Chapter 8 - Blood Flow

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Introduction

- The development of **colour flow imaging** has significantly enhanced blood flow analysis for diagnosing **vascular and non-vascular disorders**.
- Understanding **blood flow physics** is crucial for accurate interpretation of **colour flow images** and **Doppler spectra**.
- **Reverse flow** observed in a colour image may indicate disease or represent **normal physiological flow** within a vessel.
- **Velocity changes** and **Doppler spectrum variations** assist in identifying and quantifying diseases.
- Misunderstanding **normal and pathological blood flow** can lead to **misdiagnosis** and loss of important clinical data.
- Blood flow is inherently **pulsatile** and occurs in a **non-homogeneous fluid** within **elastic tubes**.
- A simplified model of **steady flow in a rigid tube** provides basic insights into blood flow dynamics.

Structure of the Vessel Walls

- **Arterial walls** have a **three-layered structure**:
  - **Intima**: Inner **endothelial layer** on an **elastic membrane**.
  - **Media**: **Smooth muscle** and **elastic tissue**.
  - **Adventitia**: **Connective tissue**, including **collagen** and **elastic fibers**.
- **Ultrasound visualization** of the **intima-media layer** is possible in **carotid arteries**, typically measuring **0.5–0.9 mm**.
- **Arterial diseases** can alter **vessel wall thickness**, reducing **blood flow** and potentially leading to **embolic events**.
- **Veins** have a similar **three-layer structure** but feature a **thinner media layer**.
- Blood vessels are **not just conduits**; they dynamically respond to **nervous** and **chemical stimuli** to regulate blood flow.

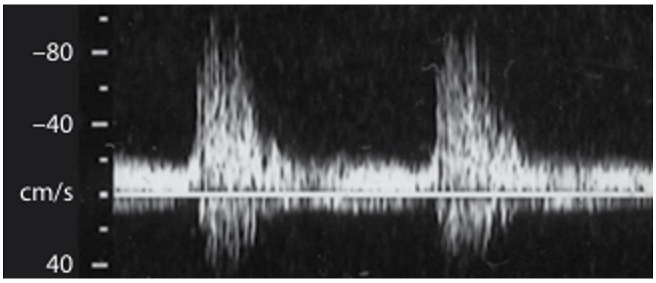
Blood Flow Dynamics

Structure of the Vessel Walls

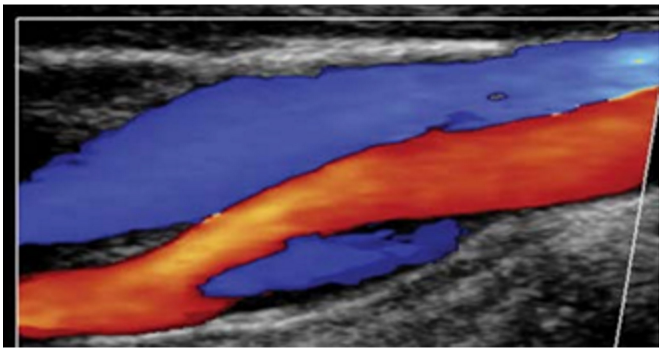
- Changes in **arterial wall structure** due to **disease** can be detected using **ultrasound**.
- The **three-layer structure** of arteries:
  - **Intima**: Inner **endothelial layer** over an **elastic membrane**.
  - **Media**: Composed of **smooth muscle** and **elastic tissue**.
  - **Adventitia**: Outer **connective tissue** with **collagen and elastic fibers**.
- **Intima-media layer** can be visualized with **ultrasound** in **carotid arteries**, with a normal thickness of **0.5–0.9 mm**.
- **Arterial disease** affects **wall thickness**, potentially **reducing blood flow** or generating **emboli**.
- **Veins** have a **similar structure** but with a **thinner media layer**.
- **Blood vessels** function not only as conduits but also **respond dynamically** to **nervous and chemical stimuli**.

Laminar, Disturbed, and Turbulent Flow

- **Laminar flow**: Blood moves in **layers**, with each layer **sliding over the other**, maintaining **velocity differences** while **cells remain within their layers**.



