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 is a three-part process. The principal features are:

- Rapidly responding neural and humoral mechanisms direct available blood flow toward vital organs.

- More slowly evolving salt and water retention by the kidneys replaces the lost plasma.

- Erythropoiesis gradually replaces the lost red blood cells.

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).
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).
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 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 below, data from Brough).
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).

![Graph showing hematocrit and plasma volume over time after hemorrhage]

The Hemorrhage Protocol

Click Restart to reestablish initial conditions and then record the control data. Go to Blood Volume. In the arterial hemorrhage box, set volume to 1000 and timespan to 10. 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. When does each have its maximum effect? Use Autonomic Efferents / Sympathetic Ganglia / Firing Rate as an indicator of sympathetic nerve activity. Does this fast response help to maintain blood flow to the brain?

The medium-term compensation is renal salt and water retention. When does this have its maximum effect? Note that while blood volume is quickly restored, red cell volume is not. Keep an eye on hematocrit.

The long-term compensation is replacement of the lost erythrocytes. Track erythropoietin as a stimulus and red cell volume as the response.

- Blood Volume (mL)
- Red Cell Volume (mL)
- Plasma Volume (mL)
- Hematocrit (%)
- Arterial Pressure (mmHg)
- Cardiac Output (mL/Min)
- Heart Rate (/Min)
- Stroke Volume (mL)
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QCP Laboratory Manual
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Erythropoietin

Brain Blood Flow

References


