HUMAN SIMULATION

HAEMORRHAGE (HYPOVOLEMIA)

BioMed Sim Centre

University of BRISTOL

Haemorrhage/ Hypovolemic shock

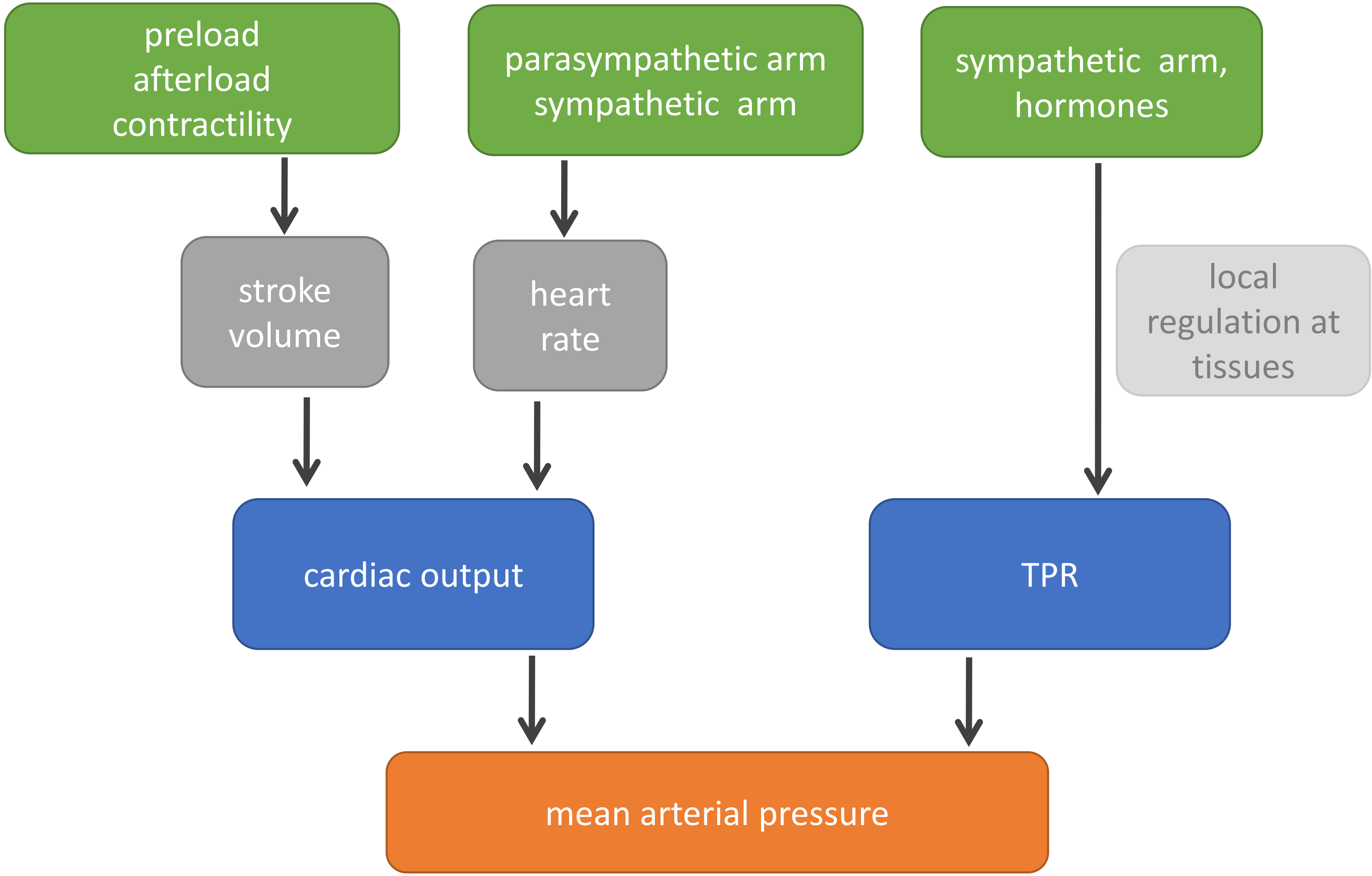
Hypovolemic shock is the most common type results from a loss of circulating blood volume, such as penetrating and blunt trauma, gastrointestinal bleeding and obstetrical bleeding.

Humans are able to compensate for significant haemorrhage through various neural and hormonal mechanisms.

