Study Guide
Physics of Fluid Flow, Part 1

Fluids can be either liquids or gases. The flow of fluids through tubes and orifices has numerous applications in anesthesia practice. Example: IV fluids flowing through tubing to the patient, gases flowing through the anesthesia delivery circuit, gases passing through the flowmeter tubes of anesthesia machines, air flow into the lungs during inspiration.

Tube: *A pathway whose length is greater than its diameter*

Orifice: *An opening that has diameter but not length.*

Flow through tubes and orifices *occur when a pressure differential develops between the two sides of the tube or orifice.*

Definition of **Flow**: the quantity of fluid (gas or liquid) passing a point in unit time.

$F = Q/t$ Where F = mean flow; Q = quantity (mass or volume) and t = time

Volume flow rate *(Q)*: *varies with the cross-sectional area of the tube, tube length, and the pressure differential and viscosity of the fluid*

There are 3 types of flow:
Steady: Uniform (i.e., all molecules traveling in the same direction and at the same velocity)
Laminar: All molecules travel a parallel path within the tube
Turbulent: Molecules travel in nonparallel paths, which gives rise to "eddy" currents

Laminar Flow and Poiseuille's Law:

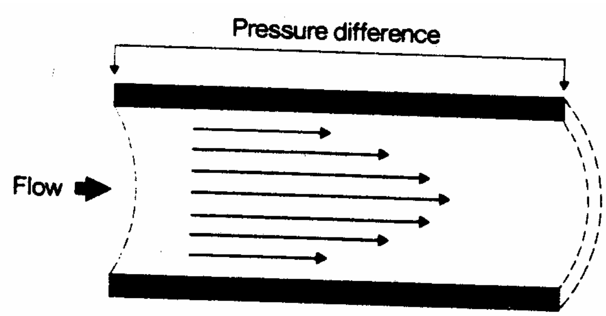


Figure 2.1 Laminar flow.

Laminar flow
1. a fluid moves in steady manner, it is orderly and streamlined
2. no eddies or turbulence
3. normally present in smooth tubes at low rates of flow
4. flow is greatest in center of the tube as illustrated above by the longer arrows . Flow in center is about twice the mean flow.
5. flow that is closer to the sides of the tube becomes slower until it almost approaches zero at the wall of the tube
6. a pressure difference must exist across the ends of the tube in order to drive fluid through the tube, in other words the difference in pressure at the entrance of the tube and the exit point of the tube is what causes flow of fluid through the tube

7. the relationship between pressure and flow is directly proportional as seen in the picture below

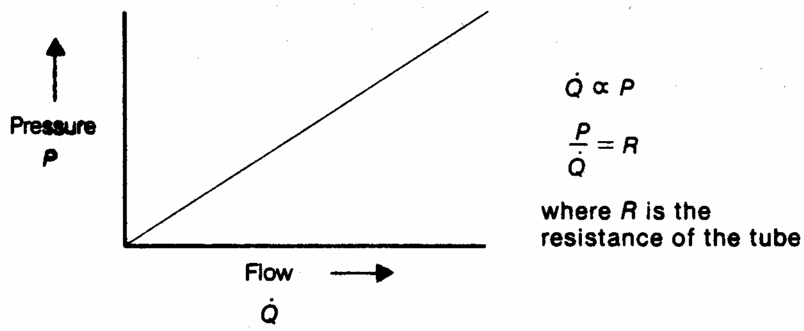


Figure 2.2 The graph shows the linear relationship of flow to pressure in laminar flow.

Resistance of the tube is depicted as R. Resistance is a ratio of pressure to flow or P/Q. So, how is resistance measured? Look at the graphic below.

Q is a constant flow passed thru a tube
P_1 is the pressure at the beginning of the tube; P_2 is pressure at the end of the tube.
The difference between these pressures ($P_1 – P_2$) is the driving pressure which allows movement thru the tube.
So, by dividing the pressure difference by the flow, the resistance of the tube is obtained. If the flow is laminar, the resistance is independent of the flow.