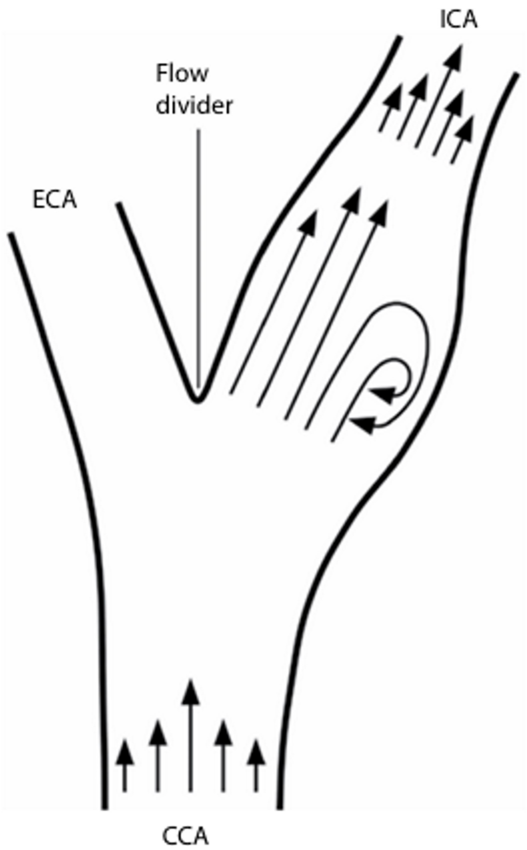
- **Turbulent flow**:
  - Occurs when **velocity increases significantly**, as in **stenosis**.
  - Blood moves **randomly** in **all directions** at **variable speeds**, but with **overall forward velocity**.
  - Requires **more energy** and results in a **greater pressure drop** to maintain **flow rate**.
  - Can be identified by **spectral Doppler broadening** (Figure 8.1).



- **Disturbed flow**:
  - Characterized by **vortices (eddies)** and **flow reversal**.
  - **Vortices** may appear **downstream of atherosclerotic plaques** and can either be **static or shed downstream** before dissipating.
  - **Flow reversal** in the **carotid bifurcation** (Figures 8.3, 8.8) is considered **normal**.

Laminar, Disturbed, and Turbulent Flow (Page 160)

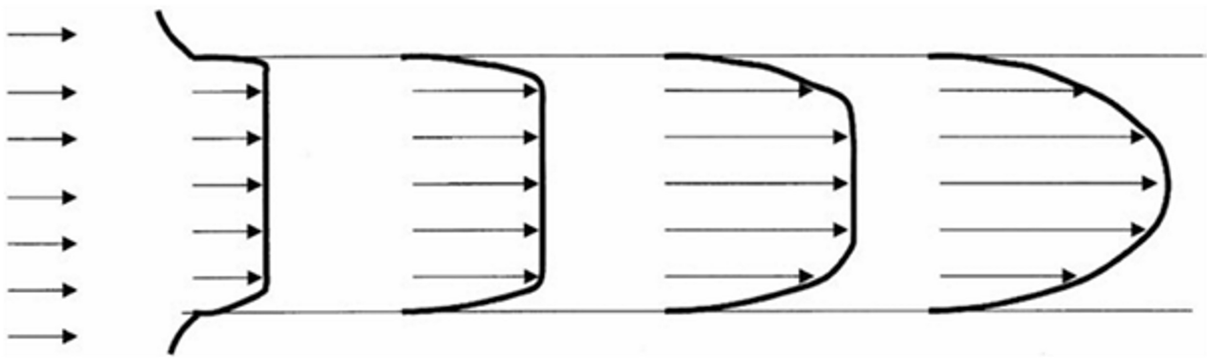
- **Laminar Flow**:
  - In normal arteries at rest, blood moves in **layers**, with each layer **sliding over the other**.
  - Different layers can have **different velocities**, but blood cells stay within their layers.
- **Turbulent Flow**:
  - If velocity **increases significantly** (e.g., due to **stenosis**), **laminar flow can break down** into **turbulence**.
  - **Turbulent flow** moves **randomly** in all directions at **variable speeds**, while still maintaining an **overall forward velocity**.
  - **More energy** is required to maintain **flow rate**, leading to a **greater pressure drop**.
  - Turbulent flow is **visible** distal to a **severe stenosis**, as seen in the **spectral Doppler waveform** (Figure **8.1**), which shows **increased spectral broadening**.
- **Disturbed Flow**:
  - The term refers to regions where **circulating vortices (eddies)** and **flow reversal** occur.
  - **Vortices** are commonly observed **distal to an atherosclerotic plaque**.
  - These vortices may be **static** or may **shed and move downstream**, dissipating after a short distance.