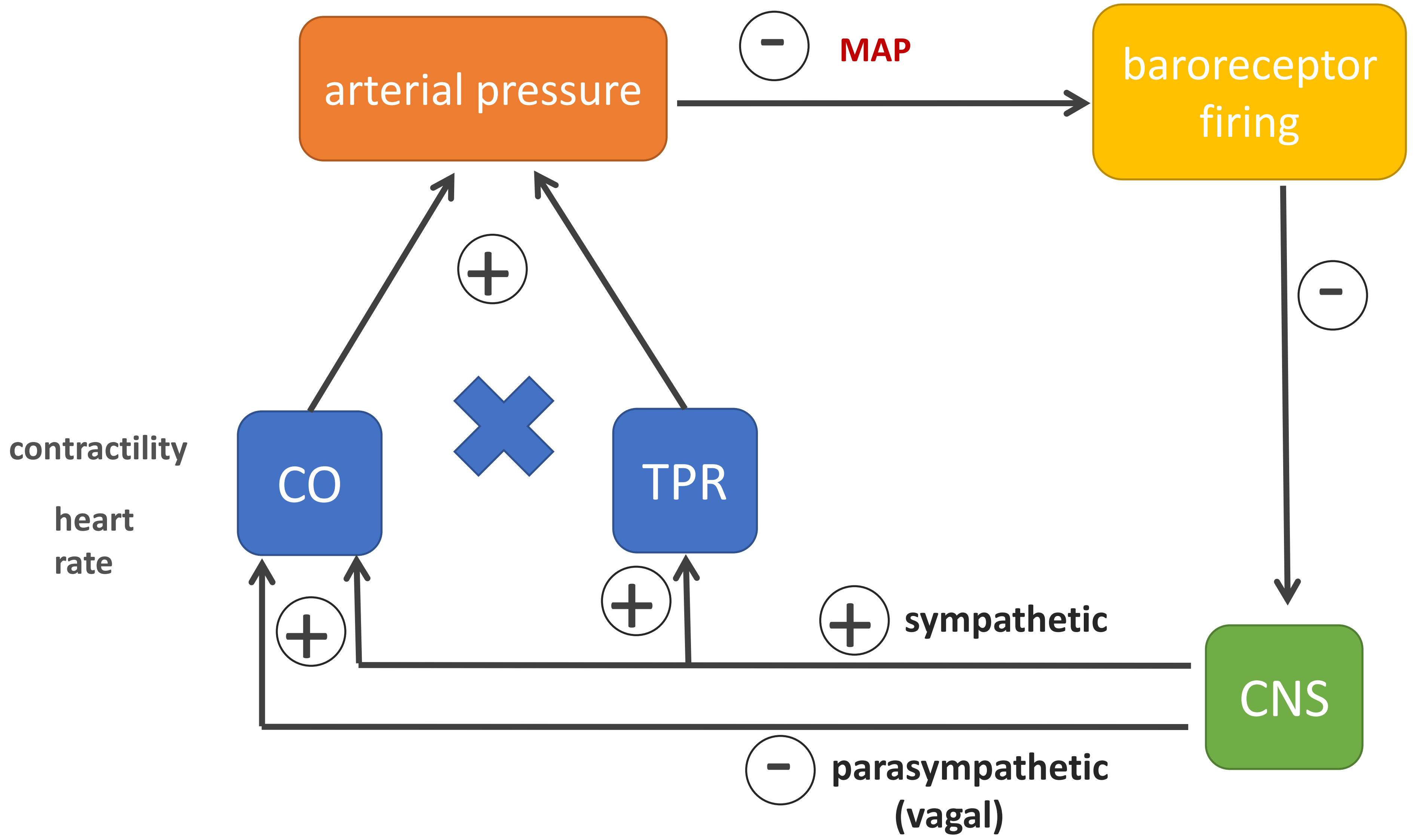
How does physiology change with hypovolemia through blood loss, how well can the body compensate through homeostatic mechanisms,

What are the controlled variables and effector mechanisms?

Determinants of MAP



The baro-response to a sudden fall in BP



Equations

There are several equations you will need to be familiar with to understand and analyse the data obtained from the simulator:

1. Heart rate (bpm) = 60 / R-R interval (s)

2. Mean arterial pressure (mmHg) = cardiac output (l/min) x total peripheral resistance (mmHg/l/min)

3. Mean arterial pressure (mmHg) = diastolic pressure (mmHg) + 1/3 pulse pressure (mmHg)

4. Pulse pressure (mmHg) = systolic pressure (mmHg) - diastolic pressure (mmHg)

5. Cardiac output (l/min) = heart rate (bpm) x stroke volume (l)

6. Volume of blood removed as a percentage of total blood volume:
   Simulated male body weight = 90 kg, simulated female = 70 kg,
   and blood volume for most humans is ~70 ml/kg

