Perfusion Fluid Mechanics
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## I. Dimensions and Units

A. Dimensions are physical quantities that can be measured. Typical dimensions include length (L), mass (M), time (t), temperature (T) and force (F). Force is not a fundamental dimension. It can be obtained from Newton's Law (force = mass · acceleration) having the dimensions $M \cdot L/t^2$.

B. Units are the scales by which dimensions are measured. There are at least two popular systems of units in use SI (or metric) and English. The medical community also has it own collection of units.

C. The fundamental units in the SI system are the meter, the kilogram and the second. The Newton is used as a derived unit of force in the SI system and is equal to 1 $kg{\cdot}m/s^2$. The conversion constant $g_c$ = 1 $kg{\cdot}m/(N{\cdot}s^2)$ and the gravitational acceleration at the surface of the earth $g$ = 9.807 $m/s^2$ in the SI system. Thus, a 1.00 kg object weighs 9.807 N on the surface of the earth.

D. The fundamental units in the English system are the foot, the pound mass ($lb_m$), the pound force ($lb_f$) and the second. The conversion constant $g_c$ = 32.17 $lb_m{\cdot}ft/(lb_f s^2)$ and the gravitational acceleration at the surface of the earth $g$ = 32.17 $ft/s^2$ in the English system. Thus, a 1.00 $lb_m$ object weighs 1.00 $lb_f$ on the surface of the earth.

E. Newton's Law can be written $F = ma/g_c$ in both system of units. The constant $g_c$ also appears in many other calculations involving pressure, work, velocity, power, acceleration, etc.

## II. Pressure

A. Pressure is perpendicular force/area.

B. Typical units pressure include $lb_f/in^2$ (psi) and $N/m^2$ (Pa).

C. Absolute pressures are measured relative to a vacuum. Negative absolute pressures are not possible. Absolute pressures (along with absolute temperatures) must be used in ideal gas law calculations.

D. Gauge pressure is the difference between the absolute pressure of interest and the absolute ambient pressure (usually 1.00 atmosphere). Blood and respiratory pressures are nearly always reported as gauge pressures.

E. Pressure increases with depth in any non-accelerating fluid in a gravitational field. The equation relating pressure to depth below the surface of a fluid is $P = P_{surface} + ñ \cdot h \cdot g/g_c$ where $P_{surface}$ is the pressure at the surface of the fluid, ñ is the density of the fluid, $h$ is the depth, $g$ is gravitational acceleration and $g_c$ is the units conversion factor defined in the previous section. Standard medical practice is to report pressures in terms of an equivalent depth (or head) of liquid. For example, blood pressures are usually reported in mm Hg.

III. Mechanical Energy Balance

A. The mechanical energy balance equations is:

$$\frac{\Delta U_b^{2}}{2 g_c} + \frac{g}{g_c} \Delta z + \frac{\Delta P}{r} = 0$$

where $U_b$ is the bulk velocity, $z$ is the height, $P$ is the pressure and *ñ* is the fluid density. In the term *Ä*$U_b^2$, the velocities should be squared before the difference is determined. The bulk velocity is defined as $Q/A_{cs}$ where Q is the volumetric flow rate and $A_{cs}$ the cross-sectional area of the flow.

This equation applies between any two points in a frictionless, plug flow. It is generally used when the flow is turbulent and pressure changes due to velocity and/or elevation changes are much greater that those due to friction (viscosity).

In the circulation, the mechanical energy balance can be used to calculate the pressure changes in aneurysms and stenosis. It can also be used to calculate the changes in blood pressures that result from the changes in blood velocity between the aorta, the larger arteries and the large veins.

IV. Vascular Resistances

A. SVR = $(P_A - P_V)/Q$ [=] mm Hg/(l/min) where SVR is the systemic vascular resistance, $P_A$ is the arterial pressure, $P_v$ is the venous pressure and Q is blood flow rate (often the cardiac output). The SVR is a mechanistic and linear quantity.

B. TPR = MAP/Q [=] mm Hg/(l/min) where TPR is the total peripheral resistance, MAP is the mean arterial pressure and Q is blood flow rate (often the cardiac output). The TPR is easy to compute and useful, but is not mechanistic nor linear.