Control of blood tissue blood flow

Faisal I. Mohammed, MD, PhD
Objectives

• List factors that affect tissue blood flow.
• Describe the vasodilator and oxygen demand theories.
• Point out the mechanisms of autoregulation.
• Describe how angiogenesis occurs.
• Inter-relate how various humoral factors affect blood flow.
Local Control of Blood Flow

- Each tissue controls its own blood flow in proportion to its needs.

- Tissue needs include:
  1) delivery of oxygen to tissues
  2) delivery of nutrients such as glucose, amino acids, etc.
  3) removal of carbon dioxide hydrogen and other metabolites from the tissues
  4) transport various hormones and other substances to different tissues

- Flow is closely related to metabolic rate of tissues.
## Variations in Tissue Blood Flow

<table>
<thead>
<tr>
<th>Tissue</th>
<th>Percent</th>
<th>ml/min</th>
<th>ml/min/100 gm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brain</td>
<td>14</td>
<td>700</td>
<td>50</td>
</tr>
<tr>
<td>Heart</td>
<td>4</td>
<td>200</td>
<td>70</td>
</tr>
<tr>
<td>Bronchi</td>
<td>2</td>
<td>100</td>
<td>25</td>
</tr>
<tr>
<td>Kidneys</td>
<td>22</td>
<td>1100</td>
<td>360</td>
</tr>
<tr>
<td>Liver</td>
<td>27</td>
<td>1350</td>
<td>95</td>
</tr>
<tr>
<td>Portal Arterial</td>
<td>(21)</td>
<td>(1050)</td>
<td></td>
</tr>
<tr>
<td>Muscle (inactive state)</td>
<td>15</td>
<td>750</td>
<td>4</td>
</tr>
<tr>
<td>Bone</td>
<td>5</td>
<td>250</td>
<td>3</td>
</tr>
<tr>
<td>Skin (cool weather)</td>
<td>6</td>
<td>300</td>
<td>3</td>
</tr>
<tr>
<td>Thyroid gland</td>
<td>1</td>
<td>50</td>
<td>160</td>
</tr>
<tr>
<td>Adrenal glands</td>
<td>0</td>
<td>.525</td>
<td>300</td>
</tr>
<tr>
<td>Other tissues</td>
<td>3.5</td>
<td>175</td>
<td>1.3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100.0</strong></td>
<td><strong>5000</strong></td>
<td><strong>---</strong></td>
</tr>
</tbody>
</table>
Acute Control of Local Blood Flow

- Increases in *tissue metabolism* lead to increases in blood flow.

- Decreases in *oxygen availability* to tissues increases tissue blood flow.

- Two major theories for local blood flow are:
  1) *The vasodilator theory*
  2) *Oxygen demand theory*
Effect of Tissue Metabolic Rate on Tissue Blood Flow

![Graph showing the effect of tissue metabolic rate on blood flow. The graph plots blood flow (x normal) against the rate of metabolism (x normal). There is a normal level marked on the graph.](image-url)
Effect of Tissue Oxygen concentration on Blood Flow

![Graph showing the effect of Tissue Oxygen concentration on Blood Flow. The graph illustrates an upward trend, indicating that as Tissue Oxygen concentration decreases, Blood Flow increases.](image-url)
Relationship between Pressure, Flow, and Resistance

- $F = \Delta P / R$

- Flow ($F$) through a blood vessel is determined by:
  1) The pressure difference ($\Delta P$) between the two ends of the vessel
  2) Resistance ($R$) of the vessel
Vasodilator Theory for Blood Flow Control

Local Vasodilators: **Adenosine**, **CO2**, **Lactic acid**, **ADP compounds**, **Histamine**, **K⁺ ions**, **H⁺ ions**, **Prostacyclin**, **Bradykinin**, and **Nitrous oxid (NO)**
Oxygen Demand Theory for Blood Flow Control

TISSUE METABOLISM OR
OXYGEN DELIVERY TO TISSUES

TISSUE OXYGEN CONCENTRATION

ARTERIOLE RESISTANCE

BLOOD FLOW
**Autoregulation of Blood Flow**

*Autoregulation* - ability of a tissue to maintain blood flow relatively constant over a wide range of arterial pressures.
Blood Flow Autoregulation Theories

- **Metabolic theory** suggests that as arterial pressure is decreased, oxygen or nutrient delivery is decreased resulting in release of a vasodilator.