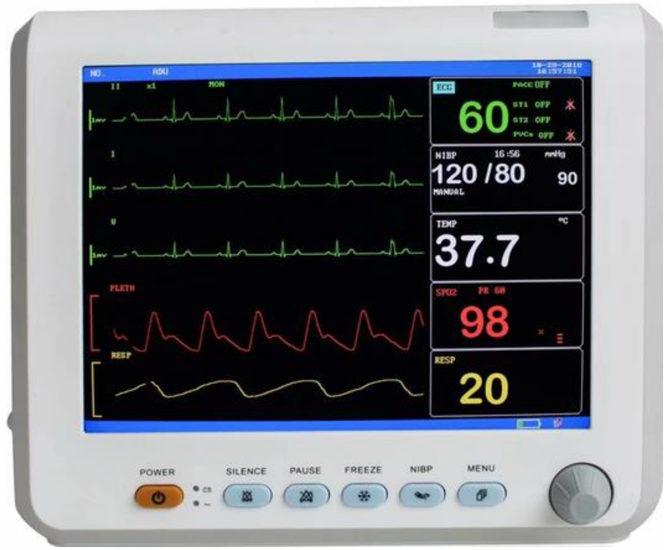
7. Note that TPR cannot be measured directly, so has to be calculated from the Ohm's Law relationship of MAP = CO x TPR.