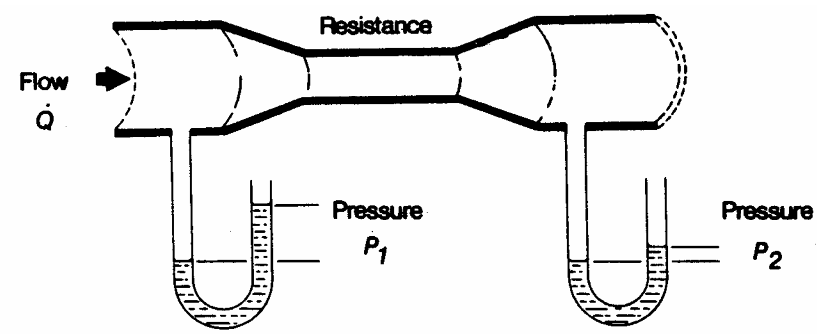


Figure 2.3 Measurement of flow-resistance.

Look at the effect the radius of the tube has on the resistance to flow. (Remember that the radius is ½ of the diameter).

The picture below shows this effect. Decreasing the radius of the tube by one-half reduces the flow to $1/16^{th}$ of its original value if the pressure drop along the tube remains the same. **Flow is proportional to the 4^{th} power of the radius**. Clinical application: a slight reduction of the radius of an endotracheal tube can have an appreciable effect on resistance and therefore on flow.

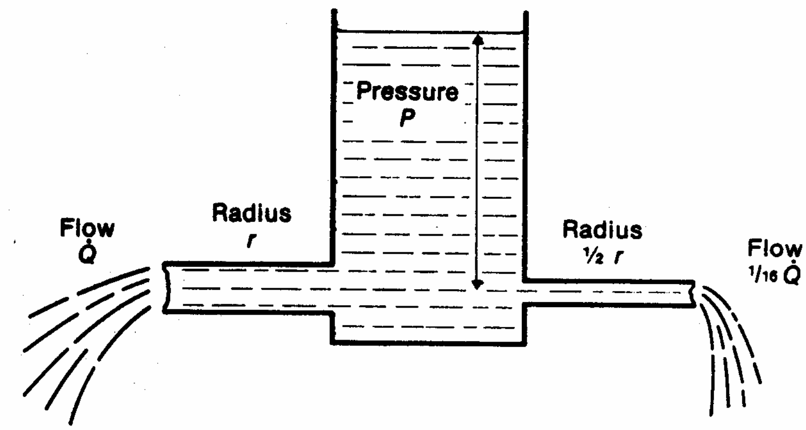


Figure 2.4 Effect on flow of halving the tube radius.

Now, look the effect of altering the length of the tube. This effect is much less than changing the radius. If the length of the tube is halved, the flow will double with other factors being kept constant. This effect is shown in the picture below.

