Mr. Parks

Load Mr. Parks (MR\_PARKS.ICS) using the **File / Load Initial Conditions** main menu selection.

Is Mr. Parks OK? Actually, the thumbnail sketch on the  Charts panel suggests that he is not OK.

Check Mr. Parks’ blood pressure, heart rate, temperature and respiration using the  Monitor panel.

Normal values were taken from Norm Subject.

|  |  |  |  |
| --- | --- | --- | --- |
| **Variable** | **Mr. Parks** | **N. Subject** | **Units** |
| Blood Pressure |  | 120 / 81 | mmHg |
| Heart Rate |  | 73 | Beats / Min |
| Temperature |  | 98.8 | degree F |
| Respiration Rate |  | 12 | Breaths / Min |

Estimating Cardiac Output

We'll use some basic hemodynamic concepts in this section to make an estimate of Mr. Park's cardiac output (See G&H, pp. 152 - 156).

|  |  |  |
| --- | --- | --- |
| **Variable** | **Symbol** | **Units** |
| Cardiac Output | CO | mL/Min |
| Heart Rate | HR | /Min |
| Stroke Volume | SV | mL |
| Pulse Pressure | PP | mmHg |
| Proportionality | K | mL/mmHg |

Cardiac output is equal to heart rate multiplied by stroke volume.

CO = HR \* SV (1)

We can observe heart rate at this point but not stroke volume. But, pulse pressure is proportional to stroke volume for each cardiac ejection -- and we can observe pulse pressure. Equation (1) is modified to get

CO = HR \* K \* PP (2)

The proportionality constant K is currently unknown. We will take data from Norm Subject to apply to Mr. Parks, hoping that these two have roughly the same arterial compliance.

|  |  |  |
| --- | --- | --- |
| **Symbol** | **Value** | **Units** |
| CO | 5368 | mL/Min |
| HR | 73 | /Min |
| PP | 39 | mmHg |
| K | 1.9 | mL/mmHg |

Solving Equation (2) for K using Norm Subject's data yields a value for K of 1.9.

Use this value of K and Mr. Parks hemodynamic data to estimate his cardiac output.

|  |  |  |
| --- | --- | --- |
| **Variable** | **Value** | **Units** |
| Pulse Pressure |  | mmHg |
| Proportionality | 1.9 | mL/mmHg |
| Heart Rate |  | /Min |
| Cardiac Output |  | mL/Min |

At this point, what is your preliminary diagnosis? Why?

Invasive Hemodynamics

Use the **View / Basic Physiology** main menu selection to install the basic physiology toolbar buttons.

Select the  Blood Flow panel and read Mr. Parks' true stroke volume and cardiac output.

|  |  |  |  |
| --- | --- | --- | --- |
| **Variable** | **Value** | **N. Subject** | **Units** |
| Stroke Volume |  | 73 | mL |
| Cardiac Output |  | 5368 | mL/Min |

Select the  Blood Volume panel and read Mr. Parks' blood volume.

|  |  |  |  |
| --- | --- | --- | --- |
| **Variable** | **Mr. Parks** | **N. Subject** | **Units** |
| Blood Volume |  | 5400 | mL |
| Red Cell Volume |  | 2400 | mL |
| Plasma Volume |  | 3000 | mL |
| Hematocrit |  | 44 | % |

Acute Compensations

Hemorrhage elicits a variety of compensations that help to maintain blood flow to vital organs by supporting blood pressure and redistributing flow toward vital organs (See G&H, Chapter 24). We'll consider two here: increased autonomic nerve activity and increased plasma angiotensin concentration.

Select the  Autonomic Efferents panel and read general and kidney autonomic firing rates.

Select the  Angiotensin panel and read the plasma angiotensin concentration.

|  |  |  |  |
| --- | --- | --- | --- |
| **Variable** | **Mr. Parks** | **N. Subject** | **Units** |
| General Autonomic Firing Rate |  | 1.5 | Hz |
| Renal Autonomic Firing Rate |  | 1.5 | Hz |
| Plasma [AII] |  | 20 | pG/mL |

Time permitting, you might try blocking the increase in autonomic activity and increase in plasma angiotensin to obtain an indication of their effect on arterial pressure.

