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Systemic Stress Response

M1 – Cardiovascular/Respiratory Sequence
Louis D’Alecy, Ph.D.
Wednesday 11/12/08, 9:00
Systemic Stress Response
(After Baroreceptor Reflex)
34 slides, 50 minutes

1. Reflex response to hemorrhagic stress

2. What happens next?

3. Starling forces and fluid shifts
4. Lymph flow
5. Vasoconstriction & absorption
6. VR and CO in hemorrhage
Arterial Baroreceptor Reflex(s)

- minimize changes in arterial blood pressure
- tend to restore MAP to initial value
- moves pressure opposite disturbance
- utilizes (controls) HR, SV, TPR, “other” changes
- can be over ridden by other reflexes and controls
Intact baroreceptor reflexes minimize the response to hemorrhage involving 20% loss of blood.
Cardiovascular effects of hemorrhage

- Stroke volume
- Heart rate
- Cardiac output (SV x HR)
- Total peripheral resistance
- Mean arterial pressure (CO x TPR)

Partial restoration of MAP
HEMORRHAGE

↓ blood volume

↓ arterial blood pressure

partial restoration of blood volume

baroreceptor mediated arteriolar vasoconstriction

↓ capillary blood pressure \( P_c \)

absorption of interstitial fluid
### Fluid Shifts after Hemorrhage

<table>
<thead>
<tr>
<th></th>
<th>Normal</th>
<th>Immediately after hemorrhage</th>
<th>18h after hemorrhage</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total blood volume, mL</strong></td>
<td>5000</td>
<td>4000 (↓20%)</td>
<td>4900</td>
</tr>
<tr>
<td><strong>Erythrocyte volume, mL</strong></td>
<td>2300</td>
<td>1840 (↓20%)</td>
<td>1840</td>
</tr>
<tr>
<td><strong>Plasma volume, mL</strong></td>
<td>2700</td>
<td>2160 (↓20%)</td>
<td>3060</td>
</tr>
<tr>
<td><strong>Plasma albumin mass, g</strong></td>
<td>135</td>
<td>108 (↓20%)</td>
<td>125</td>
</tr>
</tbody>
</table>

**Hematocrit**

46

46

37

*Erythropoiesis*

*Hematocrit = % of blood volume occupied by red blood cells*
Fluid movement across capillaries

**STARLING FORCES**

- Capillary hydrostatic pressure \( (P_C) \)
- Interstitial-fluid hydrostatic pressure \( (P_{IF}) \)
- Osmotic force due to plasma protein concentration \( (\pi_P) \)
- Osmotic force due to interstitial-fluid protein concentration \( (\pi_{IF}) \)

Net filtration pressure = \( (P_C - P_{IF}) - (\pi_P - \pi_{IF}) \)

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CAUSES OF DECREASED PLASMA COLLOID OSMOTIC PRESSURE

1. ↓ Synthesis of albumen by liver
   A. protein malnutrition - decreased amino acid availability
   B. liver disease - decreased formation of plasma proteins

2. ↑ Loss of albumen across capillary walls
   A. burns
   B. kidney disease
   C. GI disease

3. Iatrogenic (excess IV salt solutions, hemodilution)
LYMPHATIC SYSTEM

veins

One-way valves

capillaries

filtration

absorption

20 L per day

17 L per day

3 L per day

lymphatic capillaries permeable to proteins
pores
valves
lymphatic capillaries
collecting lymphatic
endothelial cells
anchoring filaments
Source Undetermined
LYMPH FLOW

Bulk fluid flow into lymphatic capillaries

Hydrostatic pressure gradient
1. Increased interstitial fluid volume increases $P_{isf}$
2. Decreased pressure in lymphatic capillaries

Bulk fluid flow along lymphatic network

1. Rhythmic contractions of lymphatic smooth muscle
   (one way flow due to valves in lymphatics)
2. Tissue compression - skeletal muscle pump
Lymph vessel flows toward thoracic duct.