8. Shock Index = heart rate (bpm) / systolic pressure (mmHg)

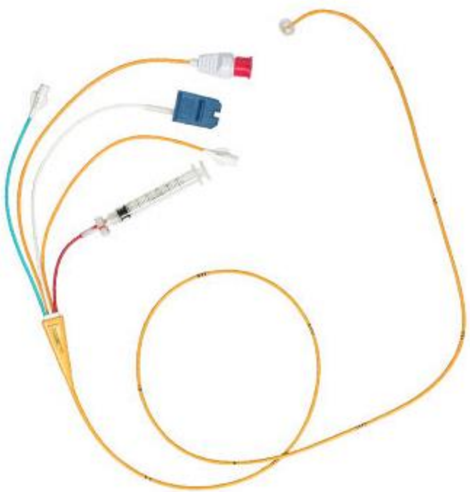
Data acquisition today

Cardiac output

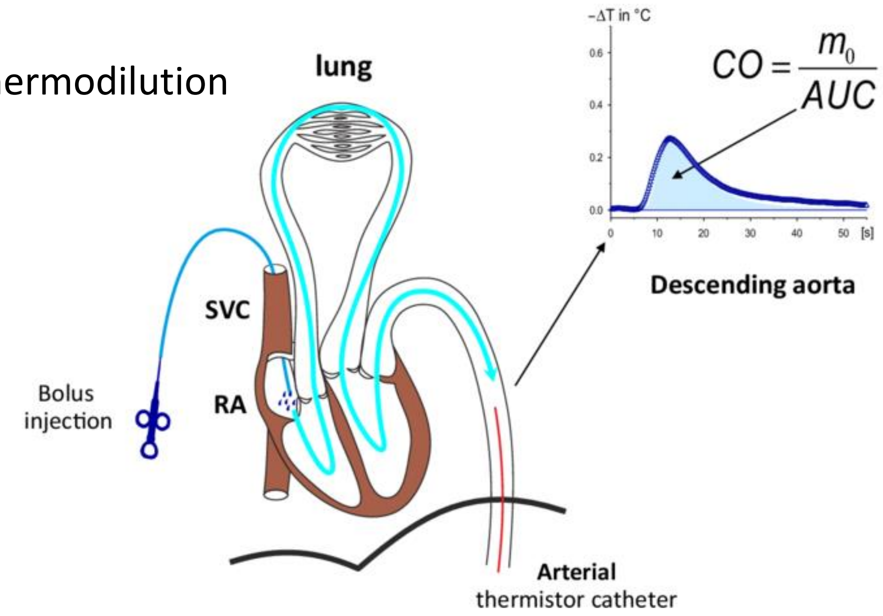
Simulated clinical monitor



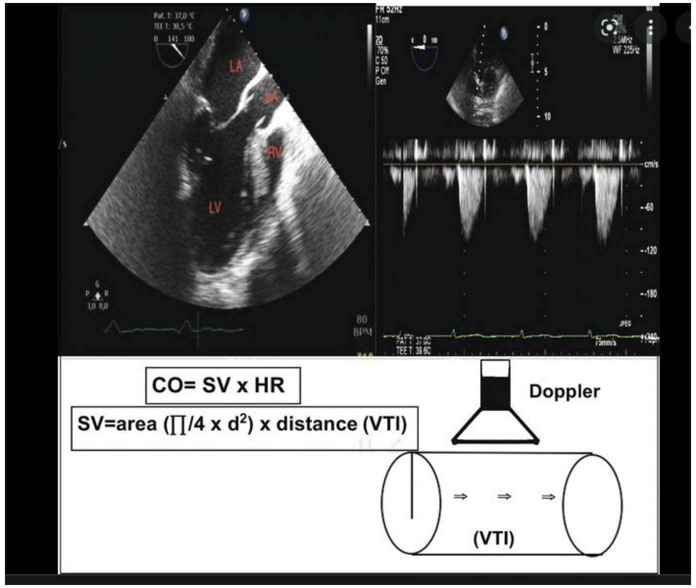
Swan-Ganz catheter



Thermodilution



Doppler ultrasound



Wetterslev et al. 2016. Int Care Med 42, 1223–1233

Let's run the simulation

A 35-yr-old male, without significant medical history and weighing around 90kg

First let's turn back time and look at 'baseline data'

Fill in Table 2 and the blanks section that follows in your notes and the first column of Table 3; typical blood volume male = 70 ml/kg

Table 3

Fluid volume deficit (ml)	0	600	3000	2100	1200	hypervolemic
* Fluid deficit (% of total blood volume)	-					
*Stage of shock	-					
Heart rate (beats/min)	66					
Systolic pressure (mmHg)	123					
Diastolic pressure (mmHg)	77					
* Pulse pressure (mmHg)						
* Mean arterial pressure (mmHg)						
*Change in MAP %						
Central venous pressure (mmHg)	2					
Cardiac output (l/min)	5.5					
*Change in C.O. %						
* Stroke volume (ml)						
* Total peripheral resistance (mmHg/l/min)						
*Change in TPR %						
Breathing rate (breaths/min)	11					
*Shock Index						

90 kg, 700 ml per kg = 6.3 l

PP = SYS - DIAS

MAP = 1/3 SYS + 2/3 DIAS

SV = CO/HR

TPR = MAP/CO

Fluid volume deficit (ml)	0	600	3000	2100	1200	hypervolemic
* Fluid deficit (% of total blood volume)	0	9.5				
*Stage of shock	-					
Heart rate (beats/min)	66					
Systolic pressure (mmHg)	123					
Diastolic pressure (mmHg)	77					
* Pulse pressure (mmHg)						
* Mean arterial pressure (mmHg)	94					
*Change in MAP %	0					
Central venous pressure (mmHg)	2					
Cardiac output (l/min)	5.5					
*Change in C.O. %	0					
* Stroke volume (ml)	83					
* Total peripheral resistance (mmHg/l/min)	17					
*Change in TPR %	0					
Breathing rate (breaths/min)	11					
*Shock Index	0.5					

The case

A 35-yr-old man, without significant medical history and weighing around 90kg, sustained a severe motor vehicle accident (MVA). He was admitted to hospital after ambulance transport. On the first clinical examination, the patient was hemodynamically stable and alert. He has chest pain and difficulty breathing, upon examination he has bruises on chest

- bleeding from trauma is not identified easily
- the pleural space, abdominal cavity, mediastinum and retroperitoneum are all spaces that can hold enough blood to cause death from blood loss

Let’s continue the simulation

A 35-yr-old male, without significant medical history and weighing around 90kg

He has now experienced a trauma

Fill in column 2 of Table 3 (and others when instructed)

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Fluid volume deficit (ml)	0	600	3000	2100	1200	hypervolemic
* Fluid deficit (% of total blood volume)	-	10				
*Stage of shock						
Heart rate (beats/min)	66	71				
Systolic pressure (mmHg)	123	118				
Diastolic pressure (mmHg)	77	78				
* Pulse pressure (mmHg)						
* Mean arterial pressure (mmHg)						
*Change in MAP %						
Central venous pressure (mmHg)	2	1				
Cardiac output (l/min)	5.5	5.3				
*Change in C.O. %						
* Stroke volume (ml)						
* Total peripheral resistance (mmHg/l/min)						
*Change in TPR %						
Breathing rate (breaths/min)	11	15				
*Shock Index						

Is this volume loss life-threatening?

