PRINCIPAL COORDINATING AND INTEGRATING SYSTEMS OF THE BODY

• THE NERVOUS SYSTEM
• THE ENDOCRINE SYSTEM
• THE CIRCULATORY SYSTEM
  – Transports & distributes essential substances.
  – Removes products of metabolism.
  – Participates in homeostatic mechanisms:
    • regulation of body temperature
    • humoral communication
    • adjustments of oxygen and nutrient supply
COMPOSITION OF CARDIOVASCULAR SYSTEM

• A PUMP
• A SERIES OF DISTRIBUTING AND COLLECTING TUBES
• AN EXTENSIVE SYSTEM OF THIN VESSELS THAT PERMIT RAPID EXCHANGE BETWEEN THE TISSUES AND THE VASCULAR CHANNELS
OVERALL DESCRIPTION OF CV SYSTEM

Heart consists of two pumps in series:
   One to propel blood through the lungs (the \textit{pulmonary circulation}), and the other to propel blood to all other tissues of body (the \textit{systemic circulation}).

Unidirectional flow because of flap valves.

Ventricular Contraction = \textit{systole}

Ventricular Relaxation = \textit{diastole}
Figure 1-1  ■ Internal diameter, wall thickness, and relative amounts of the principal components of the vessel walls of the various blood vessels that compose the circulatory system. Cross sections of the vessels are not drawn to scale because of the huge range from aorta and venae cavae to capillary. (Redrawn from Burton AC: Physiol Rev 34:619, 1954.)
DETERMINANTS OF FLOW (Q) THROUGH A TUBE
PRESSURE DIFFERENCE ACROSS THE TUBE

\[ Q \propto (P_i - P_o) \]
THE RADIUS OF THE TUBE

\[ Q \propto r^4 \]
RELATIONSHIP OF LENGTH OF TUBE (l) TO FLOW

Q \propto \frac{1}{l}
RELATIONSHIP OF VISCOSITY ($\eta$) OF FLOWING FLUID TO VOLUME FLOW

$$Q \propto \frac{1}{\eta}$$
Fig. 3-5. For a Newtonian fluid, the viscosity, $\eta$, is defined as the ratio of shear stress, $\tau$, to rate of strain, $du/dy$. For a plate of contact area, $A$, moving across the surface of a liquid, $\tau$ equals the ratio of the force, $F$, applied in the direction of motion to the contact area, $A$, and $du/dy$ equals the ratio of the velocity of the plate, $U$, to the depth of the liquid, $Y$. 

$$\eta = \frac{\tau}{\frac{du}{dy}} = \frac{F/A}{U/Y}$$
Fig. 3-4. The flow, $Q$, of fluid through a tube is inversely proportional to the length, $l$, and directly proportional to the fourth power of the radius, $r$, of the tube.
TAKEN TOGETHER, THEN, THESE RELATIONSHIPS MAY BE EXPRESSED AS:

\[ Q \propto (P_i - P_o) \frac{(r^4)}{\eta l} \]
TO CONVERT A PROPORTION TO EQUALITY REQUIRES A PROPORTIONALITY CONSTANT, WHICH IN THIS CASE IS:

\[ \pi/8 \]

AND, THE FINAL EQUATION EXPRESSING THE RELATIONSHIP OF FLOW TO PRESSURE, RADIUS, TUBE LENGTH AND VISCOSITY IS:

\[ Q = \pi(P_i - P_o)r^4 / 8\eta l \]
RESISTANCE TO FLOW

In fluid mechanics, the hydraulic resistance, R, may be defined as the ratio of pressure drop, \( P_i - P_0 \), to flow, Q. Thus, by rearrangement of Poiseuille’s law, the hydraulic resistance equation is obtained:

\[
R = \frac{(P_i - P_0)}{Q} = \frac{8\eta l}{\pi r^4}
\]