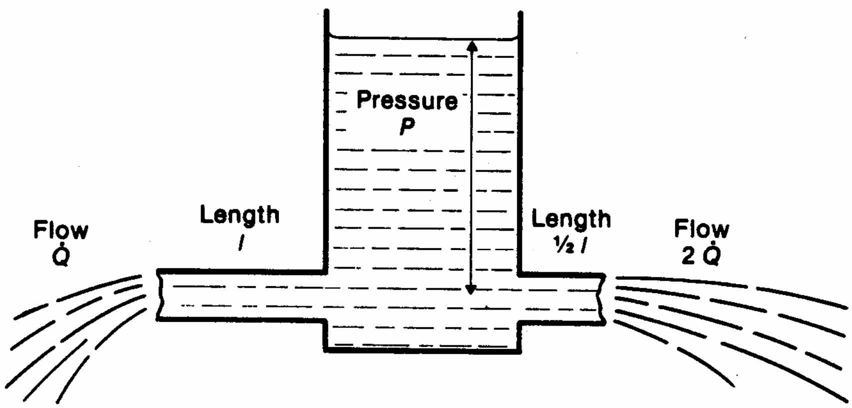


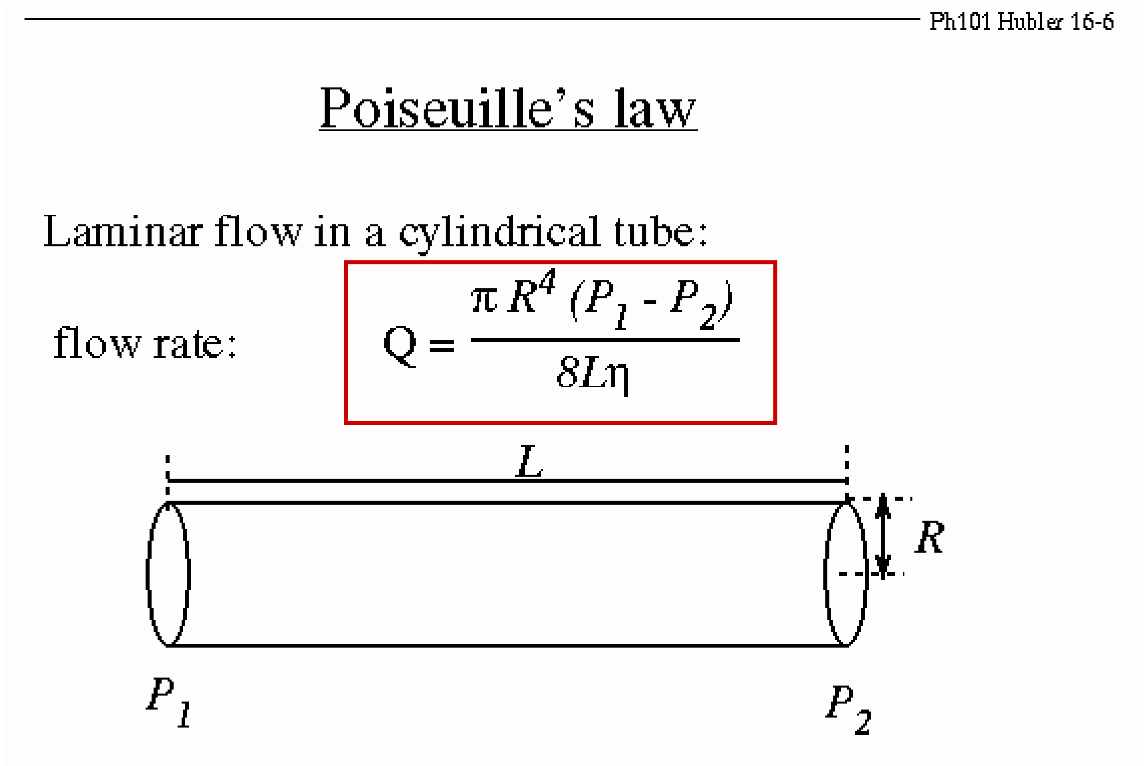
Figure 2.5 Effect on flow of halving the length of a tube.

Another factor that affects laminar flow is viscosity of the fluid that is flowing thru the tube. Viscosity of the fluid affects **resistance** to the flow. The higher the viscosity, the slower the flow. Viscosity is the measure of the frictional forces acting between the layers of the fluid as it flows along the tube. Viscosity is presented by the Greek letter eta (η).

So the factors that affect laminar flow thru a tube are:

1. **P** = pressure difference across the tube
2. **r** = radius of the tube
3. **L**= length of the tube
4. **η** = viscosity of the fluid flowing thru the tube

Laminar flow is described mathematically as **Poiseuille's Law**. This equation is shown below. The pi sign π is a constant (k). (Note: you will NOT have to calculate anything with this formula. However, you are expected to understand the components of the formula for laminar flow and the concepts of how changing components, i.e., radius, length, viscosity, will impact flow).



(For laminar flow in a cylindrical tube) the volume flow rate (Q) is:

1. **directly proportional to the pressure difference**
2. **directly proportional to the fourth power of the radius**
3. **inversely proportional to tube length and,**
4. **inversely proportional to viscosity**

1. Q is directly proportional to the pressure difference across the tube. *Clinical application: raising the IV pole increases the pressure gradient in the fluid delivered to the patient by gravity; flow increases proportionately.*

2. Q is directly proportional to the fourth power of the *radius* (r^4). ***Doubling the radius of the tube increases the flow rate 16 times. ($2r^4$) = (2) (2) (2) (2)r^4 = $16r^4$. Tripling the radius increases flow 81 times.*** *Halving the radius decreases flow to 1/16th of the original value.* ***Changing the radius has the most dramatic effect on flow.*** *Clinical application: flow thru a large bore needle is faster than through a small one.*

3. Q is inversely proportional to the length of the tube. *Clinical application: reducing the needle length increases the flow of fluids from an IV bag hanging on a pole.*

4. Q is inversely proportional to fluid viscosity. **Important to know: the property of fluid that determines flow when flow is laminar is viscosity**. *Clinical application: The anemic patient has decreased blood viscosity, therefore greater flows through tissues will*

result. Polycythemic patients have high blood viscosity, so flow through blood vessels is reduced, other factors remaining constant.