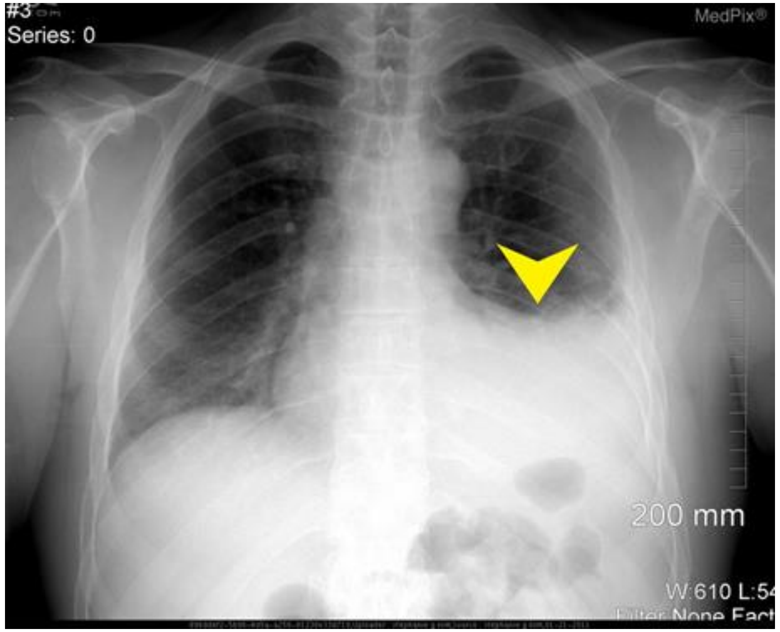
and what are the compensatory processes?

Deterioration!

After 15 to 20 minutes his condition deteriorated.

X-rays showed multiple fractures and small haemothorax in left lung.

Scans show a traumatic rupture of the blood vessels in chest, and multiple rib fractures.



Let’s continue the simulation -deterioration!

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Signs we might observe

Extremities cool to the touch
"Thready" pulse
The patient may be cyanotic due to hypoxemia
Sweating results in a moist, clammy feel
Digits will have severely slowed capillary refill
Decrease in urinary output

What causes these signs?

Stages of haemorrhagic shock

Parameter	I	II	III	IV
Blood loss (ml)	<750	750-1500	1500-2000	>2000
Blood loss (%)	<15	15-30	30-40	>40
Heart rate (bpm)	<100	>100	>120	>140
Blood pressure	Normal	orthostatic	hypotension	Severe hypotension
CNS symptoms	Normal	Anxious	Confused	Unconscious

Fluid volume deficit (ml)	0	600	3000	2100	1200	hypervolemic
* Fluid deficit (% of total blood volume)	-	10	48			
*Stage of shock						
Heart rate (beats/min)	66	71	131			
Systolic pressure (mmHg)	123	118	37			
Diastolic pressure (mmHg)	77	78	29			
* Pulse pressure (mmHg)						
* Mean arterial pressure (mmHg)						
*Change in MAP %						
Central venous pressure (mmHg)	2	1	-3			
Cardiac output (l/min)	5.5	5.3	1.6			
*Change in C.O. %						
* Stroke volume (ml)						
* Total peripheral resistance (mmHg/l/min)						
*Change in TPR %						
Breathing rate (breaths/min)	11	15	33			
*Shock Index						

Let's continue the simulation

What is the critical physiological problem?
What might be a first line of treatment for our patient?

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Fluid volume deficit (ml)	0	600	3000	2100	1200	hypervolemic
* Fluid deficit (% of total blood volume)	-	10	48	33	19	
*Stage of shock						
Heart rate (beats/min)	66	71	131	129	102	48
Systolic pressure (mmHg)	123	118	37	63	98	138
Diastolic pressure (mmHg)	77	78	29	49	73	82
* Pulse pressure (mmHg)						
* Mean arterial pressure (mmHg)						
*Change in MAP %						
Central venous pressure (mmHg)	2	1	-3	-2	-1	21
Cardiac output (l/min)	5.5	5.3	1.6	2.6	4.2	5.3
*Change in C.O. %						
* Stroke volume (ml)						
* Total peripheral resistance (mmHg/l/min)						
*Change in TPR %						
Breathing rate (breaths/min)	11	15	33	29	21	
*Shock Index						

After the simulation

Complete table 2. Then…

Graphical analyses

Plot the following graphs as instructed below (omit the hypervolemic data). ***You will need to order the data correctly as explained above to plot the graphs as progressive volume reduction (0, 600, 1200, 2100, 3000 ml deficit, or as a percentage as instructed).***

Graph 1. The relationship between the percentage of circulating blood volume removed and the systolic and diastolic arterial blood pressures (mm Hg) and heart rate (beats/min). You **may** need to use two vertical axes, one for blood pressure, the other for heart rate. Start both vertical axes from zero.

Graph 2. The relationship between central venous pressure (mm Hg) on the horizontal axis and stroke volume (ml). Sometimes you get 2 'x' values the same for CVP (e.g. 2 values for SV at 1 mmHg CVP) which can make plotting tricky but this graph only needs to show the overall trend.

