Hemodynamics of Arterial Vascular Disease

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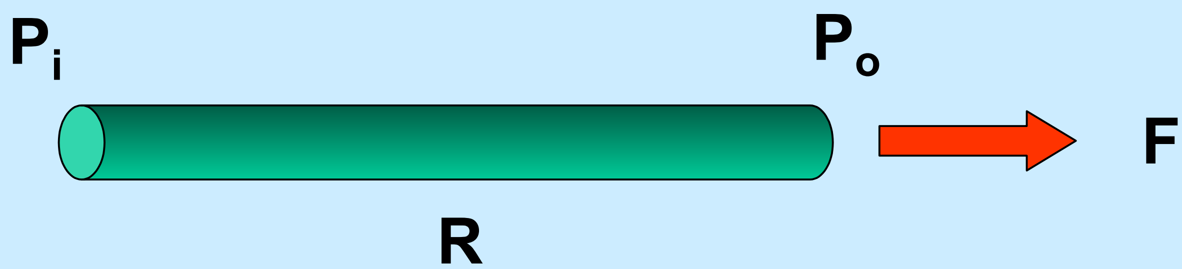
Learning Objectives

- Understand the relationships between pressure, flow and resistance for laminar and turbulent flow
- Describe in quantitative terms how changes in vessel radius alter single vessel resistance
- Discuss the concept of “critical stenosis” and why large reductions in vascular radius are required to affect resting and maximal distal flows
- Describe the hemodynamic consequences of single and multiple stenotic lesions
- Describe the hemodynamic basis for “vascular steal”

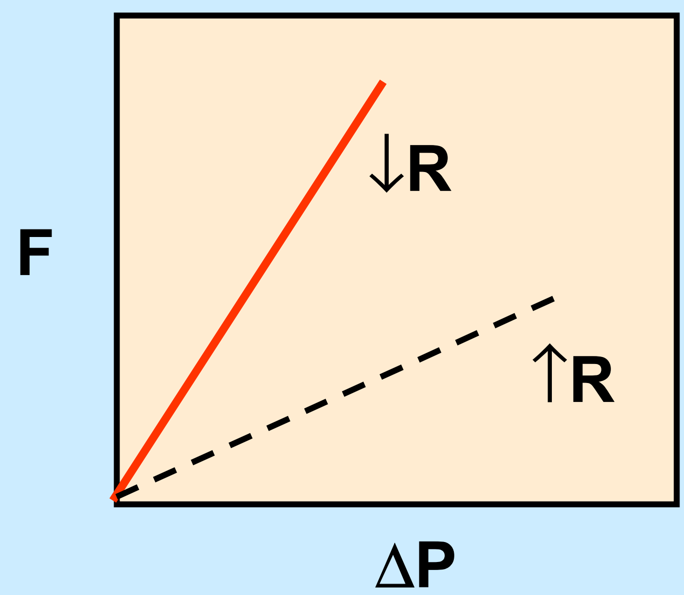
Single Vessel Hemodynamics

- Pressure, flow, and resistance
- Laminar vs. turbulent flow
- Vascular stenosis

