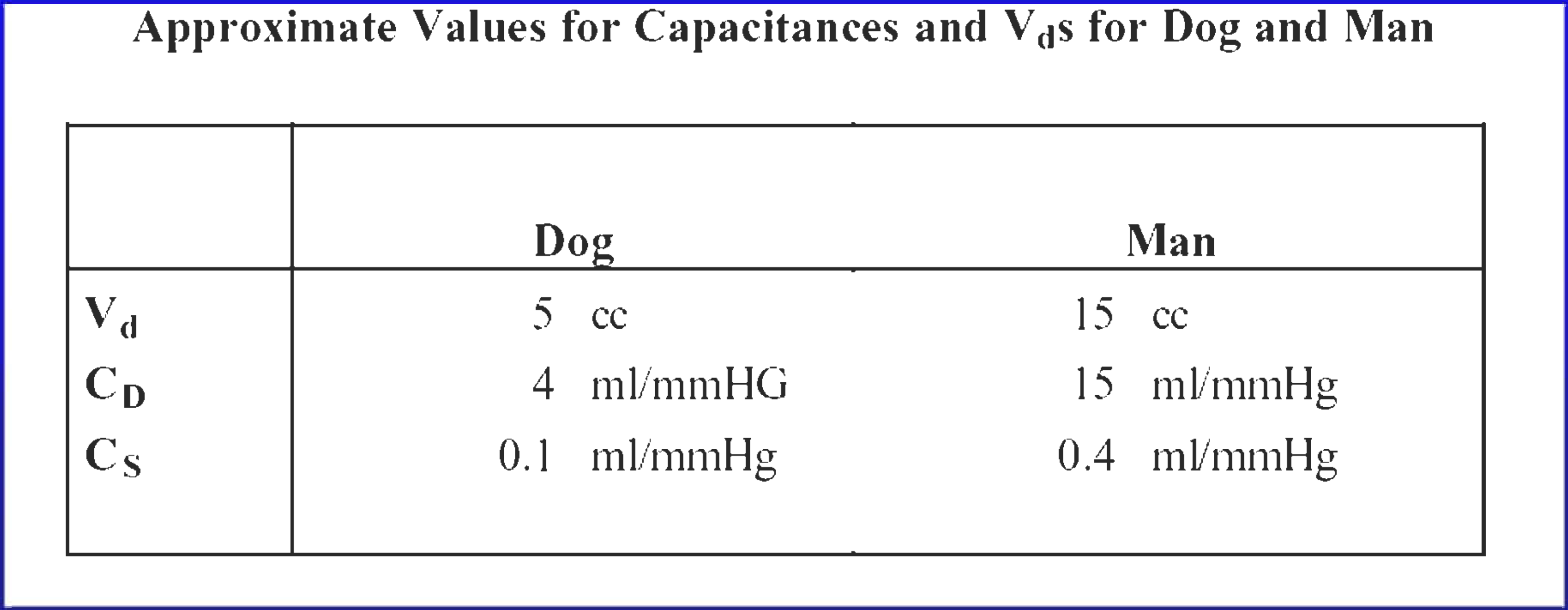


Estimates of Systolic and Diastolic Capacitances



$$C_S \approx \frac{60}{120} = 0.5$$

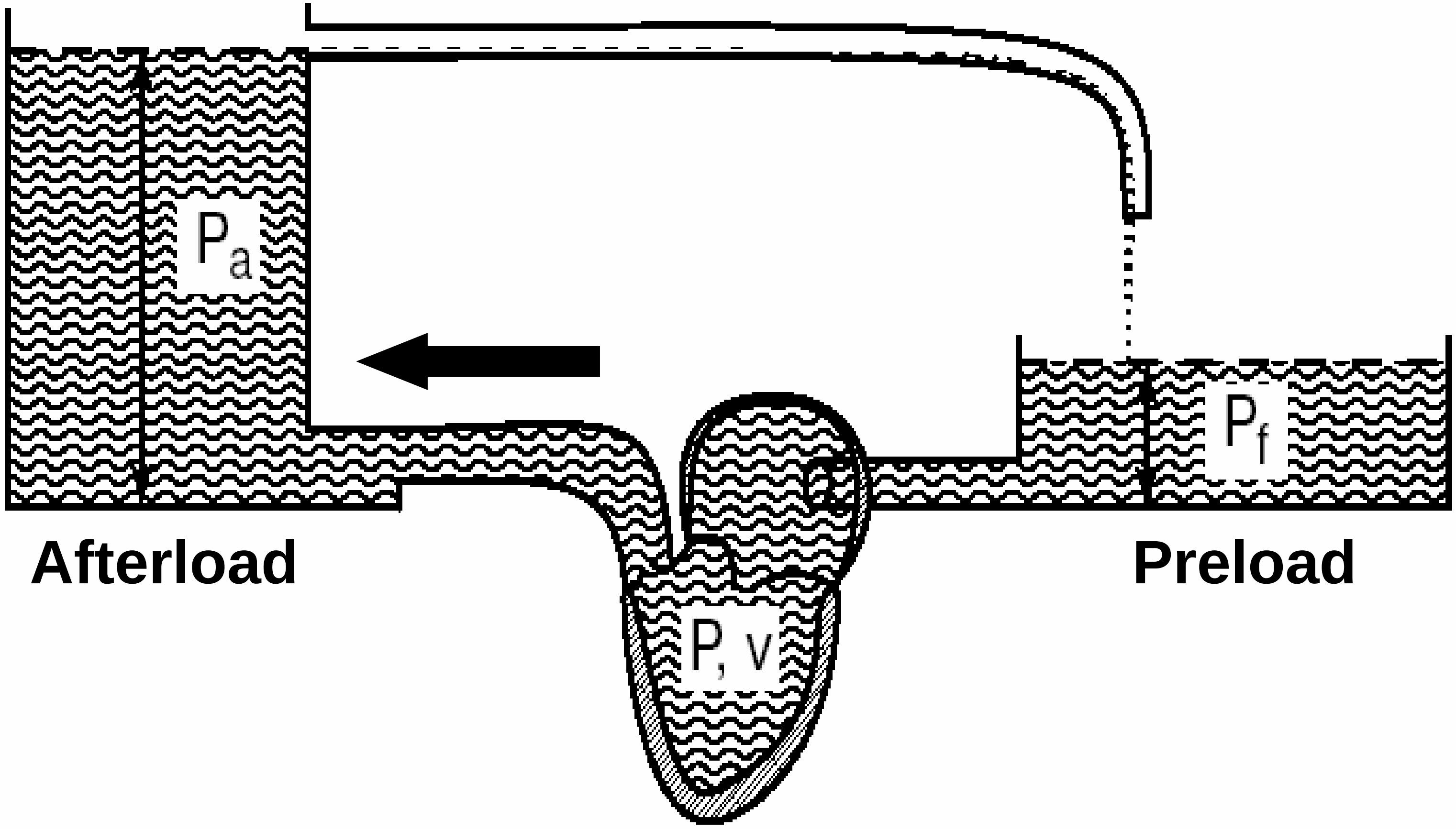
$$C_D \approx \frac{150}{10} = 15$$



Approximate Values for Capacitances and V_ds for Dog and Man

	Dog	Man
V_d	5 cc	15 cc
C_D	4 ml/mmHG	15 ml/mmHg
C_S	0.1 ml/mmHg	0.4 ml/mmHg

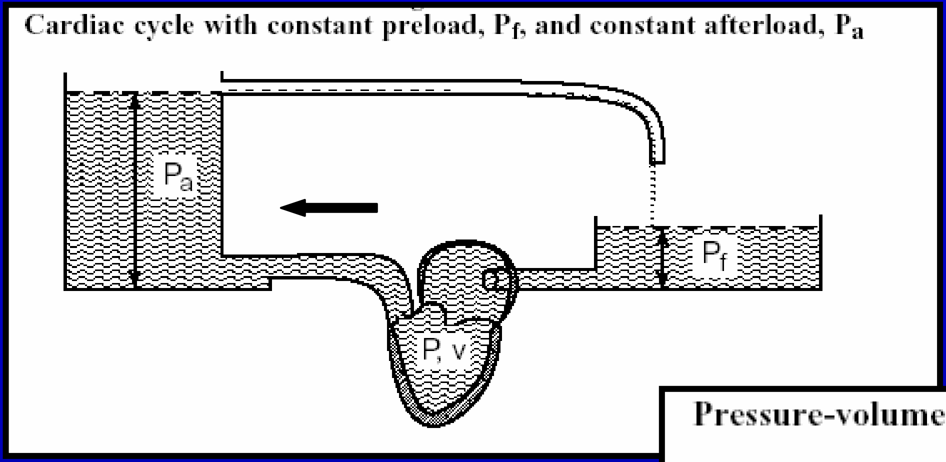
Cardiac cycle with constant preload, P_f, and constant afterload, P_a