Graph 3. The relationship between the percentage of circulating blood volume removed (horizontal axis) and changes in cardiac output, mean arterial pressure and total peripheral resistance (systemic vascular resistance). Express all these values on **the same** vertical axis as **the percentage change** in each variable in relation to its baseline (i.e. pre-bleeding) value. You **may** wish to show decreases as negative values.

Complete baroreceptor schematic.

ANY QUESTIONS?

The following slides are for instructor use

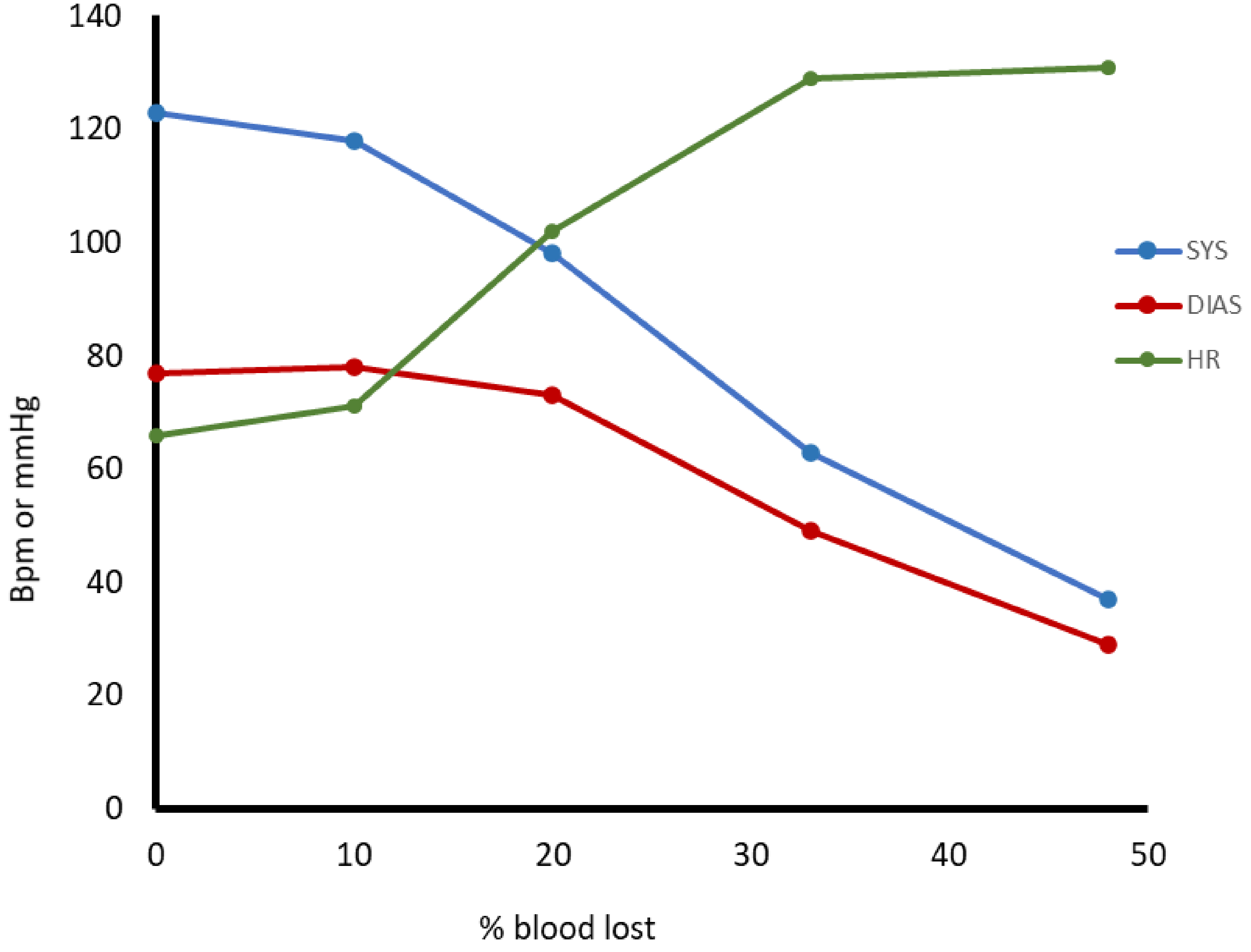
Completed Table 3

Fluid volume deficit (ml)	0	600	3000	2100	1200	hypervolemic
* Fluid deficit (% of total blood volume)	-	10	48	33	19	n/a
*Stage of shock	-	1	4	3	2	n/a
