Arterial blood pressure

Just because something is invasive doesn't mean it improves survival.

The Mean Arterial Pressure

- MAP = (Systemic vascular resistance) x (cardiac output)
- Crudely, MAP = (diastolic pressure) + (pulse pressure divided by 3)

Why is the MAP more relevant than systolic and diastolic blood pressure?

- Least dependent on measurement site or technique (whether invasive or not)
- Least altered by damping
- Determines tissue blood flow via autoregulation

Non-invasive (oscillometric) cuff blood pressure monitoring:

- Wildly inaccurate.
  - Underestimates high blood pressures
  - Overestimates low blood pressure
  - For the normal range, the 95% confidence interval is +/- 15mmHg!
  - In case of arrhythmia, the accuracy is even worse.
Arterial line mechanics

Which artery should I puncture?
- There does not appear to be any difference in complications, irrespective of site.
- **Femoral artery is better in low output states** (better reflects the aortic pressure).

The monitoring device

- The arterial pressure wave travels at 6-10 metres/sec
- The cannula in the artery is connected to the transducer via some non-compliant fluid-filled tubing

Priming the non-compliant pressure tubing
- The idea is that the fluid in the tubing transmits the pressure wave to the transducer
- The whole principle rests on a continuous cylinder of saline connecting the artery to the pressure transducer

“Damping”: anything that has a “shock absorber” effect on the art line
- Air bubbles, long tubing, or compliant tubing – all of these absorb some of the force of the pulse wave decreasing the amplitude of the oscillations.
- **Damping** results in a slurred waveform with overestimation of the diastolic and underestimation of systolic; however, the MAP value is usually preserved.
- In contrast, a kinked or clogged art line will see MAP systolic and diastolic all trending towards zero.

Zeroing the art line
- The system is “zered” at the phlebostatic axis (otherwise it would read diastolic blood pressures of ~760mmHg)
- The device is zeroed when the air-fluid interface is opened to atmospheric pressure

Leveling the art line
- The transducer has to be zeroed at the phlebostatic axis.
- If it is zeroed at the level of the cannula, the hydrostatic pressure of the column of blood will be added to the measured blood pressure. For every 10cm below the phlebostatic axis, the art line will add 7.4mmHg of pressure.

Which fluid should I flush with?
- Heparinized saline increases accuracy, but does not prolong patency.
- Constant infusion 3ml/hr; when flushed, flush rate is 30-60ml/hr

Normal arterial line waveforms

The normal arterial line waveform

![Diagram of arterial line waveform]

- **Anacrotic limb**
- **Dicrotic limb**
- **Dicrotic notch**: caused by the closing of the aortic valve and retrograde flow against it.
- **Area under the graph = MAP**

Difference in arterial waveforms according to site of insertion

- **Aorta**: big elastic vessel; the trace is slurred because it damps
- **Brachial artery**
- **Radial artery**
- **Femoral artery**
- **Dorsalis pedis**

The further you get from the aorta,
- **The taller the systolic peak**
- **The further the dicrotic notch**

The systolic peak is steeper the further down the arterial tree you travel because of "reflected waves".

That is to say, the narrowing and bifurcation of blood vessels reflects some of the pulse back at the aortic valve.

In young people, this is a positive feature, as their relatively elastic vessels recoil slowly and the reflection wave is delayed, arriving to the aortic valve after it closes, and nourishing the coronary arteries.

Respiratory variation of arterial line waveforms

In a spontaneously breathing patient, it is normal to observe a downward displacement of the arterial pressure baseline with each inspiration. This phenomenon is exaggerated in patients with cardiac tamponade or restrictive pericarditis.

In a mechanically ventilated patient, it is normal to observe a decrease in arterial pressure baseline, systolic blood pressure and mean arterial pressure. This phenomenon is exaggerated in patients who are hypovolemic, as it is the influence of the tug-of-war between positive pressure of the ventilator and the diastolic pressure of the venous system. It's a fight: PEEP vs central venous pressure.

If the PEEP wins, the right heart doesn't fill enough, consequently the left heart doesn't fill enough, and the stroke volume is decreased as per the Frank-Starling mechanism.

If the patient has low central venous pressure (eg. dehydrated or hemorrhaging), PEEP wins more often.

Of course all of this goes out the window if the ventricles are abnormal, eg. in LV dysfunction- then, the positive pressure might actually INCREASE the stroke volume, because it augments the transmural pressure of the barely coping ventricle, and assist in ejecting the blood from the thorax.

Abnormal arterial line waveforms

Pathological arterial line waveforms

- **Atherosclerosis and hypertension**
  - Steep sharp systolic peak
  - Reflected waves are visible
  
  In the atherosclerotic elderly the vessels have poor compliance, and the reflection wave returns early, before the aortic valve closes. Thus, it contributes to afterload. You can sometimes see it on the art line trace. This contribution disappears in vasodilation, and appears with vasoconstriction. The non-compliant vessels do not stretch in response to the systolic pressure, and thus the pressure rises rapidly at the beginning of systole.

- **Aortic stenosis**
  - Slurred gradual systolic peak
  
  In presence of resistance to outflow, the systolic peak will be slow to arrive (as the left ventricle struggles to squeeze blood past the aortic valve). The dicrotic limb should remain relatively normal.

- **Aortic regurgitation**
  - Abnormally widened pulse pressure
  
  The diastolic will be well below the systolic, with abnormally widened pulse pressure, because the blood regurgitates easily back into the left ventricle as it fills. The compliance of the left ventricle causes the arterial pressure to dip in diastole as some of the pressure is absorbed by the act of left ventricular filling.
Arterial line dynamic response testing

Dynamic Response is a function of Natural Resonant Frequency and Damping Coefficient

- **The Natural Resonant Frequency:** How fast the system vibrates in response to a pressure signal
- **The Damping coefficient:** How quickly those vibrations come to rest in the system

**The Square Wave Test**
When you squeeze the fast flush valve, you let the transducer taste some of the 300mmHg in the pressurized saline bag. This produces a waveform that rises sharply, plateaus, and drops off sharply when the flush valve is released again. This is the “square wave”.

**The accurate, responsive, adequately damped art line trace**

- The dicrotic notch is clear and distinct
- Fast flush valve is activated
- Two oscillations occur after the flush valve is released; each oscillation’s amplitude must be no more than \( \frac{1}{3} \)rd of the previous oscillation.

A good art line trace has a distinct dicrotic notch, and after the fast flush test there are two oscillations only.

**The over-damped art line trace**

- The dicrotic notch is lost, the waveform appears abnormally smooth and curved.
- Fast flush valve is activated
- Just one oscillation after the flush, and then they die off, absorbed in the air bubble or clot or whatever else is overdamping the system.

The over-damped trace will lose its dicrotic notch, and there won’t be more than one oscillation. This happens when there is clot in the catheter tip, or an air bubble in the tubing.

**The under-damped art line trace**

- Fast flush valve is activated
- “Ringing”, repeated oscillations; the line oscillates like a gong.
- There is so little damping that these oscillations just won’t die, and continue to reverberate through the circuit.

The under-damped trace will overestimate the systolic, and there will be many post-flush oscillations.