- **Disturbed flow alone does not necessarily indicate disease**—for example, **flow reversal in the carotid bifurcation** (Figures **8.3** and **8.8**) is considered **normal**.

Velocity Profiles (Page 160)

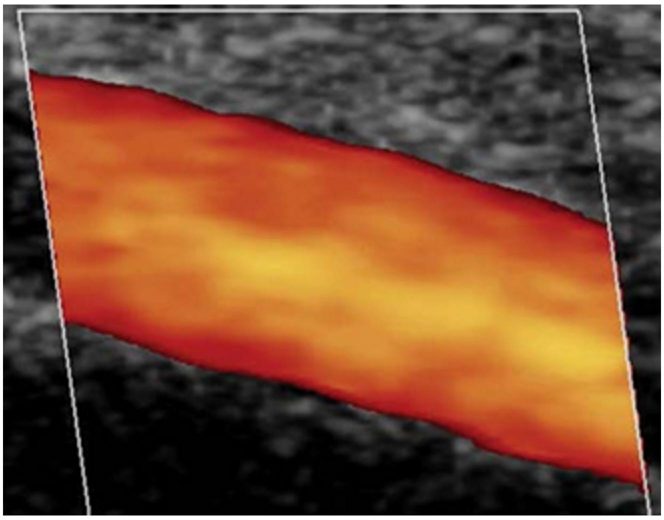
- Blood within a vessel does not all move at the **same velocity** at a given time.
- Typically, **faster flow** occurs in the **center** of the vessel, while **slower-moving blood** is found near the **walls**.
- This variation in velocity across the vessel is called the **velocity profile**.
- The shape of the velocity profile **affects both the color flow image and the Doppler spectrum**.
- In a simple system with **steady (non-pulsatile) flow** entering a long, rigid tube, the velocity profile transitions:
  - From a **blunt profile** (uniform velocity) to a **parabolic profile** (higher velocity in the center).
  - This transition occurs due to **viscous drag exerted by the vessel walls**, causing a velocity gradient across the diameter of the vessel.



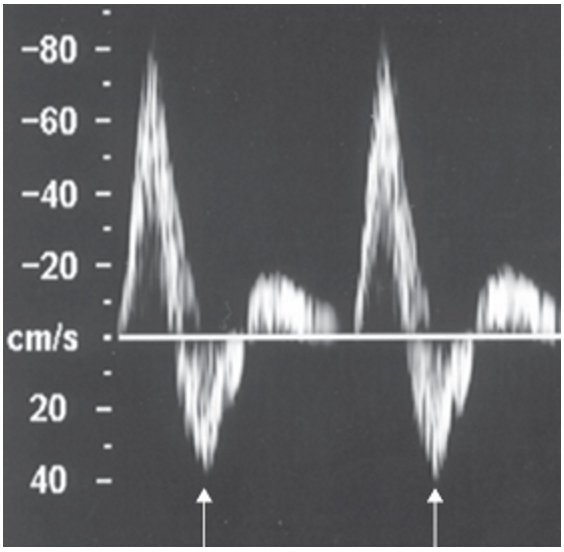
  - The distance required for this transition depends on **tube diameter and fluid**

velocity (Figure **8.4**).

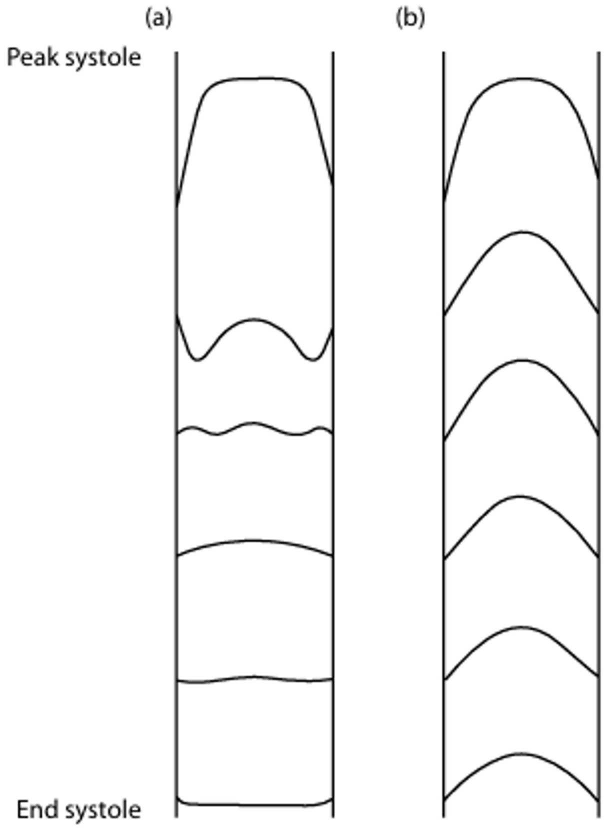
- Different vessels show different velocity profiles:
  - **Ascending aorta**: Typically **blunt** flow profile.
  - **Mid-superficial femoral artery**: More **parabolic** profile.
- **Pulsatile nature of blood flow** complicates the velocity profile further.
  - Flow reversal during certain phases of the **cardiac cycle** affects velocity distribution.