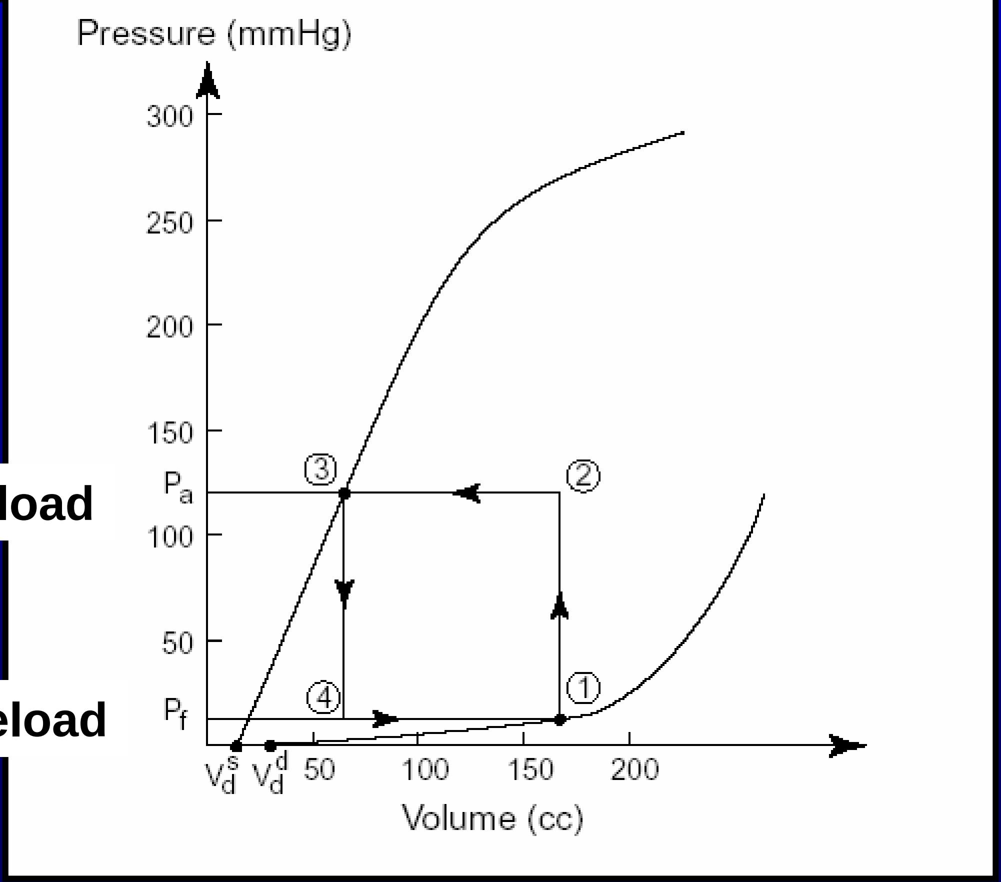
Afterload

Preload

Cardiac cycle with constant preload, P_f, and constant afterload, P_a



Pressure-volume loop during constant pre- and afterload

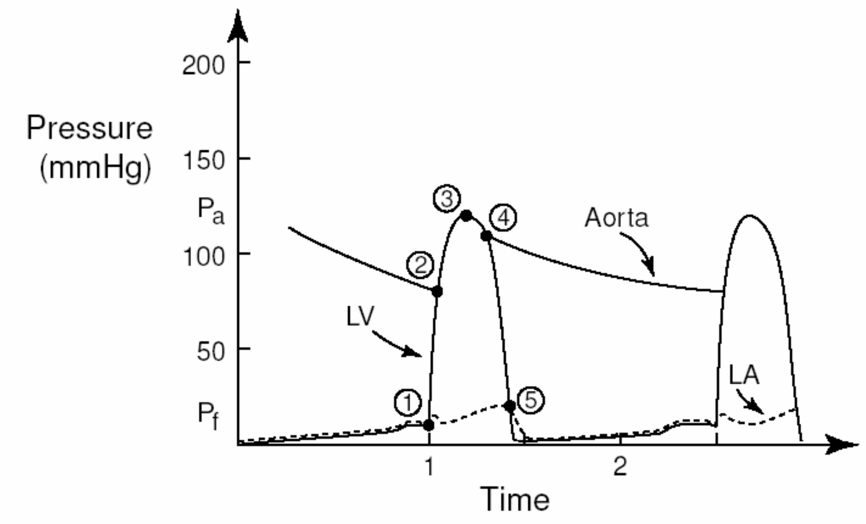


Afterload

Preload

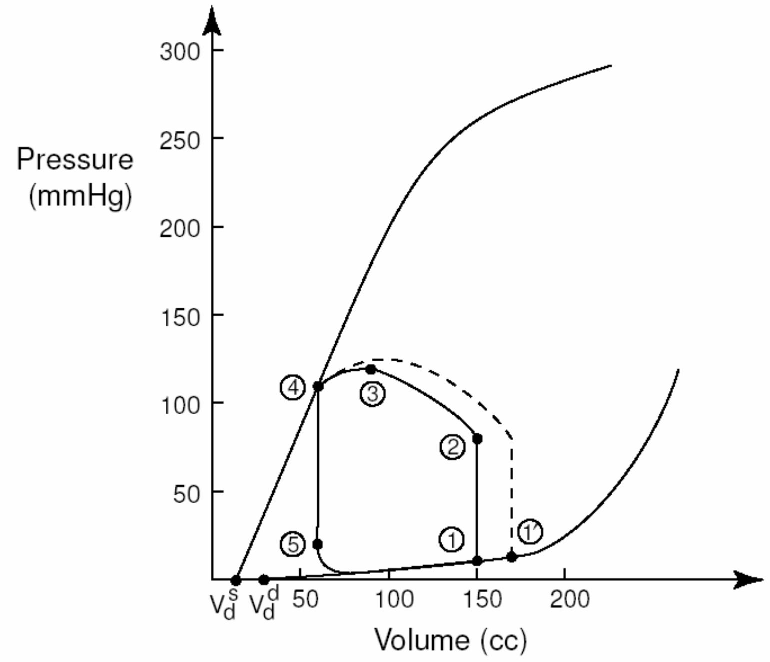
Pressure vs Time With Aortic Load

