In my presentation I will explain the revised Starling principle of transvascular fluid exchange with emphasis on the situation where capillary pressures in the peripheral microcirculation have been reduced as the result of vasoconstriction and severe sympathetic stimulation. I will illustrate the application of the revised Starling principle by comparing fluid retention after crystalloid infusion into the vascular space with and without such vasoconstriction. The classical Starling principle states that the loss of fluid from the plasma volume due to the hydrostatic pressure in exchange microvessels is opposed by the oncotic pressure of plasma proteins (specifically, the difference in their concentration in plasma and the bulk interstitial fluid). One of the common textbook examples of an application of the classical Starling principle shows net filtration on plasma the arterial end of the microcirculation and reabsorption on the venular side. According to this picture, vasoconstriction will increase reabsorption, a process that continues until plasma volume is restored or mechanism, such as local metabolites accumulation, overcome central sympathetic drive for vasoconstriction. This picture far from correct. There is never a steady state balance of microvascular filtration and reabsorption in a normal individual, and there is at best, only transient re-absorption as the result of a drop in microvessel pressure. This is because in the normal circulation there is slow filtration at all along the microvessels. The filtration of relatively protein free fluid across the endothelial glycocalyx maintains a region under the endothelial glycocalyx that has lower protein concentration than the bulk interstitial fluid (Reference 1 and Fig 1 below). The effective osmotic pressure opposing filtration across the glycocalyx depends of the coupling of water and protein fluxes beneath the glycocalyx, not the difference between plasma and bulk interstitial protein concentrations. The result is a relation between transvascular filtration and capillary pressure that has the shape of a hockey stick with very little change in filtration rate with capillary pressure until microvascular pressures exceed the oncotic pressure of the plasma proteins (See Figure 2 and references 1,2). The two curves in Figure 2 compare filtration rates in microvessels in which the colloid oncotic pressure of the plasma proteins has been reduced by crystalloid infusion. With severe vasoconstriction and reduced capillary pressures, Figure 2 shows that infused saline will likely be just as effectively retained in the plasma volume as colloid containing fluids. This is because fluid retention depends on the very low filtration rate described by the revised Staling principle (and the resulting hockey- stick curve) and not oncotic pressure differences between plasma and the bulk interstitial fluid. A detailed discussion of the revised Starling principle and its application to fluid therapy as well as the structure and functions of the endothelial glycocalyx is given in references 2 and 3.

References:
2) Michel CC, Arkill KP, and Curry FE The revised Starling Principle and its relevance to peri-operative fluid management. . In Farag E
and Kunz A Editors “Perioperative Fluid Management” Springer (Cham, Switzerland) Chapter 2, pp31-74, 2016


Figures with key ideas highlighted are added below.

Figure 1 (modified from Reference 1)

The oncotic pressure difference opposing filtration (\(\Pi_c-\Pi_g\)) is across the endothelial glycocalyx (plasma to sub-glycocalyx space) not plasma to bulk interstitial space (\(\Pi_c-\Pi_i\)). In steady state (\(\Pi_c-\Pi_g\)) adjusts to oppose capillary pressure, \(P_c\)
Fig 2(a) The red curve shows the steady state “hockey stick” curves from the Revised Starling Principle after the colloid osmotic pressure has been reduced by 10 mmHg from the normal state (blue curve) by infusion of a crystalloid solution.

When capillary pressure is normal (22 mmHg) crystalloid infusion would result in increased filtration (A to B) and loss of infused crystalloid. In contrast, when capillary pressure is reduced (e.g., during severe vasoconstriction after blood loss) crystalloid infusion results in a much smaller increase in filtration (C to D).

Fig 2(b) With vasoconstriction (reduced capillary pressure as in C to D of part a), crystalloid is retained (red curve) compared with normal (blue curve). Also, more colloid makes little difference (C to A). This may explain why crystalloid infusion be as effective as colloid containing solution to restore plasma volume.