Similar to venous blood flow but lower pressure and lower volume.

Contracted muscles = closed valve

Please see: http://www.vhlab.umn.edu/atlas/phystutorial/graphics/fig3.jpg
# LYMPH vs. PLASMA

## Flow:

<table>
<thead>
<tr>
<th>Lymph</th>
<th>Plasma</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 L / day</td>
<td>4320 L / day</td>
</tr>
<tr>
<td>2 mL / min</td>
<td>3000 mL / min</td>
</tr>
</tbody>
</table>

## Lymph Volume

4 L (35% of 11 L of interstitial fluid)

## Composition

No RBC, some WBC

Small molecular composition equal to venous plasma

Protein composition equal to interstitial fluid

<table>
<thead>
<tr>
<th>protein g / L</th>
</tr>
</thead>
<tbody>
<tr>
<td>plasma</td>
</tr>
<tr>
<td>muscle lymph</td>
</tr>
<tr>
<td>intestinal lymph</td>
</tr>
<tr>
<td>liver lymph</td>
</tr>
</tbody>
</table>
How does this happen?

Back Into the Plasma Compartment
What determines capillary hydrostatic pressure $P_c$?

- $\downarrow$ Arterial pressure $\downarrow P_c$
- $\downarrow$ Venous volume (pressure) $\downarrow P_c**$
  - Closure of arteriole $\downarrow P_c$
  - Closure of a venule $\uparrow P_c$
- **Local arteriolar vasoconstriction $\downarrow P_c$**
- **Local venoconstriction $\uparrow P_c$**
Localized arteriolar vasodilation/vasoconstriction

- Artery
- Arteriole
- Capillary

Blood pressure (mmHg)

Distance along systemic blood vessels

Vasodilation

Initial state

Source Undetermined
Normal Balance

Net filtration pressure = \((P_C - P_{IF}) - (\pi_P - \pi_{IF})\)

(b)

Arterial end of capillary

\(P_C = 35\) \(\pi_P = 28\)

\(P_{IF} = 0\) \(\pi_{IF} = 3\)

Venous end of capillary

\(P_C = 15\) \(\pi_P = 28\)

\(P_{IF} = 0\) \(\pi_{IF} = 3\)

Net filtration pressure = 
\((35 - 0) - (28 - 3) = 10\) mmHg 10 mmHg favoring filtration

Net filtration pressure = 
\((15 - 0) - (28 - 3) = -10\) mmHg 10 mmHg favoring absorption
<table>
<thead>
<tr>
<th>Arterial end</th>
<th>Venous end</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hydro - Osmo = ?</strong></td>
<td><strong>Hydro - Osmo = ?</strong></td>
</tr>
<tr>
<td>(35-0) - (28-3) = 10 fil</td>
<td>(15-0) - (28-3) = -10 abs</td>
</tr>
</tbody>
</table>

Then Constrict Arterioles & decrease capillary pressure

<table>
<thead>
<tr>
<th>Arterial end</th>
<th>Venous end</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hydro - Osmo = ?</strong></td>
<td><strong>Hydro - Osmo = ?</strong></td>
</tr>
<tr>
<td>(25-0) - (28-3) = 0</td>
<td>(5-0) - (28-3) = -20 abs</td>
</tr>
</tbody>
</table>

Reduced filtration Interstitial Absorption
Increased Capillary Hydrostatic Pc

Decreased Hydrostatic Pc

If localized vasoconstriction or vasodilation

Increased Systemic Pressure

Decreased Systemic Pressure

If generalized vasoconstriction or vasodilation

Arterial Baroreceptor Reflex(s)

- minimize changes in arterial blood pressure
- tend to **restore** MAP to initial value
- moves pressure opposite disturbance
- utilizes (controls) HR, SV, TPR, “other” changes
- can be over ridden by other reflexes and controls
Decrease in blood volume