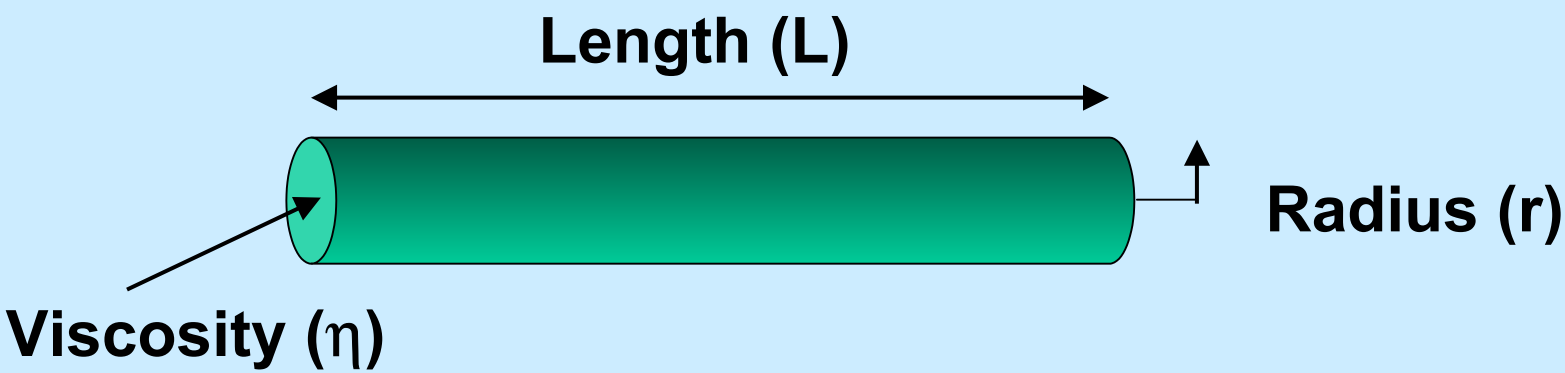
Pressure, Flow, and Resistance



$$F = \frac{P_i - P_o}{R}$$



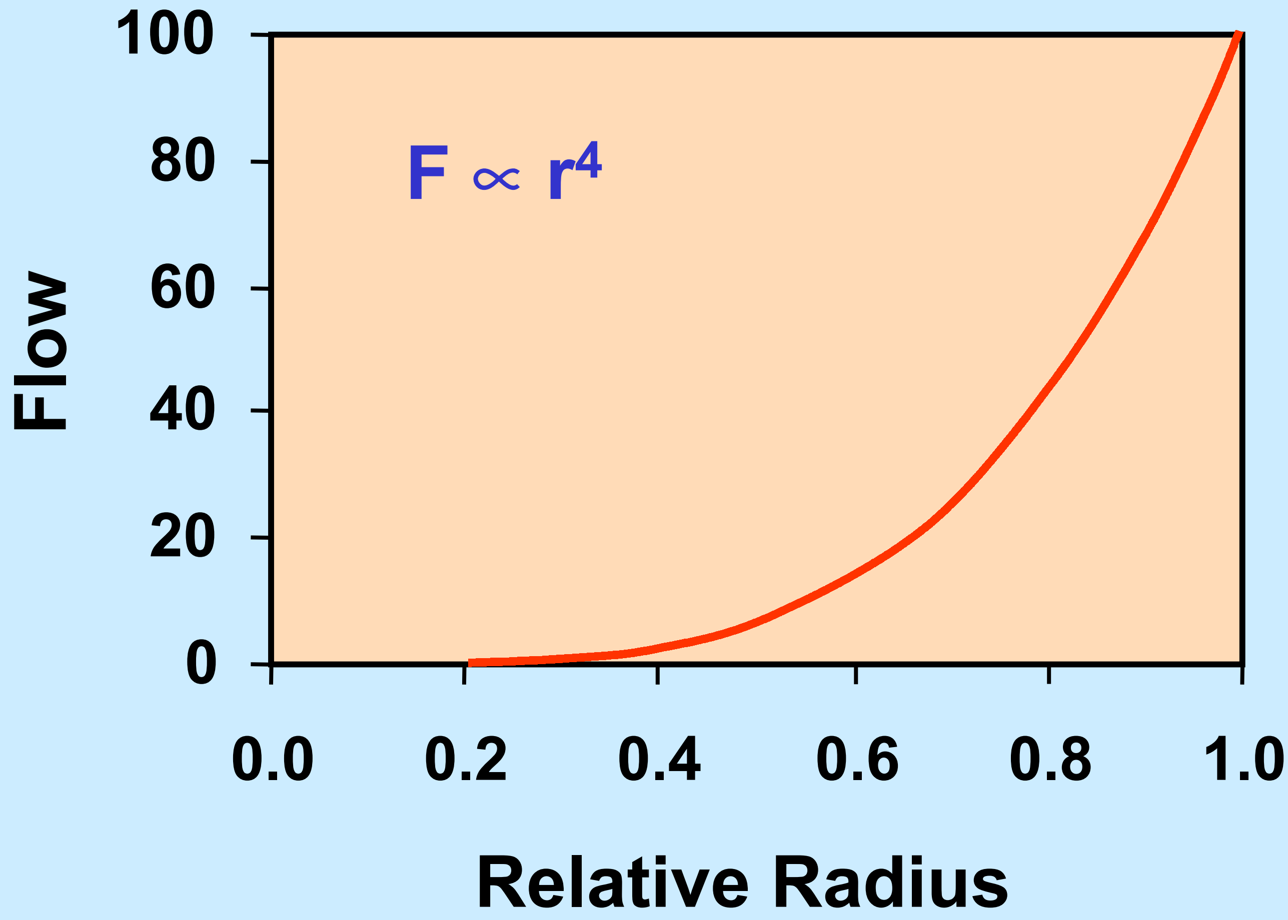
Pressure, Flow, and Resistance *cont.*



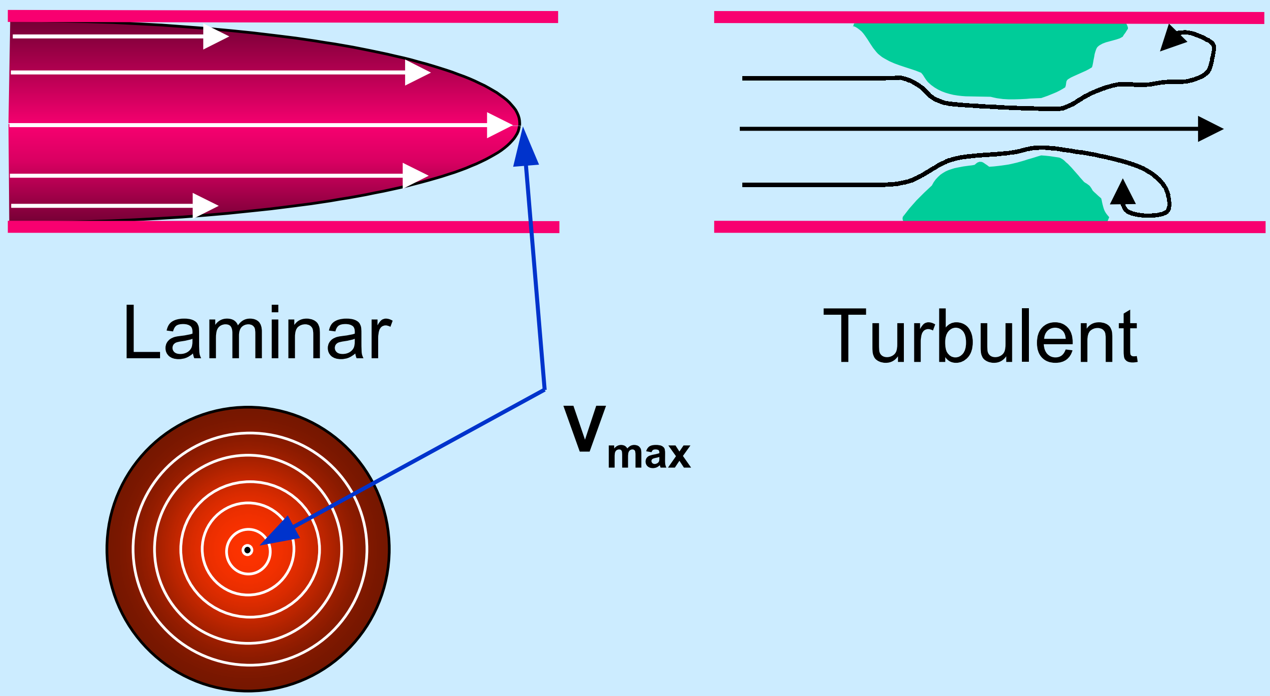
Poiseuille's Equation

$$R \propto \frac{\eta\ L}{r^4} \qquad \textit{therefore} \qquad F \propto \frac{\Delta P\ r^4}{\eta\ L}$$

