

# Hemorrhage

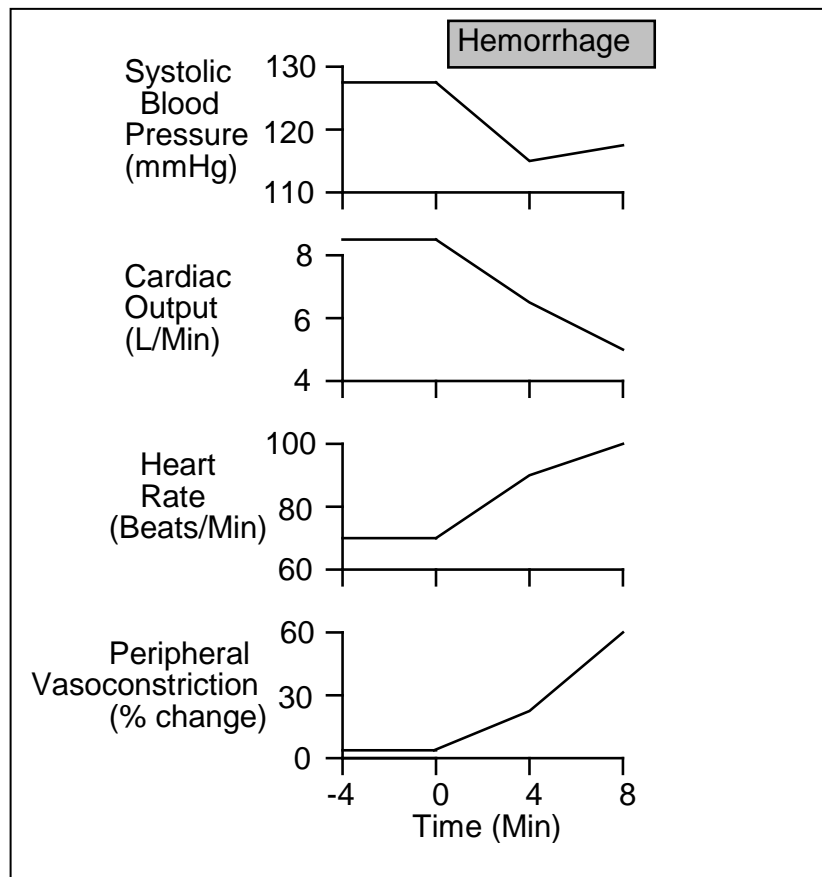
An adequate cardiac output depends on an adequate blood volume. This is evident in hemorrhage when blood loss decreases cardiac output and imperils oxygen delivery.

The physiological response to hemorrhage occurs over three time scales, each replacing a different critical element of cardiovascular physiology. The principal features are:

- Rapidly responding neural and humoral mechanisms direct available blood flow toward vital organs and keep perfusion pressure high enough to prevent tissue damage (immediate-1 day).
- The kidneys replace restore the homeostatic set point for water by retaining additional salt and water (1-10 days).
- Erythropoiesis gradually replaces the lost red blood cells (10-21 days).

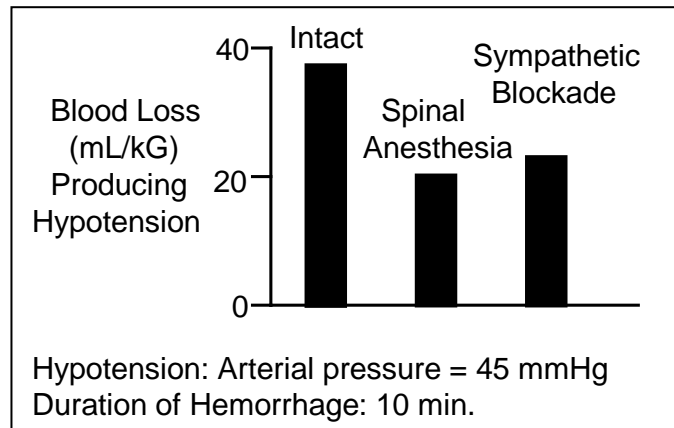
## Acute Response to Hemorrhage

The acute response includes a primary decrease in cardiac output, a secondary decrease in arterial pressure and compensatory increases in heart rate and vascular resistance (shown below, data from Barcroft). Depending on the speed of hemorrhage, a period of normotensive normocardia will be followed by a period of hypotensive tachycardia due to a baroreceptor response.



