Many multi-cellular organisms rely on internal pumps to provide nutrients and oxygen throughout their bodies. Gravity can be a counteracting force. As one example, consider a python lying horizontal on the grass versus climbing a tree, head-first. Snake lengths vary, the heart is usually situated about 0.25 of the total length, behind the head (for tree climbers, non-tree climbers are at about 0.37). So, for a 10 meter snake, the heart is 2.5 meters behind the head. The blood pressure of a tree climbing snake is about 10.5 kiloPascals.

Quantify the challenge(s) a snake faces when it climbs a tree.

First, we can consider the gravitational effect —ϱgh— versus the blood pressure P:

$$\frac{\rho g h}{P}$$ must be less than 1 for the organism to overcome gravity

For the python:

$$\frac{\left(10^3 \text{ kg/m}^3\right)\left(9.8 \text{ m/s}^2\right)\left(2.5 \text{ m}\right)}{\left(10.5 \cdot 10^3 \text{ kg/m} \cdot \text{s}^2\right)} = 2.33$$ (dimension-less)

The python is ‘gravity-challenged’. In fact, it is known that heart pressure increases in arboreal snakes in the ‘heads-up’ positon to overcome the gravity constraint.

There is another physical aspect at play: volume supply. Oxygen must be supplied at a rate sufficient to support respiration in the brain. Hypoxia would likely cause the snake (or human for that matter) to faint and fall.

For volume flow:

$$J_v = \left(\frac{\Delta P}{l}\right)\left(\frac{\pi}{8\eta}\right)\left(r^4\right)$$

pressure gradient *viscosity* *vessel radius (to the fourth power)*

and

$$J_v = \left(\text{heart chamber volume}\right)\left(\text{heart beat rate}\right)$$

Two factors are at play: 1) The pressure required to overcome blood vessel resistance to flow, and 2) Whether there is sufficient flow to provide the required oxygen. We can construct a comparative equation:

$$J_v = \left(\frac{\Delta P}{l}\right)\left(\frac{\pi}{8\eta}\right)\left(r_1^4\right) = \left(\frac{\Delta P + \rho g h}{l}\right)\left(\frac{\pi}{8\eta}\right)\left(r_2^4\right)$$

and simplify.

To determine the change in vessel radius required to provide the brain with the same volume of oxygenated blood, we can construct and simplify the following equation:

$$J_v = \left(\frac{\Delta P}{l}\right)\left(\frac{\pi}{8\eta}\right)\left(r_1^4\right) = \left(\frac{\Delta P + \rho g h}{l}\right)\left(\frac{\pi}{8\eta}\right)\left(r_2^4\right)$$

$$\Delta P\left(r_1^4\right) = \left(\Delta P + \rho g h\right)\left(r_2^4\right)$$

$$\frac{r_1^4}{r_2^4} = \frac{\left(\Delta P + \rho g h\right)}{\Delta P} = \frac{11.5 + 24.5}{11.5} = 3.13$$

$$\frac{r_1}{r_2} = \sqrt[4]{3.13} = 1.33$$

A decrease in radius by 75% will provide the same volume at the higher pressure. Alternatively, at a lower pressure, a slight increase in radius is sufficient.

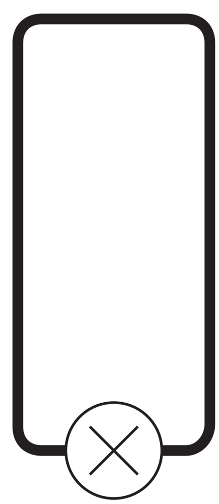
If we assume arterial vessel diameter will be unchanged, then we can determine the required increase in volume pumping that could be caused by increased heart rate:

$$\frac{J_{v_2}}{J_{v_1}} = \frac{\left(\Delta P + \rho g h\right)}{\Delta P} = 3.13$$

A 3.13-fold increase in heart beat will provide the required oxygenated blood in the ‘heads-up’ posiiton. This is in fact what happens when a python climbs a tree: Their heart speeds up.

As seems to be the norm when applying physical approaches to biological problems, the real situation is more complex. In a python (or other organisms with hearts), is it a closed piping system? And if so, does gravity actually matter?

versus



For animals, the blood ‘piping’ is not completely closed, so gravity does matter, but not as much as if it were a completely open system.

Another biological aspect is the hydrostatic pressure. It could cause blood pooling at the tail of the python, and could even be high enough to cause rupture of the blood vessels. In vascular physiology, LaPlace’s Law is the foundational equation used to explore the relation between pressure and tensile strength on a blood vessel: T=ΔPR (T is the wall tension, P the pressure and R is the radius).

Literature Sources

If you want to explore the hearts of climbing snakes in greater depth, here are example publications from the primary literature.

Seymour RS, Hargens AR, Fedley TJ (1993) The heart works against gravity. American Journal of Physiology 265:R715–R720.

Lillywhite HB (1993) Orthostatic intolerance of viperid snales. Physiological Zoology 66:1000–1014.

Seymour RS, Arndt JO (2004) Independent effects of heart-head distance and caudal blood pooling on blood pressure regulation in aquatic and terrestrial snakes. Journal of Experimental Biology 207:1305–1311.