Effects of Radius on Flow in a Single Vessel



Laminar vs. Turbulent Flow

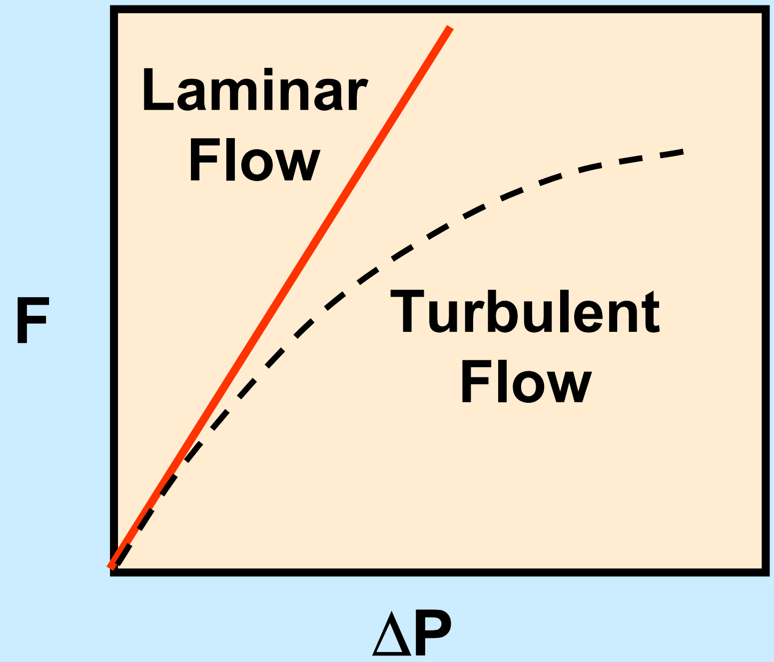


Turbulence

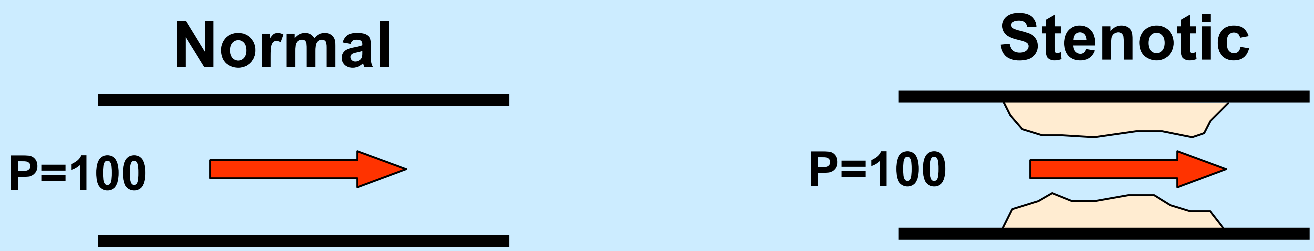
- Disruption of laminar flow causes turbulence
- Regions of stenosis, with increased flow velocity, can cause turbulence, particularly distal to stenosis *(Flow = Velocity x Area, therefore Velocity $\propto$ 1/radius ^{2})*
- Reynolds number (Re) $\propto$ (vel · diam)/viscosity
  - Increased Re increases likelihood of turbulence
- Turbulence causes endothelial dysfunction, and increased thrombogenicity

Turbulence cont.

- Turbulence causes energy losses that greatly exceed those predicted by Poiseuille's law which assumes laminar flow conditions