Laminar flow and resistance:

1. Resistance is inversely proportional to r^4 (the greater the radius, the smaller the resistance to flow). Resistance is decreased 16-fold when radius is doubled and 81-fold when radius is tripled.
2. Resistance is directly proportional to fluid viscosity (the greater the blood viscosity, the greater the resistance).
3. Resistance is directly proportional to tube length (the longer the tube, the greater the resistance).

Poiseuille's Law explains:

1. decreasing the needle gauge (increasing the radius—18 gauge is smaller than 16 gauge angiocath) on an IV line can increase flow
2. selecting needle with a shorter length can increase flow thru an IV line
3. increasing hydrostatic pressure in the IV bag by increasing its height increases flow
4. polycythemic patient has decreased blood flow thru tissues (increased blood viscosity) and the anemic patient has increased blood flow thru tissues (decreased blood viscosity)

Look at the drawings below:

In Fig. 177 – In this drawing, the level of the fluid in the IV bag is 2 feet above the needle. The needle has an internal diameter of 0.36 mm and a length of 3 cm. In one minute, 4.5 ml of liquid pass thru the needle.

In Fig. 178 – The IV bag is raised to 4 feet—the original flow of fluid is approximately doubled to 9 ml of liquid in one minute. Thus, the flow thru the need is directly proportional to the pressure difference.

In Fig 179 – The IV bag is lowered to its original height of 2 feet. However, a larger bore needle (internal diameter of 0.93 mm) is substituted; its length is again 3 cm. The flow is about 17 times greater than the flow in Fig. 177. It is now 75 ml of liquid in one minute.

Point: A rapid flow of liquid is likely to be needed during a transfusion, use a large bore needle in preference to relying on an increase in pressure.