  - The velocity profile may be visible on a **color flow image**, where **slower-moving blood near the walls** is apparent (Figure **8.5**).
- **Normal velocity profiles in arteries** vary with time and location due to:
  - Pressure pulses from the **heart**.
  - Reflection of pressure waves from **distal vessels**.



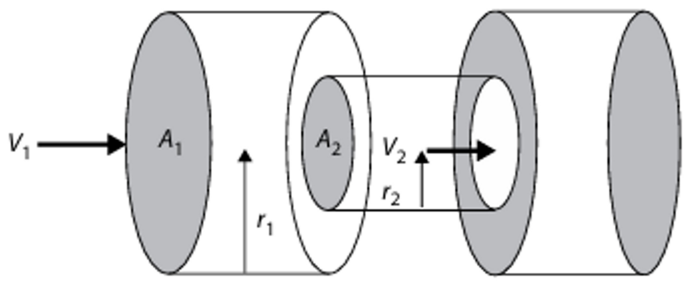
  - High distal **resistance**, which can cause **flow reversal during diastole** (Figure **8.6**).
- **Different arterial locations** have distinct profiles:
  - **Common carotid artery**: Typically does not show **flow reversal**.
  - **Common femoral artery**: Exhibits **diastolic flow reversal**, visible in Doppler spectra.



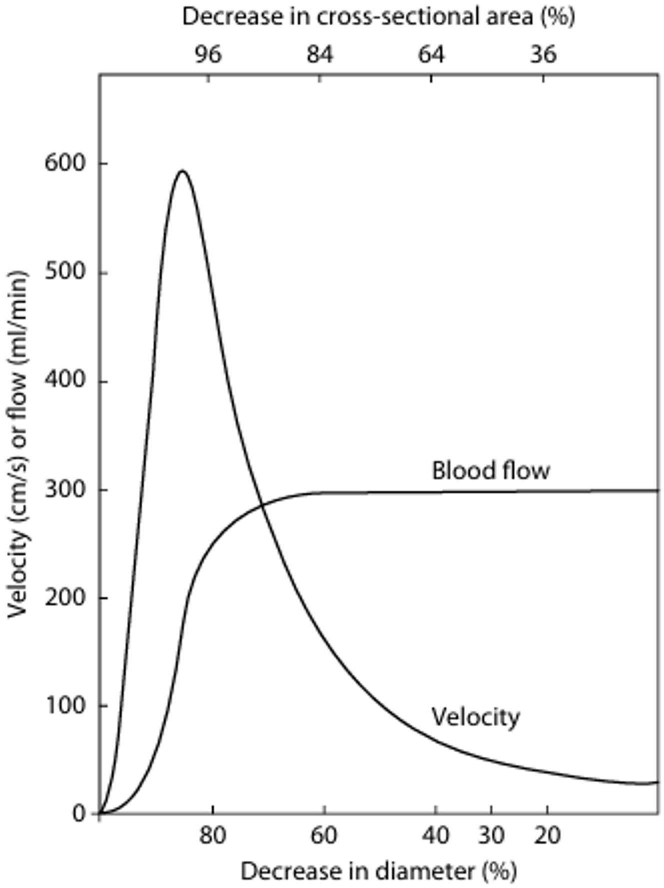
- Flow direction changes can be observed in **color flow imaging** as shifts from **red to blue** or **blue to red**, depending on the transducer orientation (Figure **8.7**).