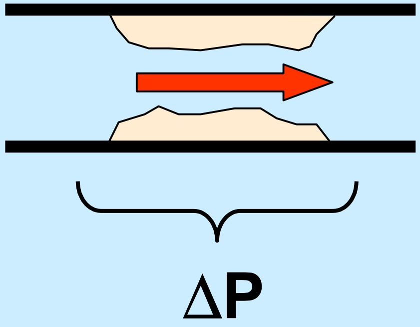
Energy Losses Across Stenotic Lesions

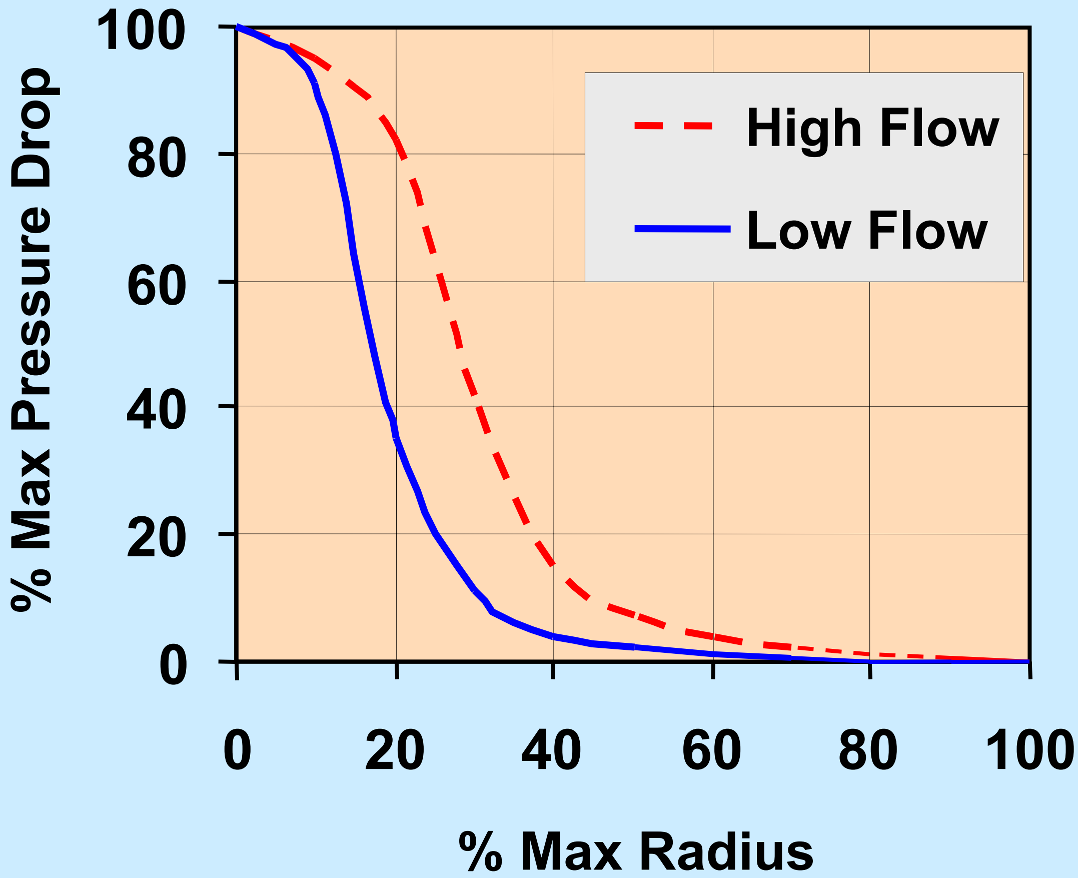


ΔP = 0.1	**Resting Flow**	**ΔP = 10**
ΔP = 0.2	**2X Flow**	**ΔP = 35**

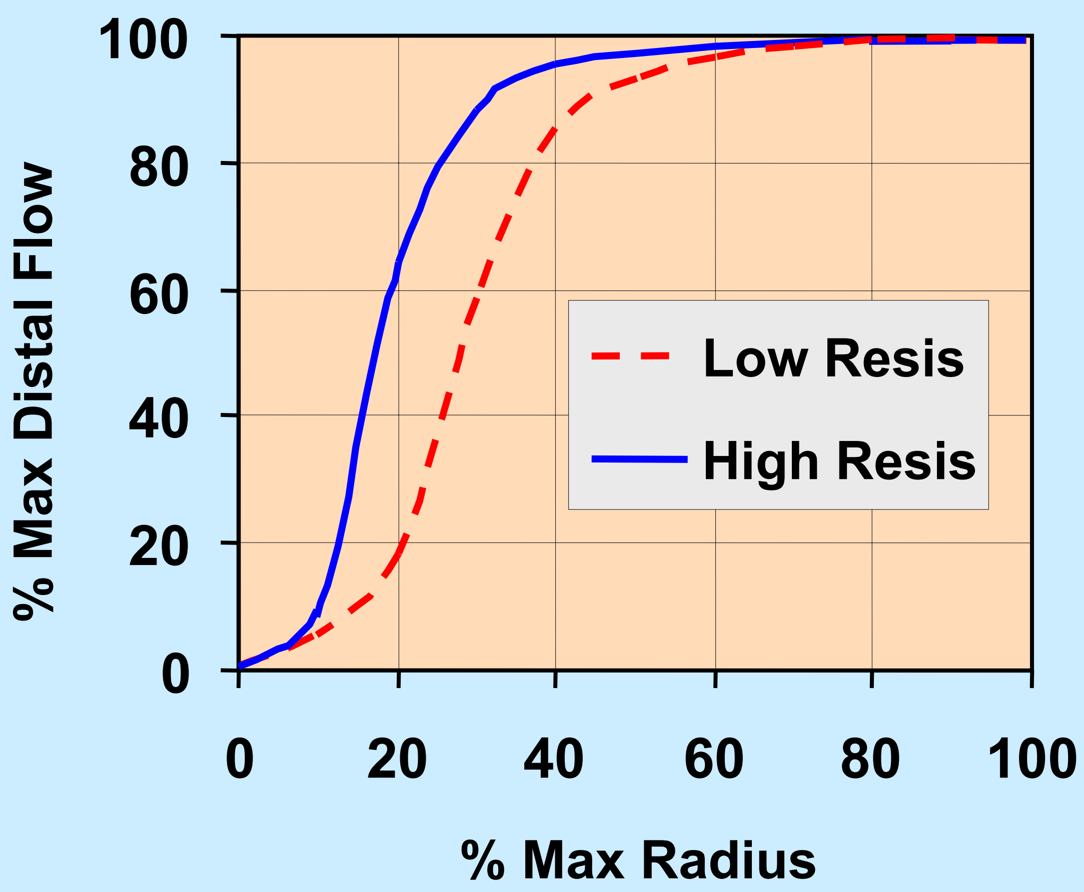
Energy losses (pressure drops) across stenotic lesions increase disproportionately to increases in flow

Concept of Critical Arterial Stenosis





Concept of Critical Arterial Stenosis



Question

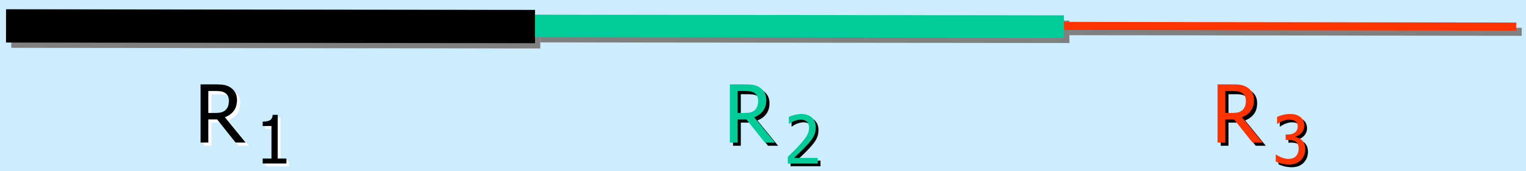
If radius is such an important determinant of flow, why does a critical stenosis require a radius reduction of >50% (corresponding to a reduction in cross-sectional area of >75%)?