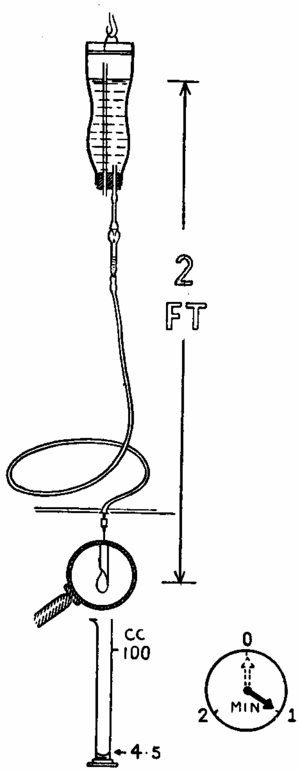


Fig. 177

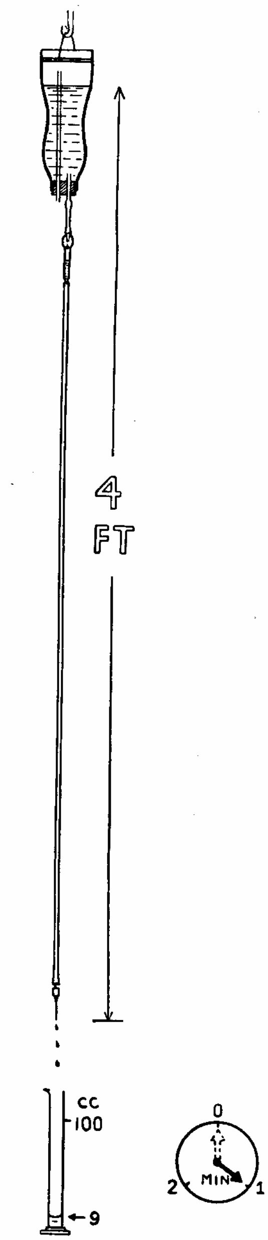


Fig. 178

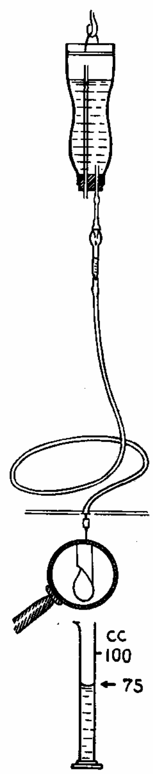
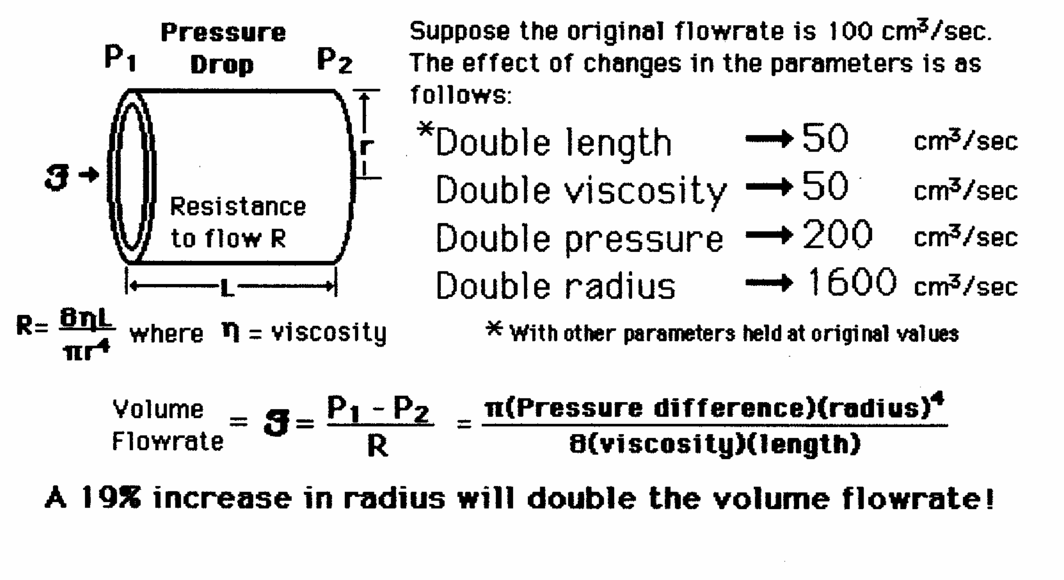
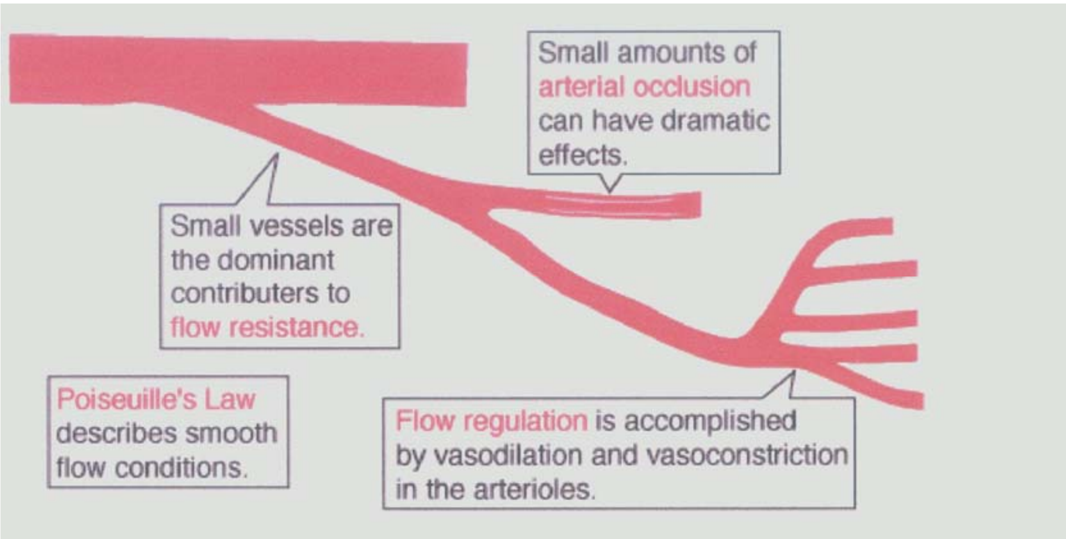