Velocity Changes Within Stenosis (Page 163)

- Changes in **velocity across a narrowing (stenosis)** are essential for **detecting and quantifying** arterial disease.
- The relationship between **steady flow (Q), velocity (V), and cross-sectional area (A)** is given by: Q=V×AQ = V \times AQ=V×A
  - If no fluid is lost along the tube, flow remains constant, meaning **velocity must change** as **cross-sectional area decreases**.



- **Figure 8.12** illustrates this principle:
  - As **vessel area decreases**, **velocity increases**.
  - The **velocity ratio** between different points in the vessel helps assess stenosis severity.

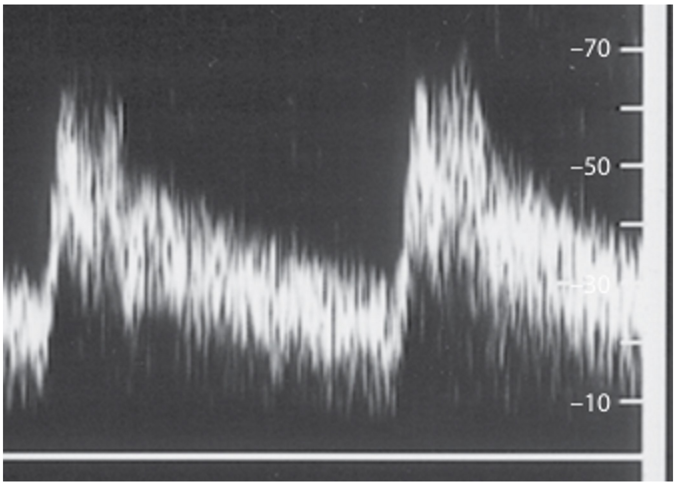


- **Theoretical model predictions** (Figure 8.13):
  - **Mild stenosis (<70-80% diameter reduction)**: Flow remains relatively unchanged.
  - **Severe stenosis (>80% diameter reduction)**: Flow becomes restricted (hemodynamically significant stenosis).
  - **Velocity increases within the stenosis** even when **flow remains constant**.
  - **Beyond a critical narrowing**, flow reduces significantly, causing a **drop in velocity** ("trickle flow").
- **Clinical application**:
  - **Velocity changes** are more sensitive than **flow reduction** for detecting stenosis.
  - **Doppler ultrasound** can identify these changes, as shown in **Figure 8.14**, which displays a **velocity increase at a superficial femoral artery stenosis**.

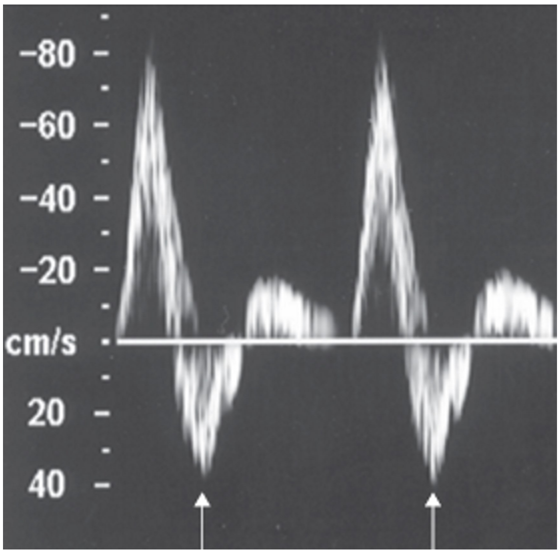
Resistance to Flow (Page 165)

- **Blood flow depends on the pressure difference between two points** in a vessel and the **resistance to flow**.
- Resistance is described by **Poiseuille's equation**: Pressure drop=Flow×Resistance \text{Pressure drop} = \text{Flow} \times \text{Resistance}
  - Resistance is influenced by: Resistance=8×Viscosity×Lengthπ×Radius4 \text{Resistance} = \frac{8 \times \text{Viscosity} \times \text{Length}}{\pi \times \text{Radius}^4}
  - The **radius of the vessel** has the greatest impact on resistance (**inversely proportional to the fourth power of the radius**).
- **Clinical relevance**:
  - In the normal circulation, most resistance occurs at the **arteriole level**.
  - Different organs have different resistance levels:
    - **Brain, kidney, placenta → Low-resistance vascular beds**.
    - **Resting muscles → Higher resistance**.
  - **Pathological changes**:

