CONTROL OF BLOOD FLOW AND BLOOD PRESSURE (Lectures 3b and 4)

1) REASON: Body needs different levels of nutrient delivery and metabolic removal for differing levels of activities

   High Activity $\rightarrow$ High blood Flow
   Low Activity $\rightarrow$ Low Blood Flow

2) PRINCIPLE: Blood flow is regulated to minimal level to just meet needs
HOW BLOOD FLOW IS CONTROLLED

Local Control in Tissue (Intrinsic)

Figure 1  Structure of local vascular bed
ANATOMY OF MICROCIRCULATION

1) ARTERIOLE
   - Vessel through which blood enters capillaries
   - Dense smooth muscle coat

2) METARTERIOLE
   - Vessels which branch out from arteriole
   - More sparse, but highly active smooth muscle coat

3) PRECAPILLARY SPHINCTER
   - Point where capillaries leave metarteriole
   - Consists of single smooth muscle strand surrounding entrance to capillaries

ANATOMY OF MICROCIRCULATION (cont.)

4) TRUE CAPILLARIES
   - Exchange of nutrients and metabolic wastes
   - No muscle coat

5) VENULE
   - Vessel through which blood leaves capillaries
   - Has smooth muscle coat, not as extensive as arterioles

6) PREFERENTIAL CHANNEL
   - Vessel large capillary which goes directly to the venule
ROLE OF MUSCLES SURROUNDING VASCULATURE IN THE CONTROL OF BLOOD FLOW

CONSTRICTION → DECREASES BLOOD FLOW

DILATION → INCREASES BLOOD FLOW

LOCAL CONTROL IN TISSUE

A) SHORT TERM
   1) CHARACTERISTICS
      a) Timing: minutes
         b) Extent of correction: 75% of requirement
   2) THEORIES
      a) Oxygen Demand Theory
         - Oxygen is required to maintain muscle contraction. With increased activity, there is a decrease in oxygen which causes blood vessels to dilate.
      b) Vasodilator Theory
         - Some metabolic product acts as a vasodilator causing relaxation of muscles surrounding the vasculature
           (Candidates: carbon dioxide, lactic acid, adenosine)
Figure 2  Effect of increasing rate of metabolism on tissue blood flow


Figure 3  Effect of arterial oxygen saturation on blood flow

LOCAL CONTROL IN TISSUE

B) LONG TERM

1) MECHANISM
   - With extended oxygen depletion there is increase in number of capillary blood vessels

2) EXAMPLES
   - Animals at high altitudes
   - Premature infants: Retrolental Fibroplasia without gradual adjustment to normal atmosphere after oxygen tent

Blood Flow

\[ \Delta V = IR \]

Equation for blood flow through tissue:
\[ \Delta P \text{ (Arterial - Venous)} \propto (\text{Blood Flow}) \times (\text{Resistance}) \]
\[ \Delta P/\text{Resistance} \propto \text{Blood Flow} \]
Body’s Maintenance of Constant Arterial Pressure

1) **Mean Arterial Pressure**
   - 95 – 100 mm Hg
2) **Systolic Pressure** (pressure after contraction of left ventricle)
   - 120 mm Hg
3) **Diastolic Pressure** (pressure with blood filling chambers)
   - 80 mm Hg

GENERAL MECHANISMS OF ARTERIAL PRESSURE CONTROL

1) **Short Term General Mechanisms:**
   - Constriction of blood vessels
   - Change in heart contractability
   - Change in heart rate
2) **Long Term General Mechanism:**
   - Regulating the volume of the blood by changing urinary output
Body’s Maintenance of Constant Arterial Pressure

1) Fundamental Relationship
Arterial Pressure is proportional to:
Cardiac Output x Total Peripheral Resistance

2) Illustration of Relationship
With a momentary decrease in arterial pressure:
   a) Cardiac output is increased:
      - Increased strength and/or rate of contraction
      - Increased volume of blood delivered to heart
   b) Peripheral resistance is increased:
      - Constriction of vasculature

Figure 11  Baroreceptors, chemoreceptors, CNS Ischemic Response effect on vasomotor center which controls vasoconstrictor nerves connected to systemic circulation (shown above)
SPECIFIC MECHANISMS OF SHORT TERM ARTERIAL PRESSURE CONTROL

1) Constriction of vasculature (arteries, arterioles, veins, venules) through nervous system
   a) Baroreceptors (Also affects heart rate and contractability)
   b) Chemoreceptors
   c) CNS Ischemia

2) Hormonal
   a) Norepinephrine and epinephrine
   b) Vasopressin (anti diuretic hormone; ADH)
   c) Angiotensin II

3) Capillary Fluid Shift

4) Stress Relaxation

Figure 8  Various controls of blood pressure showing effectiveness and response speed
NERVOUS SYSTEM CONTROL

1) **Blood vessels:** Controls extent of constriction

2) **Heart:** Controls rate and strength of contractability

3) **Adrenal Glands:** Stimulates adrenal medulla to produce the vasoconstrictors epinephrine and norepinephrine

NERVES 101

1) **Autonomic:** Controls involuntary body functions
   a) Parasympathetic – energy conserving processes
   b) Sympathetic- energy expending processes

2) **Somatic Motor:** Voluntary skeletal muscles
VASOMOTOR CENTER
COMMAND CONTROL FOR
BLOOD PRESSURE CONTROL

1) Controls sympathetic vasoconstrictor fibers innervating blood vessels
   - Arterioles are extensively innervated
   - Venules are innervated to a lesser extent
   - Metarterioles, precapillary sphincter are not innervated
   - Lateral portion of center stimulates vasoconstrictor fibers
     while medial portion inhibits vasoconstriction

2) Control of heart activity
   a) One location within the vasomotor center controls sympathetic nerves
      - Increased heart rate and strength of contractability
   b) Another location within the vasomotor center controls parasympathetic nerves
      - Decreased heart rate and strength of contractability

VASOMOTOR CENTER
COMMAND CONTROL FOR BLOOD FLOW CONTROL
(cont.)