But other volume losses
OTHER FLUID LOSS - **diarrhea** or **sweating**

**fluid loss**

↓ extracellular fluid volume

↓ plasma volume

↓ $P_c$

↑ $COP_p$

due to loss of plasma water

↑ absorption of interstitial fluid

partial restoration of plasma volume
SWELLING AT SITES OF TISSUE INJURY

tissue damage

release of local chemical agents (paracrines)
e.g. histamine

arteriolar dilation

↑ Pc

↑ ultrafiltration

↓ Plasma volume

↑ COP_{isf}

fluid absorption

capillary permeability to plasma proteins

↓ tissue swelling edema

Plasma volume
INTERSTITIAL FACTORS OPPOSING EDEMA (& PLASMA LOSS)

\[ \text{\uparrow net filtration} \]
\[ \text{\uparrow interstitial fluid} \]

\[ \text{\downarrow ultrafiltration} \]
\[ \text{\uparrow lymph flow} \]

\[ \text{\downarrow COP}_{\text{ifs}} \]

\[ \text{\uparrow osmotic absorption} \]

Initial cause of Edema

By diluting interstitium
Direct effects of primary disturbance (uncompensated)

Cardiogenic shock
- Myocardial failure

Hypovolemic shock
- Fluid loss

Anaphylactic, septic shock
- Vasodilator release

Neurogenic shock
- Sympathetic nerve activity

- Venous tone
- Mean circulatory filling pressure
- Central venous pressure
- Arteriolar tone

- Cardiac contractility
- Cardiac filling

- Cardiac output
- Total peripheral resistance

- Mean arterial pressure

- Activity of arterial baroreceptors
- Below = 80 mmHg
- Cerebral ischemic response

Medullary cardiovascular centers
Figure 11–1. Cardiovascular alterations in shock.
Cardiac output curve

Venous return curve

Normal cardiac output curve
Some Hemorrhage Responses

Figure 8-7: Cardiovascular adjustments to hemorrhage.
Hemorrhage on VR and CO curves 1

<table>
<thead>
<tr>
<th>CVP</th>
<th>VR</th>
<th>CO</th>
</tr>
</thead>
</table>
| 2 mmHg| 5L /min | 5L /min | Original curves

Hemorrhage shifts to new “hemorrhage” VR curve and momentarily unbalances system.

<table>
<thead>
<tr>
<th>A’</th>
<th>2 mmHg</th>
<th>2L /min</th>
<th>5L /min</th>
<th>Unstable (imaginary)</th>
</tr>
</thead>
</table>

central pool emptying and lowering CVP from 2 to 1 mmHg on

“Hem “ VR curve brings you to B
### Hemorrhage on VR and CO curves 2

<table>
<thead>
<tr>
<th>CVP</th>
<th>VR</th>
<th>CO</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>1mmHg</td>
<td>3 L/min</td>
</tr>
</tbody>
</table>

The reduced CO lowers MAP, triggers arterial baroreceptor reflex and first step (illustrated) is positive inotropic and chronotropic effects on heart. This shifts you to a new CO function curve and further empties CV pool.

You move along the VR curve from **B to C**
### Hemorrhage on VR and CO curves 3

<table>
<thead>
<tr>
<th></th>
<th>CVP</th>
<th>VR</th>
<th>CO</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>0.3mmHg</td>
<td>4 L /min</td>
<td>4L /min</td>
</tr>
</tbody>
</table>

Compensation further lowers CVP increasing VR and partially restores CO with SV and HR increases.

<table>
<thead>
<tr>
<th></th>
<th>CVP</th>
<th>VR</th>
<th>CO</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>0.5mmHg</td>
<td>4.5L /min</td>
<td>4.5L /min</td>
</tr>
</tbody>
</table>

Venoconstriction shifts to a new VR curve and new stable point. Even with near immediate baroreceptor reflex compensations the system still has not fully compensated. The heart is being autonomically (sympathetic and parasympathetic) driven, peripheral vessels are constricted and this is a temporary “fix”.
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