Heart rate (beats/min)	66	71	131	129	102	48
Systolic pressure (mmHg)	123	118	37	63	98	138
Diastolic pressure (mmHg)	77	78	29	49	73	82
* Pulse pressure (mmHg)	46	40	8	14	25	56
* Mean arterial pressure (mmHg)	94	93	31	54	82	100
*Change in MAP %	0	1	67	43	13	6
Central venous pressure (mmHg)	2	1	-3	-2	-1	21
Cardiac output (l/min)	5.5	5.3	1.6	2.6	4.2	5.3
*Change in C.O. %	0	4	71	53	24	4
* Stroke volume (ml)	83	75	12	20	11	108
* Total peripheral resistance (mmHg/l/min)	17	17.5	19	20.1	20	19
*Change in TPR %	0	3	14	18	15	12
Breathing rate (breaths/min)	11	15	33	29	21	21
*Shock Index	0.5	0.8	3.6	2	1+	n/a

lost consciousness by 3000 ml loss

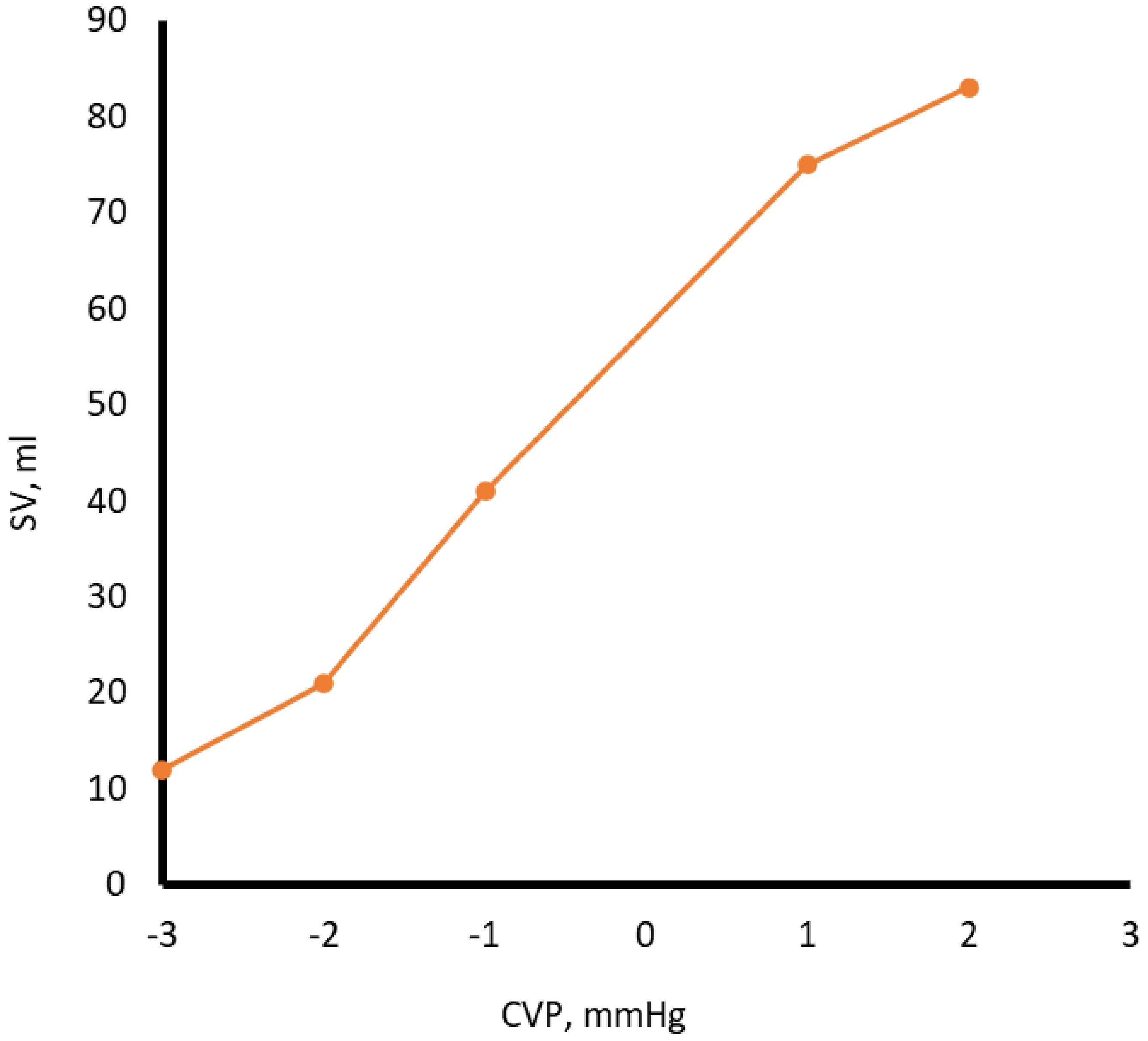
the numbers you have recorded may vary slightly