Left ventricular (LV), aortic, and left atrial (LA) pressure versus time

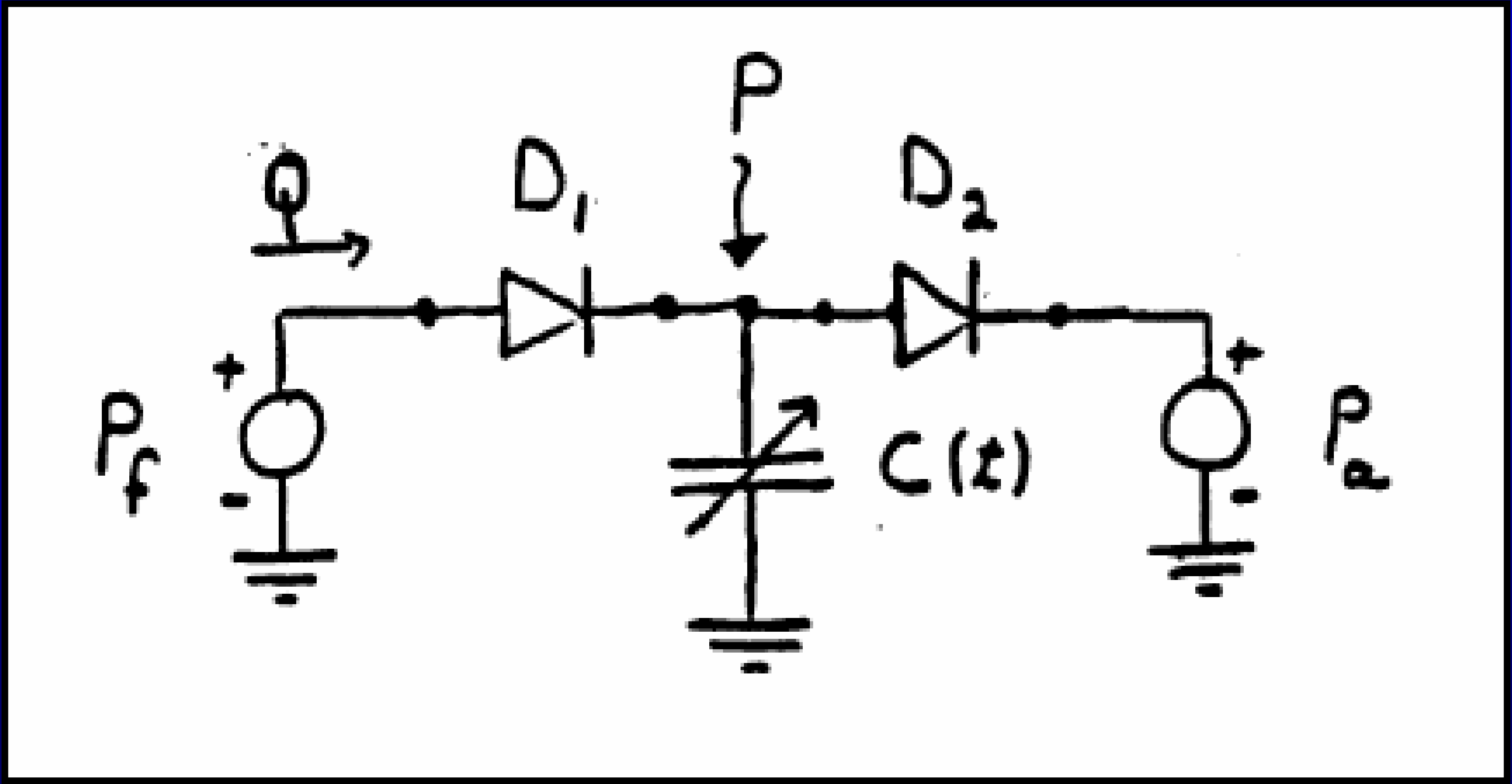


Pressure vs Volume

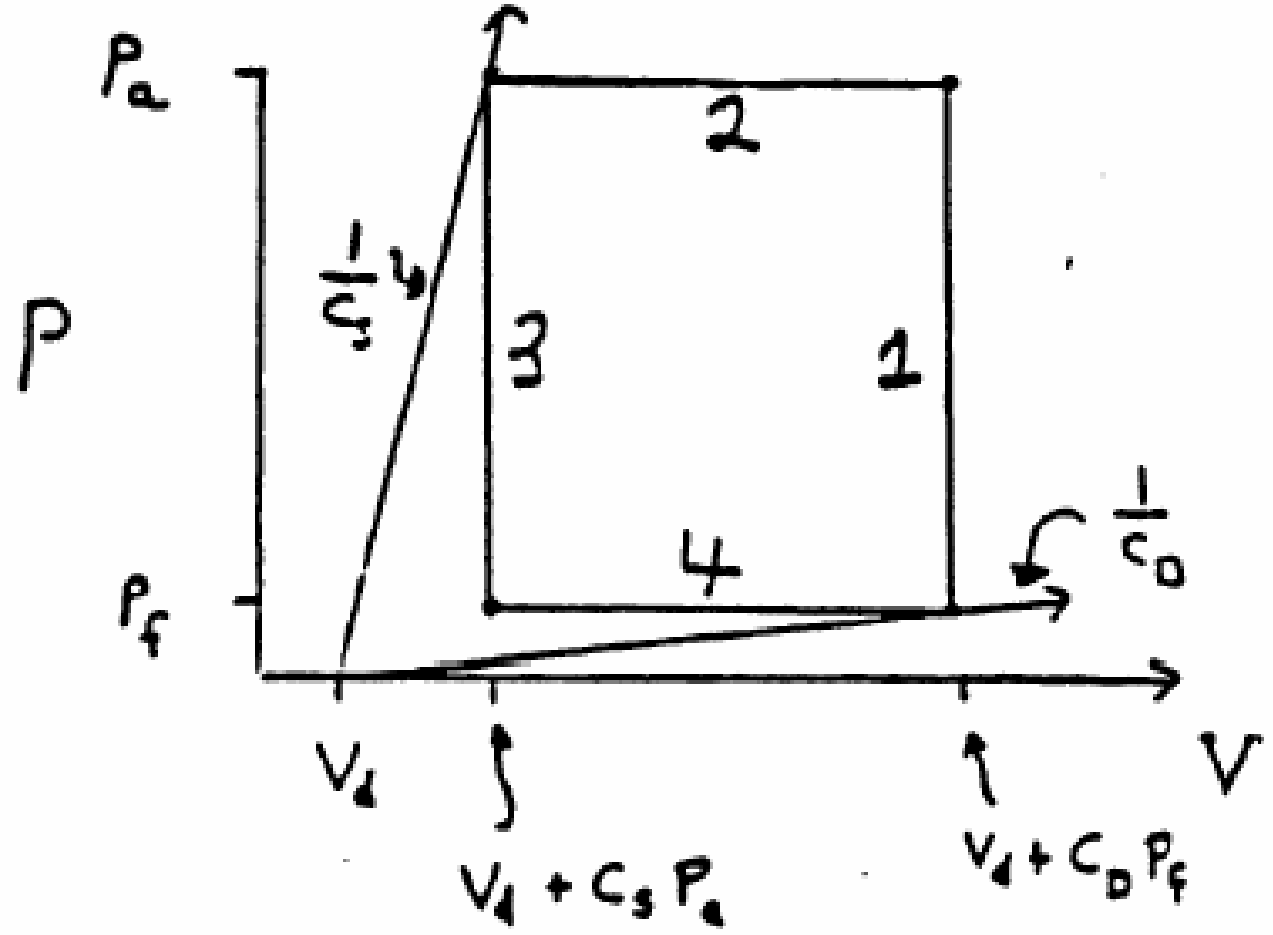
The LV pressure-volume loop when the heart is attached to the aorta



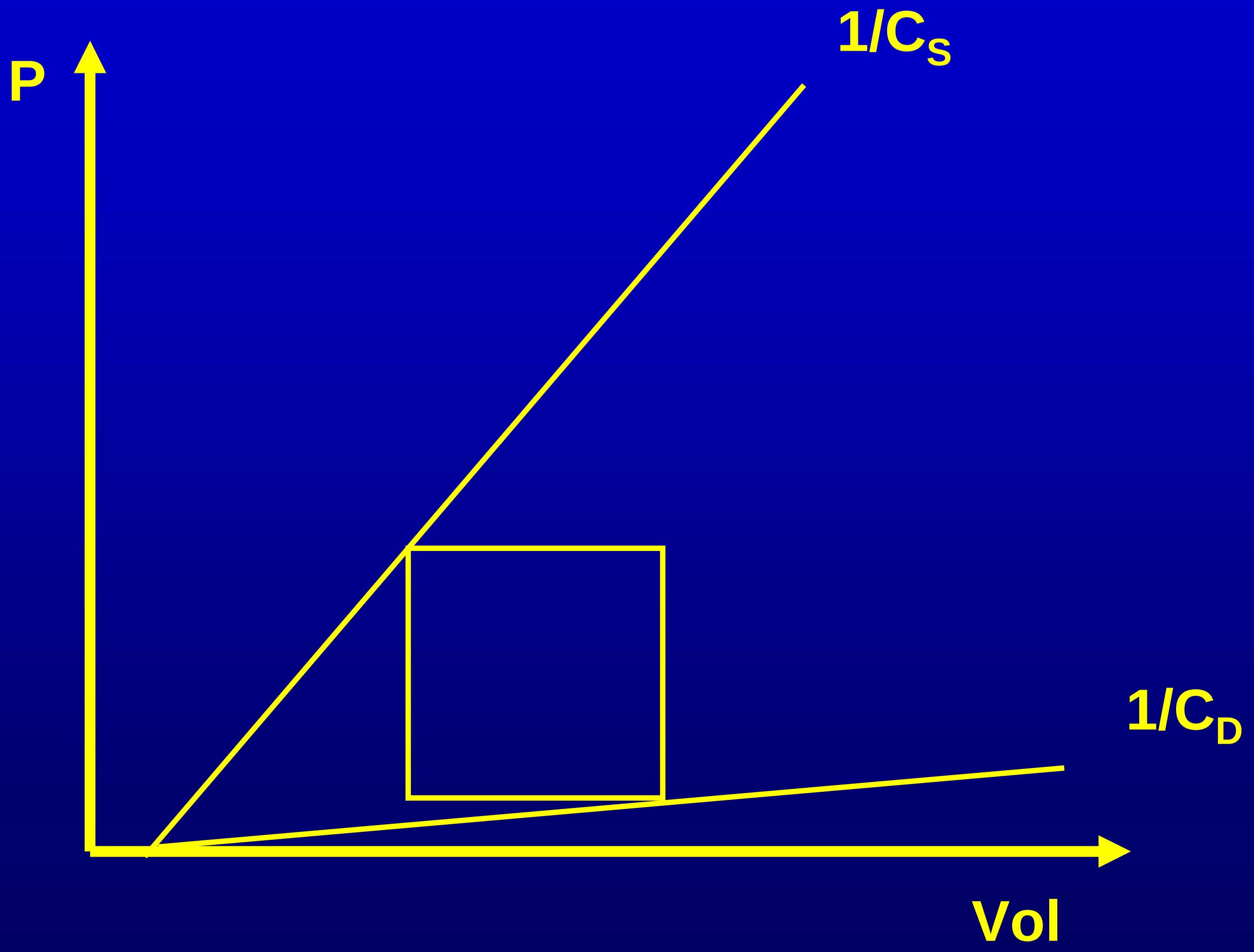
Ventricular Model with Constant Preload and Afterload