        - **Placental abnormalities** → High-resistance placenta, leading to **reduced fetal oxygen and nutrition**.
        - **Arterial narrowing (e.g., superficial femoral artery disease)** → Increased resistance, causing **reduced blood flow and pain**.
- **Waveform characteristics**:
    - The **shape of the Doppler waveform** depends on the resistance of the vascular bed.
    - **Low-resistance arteries (e.g., internal carotid artery, renal arteries)**:



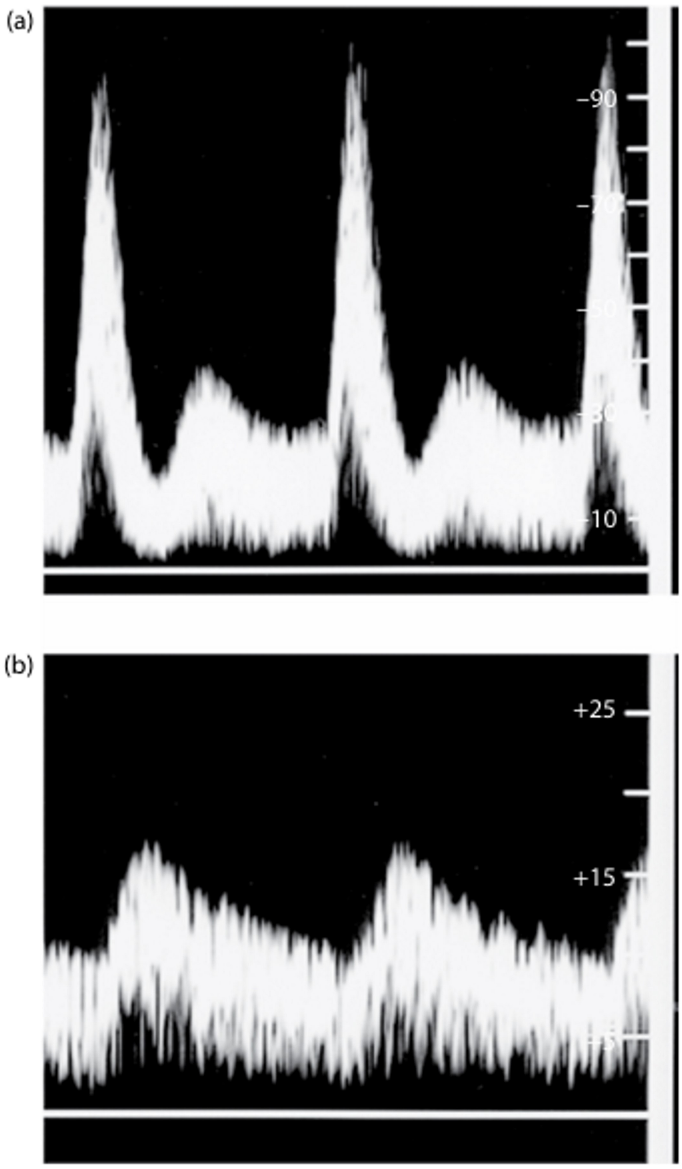
        - Continuous forward flow during **diastole** (Figure **8.15**).
    - **High-resistance arteries (e.g., superficial femoral artery)**:



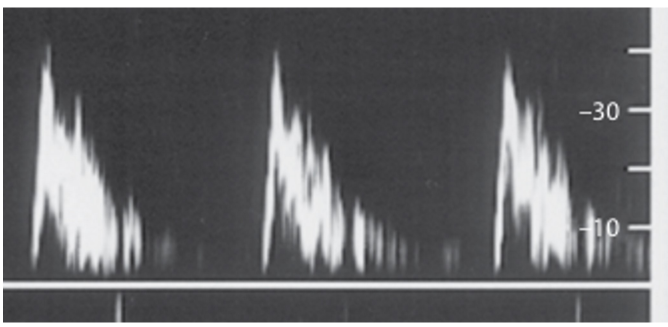
        - **Diastolic flow reversal** seen in the **Doppler waveform** (Figure **8.6**).
- **Significance in vascular disease**:
    - Identifying **resistance changes** in Doppler waveforms can help diagnose **vascular abnormalities**.