After all, Poiseuille's law says that flow is proportional to the radius to the fourth power; therefore, a 50% reduction in radius should decrease flow 16-fold.

Hemodynamics of Vascular Networks

- In-series resistances
- Vascular disease in the human limb
  - Single vessel stenotic lesions
  - Multiple vessel stenotic lesions

Series Resistances



$R_T = R_1 + R_2 + R_3$

$R_T = 1 + 29 + 70$

$R_T = 100$

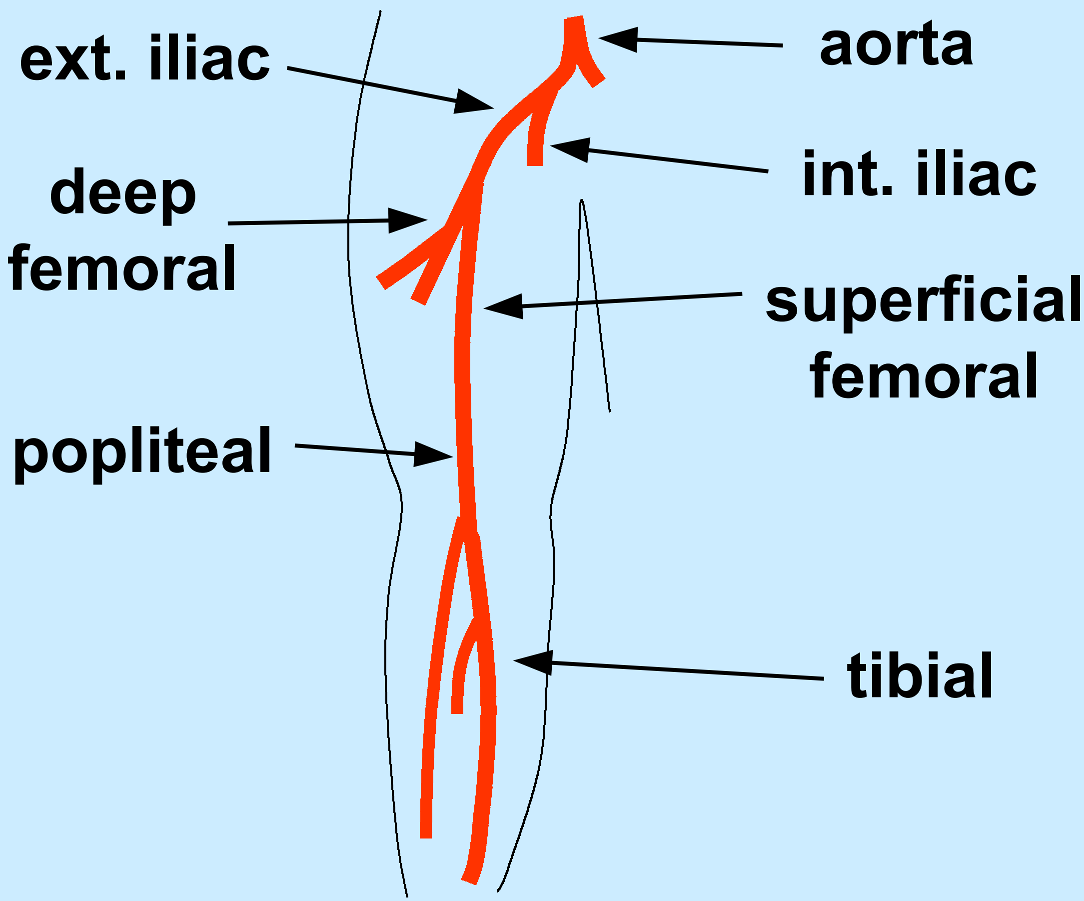
$$F = \frac{\Delta P}{R_1 + R_2 + R_3}$$

Therefore, several-fold increases in R_1 will have relatively little effect on flow because R_1 is so small relative to R_T.

Important Series Network Concepts:

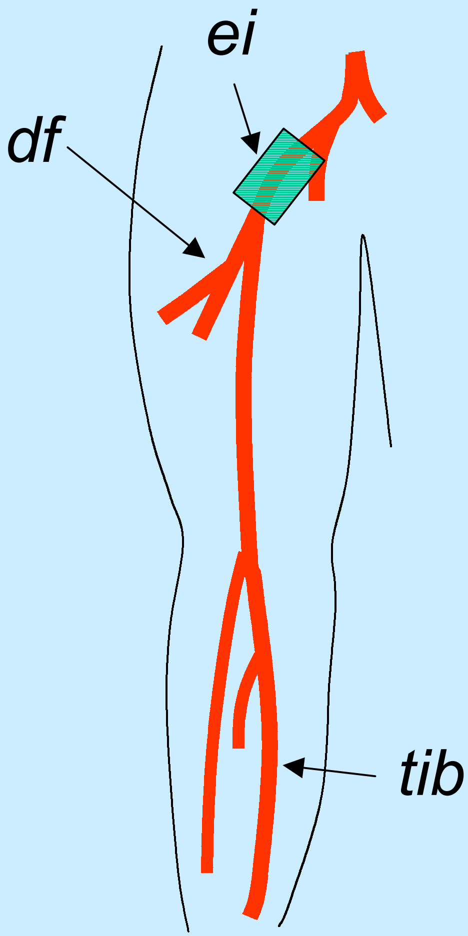
- Distributing arteries normally have very low resistance relative to the microvascular beds they are supplying (~0.1% of R_T).
- Therefore, flow in a vascular bed is normally determined by the resistance of the microvascular bed within the organ and not by the distributing artery.
- However, significant stenotic lesions will limit maximal blood flow by increasing R_T (and decreasing pressures distal to lesion), and may even limit resting blood flow.