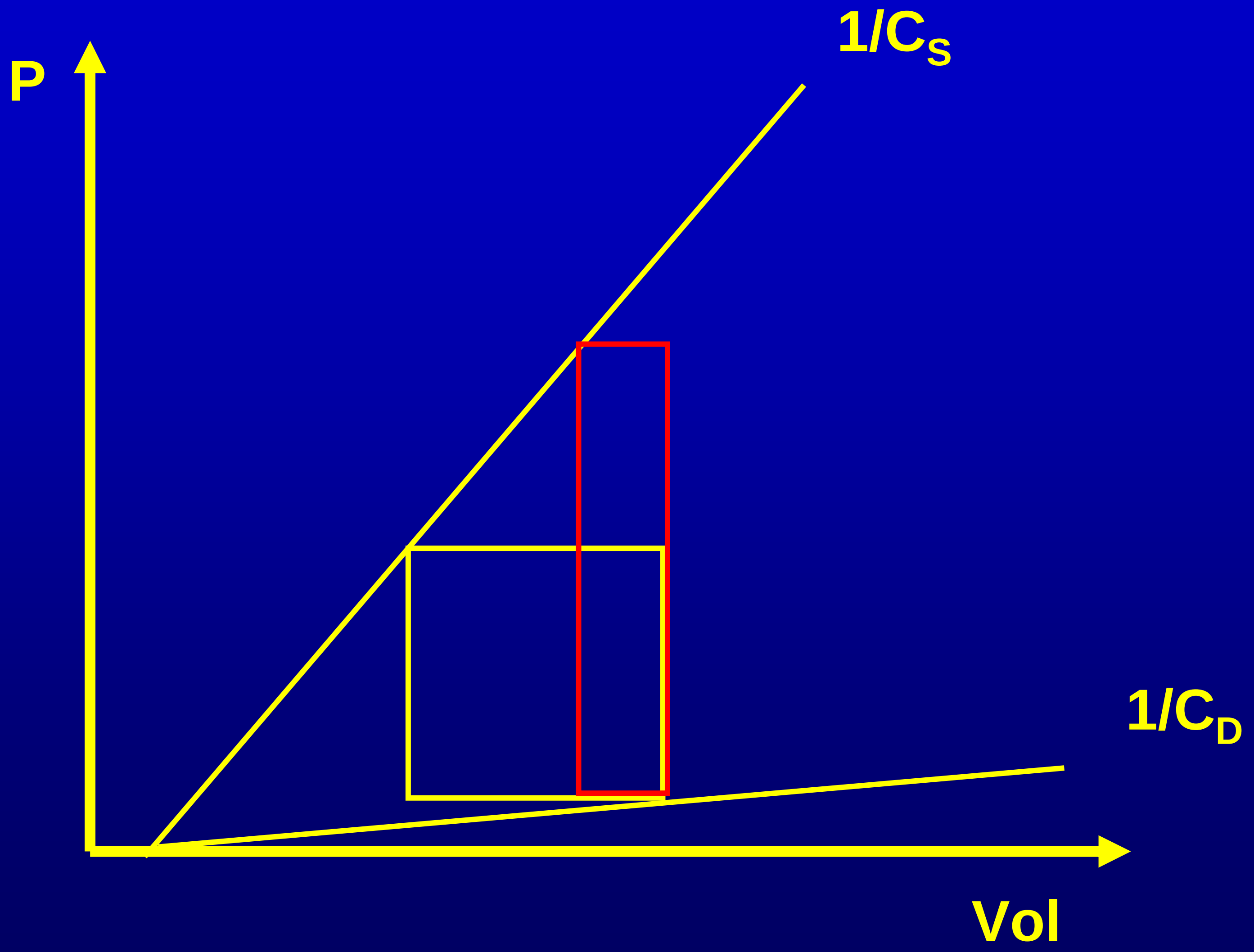
Cardiac Cycle in the P-V Plane



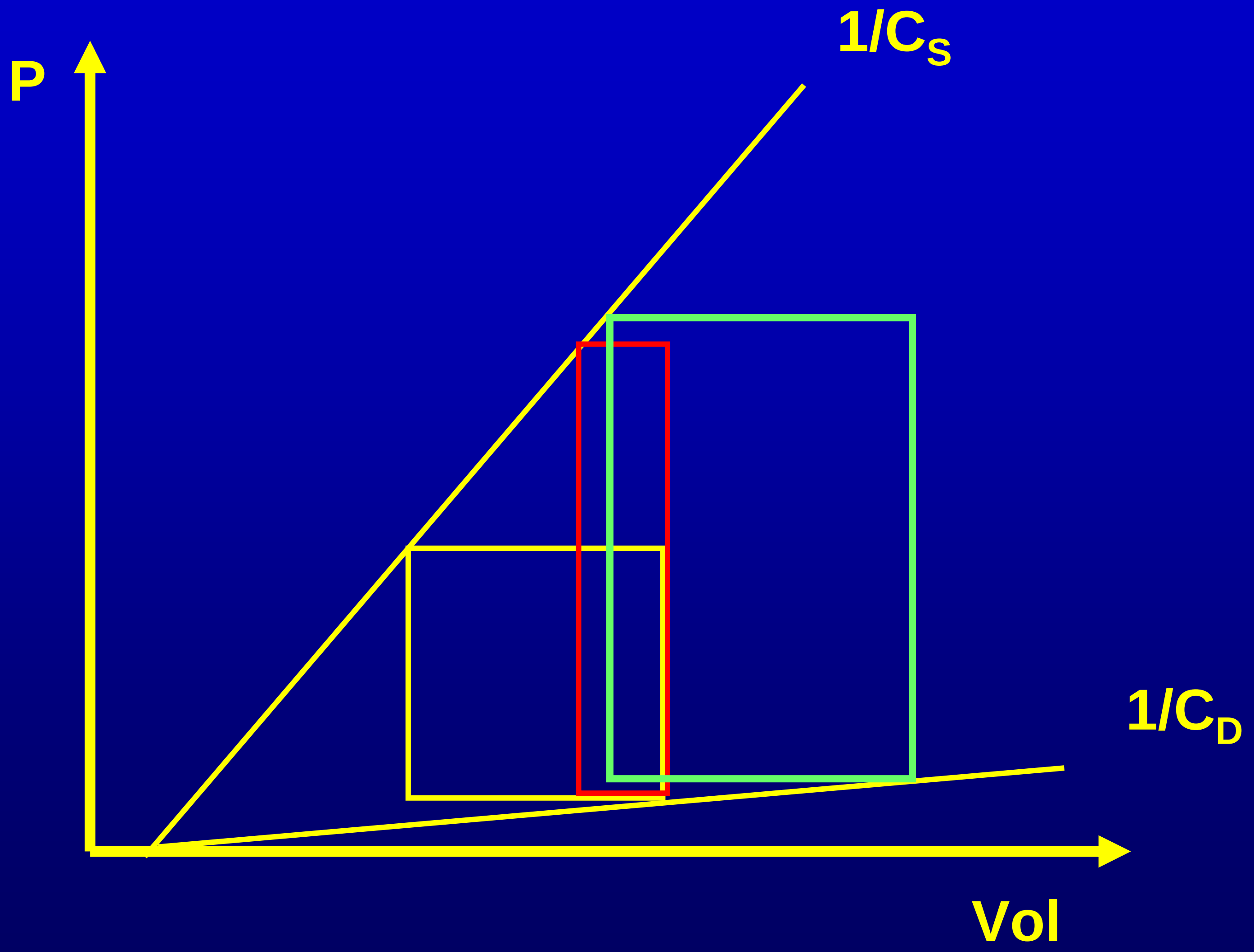
Varying Pre- and Afterloads



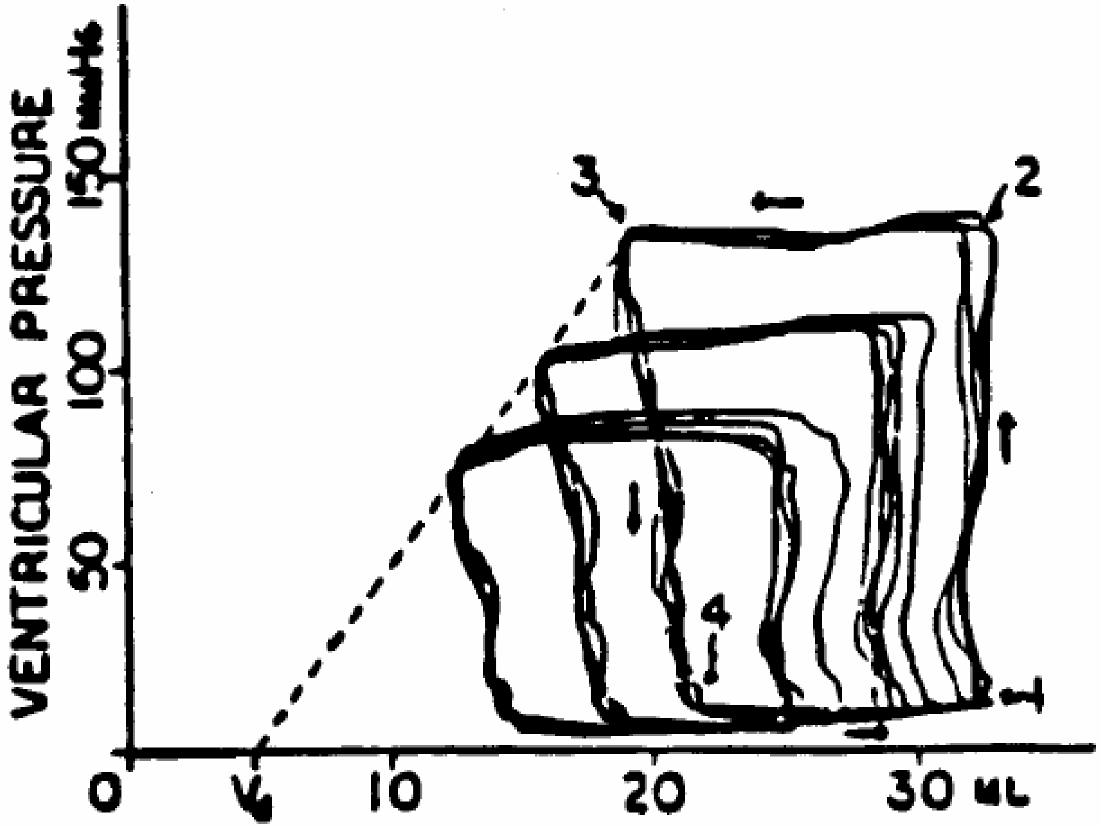
Varying Pre- and Afterloads



Varying Pre- and Afterloads