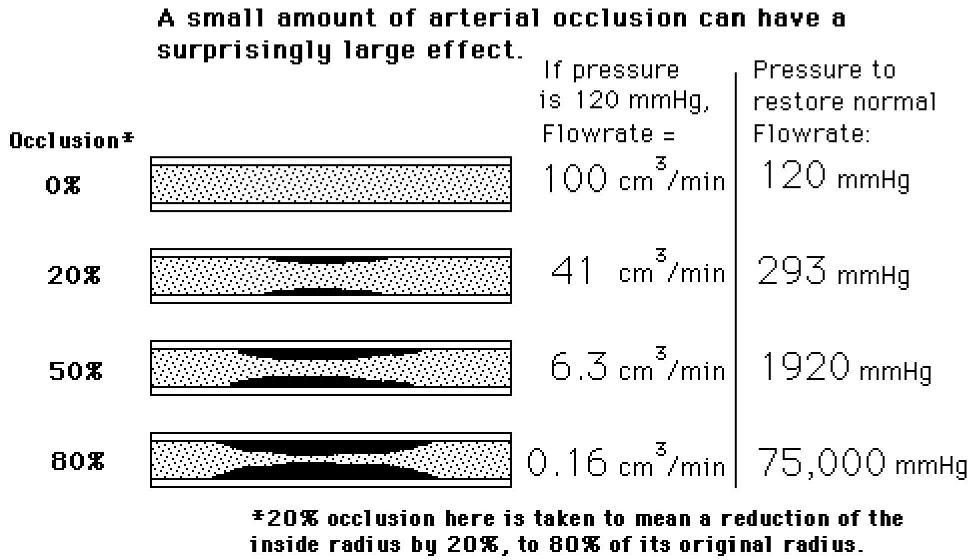
Fig. 179

The picture below shows the impact of length, viscosity, pressure, and radius on the flow rate.

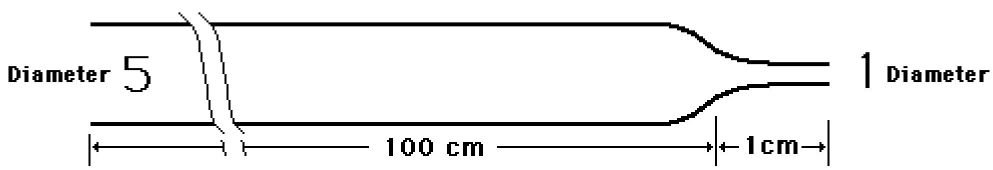


The next few pictures show how Poiseuille's Law relates the body's way of increasing blood flow or increasing resistance in vessels.



