Journal of Physics Special Topics

P3_4 Reducing blood loss through injury

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November 05, 2014

Abstract

On event of sustaining an injury which results in bleeding, it is advised to apply pressure on the wound and also elevate the injury above the height of the heart [1]. This paper investigates the physics behind the two actions, and shows that both cases result in the decreasing of the volumetric flow rate, and hence reduce the rate at which blood is lost.

Introduction

Compression and elevation aim to reduce the blood flow rate out of a bleeding injury, by influencing the pressure within the blood vessels. This pressure comes from two main sources, the dynamic pressure caused by the velocity of the blood flow in the vessels, and the hydrostatic pressure, which is as a result of gravitational influence. Compression can be considered as an external source, which applies a pressure in order to compress the blood vessels, resulting in less blood flow. This process also allows a greater possibility of the blood clotting over the wound. Blood circulating around the body is also subject to gravitational influence. In the second scenario elevating the injury aims to reduce the pressure in the arm, which leads to a reduction in blood flow. In this paper for simplicity we assume that blood flow is laminar, and that blood vessels are non-elastic.

Theory

Elevation: For simplicity, we look at the blood flow through an arteriole, which has an average pressure of 60mmHg, a radius of $0.05\text{x}10^{-3}$m and length of 2mm [2]. The change in pressure due to gravitational effects can be given by the following equation [2], where P_0 is a reference pressure (in this case the diastolic pressure from the heart), ρ is the density of the fluid, g is the acceleration due to gravity, and h is the height above the heart.

$$P = P_0 + \rho g h \quad (1)$$

The corresponding flow rate, Q as a result of this change in pressure is given by equation 2, where r is the radius of the vessel, $(P_1 - P_2)$ denotes the change in pressure, η is the viscosity of the fluid, and L is the length of the vessel [2].

$$Q = \frac{\pi r^4 (P_1 - P_2)}{8\eta L} \quad (2)$$

From the flow rate, the velocity of the blood flow can also be calculated using equation 3 where A is the cross sectional area, and $\boldsymbol{v}$ is the velocity [2].

$$Q = \boldsymbol{v}.A \quad (3)$$

Compression: We now look at the blood flow through a capillary, due to the fact that they are close to the surface. This is so we can assume that the external pressure on the capillary wall is equal to the applied compression pressure. Equation 4 can then be used to calculate the changing radius, as given below [3],

$$P_\alpha - P_\beta = \frac{\gamma}{r} \quad (4)$$

Where $P_\alpha - P_\beta$ is the transmural pressure, which is the pressure difference between the internal (P_α) and external (P_β) pressure on a boundary wall, in this case the capillary wall. γ is the tension of the wall and r is the radius of the vessel. In this instance it is assumed that the wall tension remains constant.

Results

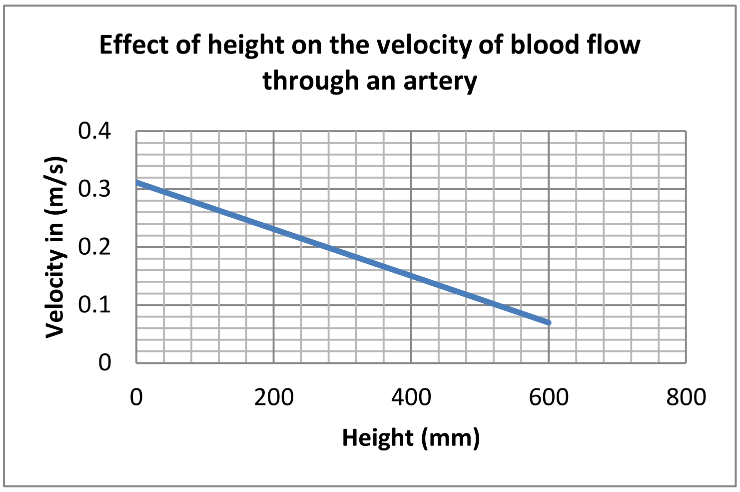

Figure 1: Relationship between the height above the heart at which the artery is situated, against the corresponding flow velocity of blood traveling through the artery.

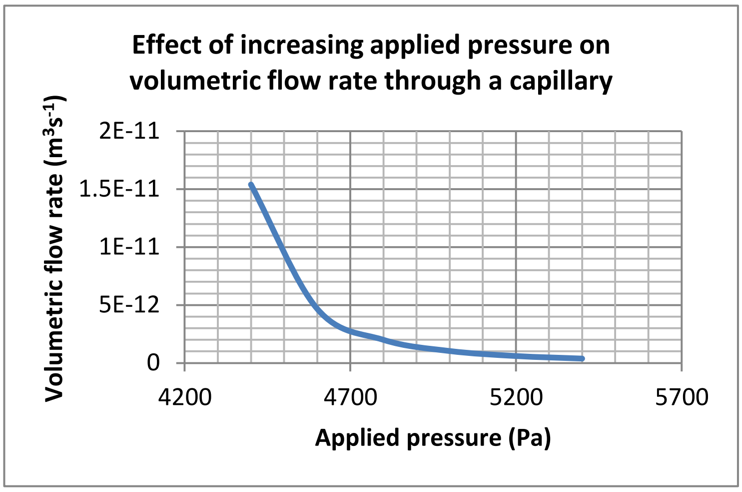

Figure 2: Relationship between the increasing pressures applied to an injury, specifically the capillary under the skin, and the volumetric flow rate of blood travelling through the capillary.

Elevation: Equation 1 was used to calculate the change in pressure $(P - P_0)$ at various heights by varying the value of h, using a reference pressure of 80mmHg (diastolic pressure at the height of the heart) and a density of 1060kgm^{-3} [2]. The pressure change at each height was then inserted into equation 2 to calculate the corresponding flow rates, using a blood viscosity value of 4x10^{-3}Pa [2]. The volumetric flow rate was then used to calculate the velocity using equation 3, the results of which are displayed in figure 1. The graph shows the linear decreasing trend, suggesting that elevation is a technique which can help slow the rate of blood flow.

Compression: For compression of the capillaries to occur the external pressure must be greater than the internal blood pressure of the pipe [4]. Equation 4 was used to calculate the radius at different pressure differences, which were calculated using a standard internal capillary pressure of 20mmHg and varying the applied pressure. The radius outcomes were inserted into equation 3 to calculate the corresponding volumetric flow rates. This time there is an asymptotic curve which decreases with the increase in applied pressure, suggesting that compressing the valves does reduce the flow rate.

Conclusion

In conclusion both actions appear to reduce the volumetric blood flow rate out of a wound, through changes in pressure gradient, with compression taking precedent since the flow rate is proportional to a factor of r^4, so results in a larger change. However this is a simplistic look into the blood flow around the body, and we have not accounted for any pressure feedback systems in the circulatory system, which could also change the speed of flow.

References

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