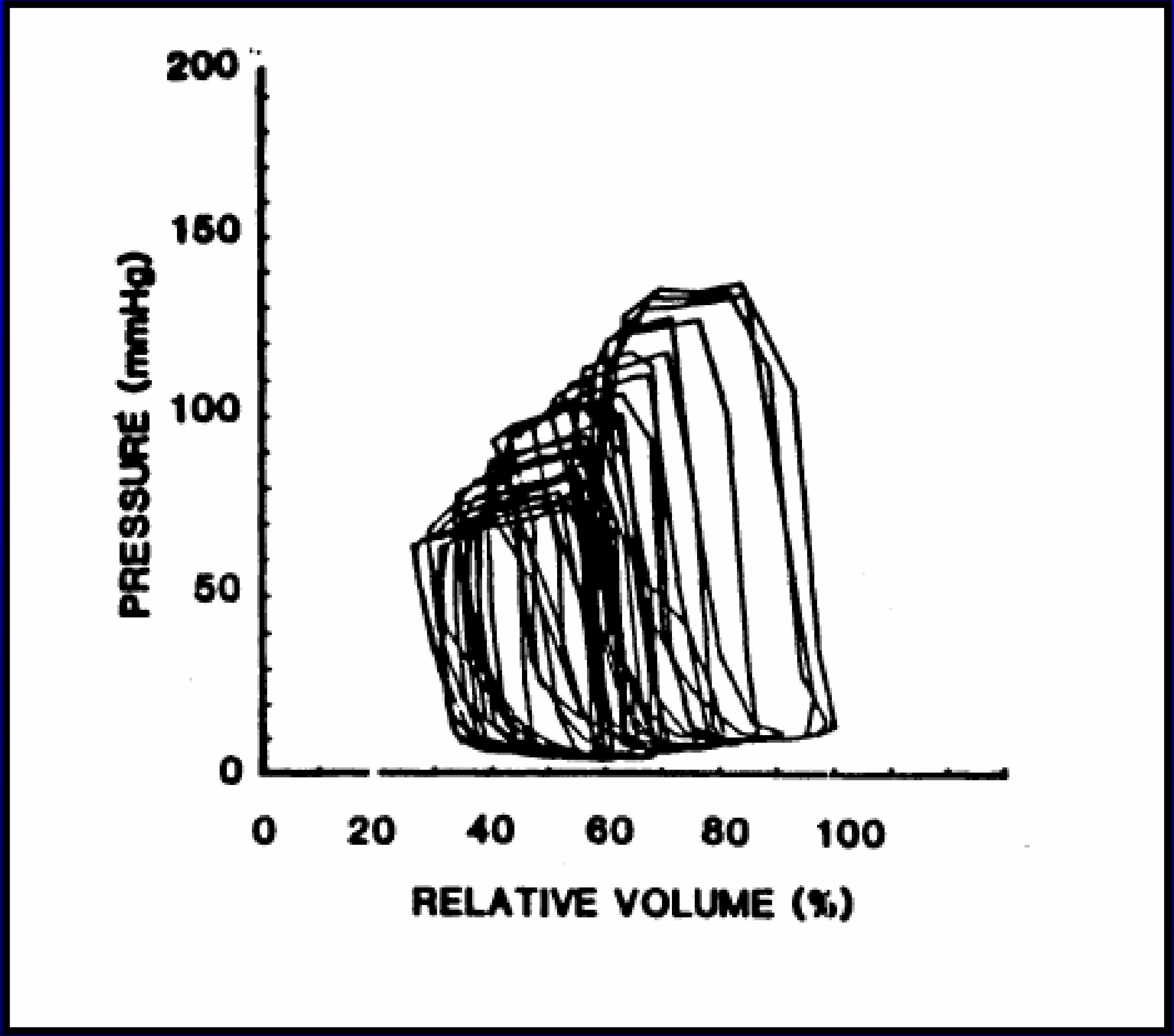


PV Loops(dog): fixed contractility

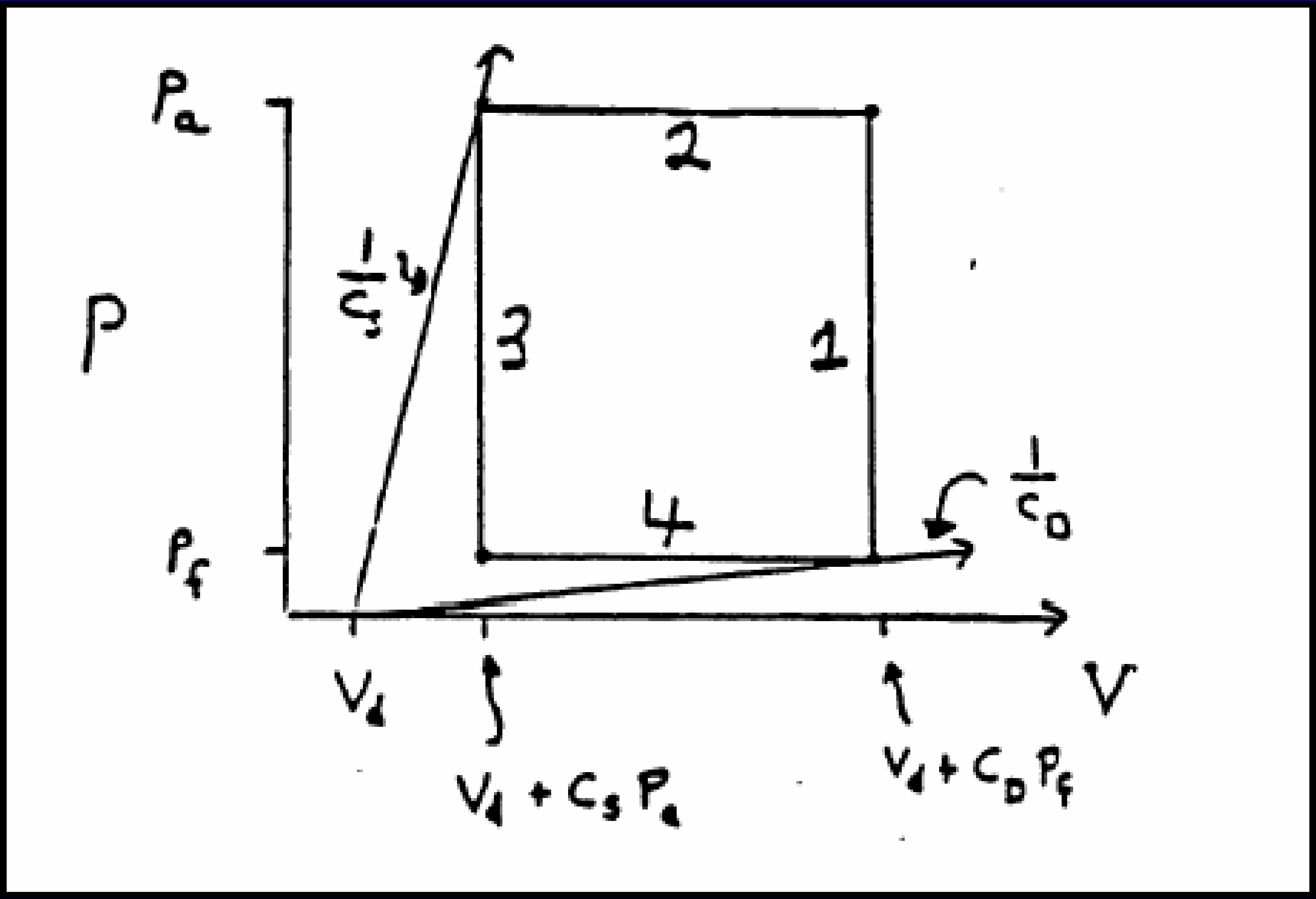


(From Suga and Sagawa 1972.)

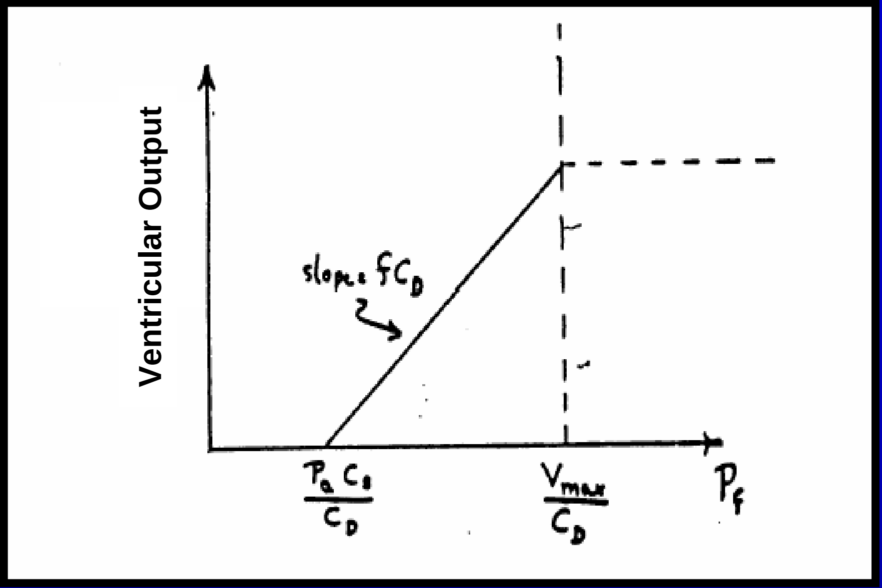
Pressure Volume Loops in Human Using Impedance Catheter