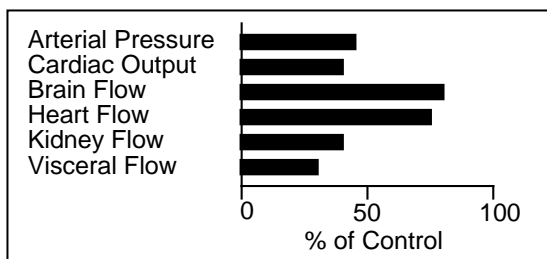
## Autonomic Involvement

Increased heart rate and peripheral vasoconstriction signal the autonomic nervous system's participation in the acute response to hemorrhage. Autonomic dysfunction decreases the body's tolerance to blood loss (shown below, data from DuCharme). Experiments have identified factors that correlate with tolerance to blood loss, including resting heart rate, gain in cardiac baroreceptor response, and resting sympathetic nerve activity. All of these factors indicate that the autonomic nervous system is critical to maintain the body's acute response to hemorrhage.



## Selective Vasoconstriction

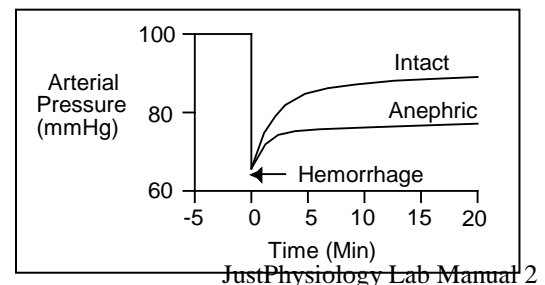
Sympathetic vasoconstriction during hemorrhage is selective. Many organs show intense vasoconstriction, while the cerebral and coronary circulations show little response to increased sympathetic outflow (shown below, data from Kaihara).



The benefit of selectivity is that available blood flow, as meager as it may be, is preferentially directed to the brain and heart -- the vital organs.

## Support from the Renin-Angiotensin System

The renin-angiotensin system supports arterial pressure in hemorrhage by constricting non-vital organs. This response is slower than the response of the sympathetic nervous system, but it is still an important part of the acute circulatory

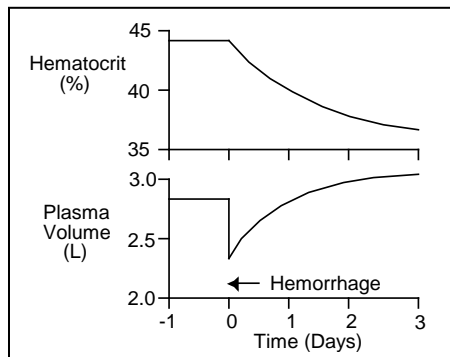


response to hemorrhage (shown at right, data from Brough).

*Question: By what mechanisms are the renin-angiotensin system included in the acute hemorrhage response?*

## Salt And Water Retention

After hemorrhage, with no intervention, salt and water retention over several days will increase blood volume to normal or above. Erythrocytes are replaced much more slowly, so a fairly severe anemia can result (shown below, data from Ebert, Adamson).



## The Hemorrhage Protocol

Establish initial conditions and then record the control data. Set rate to 100 ml/min, turn the hemorrhage switch on and advance the solution 10 minutes.

We are interested in the immediate impact of the hemorrhage and the subsequent compensations.

Fast compensations are activation of the sympathetic nervous system and increased secretion of renin.

*Question: When does renin secretion peak? When does sympathetic activity peak?*

*Question: Consider the splanchnic circulatory volume; how does hemorrhage rate affect its volume and role in the acute response to hemorrhage? What mechanism might underline the rate differences?*

*Question: If hemorrhage rate is slowed (for example in a gastrointestinal bleed) how does this change the acute response?*

The medium-term compensation is renal salt and water retention.

*Question: When does urine excreted sodium reach its minimum? What about urine water excretion?*

Note that while blood volume is quickly restored, red cell volume is not. The long-term compensation is replacement of the lost erythrocytes. Track erythropoietin as a stimulus and red cell volume as the response.

## References

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