- **Myogenic theory** proposes that as arterial pressure falls the arterioles have an intrinsic property to dilate in response to decreases in wall tension.

- Certain tissues have other mechanisms for blood flow control the kidneys have a feedback system between the tubules and arterioles and the brain blood flow is controlled by carbon dioxide and hydrogen ion conc.
Laplace’s Law: Myogenic mechanism

TENSION (dynes/cm) = PRESSURE (dynes/cm²) x RADIUS (cm)

↑ PRESSURE → ↑ TENSION → ↓ RADIUS (to maintain tension constant)

↓ PRESSURE → ↓ TENSION → ↑ RADIUS (to maintain tension constant)
Long-term Regulation of Blood Flow

- Long-term regulatory mechanisms which control blood flow are more effective than acute mechanism.

- Long-term local blood flow regulation occurs by changing the degree of vascularity of tissues (size and number of vessels).

- Oxygen is an important stimulus for regulating tissue vascularity.
Long-term Regulation of Blood Flow

![Graph showing long-term and acute regulation of blood flow vs arterial pressure](image)
Angiogenesis

- Angiogenesis is the growth of new blood vessels.
- Angiogenesis occurs in response to angiogenic factors released from:
  1) ischemic tissue
  2) rapidly growing tissue
  3) tissue with high metabolic rates
- Most angiogenic factors are small peptides such as vascular endothelial cell growth factors (VEGF), fibroblast growth factor (FGF), and angiogen.
- Example of angiogenesis is Retrolental Hyperplasia
Humoral Regulation of Blood Flow

- **Vasoconstrictors**
  - Norepinephrine and epinephrine
  - Angiotensin
  - Vasopressin
  - Endothelin

- **Vasodilator agents**
  - Bradykinin
  - Serotonin
  - Histamine
  - Prostaglandins
  - Nitric oxide
Blood Flow: Skeletal Muscle Regulation

- Muscle blood flow can increase tenfold or more during physical activity as vasodilation occurs
  - Low levels of epinephrine bind to $\beta$ receptors
  - Cholinergic receptors are occupied
- Intense exercise or sympathetic nervous system activation result in high levels of epinephrine
  - High levels of epinephrine bind to $\alpha$ receptors and cause vasoconstriction
    - This is a protective response to prevent muscle oxygen demands from exceeding cardiac pumping ability
Arteriole Resistance: Control of Local Blood Flow

(a) Active hyperemia

- ↑ Tissue metabolism
- ↑ Release of metabolic vasodilators into ECF
- Dilation of arterioles
- ↓ Resistance creates ↑ blood flow
- O₂ and nutrient supply to tissue increases as long as metabolism is increased

(b) Reactive hyperemia

- ↓ Tissue blood flow due to occlusion
- Metabolic vasodilators accumulate in ECF
- Dilation of arterioles, but occlusion prevents blood flow
- Remove occlusion
- ↓ Resistance creates ↑ blood flow
- As vasodilators wash away, arterioles constrict and blood flow returns to normal
Blood Flow: Brain

- Blood flow to the brain is constant, as neurons are intolerant of ischemia
- Metabolic controls – brain tissue is extremely sensitive to declines in pH, and increased carbon dioxide causes marked vasodilation
- Myogenic controls protect the brain from damaging changes in blood pressure
  - Decreases in MAP cause cerebral vessels to dilate to insure adequate perfusion
  - Increases in MAP cause cerebral vessels to constrict
Blood Flow: Brain

- The brain can regulate its own blood flow in certain circumstances, such as ischemia caused by a tumor.
- The brain is vulnerable under extreme systemic pressure changes.
  - MAP below 60mm Hg can cause syncope (fainting).
  - MAP above 160 can result in cerebral edema.
Blood Flow: Skin

- Blood flow through the skin:
  - Supplies nutrients to cells in response to oxygen need
  - Aids in body temperature regulation and provides a blood reservoir

- Blood flow to venous plexuses below the skin surface:
  - Varies from 50 ml/min to 2500 ml/min, depending upon body temperature
  - Is controlled by sympathetic nervous system reflexes initiated by temperature receptors and the central nervous system
Blood Flow: Lungs