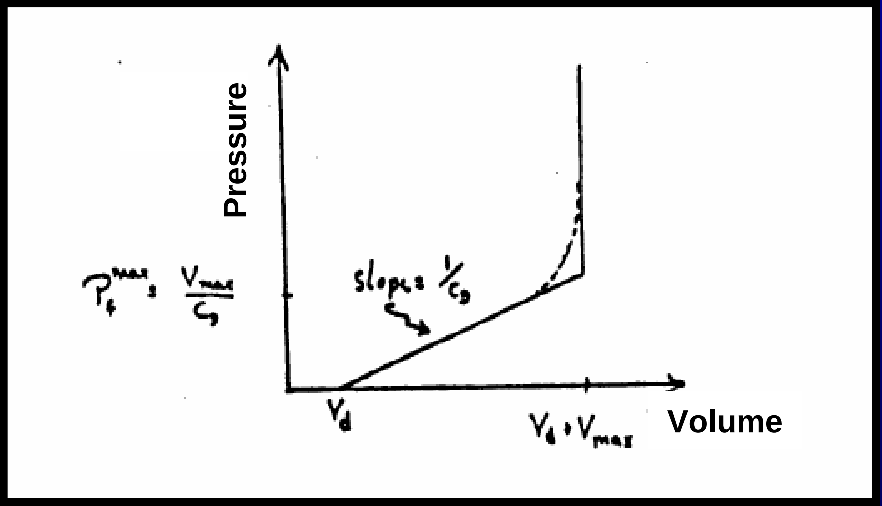
Cardiac Cycle in the P-V Plane



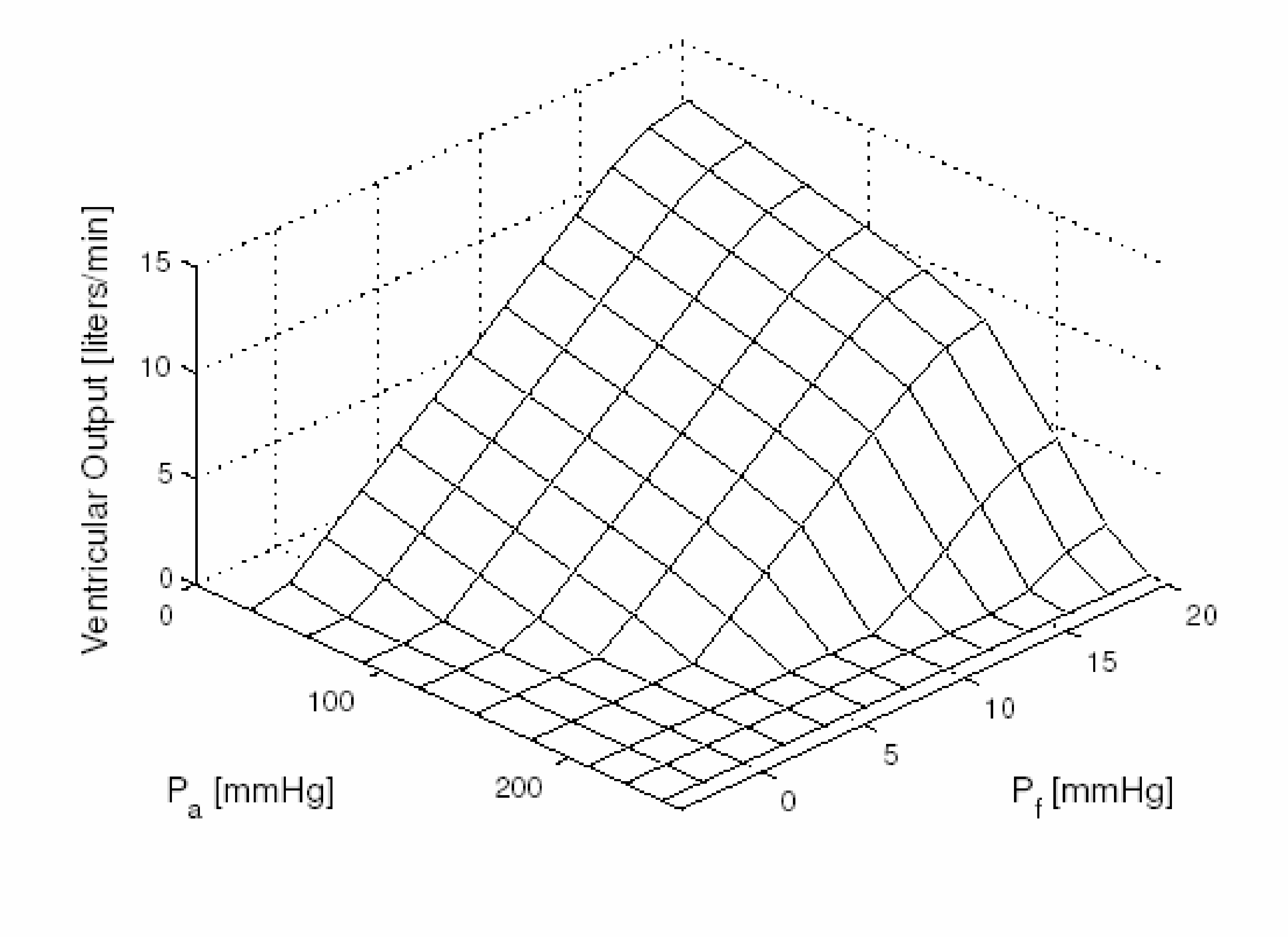
Ventricular Output Curve



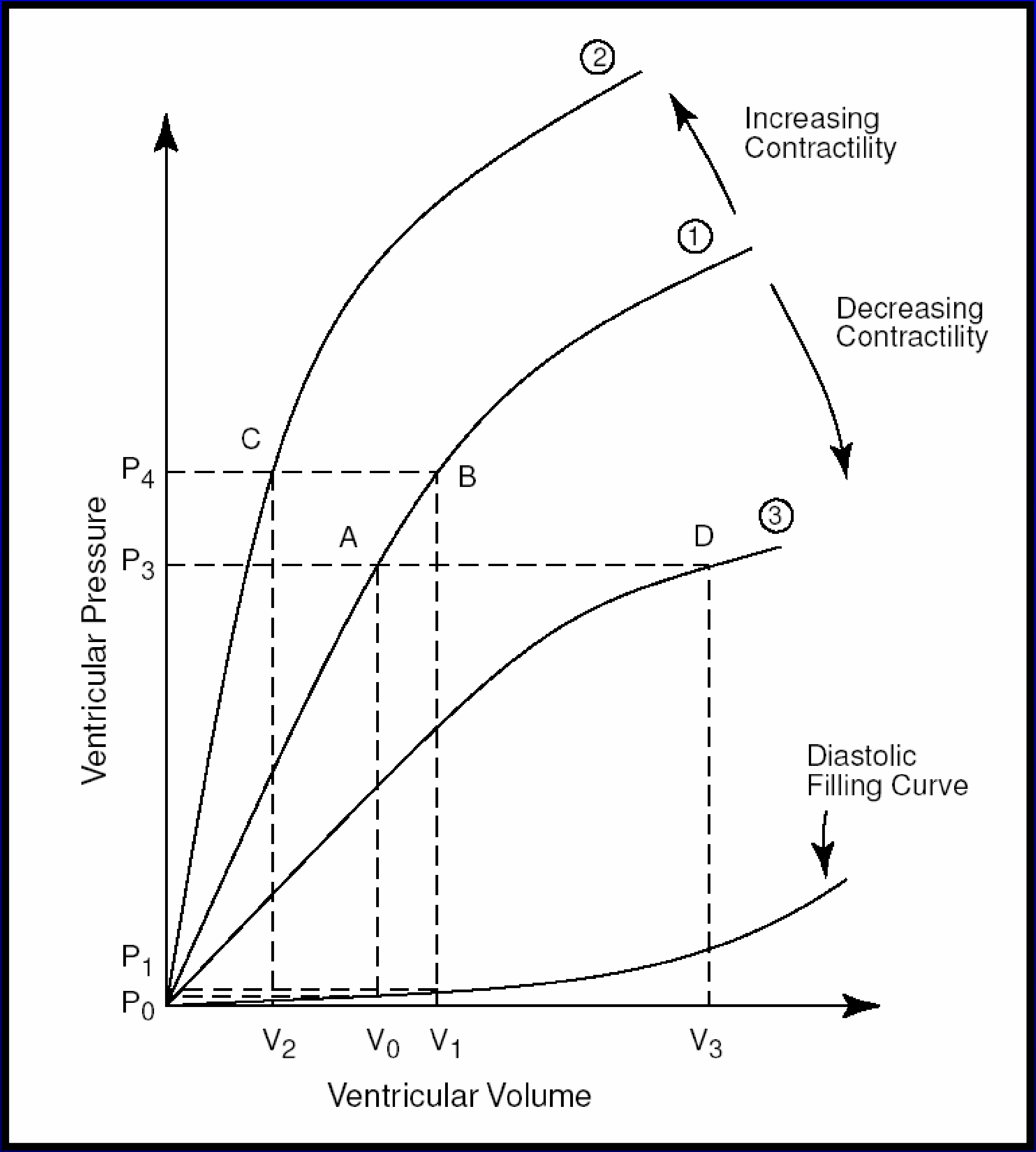
$$
\begin{aligned}
\text{V.O.} &= f\left(C_D P_f - C_S P_a\right) && \text{if } \frac{P_a C_S}{C_D} < P_f \le \frac{V_{\max}}{C_D} \\