3) Stimulates adrenal medulla to produce the vasoconstrictors epinephrine and norepinephrine
Figure 4
Nervous system regulation of circulation through vasomotor system

Figure 5 Innervation of vasculature
 Signals Sent to Vasomotor Center

A) Baroreceptors

1) Pressure receptors on arteries (sensitive to blood pressure)
   - Particularly abundant on internal carotid and aortic arch
   - Stimulated with increase of pressure

2) Mechanism when baroreceptor is stretched (incr. pressure)
   a) Signals are sent to the vasomotor center that inhibit
      the vasoconstrictor location
      -Causes vasodilation throughout the periphery
   b) Signals are sent that excite the vagal center
      -Causes decreased heart rate and decreased
      strength of contraction

Figure 6
The baroreceptor system
Figure 4
Nervous system regulation of circulation through vasomotor system

Figure 5 Innervation of vasculature
A. Baroreceptors (cont.)

3) Characteristics
   a) Greatest sensitivity in normal range
   b) No response in 0 – 60 mm Hg range
   c) Greater response the faster the rate of pressure change
   d) Primary purpose is to reduce daily variation in arterial pressure by ½ to 1/3: with long term abnormal pressure the baroreceptors adapt

Figure 9 Response of the baroreceptors at different levels of arterial pressure
Figure 10 Shows baroreceptors control reduces variation in arterial pressure

B. Chemoreceptors
1) Location
   In aorta and carotid arteries
2) Mechanism
   a) Responds to chemical content of blood
      - Decreased oxygen, increased carbon dioxide, increased H+ causes excitation of chemoreceptor
      - Above chemical changes occurs with a decrease in blood flow
   b) Signal from chemoreceptor causes excitation of vasomotor center causing vasoconstriction
   c) Mechanism only active below 80 mm Hg
C. CNS Ischemia

1) Mechanism

Results when blood pressure falls so low that vasomotor center itself responds to nutritionally deficient blood (increased CO$_2$ is possible agent)

C. CNS Ischemia (cont.)

2) Characteristics

a) Arterial pressure at which mechanism is operational
   - At 60 mm Hg and below CNS Ischemic response is initiated
   - Greatest degree of activation is 15-20 mm Hg

b) Most powerful mechanism for correction of arterial pressure
   - Causes nearly total occlusion of peripheral vessels
   - Can elevate pressure to 270 mm Hg
   - Ceases urine production by the kidney
C. CNS Ischemia

2) Characteristics (cont.)
   c) Time limit for the CNS response
      - Within 3-10 minutes neuronal cells will die
      - Vasomotor center control of arterial pressure will be lost
      - Pressure will fall to 40-50 mm Hg

Figure 8 Various Controls of Blood Pressure Showing Effectiveness and Response Speed
SPECIFIC MECHANISMS OF SHORT TERM ARTERIAL PRESSURE CONTROL

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   c) Angiotensin II

3) Capillary Fluid Shift

4) Stress Relaxation

Figure 12 The renin-angiotensin vasoconstrictor mechanism for arterial pressure control
SPECIFIC MECHANISMS OF SHORT TERM ARTERIAL PRESSURE CONTROL

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Figure 13 Structure of capillary wall showing endothelial cells and intercellular clefts between these cells
### Table 1


<table>
<thead>
<tr>
<th>Substance</th>
<th>Molecular Weight</th>
<th>Permeability</th>
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<tr>
<td>NaCl</td>
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<td>Urea</td>
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<tr>
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</tr>
<tr>
<td>Albumin</td>
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<td>&lt;0.0001</td>
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Modified from Pappenheimer.

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![Diagram](image-url)

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SPECIFIC MECHANISMS OF SHORT TERM ARTERIAL PRESSURE CONTROL

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**Stretch Receptors - Role in Blood Volume Control**

1) Sensitive to blood volume (volume receptors)

2) Located in central veins, pulmonary vessels and right and left atria of heart

3) Receptors send signal to vasomotor center and hypothalamus when stretched by high blood volume

4) Signals sent to increase urinary output
   - signal from stretch receptors sent directly to kidney to increase urinary output
   - signal from stretch receptor sent to hypothalamus to decrease ADH, which also increases urinary output
SHORT TERM ARTERIAL PRESSURE REGULATION

1) **Speed of action**
   - Fast: acts within seconds to minutes

2) **Acts as a high frequency filter**
   - Reduces high frequency fluctuation of pressure variation

3) **Effectiveness of Control**
   - Loses capability for pressure control after few hours or few days

4) **Extent of control**
   - Does not return pressure all the way back to normal

5) **Mechanism**
   - Hormonal, nervous system, local factors
LONG TERM ARTERIAL PRESSURE REGULATION

1) **Speed of action**
   - Slow: acts in hours to days

2) **Control over period of days, weeks, and months**
   - Reduces high frequency fluctuation of pressure variation

3) **Effectiveness of Control**
   - Becomes more effective as time increases

4) **Extent of control**
   - Ability to return pressure all the way back to normal

5) **Mechanism**
   - Acts through the kidneys adjusting the blood volume