Arterial Disease in the Human Limb



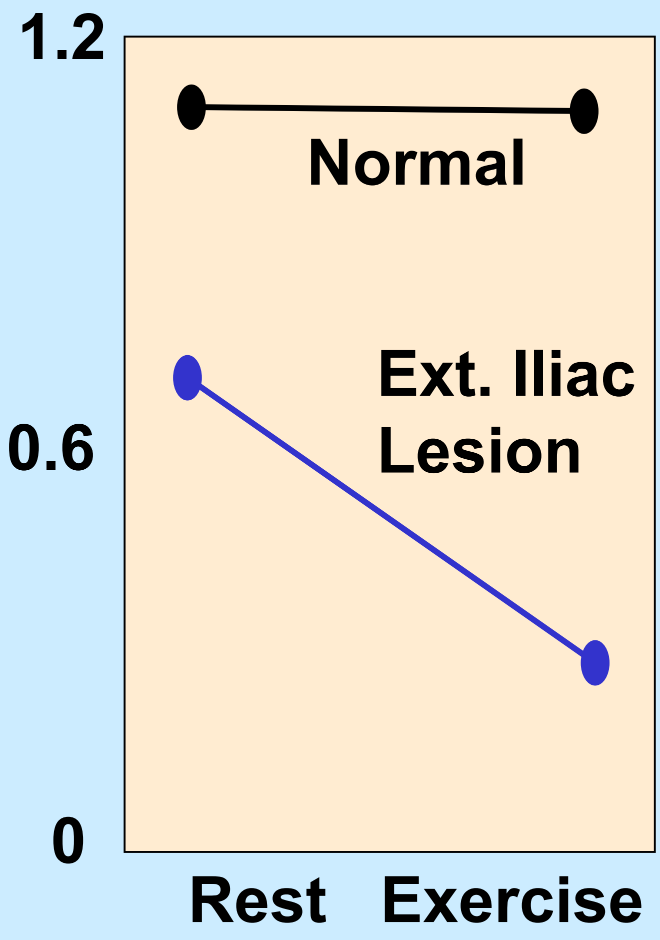
Single Vessel Stenosis

(External Iliac)



- Pressure drop across stenosis will reduce perfusion pressure to *df* and *tib*
- Resting flows in *df* and *tib* may be normal due to autoregulation.
- Maximal flow capacities of thigh and calf will be limited by the reduced perfusion pressure distal to the *ei* lesion. As flow increases across the *ei* lesion, distal pressure falls.

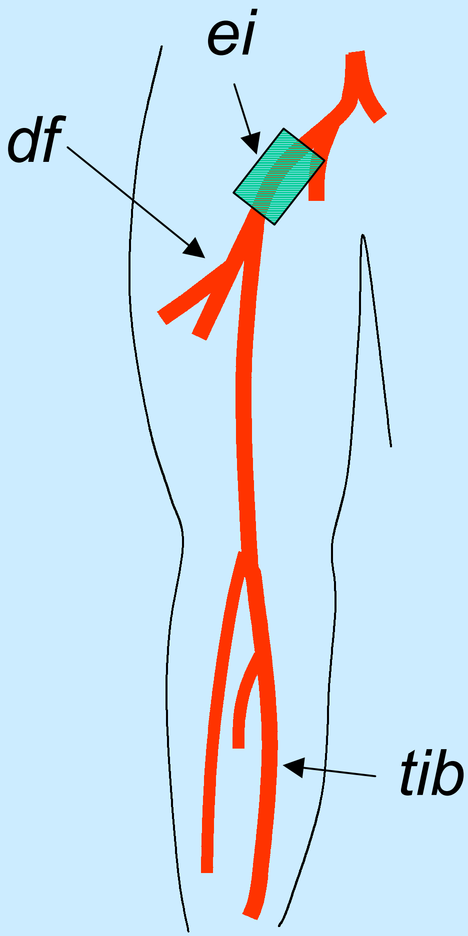
Ankle Pressure Index



- A normal index is ~1.1 at rest and post-exercise.
- The index will be reduced at rest and will fall even further after exercise when a significant lesion is present.

Single Vessel Stenosis

(External Iliac)