&= f\left(V_{\max} - C_S P_a\right) && \text{if } P_f \ge \frac{V_{\max}}{C_D} \\
&= 0 && \text{if } P_f < \frac{P_a C_S}{C_D}
\end{aligned}
$$



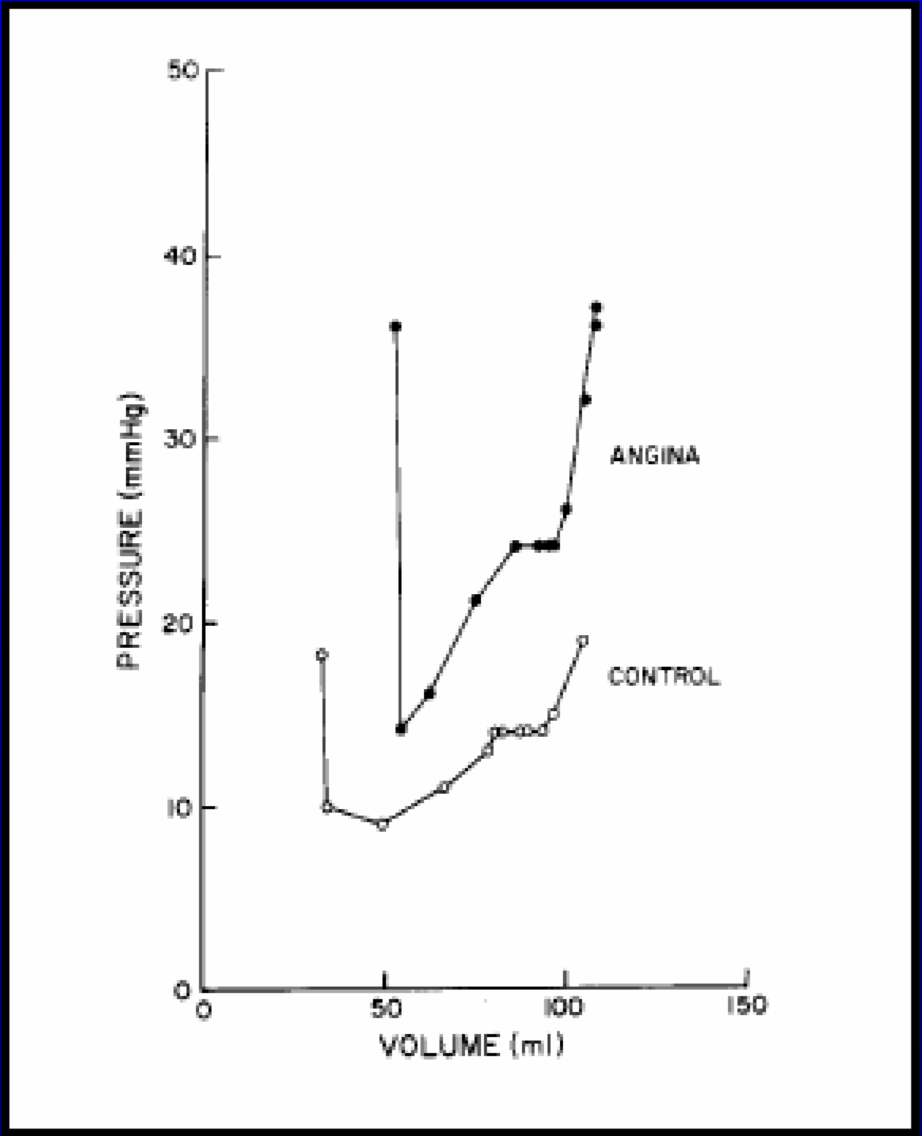
Ventricular Output vs. Preload and Afterload (computational model)