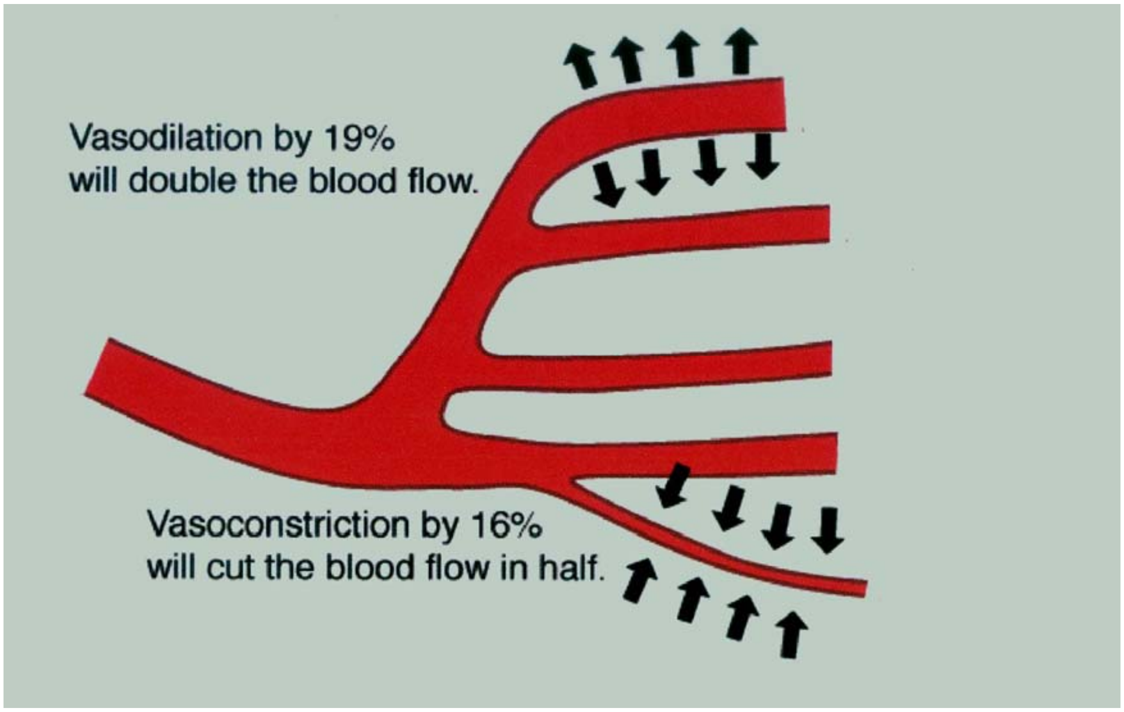


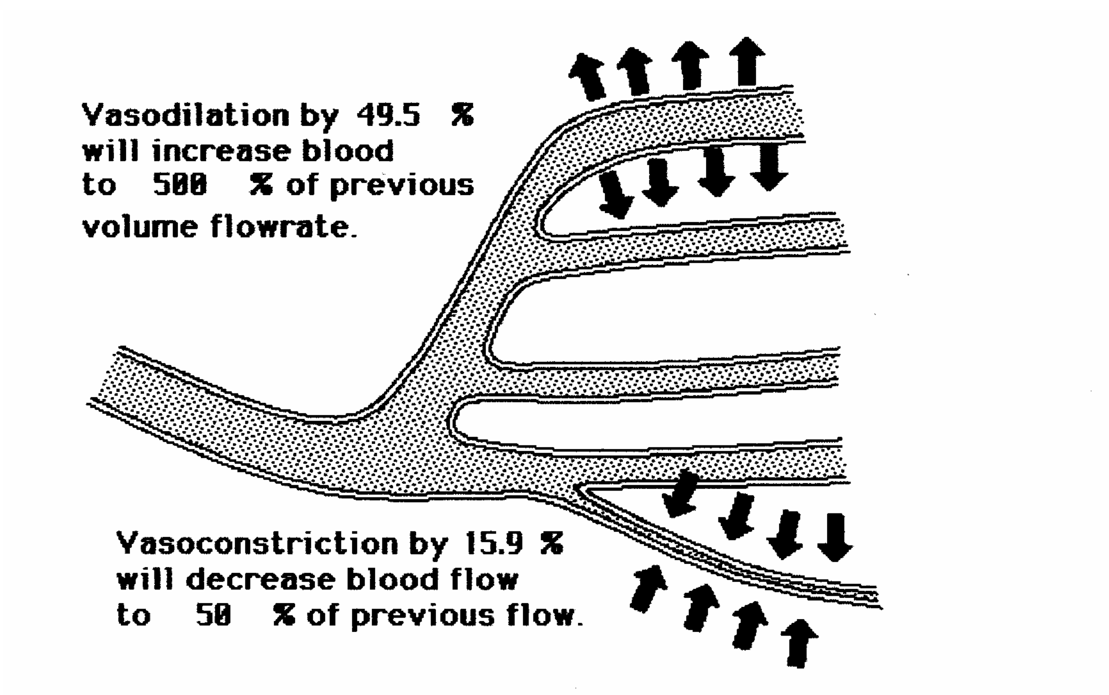
Small vessels dominate resistance



The large vessel has 100 x the length, but the small vessel has $5^4 = 625$ times the resistance per unit length. The 1 cm small section then has 6.25 x the resistance of the entire length of larger vessel.

Poiseuille's Law gives insight into the complex task of regulating blood flow to different parts of the body. In response to demand, the body must direct more oxygen and nutrients to one region of the body, and if necessary temporarily curtail the supply to a less essential region. Since the flow resistance depends on the fourth power to the interior radius of a vessel, the processes of vasodilation and vasoconstriction offer powerful control mechanisms.


Vasodilation by 19%
will double the blood flow.
Vasoconstriction by 16%
will cut the blood flow in half.


Vasodilation by 49.5 %
will increase blood
to 500 % of previous
volume flowrate.
Vasoconstriction by 15.9 %
will decrease blood flow
to 50 % of previous flow.

Suppose you have and emergency requirement for a five-fold increase in blood volume flowrate (like being chased by a big dog). How does your body supply it?

According to **Poiseuille's Law**, a five-fold increase in blood pressure would be required if the increase were supplied by pressure alone!

Blood Pressure 120 mmHg → 600 mmHg

This is not a realizable pressure.

But the body has a much more potent method for increasing volume flowrate in the **vasodilation** of the small vessels called arterioles.

Vasodilation $r \rightarrow 1.5r$

A 50% dilation of resistance vessels is within the body's control limits.

For constant pressure, this increases volume flowrate by a factor of $(1.5)^4 = 5.06$