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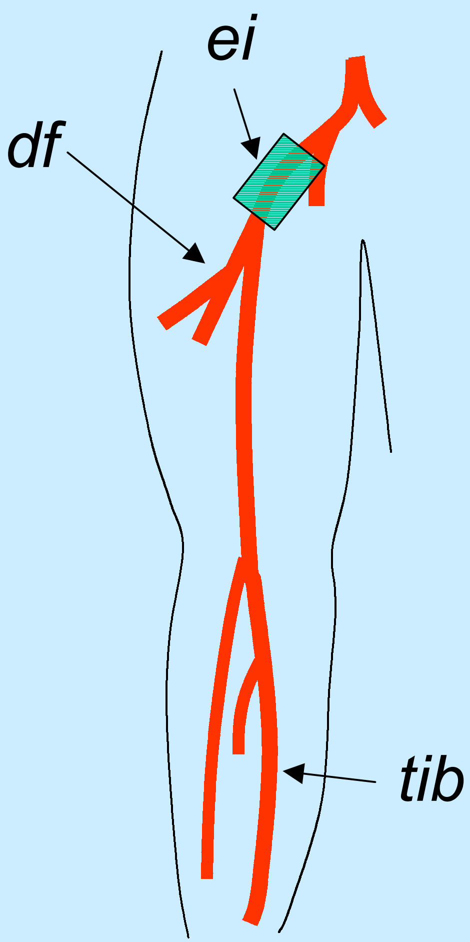
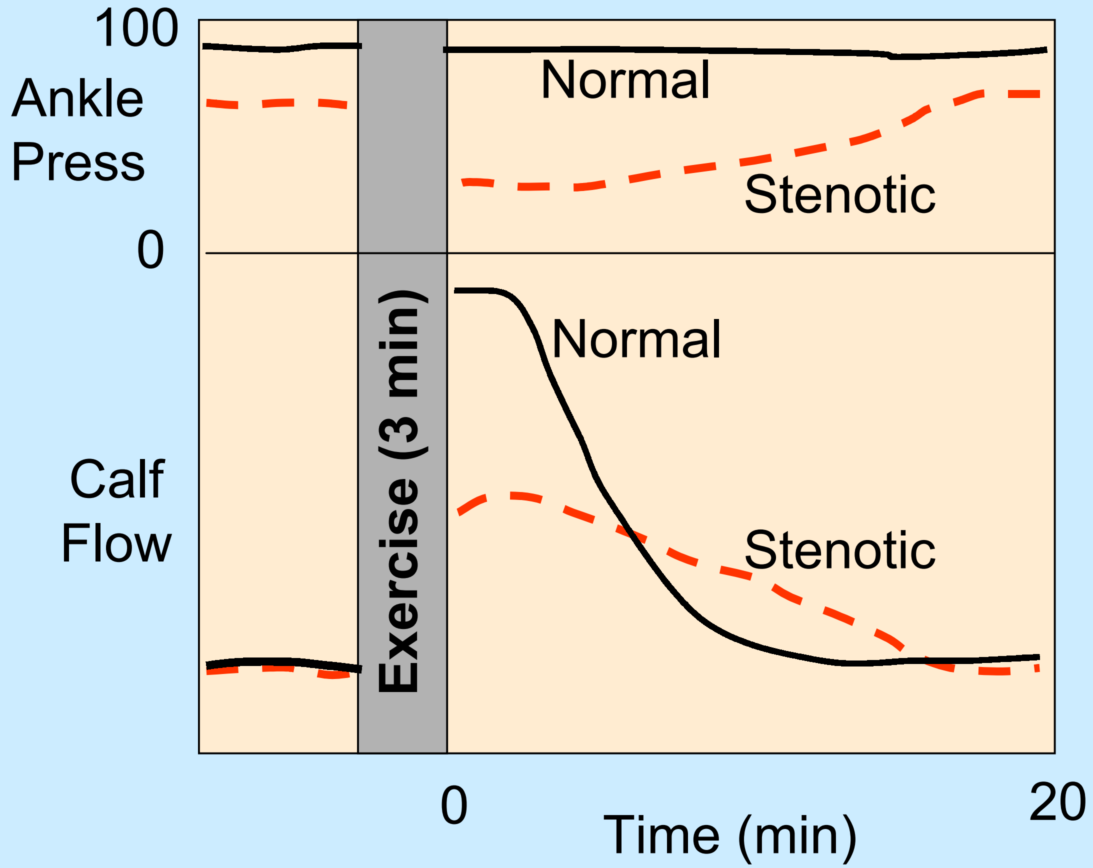
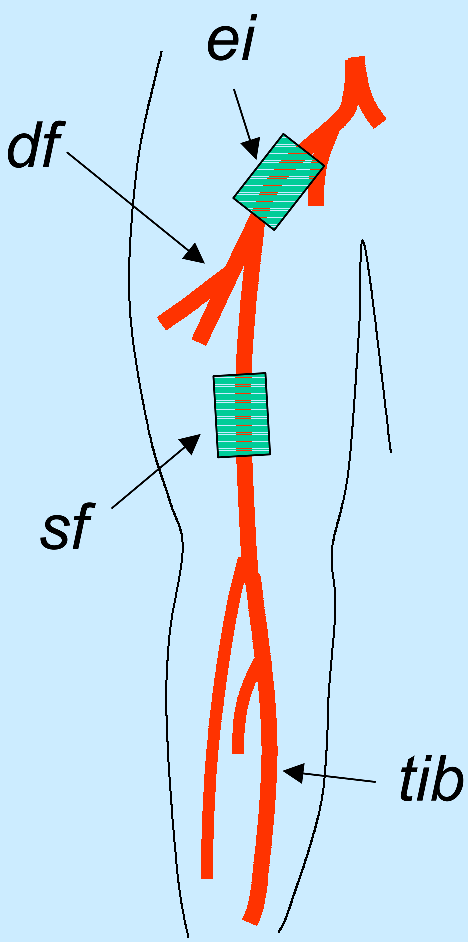




