Fluids, blood and the microcirculation

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Most anaesthetists consider red cells an effective volume expander. Despite concerns about the lack of effective oxygen delivery from aged red cells, the product is often given when patients are hypotensive and tachycardic, and the general impression is that it supports the intravascular volume better than crystalloids and synthetic colloids. Studies have recently been undertaken to define what causes this improved effect, and how it may give insights into future colloid developments.

As haemodilution occurs, the characteristics of flow through the microcirculation changes. Flow through capillaries depends on the hydrostatic pressure to a certain degree, but more importantly on the tone of the pre-capillary arterioles, which dilate and constrict to preferentially allow flow to certain areas. Flexible red cells move through these so that red cells flow no more than 2 cell diameters away from cells, allowing oxygen diffusion to occur. In most circumstances oxygen delivery is not dependent of capillary flow, and this can be reduced significantly without hypoxia occurring. It can also increase in the presence of haemodilution, and oxygen delivery is maintained.

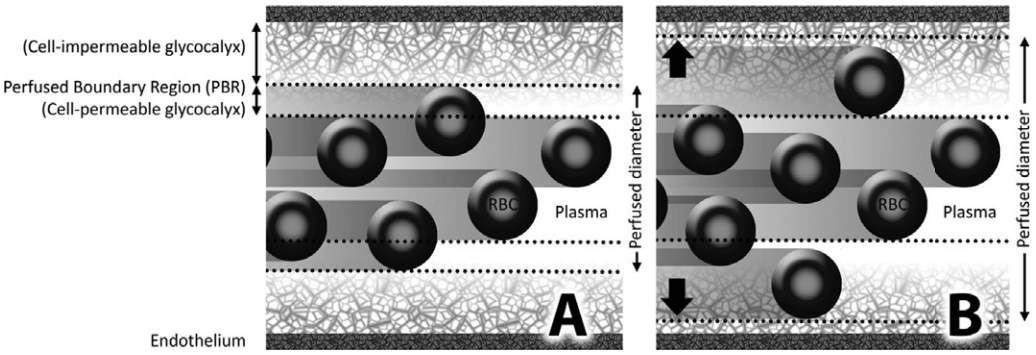
It is important to remember that capillary flow is not pulsatile, and arteriolar tone has a major effect on the rate of transcapillary transit. In addition, restoration of the microcirculation does not imply microcirculatory delivery of oxygen to tissues. Heterogeneity of blood flow appears to be a key characteristic of the disease state, even when adequate systemic oxygen carrying capacity is maintained.

Capillary diameter is also a function of the glycocalyx, and the endothelial cell diameter. In shock states these can both change, and impede capillary flow. This can have a profound effect on Functional Capillary Density. (FCD) This is the calculated capillary vessel numbers that are functioning with flow multiplied by the velocity.

Fluid viscosity is caused by the frictional (or viscous) resistance between the moving blood and the stationary vessel wall. Many suspended particulates in a fluid exhibit non-Newtonian behaviour, where the viscosity decreases when the velocity increases when travelling through a tube. Paint and blood are two examples.