Graph 1

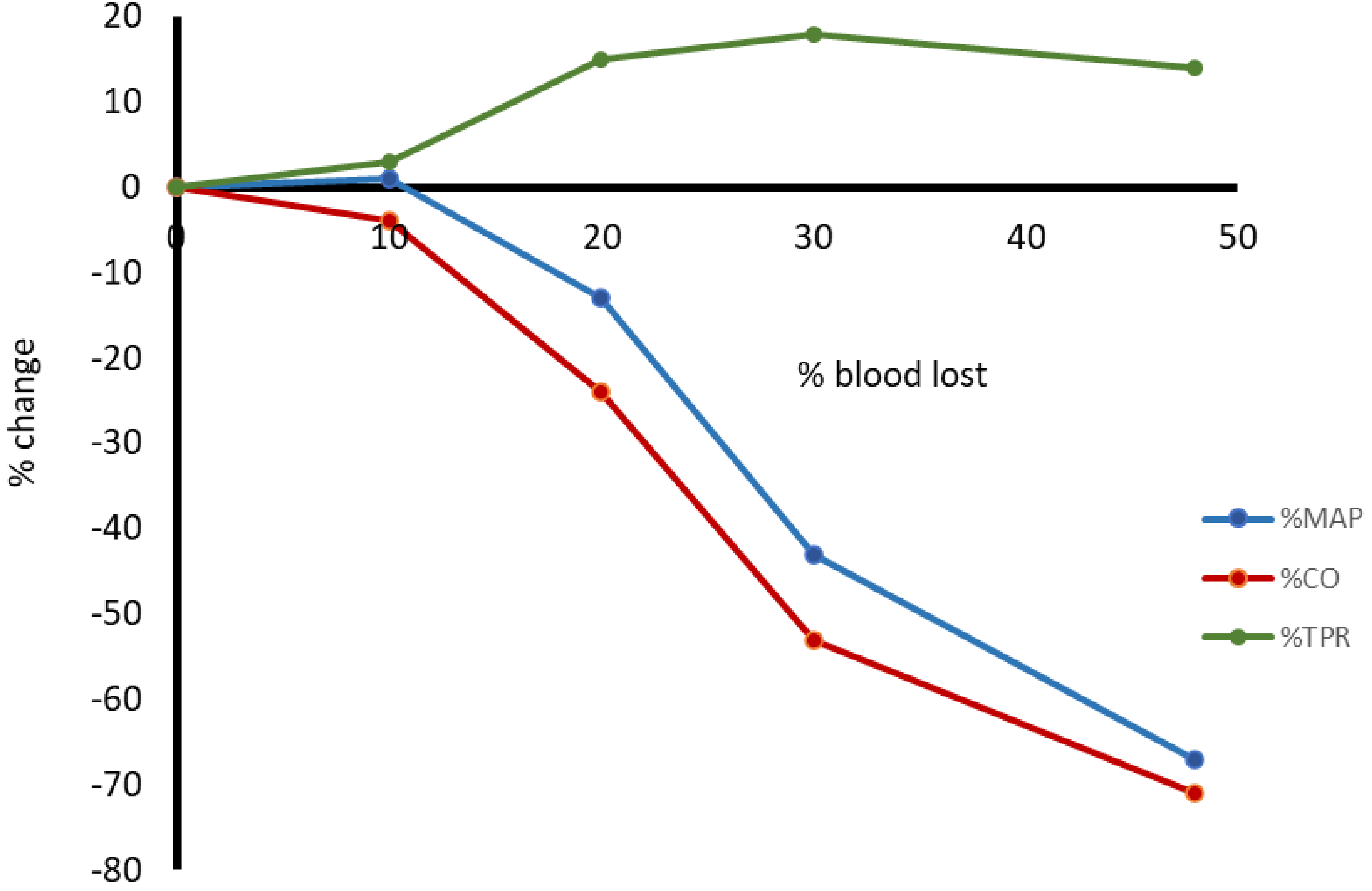


140
120
100
80
60
40
20
0
Bpm or mmHg
0
10
20
30
40
50
% blood lost
SYS
DIAS
HR

Graph 2



Graph 3


20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
% change
0
10
20
30
40
50
% blood lost
%MAP
%CO
%TPR