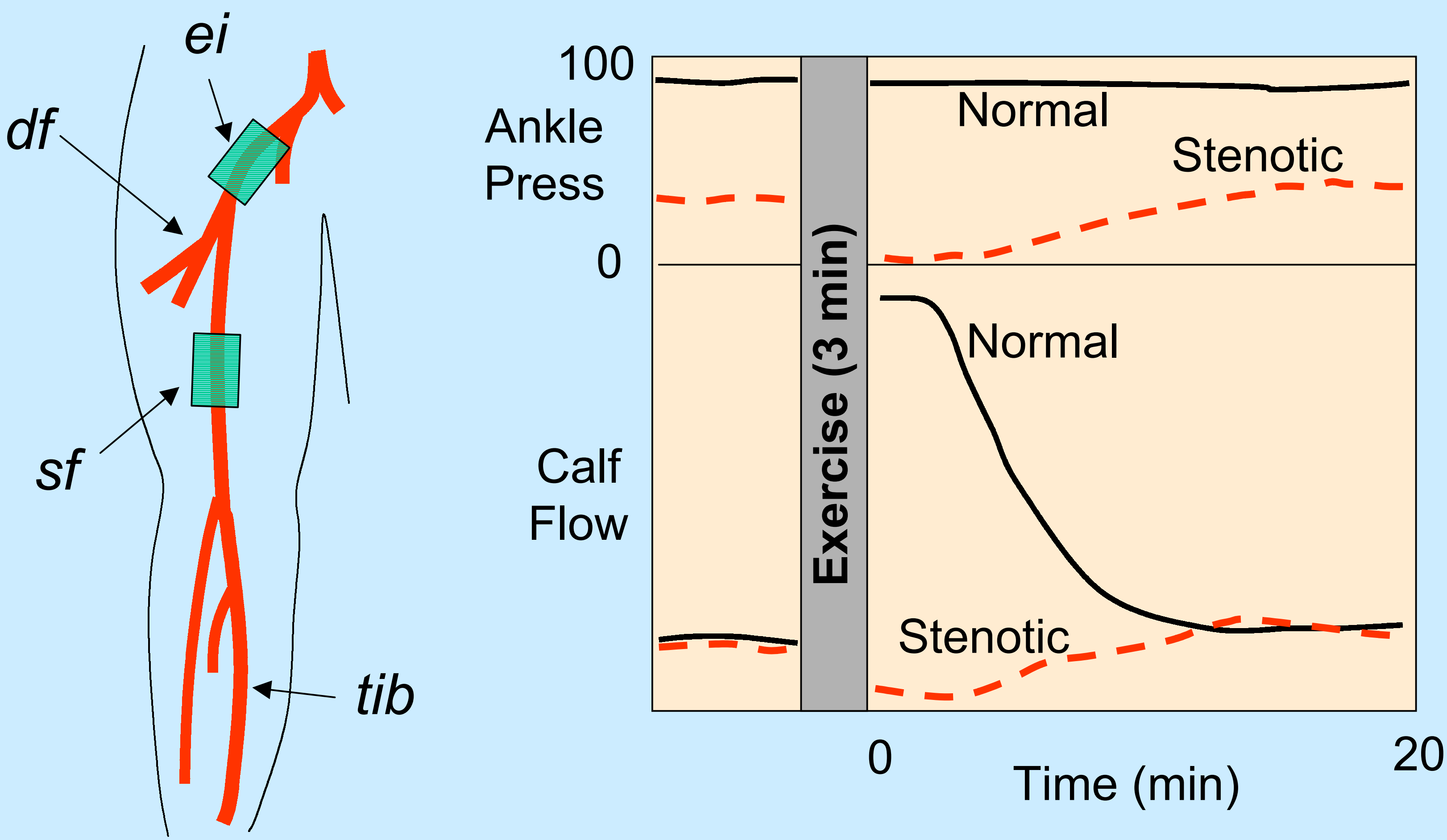
Multiple Vessel Stenosis
(External Iliac and Superficial Femoral)



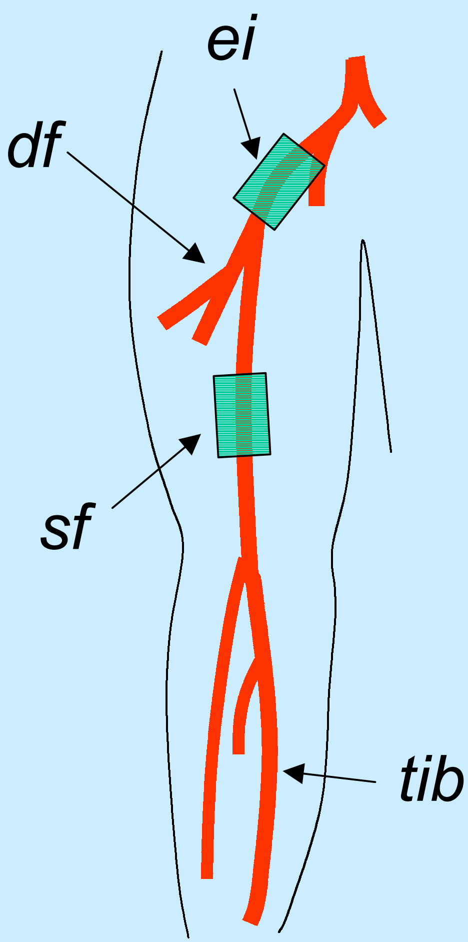
- Pressure drop across stenoses will reduce perfusion pressure to *df* and particularly to *tib.*
- Resting flow in *df* may be normal due to autoregulation, but reduced in the *tib*.
- In response to exercise, calf *(tib)* blood flow will <u>decrease</u> as thigh *(df)* flow increases - "*vascular steal*"

Multiple Vessel Stenosis

(External Iliac and Superficial Femoral)



Vascular Steal



- Occurs in a distal vascular bed when two stenotic lesions are separated by a proximal vascular bed that has vasodilator reserve.
- Vascular steal is not a “stealing” of blood from one vascular bed to another, but rather blood flow simply decreasing to the distal bed due to a large fall in pressure distal to the proximal lesion as flow increases to the proximal vascular bed.

What Have We Learned?

- Relationship between pressure, flow and resistance for laminar and turbulent flow
- How small changes in vessel radius alter single vessel resistance
- Why large reductions in vascular radius are required to reduce resting and maximal distal flows in a vascular bed and how this relates to the concept of a “critical stenosis”.
- Hemodynamic consequences of single and multiple stenotic lesions in the circulation of the human leg
- Hemodynamic basis for “vascular steal”

Review Questions

- What is a “critical stenosis”?
- Why is the radius reduction required for a critical stenosis so much greater than what would be suggested by the Poiseuilles relationship?
- How important are inertial factors such as turbulence in determining the pressure drop across a stenotic lesion?

- How do changes in flow across a stenotic lesion affect the pressure distal to the lesion?
- What is “intermittent claudication” and why does it occur?
- Why can intermittent claudication occur when resting blood flows are normal?
- What is “vascular steal” and why does it occur?