Blood flow in the pulmonary circulation is unusual in that:

- The pathway is short
- Arteries/arterioles are more like veins/venules (thin-walled, with large lumens)
  - They have a much lower arterial pressure (24/8 mm Hg versus 120/80 mm Hg)
- The autoregulatory mechanism is exactly opposite of that in most tissues
  - Low oxygen levels cause vasoconstriction; high levels promote vasodilation
  - This allows for proper oxygen loading in the lungs
Blood Flow: Heart

- Small vessel coronary circulation is influenced by:
  - Aortic pressure
  - The pumping activity of the ventricles

- During ventricular systole:
  - Coronary vessels compress
  - Myocardial blood flow ceases
  - Stored myoglobin supplies sufficient oxygen

- During ventricular diastole, oxygen and nutrients are carried to the heart
Thank You
Special circulations, Coronary, Pulmonary...

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Objectives

- Describe the control of blood flow to different circulations (Skeletal muscles, pulmonary and coronary)
- Point out special hemodynamic characteristic pertinent to each circulation discussed
Muscle blood flow can increase tenfold or more during physical activity as vasodilation occurs.

- Low levels of epinephrine bind to β receptors
- Cholinergic receptors are occupied

Intense exercise or sympathetic nervous system activation result in high levels of epinephrine.

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Exercise and Muscle Blood Flow

![Graph showing blood flow during rhythmic exercise and calf flow over time.](image-url)
**Muscle Blood Flow During Exercise**

- Can - 20 fold during exercise.
- Muscle makes up a large portion of body mass → great effect on Cardiac output.
- Resting blood flow = 3 to 4 ml/min/100 gm muscle.
- Oxygen delivery can be increased by increasing the extraction ratio from 25% up to 75%.
- Capillary density -’s markedly.
- Most blood flow occurs between contractions.
Local Regulation of Muscle Blood Flow during Exercise

- \( \downarrow O_2 \) during exercise affects vascular smooth muscle directly \( \Rightarrow \) vasodilation.

- Vasodilators (which ones?)
  1. \( K^+ \)
  2. Adenosine
  3. Osmolality
  4. EDRF (nitric oxide)
Nervous Regulation

- Sympathetic release of norepinephrine (mainly $\alpha$).
- Adrenals release epinephrine ($\beta$ and $\alpha$) norepinephrine ($\alpha + \text{a little } \beta$).
  - $\beta$ receptors $\Rightarrow$ vasodilation mainly in muscle and the liver.
  - $\alpha$ receptors $\Rightarrow$ vasoconstriction in kidney and gut.
Arteriole Resistance: Control of Local Blood Flow

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Characteristics of the **Pulmonary Circulation**
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Effect of Po₂ on Blood Flow

Blood Flow % Control

Alveolar Po₂
Distribution of Blood Flow

Blood Flow/Unit Volume

Distance Up Lung

Bottom

Top
Hydrostatic Effects on Blood Flow

ZONE 1
Artery → PALV → Vein

ZONE 2
Artery → PALV → Vein

ZONE 3
Artery → PALV → Vein

Ppc = capillary pressure
PALV = alveolar pressure

Distance

Flow
Blood Flow: Heart

- Small vessel coronary circulation is influenced by:
  - Aortic pressure
  - The pumping activity of the ventricles

- During ventricular systole:
  - Coronary vessels compress
  - Myocardial blood flow ceases
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- Extraction ratio is maximum (75%) during rest so an increase demand for oxygen means an increase blood flow
CORONARY CIRCULATION

(a) Anterior view of coronary arteries

(b) Anterior view of coronary veins
(a) Anterior view of coronary arteries
(b) Anterior view of coronary veins
Epicardial and Subendocardial Vasculature
Figure 10-3  Comparison of phasic coronary blood flow in the left and right coronary arteries.
Coronary bypass operation

grafted veins carry arterial blood

blocked vessels
Angioplasty

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a. Artery is closed.
b. Balloon is released.
c. Balloon is inflated.
(a) Coronary artery bypass grafting (CABG)

(b) Percutaneous transluminal coronary angioplasty (PTCA)

(c) Stent in an artery
Thank You