To block (alpha) autonomic activity, go to  Blockers and set alpha receptors % block to 100%. Then go to  Monitor to observe the effects of this blockade.

To block the formation of plasma angiotensin conversion, go to  Blockers and set AII converting enzyme inhibition to 100%. Again, go to  Monitor to observe the effects of this inhibition.

The vasoconstrictor effect of the sympathetic nervous system and angiotensin during hemorrhage is beneficial only if the vasoconstriction is selective. Namely, we hope that brain and heart blood flow (vital organs) is maintained at the expense of flow in other organs, as show below (data from Kaihara).



Select the  Blood Flow panel and estimate Mr. Parks' brain and hepatic vein blood flow from the graph. Or, select **View / Organ Details** to make the organ details toolbar buttons visible. Then select the  Brain Circulation and  Gut panels to get numerical values for blood flow.

|  |  |  |  |
| --- | --- | --- | --- |
| **Variable** | **Mr. Parks** | **N. Subject** | **Units** |
| Brain Blood Flow |  | 706 | mL/Min |
| Hepatic Vein Blood Flow |  | 1217 | mL/Min |

Severity Of Hemorrhage

Compensation can almost completely hide the hemodynamic consequences of a mild hemorrhage, such as giving a unit of blood at a blood bank. More severe hemorrhage produces obvious signs even with the strong support of the compensations. With very severe hemorrhage, the compensations are maximum and cannot contribute further; cardiovascular collapse is a real possibility.

It would be instructive to know the severity of Mr. Parks' hemorrhage. Observe Mr. Parks for 10 minutes. Use the main menu **Go** command to advance the solution by 10 minutes.

Interventions

Intervention is advised.

Lost blood volume is usually replaced by one of three types of solutions.

1. Saline. It is readily available and safe, but it tends to leak out of the circulation where it is of no or negative value. Saline dilutes the available hemoglobin.
2. Saline With Colloid Pressure. Colloid pressure keeps the replacement fluid in the circulation where it boosts cardiac output, but it also dilutes available hemoglobin.
3. Whole Or Artificial Blood. Blood is often not readily available (see G&H, Chapter 24). When it is available, it offers colloid pressure to keep the replacement fluid in the circulation and hemoglobin or a functional equivalent to carry oxygen.

We'll try each of these interventions. Note that the fundamental goal of intervention is to maintain or improve oxygen delivery to the tissues. We'll keep an eye on O2 movement in the simulations that follow.

In each case, begin by clicking **Restart** to take Mr. Parks back to his initial condition. Use the arrow buttons on the toolbar to move among the needed panels.

Saline. Select the  IV Drip panel. Set the volume to 1000 mL, the timespan to 10 Min, [NaCl] to 140 mMol and click switch to on. Go back to  Monitor, advance the solution for 1 hour and record data in the table below.

Plasma. Select the  Transfusion panel. Set the volume to 1000 mL, the timespan to 10 Min, the hematocrit to 0 % and click switch to on. Go back to  Monitor, advance the solution for 1 hour and record data in the table below.

Whole Blood. Select the  Transfusion panel. Set the volume to 1000 mL, the timespan to 10 Min, the hematocrit to 44 % and click switch to on. Go back to  Monitor, advance the solution for 1 hour and record 1-hour data in the table below.

Select the  Oxygen panel for blood oxygen data.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Variable** | **Initial** | **Saline** | **Plasma** | **Blood** |
| Blood Pressure |  |  |  |  |
| Heart Rate |  |  |  |  |
| Blood Volume |  |  |  |  |
| Red Cell Volume |  |  |  |  |
| Plasma Volume |  |  |  |  |
| Hematocrit |  |  |  |  |
| Cardiac Output |  |  |  |  |
| Arterial O2 Content |  |  |  |  |
| Venous O2 Content |  |  |  |  |

Discussion point: What are the good and bad attributes of the three replacement fluids used above, as indicated by the data collected?

Discussion point: What is the volume replacement strategy when a patient intraoperatively bleed more than his/her total blood volume?

The Natural Time Course

The physiological response to hemorrhage is a three-part process, over time. The principal features are:

Rapidly responding neural and humoral mechanisms direct available blood flow toward vital organs, as described above.

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

Erythropoiesis gradually replaces the lost red blood cells.