Physiological and Pathological Changes That Affect the Arterial Flow (Page 166)

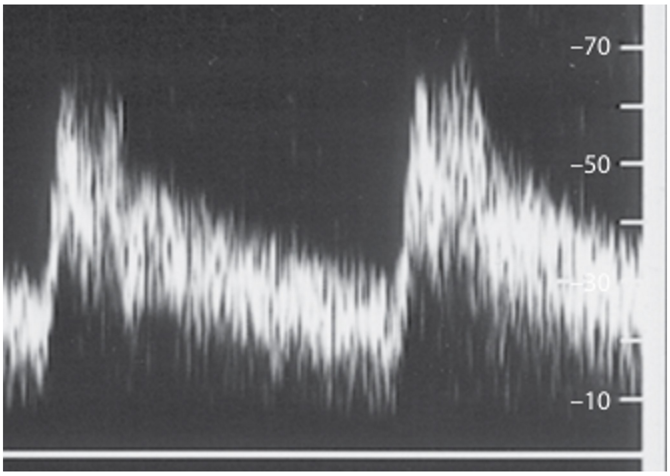
- **Tissue perfusion** is regulated by **arteriolar diameter changes**, which alter **peripheral resistance**.
- **Exercise-induced changes**:
    - Increased demand in **leg muscles** during exercise **reduces peripheral resistance** by **arteriolar dilation**, leading to **increased blood flow**.



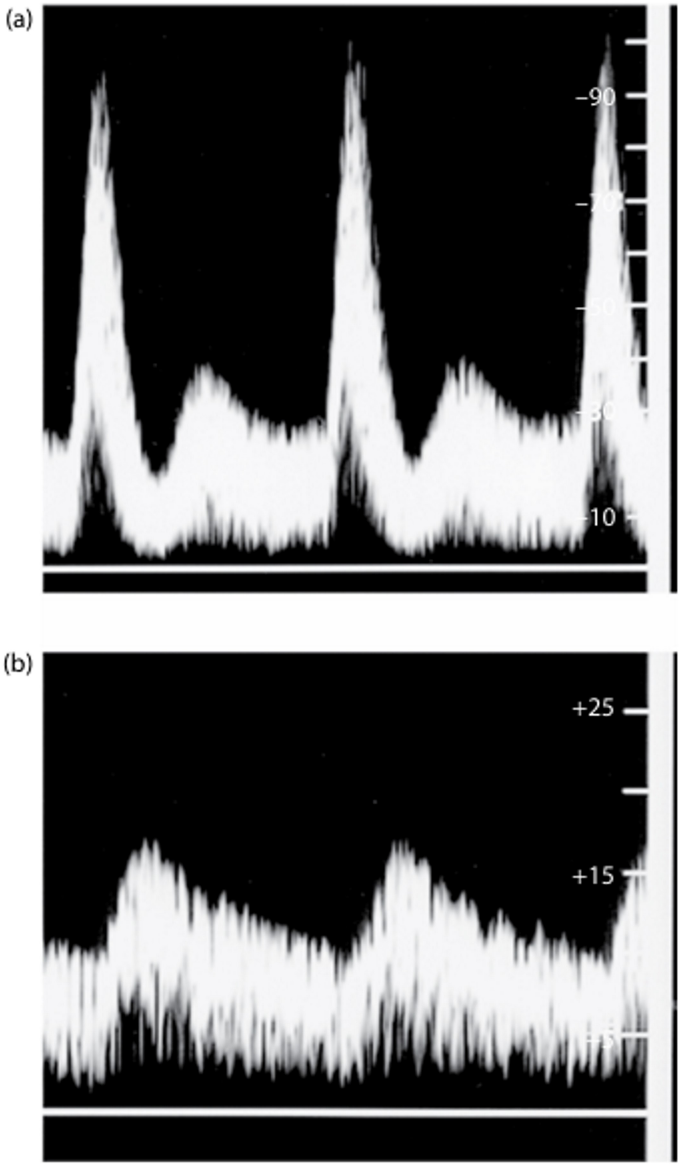
- ○ This results in a **waveform shape change**, with **diastolic flow becoming entirely forward-directed** (Figure **8.16a**).
- **Effects of arterial disease**:
    - ○ Arterial **narrowing** significantly alters **resistance to flow**.
    - ○ A **decrease in vessel diameter** causes **resistance to increase**, impacting **blood flow**.
    - ○ **Doppler waveform changes** can indicate **arterial occlusion distal to the measured site**.



- ○ **Figure 8.17** shows a **Doppler spectrum from the common carotid artery** proximal to an **internal carotid artery occlusion**:
    - ▪ **Short acceleration time** (systolic onset to peak).



- **Absence of diastolic flow**, which is normally present in the **cerebral circulation** (Figure **8.15**).