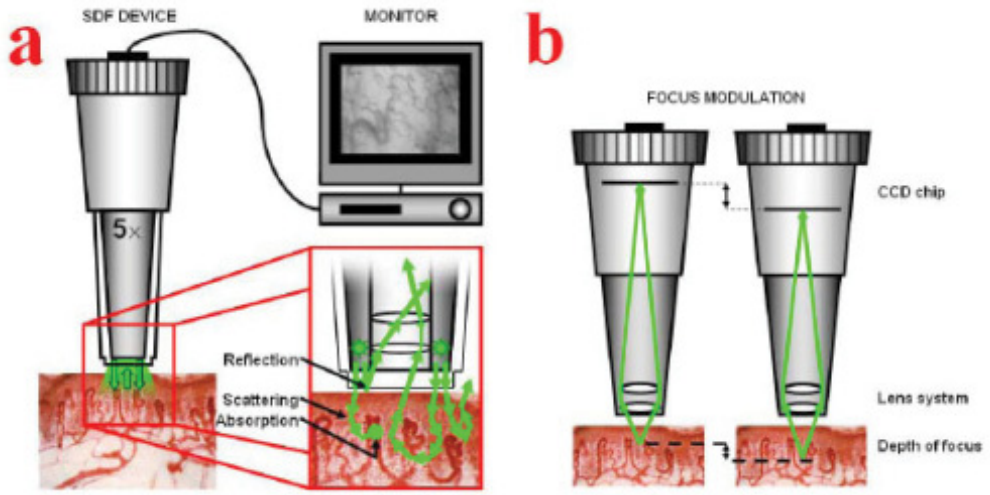
$$\tau = \frac{4\eta Q}{\pi R^3}$$

τ = fluid shear stress
η = blood viscosity
R = internal radius of vessel
Q = blood flow velocity

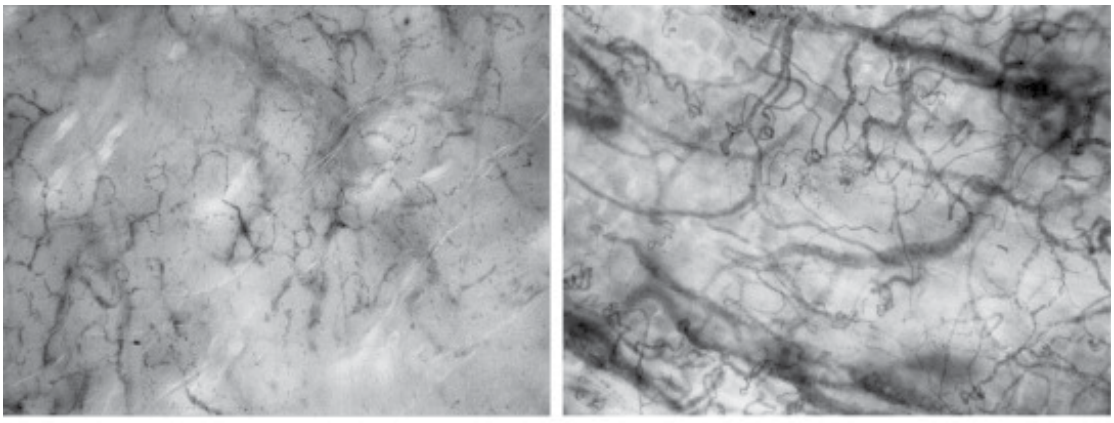


As blood acts as a Non Newtonian fluid; as its velocity increases, the spread of red cells becomes more aligned with the central portion of the flow. This obviously is more pronounced in anaemic patients. This reduces the shear forces on the lateral vessel wall. As the components of viscosity are from red cells and plasma (plasma proteins and fibrinogen), reductions in each of these will reduce the viscosity of the fluid. This reduces the outward fluid shear pressure on the arteriole, which reduces NO production and reduces arteriolar relaxation. This in turn reduces capillary flow, and induces homogenous hypoperfusion.

The Hamster chamber window model has been used as an experimental model to look at flow characteristics in hypoperfusion.



Functional capillary density (FCD) is one of the parameters obtained by microscopy using illumination of thin tissue layers. FCD, defined as the length of red cell-perfused capillaries per observation area (cm-1), has been used as an indicator of the quality of tissue perfusion in various animal models. Quantitative analysis of FCD in randomly selected regions of the tissue is performed by means of a computer-assisted video analysis system, which allows calculation of the length of RBC-perfused capillaries.



Low MFI, low capillary density

High MFI, high capillary density

Opportunities exist to use this information to create new and novel fluids that increase plasma viscosity and improve microcirculatory flow. While dextrans and starches have high viscosity, there may be other issues with these that reduce their clinical utility. Hypertonic saline, deoxygenated haemoglobin which has been pegylated, and PEG-Albumin are all under investigation to create alternate fluids that may better protect microvascular flow.

In addition photomicroscopy may offer a monitor for fluid management at the capillary level.

References:

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