In this section, we'll produce a moderate hemorrhage and observe the body's response over the following month.

Use the **Options / Reset** main menu selection to get Norm Subject back. The thumbnail sketch in  Charts should now introduce Norm Subject.

To create a hemorrhage, select the  Blood Volume panel. In the arterial hemorrhage box, set volume to 1000 and timespan to 10. Click the hemorrhage switch on and advance the solution 30 minutes.

You can verify the neural and hormonal response to hemorrhage, as previously seen above. But, there is also a renal component to be considered.

Use the **View / Nephron Details** main menu selection to add the nephron details button to the toolbar. Select the  Urine panel and read the rate of sodium and water excretion.

|  |  |  |  |
| --- | --- | --- | --- |
| **Variable** | **30 Min** | **Control** | **Units** |
| Sodium Excretion |  | 0.114 | mEq/Min |
| Water Excretion |  | 0.76 | mL/Min |

Salt and water retention should expand plasma volume and blood volume. But the lost red cells will not be acutely replaced and hematocrit will fall as shown below (data from Ebert, Adamson).



Advance the solution to 2 days and note the amount and composition of blood volume.

Select the  Erythropoietin panel to see if EPO secretion has been stimulated.

Select the  Blood Volume panel to see if red cell production is increased.

Advance the solution to 30 days, following changes in blood volume and particularly red cell volume. Note the final amount and composition of the blood.

|  |  |  |  |
| --- | --- | --- | --- |
| **Variable** | **30 Days** | **Control** | **Units** |
| Blood Volume |  | 5400 | mL |
| Red Cell Volume |  | 2400 | mL |
| Plasma Volume |  | 3000 | mL |
| Hematocrit |  | 44 | % |

References

Adamson, J. and R. S. Hillman. Blood volume and plasma protein replacement following acute blood loss in normal man. *J. Amer. Med. Assn.* 205:609-612, 1968.

Ebert, R. V., E. A. Stead, Jr. and J. G. Gibson, II. Response of normal subjects to acute blood loss. *Arch. Int. Med.* 68:578-590, 1941.

Kaihara, S., R. B. Rutherford, E. P. Schwentker and H. N. Wagner, Jr. Distribution of cardiac output in experimental hemorrhage in dogs. *J. Appl. Physiol.* 27:218-222, 1969.

Mr. Parks - Notes

Mr. Parks’ thumbnail sketch notes that he was found in a pool of blood and was rushed to the ER.

Mr. Parks has hemorrhaged and may expire if left untreated.

Creating Mr. Parks

The first step in creating Mr. Parks is to create a large hemorrhage. The new parameter values are:

“Arterial Hemorrhage, Final Volume” = 1800.0

“Arterial Hemorrhage, Duration” = 30.0

“Arterial Hemorrhage, Switch” = 1.0 // On

Then the solution was advanced for 10 minutes and Mr. Parks was constrained to lying down (1.0).

“Posture Control, Restraint” = 1.0 // Lying

Then the solution was advanced for another 20 minutes to complete the hemorrhage.

Finally, a smaller continuing hemorrhage was defined to create a dynamic setting. The new parameter values are:

“Arterial Hemorrhage, Final Volume” = 500.0

“Arterial Hemorrhage, Duration” = 10.0

“Arterial Hemorrhage, Switch” = 1.0 // On

Mr. Parks is now ready for observation and intervention.

Recap

The immediate physiological response to hemorrhage is neural and humoral vasoconstriction that directs available blood flow toward vital organs. Then, renal salt and water retention expands plasma and blood volume. The slowest part of the response is replacement of lost red cells by increased red cell production.

The effectiveness of volume replacement depends on

1. The replacement fluid's tendency to stay in the circulation.
2. The replacement fluid's net effect on oxygen delivery to the tissues.

Mr. Parks Wrap-up

Summary

The immediate physiological response to hemorrhage is neural and humoral vasoconstriction that directs available blood flow toward vital organs. Then, renal salt and water retention expands plasma and blood volume. The slowest part of the response is replacement of lost red cells by increased red cell production.

The effectiveness of volume replacement depends on

1. The replacement fluid's tendency to stay in the circulation.
2. The replacement fluid's net effect on oxygen delivery to the tissues.