Clinically, the equation is simplified further:

\[
(P_i - P_0) = Q \times R
\]

and, finally: \( BP = CO \times TPR \)
Fig. 3-6. For resistances \( R_1, R_2, \) and \( R_3 \) arranged in series, the total resistance, \( R_t \), equals the sum of the individual resistances.
Fig. 3-7. For resistances \( R_1, R_2, \) and \( R_3 \) arranged in parallel, the reciprocal of the total resistance, \( R_t \), equals the sum of the reciprocals of the individual resistances.
Viscous flow pressures in the systemic vascular circuit. Note, the greatest drop of $P (P_1 - P_2)$ is in the arterioles, which represent the chief resistance vessels. Next largest drop is in the capillaries. There is very little viscous resistance in the large arteries and veins. [Reproduced, with permission, from A. C. Guyton. *Textbook of Medical Physiology* (7th ed.). Philadelphia PA: Saunders, 1986].
Pressure drop across the vascular system in the hamster cheek pouch. *AP*, Mean arterial pressure; *VP*, venous pressure.
FIGURE 12.6 The path of blood flow through the cardiovascular system. The pulmonary and systemic circuits and major blood vessels connecting with the heart are shown. Arrows indicate direction of blood flow.
FIGURE 13.8 The relationships of blood vessels according to size and the direction of blood flow. The arrow at the upper left represents oxygenated blood (red) arriving from the heart, whereas the arrow at the upper right represents deoxygenated blood (blue) returning to the heart. Note the differences in lumen diameter and wall thickness between arteries and veins, and the presence of one-way valves in the vein.
Poiseuille’s Law:

\[ Q = \pi (P_i - P_o) r^4 / 8\eta l \]

where,

\[ Q = \text{Volume Flow}; \]
\[ P_i = \text{Inflow Pressure}; \]
\[ P_o = \text{Outflow Pressure}; \]
\[ \eta = \text{Viscosity of Flowing Fluid}; \]
\[ l = \text{length of vessel}; \]
\[ \pi/8 = \text{proportionality constant}. \]
(a)

From heart

Flow (CO)

Aorta

Constant MAP

Flow → To systemic organs

(b)

An increase in cardiac output...

... leads to an increase in the volume of blood contained in the aorta and an increase in mean arterial pressure...

... when total peripheral resistance remains the same.

Flow (CO)

Increased MAP

Flow

Increased MAP

Flow

A constant cardiac output...

... leads to an increase in the volume of blood contained in the aorta and an increase in mean arterial pressure...

... when total peripheral resistance increases.
Pressure (mm Hg)

SP = 120

DP = 80

MAP
The pulse pressure (PP) is the difference between systolic pressure (SP) and diastolic pressure (DP):

\[ PP = SP - DP \]

Using average numbers for a normal healthy adult, the pulse pressure is

\[ PP = 120 \, \text{mm Hg} - 80 \, \text{mm Hg} = 40 \, \text{mm Hg} \]
Mean arterial pressure (MAP), the average pressure occurring in the aorta during one cardiac cycle, is given by the following expression:

\[ \text{MAP} = \text{DP} + \frac{1}{3} \text{PP} \]

For a normal healthy adult, this becomes

\[ \text{MAP} = 80 \text{ mm Hg} + \frac{1}{3} (40) = 93.3 \text{ mm Hg} \]
REGULATION OF THE CIRCULATION

For the *systemic arterial* circulation, blood pressure is the regulated variable.

How is it regulated?
Each individual has a *set point* for blood pressure.

Changes in Cardiac Output and Total Peripheral Resistance are brought about to maintain blood pressure at its set point, whatever that is.

In patients with high blood pressure (hypertension), the set point is higher than it is in patients with normal blood pressure.
THEN, ARE THE MECHANISMS THAT ATTEMPT TO MAINTAIN SYSTEMIC ARTERIAL BLOOD PRESSURE INT?

ARDOVASCULAR REFLEXES (NERVOUS CONTROL)

ORMONAL CONTROL

CAL CONTROL MECHANISMS

HE RENAL-BODY FLUID MECHANISM
EXCEPT FOR THE LUNGS, EACH ORGAN OF THE BODY DETERMINES ITS OWN FLOW (AUTOREGULATION). THUS, IN AN EXCERSIZING LIMB, BLOOD FLOW IS INCREASED SOLELY TO THAT LIMB.

THE LUNGS, PER FORCE, MUST ACCEPT ALL OF THE CARDIAC OUTPUT. IN THE PULMONARY CIRCULATION, THEN, FLOW IS NOT REGULATED BUT PRESSURE IS.
**FIGURE 17-4**

Effect of different levels of arterial pressure on blood flow through a muscle. The solid curve shows the effect if the arterial pressure is raised over a period of a few minutes. The dashed curve shows the effect if the arterial pressure is raised extremely slowly over a period of many weeks.