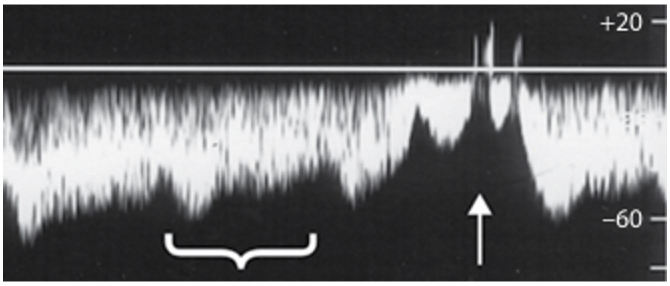


- **Waveform changes distal to occlusion**:
  - In severe **superficial femoral artery disease**, arterioles **dilate maximally** to lower **peripheral resistance** and maintain **tissue perfusion**.
  - **Figure 8.16b** shows a **damped waveform** with:
    - **Prolonged systolic acceleration time**.

        - **Increased diastolic flow**.
    - The **velocity of flow distal to the occlusion** is lower than **hyperemic flow in normal vessels** (Figure **8.16a**).
- **Collateral circulation**:
    - **Alternative pathways** (collateral flow) may **bypass stenosis or occlusion**, altering **expected waveform changes**.
    - **Good collateral circulation** can **compensate for severe disease**, influencing **resistance and waveform shape**.

Venous Flow (Page 167)

- **Veins transport blood back to the heart**, aided by **bicuspid valves** that prevent retrograde flow.
    - **Distal veins** have more **valves** compared to proximal ones.
- **Venous return mechanisms**:
    - **Pressure changes** from the **cardiac cycle** influence venous flow.

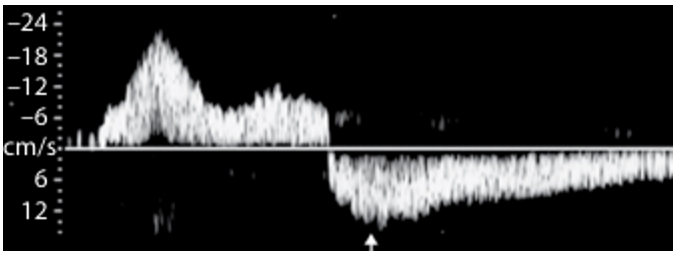


    - **Respiration** affects venous return (**Figure 8.18**).
    - **Posture changes** and **calf muscle pump action** enhance flow.
- **Central venous system effects**:
    - **Right atrial volume changes** impact **venous flow and pressure**.
    - **Proximal arm and neck veins** show **pulsatile flow patterns** in Doppler spectra due to proximity to the chest.
    - **Lower limb and peripheral arm veins** are **less affected by cardiac cycle** due to **vein compliance**, which dampens pressure changes.
    - **Venous valves** and **intra-abdominal pressure shifts** during respiration also influence venous flow, particularly in **distal veins**.

Venous Flow (Page 168)

- **Respiration and Venous Return**:
    - **Thoracic volume changes** (due to diaphragm and rib movement) assist venous return.
    - **Inspiration** expands the thorax, increasing **venous flow into the chest**.
    - **Expiration** decreases flow into the chest while increasing **flow from the legs to the abdomen**.
    - These changes are observed as **phasic flow variations** in the **Doppler spectrum of proximal veins** (e.g., **common femoral vein**) (Figure **8.18**).
- **Effect of Posture on Venous Flow**:
    - **Lying supine**: Small pressure difference between **ankle veins and right atrium**.
    - **Standing**: Increased **hydrostatic pressure gradient**, requiring the **calf muscle pump** to assist venous return.
    - The **calf muscle pump**:
        - Compresses **deep veins and venous sinuses** to **force blood toward the heart**.
        - **Valves prevent backward flow**.
        - Creates a **pressure gradient** between **superficial and deep veins**, ensuring proper drainage.
- **Venous Valve Failure and Reflux**:

- **Incompetent venous valves** result in **retrograde flow**, reducing **calf muscle pump efficiency**.
- Leads to **increased venous pressure** after muscle relaxation.
- **Chronic venous hypertension** can contribute to **venous ulcers**.



- **Colour flow imaging and spectral Doppler** are used to detect **venous incompetence**, seen as **retrograde flow after calf compression** (Figure **8.19**).
- **Venous outflow obstruction** is identified by the **loss of normal spontaneous phasic flow** on Doppler.