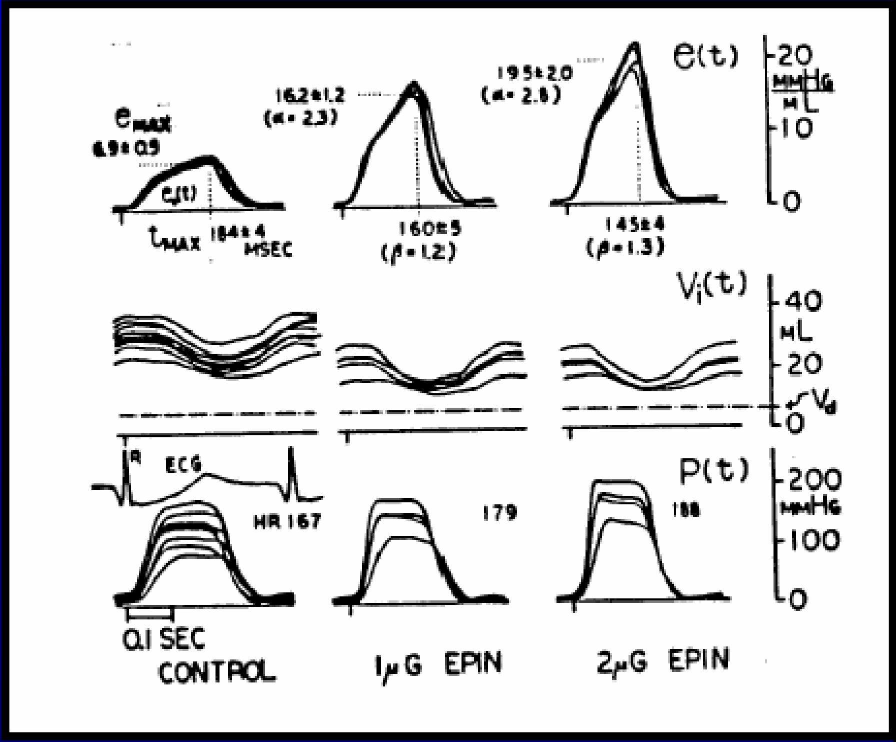
Contractility

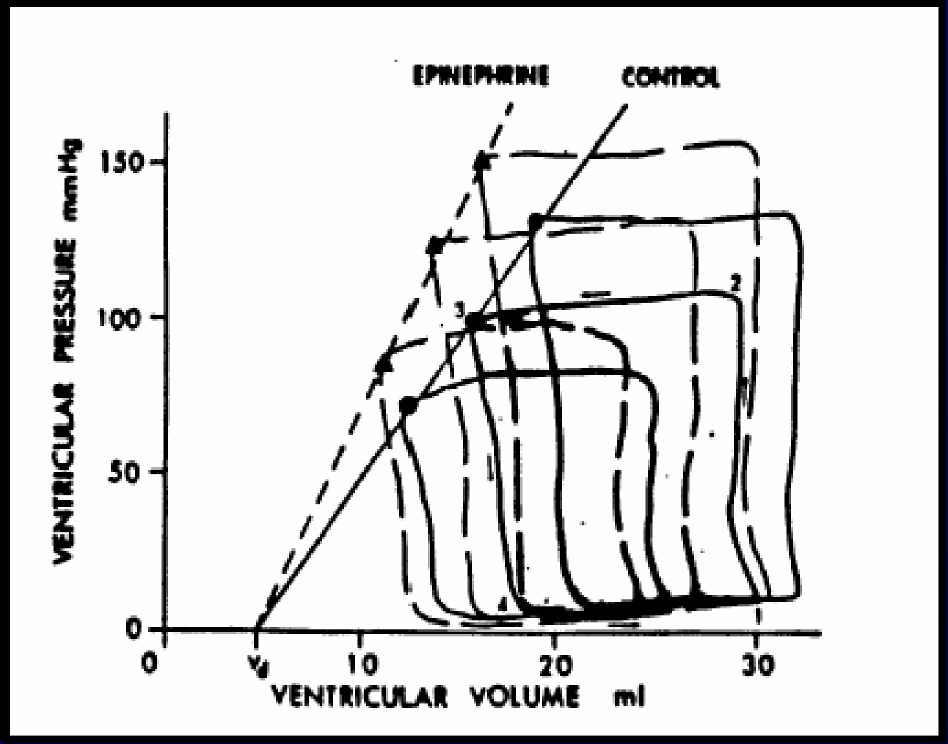


LV Diastolic Pressure-Volume Curves

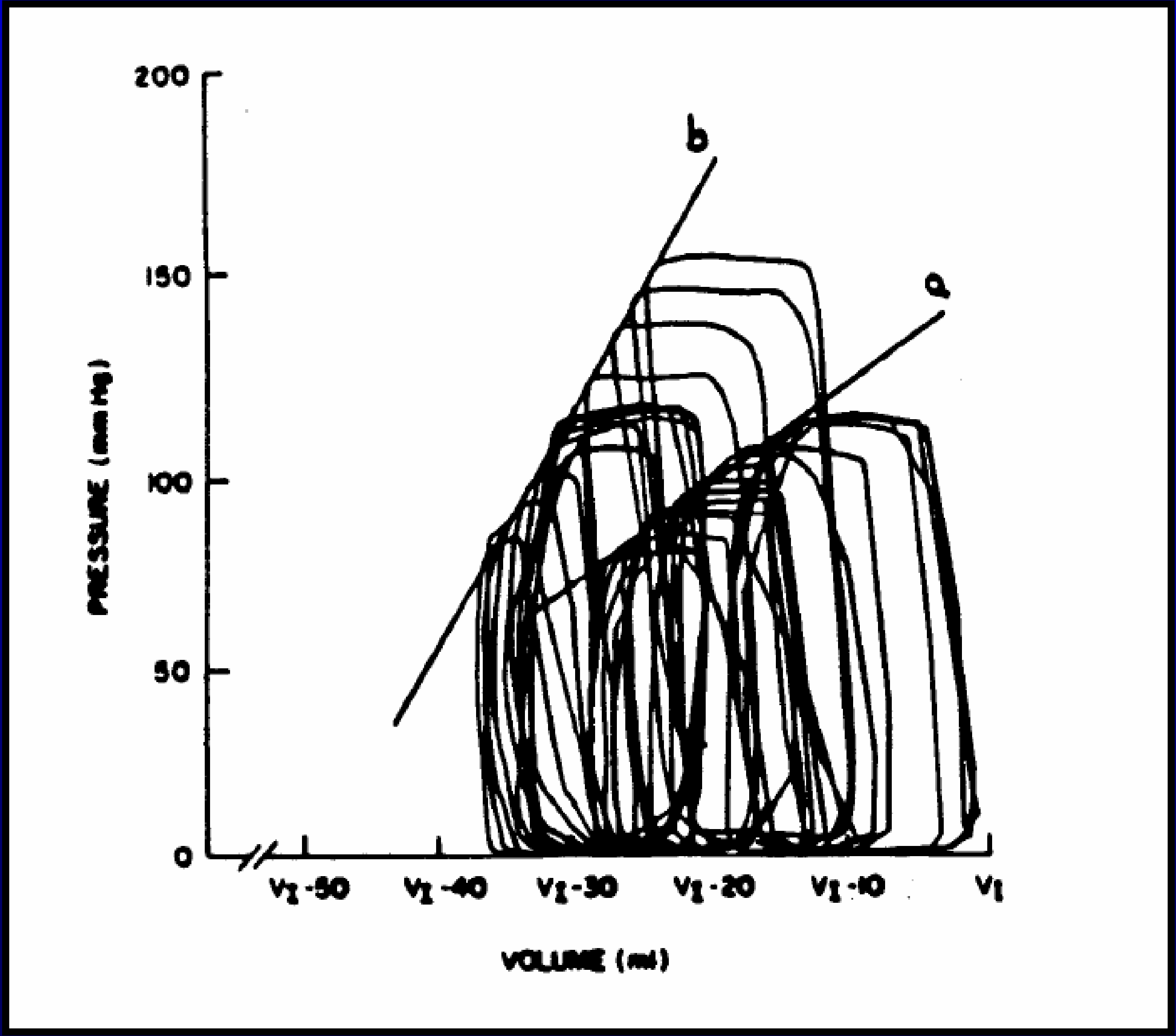


Changing Inotropic State Revealed by P-V Loops





P-V Loops in Man Using Impedance Catheter
a) Control   b) Dobutamine



P-V Loops in Man Using Impedance Catheter
a) Control   b) Epinephrine