**Phys-11B10** Describe the effects of resonance and damping on an invasive arterial blood pressure tracing.

**Background**

Arterial blood pressure may be monitored invasively using an arterial cannula connected to a pressure transducer (set up as shown below)

The arterial blood pressure oscillations $\rightarrow$ oscillations in the arterial line-tube-fluid column setup $\rightarrow$ oscillation transmitted to the transducer $\rightarrow$ converted to an electric signal

The arterial line-tube-fluid column-transducer system is a *second order system* because it oscillates in response to a primary oscillation (i.e. arterial blood flow)

The accuracy of second order systems are influenced by *resonance* and *damping* within the system. These are *dynamic factors*.

N.B. *static factors* refer to:
(1) zero errors – i.e. incorrect positioning/height of transducer relative to reference
(2) gain errors – i.e. non-linear signal response, incorrect calibration, drift

**Resonance**

*Resonance* = tendency for system to oscillate with greater amplitude at certain frequencies (i.e. at the natural frequencies)

*Natural frequencies* = the frequencies adopted by the system if it is disturbed then allowed to oscillate free

The lowest natural frequency of a system is the *fundamental frequency* and all other natural frequencies are multiples of the fundamental frequency e.g. if the fundamental frequency of a system is 1 Hz, then $2^{nd}$ harmonic frequency = 2 Hz, $3^{rd}$ harmonic = 3 Hz, etc

Heart rates 30 ~ 180 bpm correspond to fundamental frequencies of 0.5 ~ 3 Hz
If the natural frequency of the arterial line setup matches the natural frequency (or harmonics) of arterial pulsation → resonance → amplification of oscillation → error

∴ the natural frequency of arterial line setup must be at least $8 \sim 10 \times$ natural frequency of arterial blood pulsations (i.e. $> 30$ Hz) to avoid the effects of resonance.

Usually, the natural frequency of the arterial line setup is designed to be $\approx 200$ Hz but a number of factors may reduce this.

Natural frequency of arterial line setup is
(1) proportional to diameter of tubing
(2) inversely proportional to $\sqrt{\text{length of tubing}}$
(3) inversely proportional to compliance
(4) inversely proportional to fluid density

∴ ↑ length of tubing, ↓ stiffness of tubing and ↑ fluid density (e.g. blood clot in arterial line) → reduced natural frequency → potentially ↑ resonance

Consequences of ↑ resonance in the measuring system:
(1) falsely elevated systolic arterial pressure
(2) falsely reduced diastolic arterial pressure
(3) mean arterial pressure relatively unaffected

**Damping**

*Damping* = the tendency of a system to resist oscillations via dissipation of energy

![Graph showing normal, overdamped, and underdamped oscillations](image)

Overdamped system will rapidly stop oscillations
Underdamped system will very slowly stop oscillations
Undamped system will continue to oscillate indefinitely

Factors that ↑ damping:
(1) kinked tubing
(2) ↑ compliance of tubing
(3) ↑ length of tubing
(4) blood clot in tubing
(5) air bubble in tubing

Consequences of overdamping:
(1) underestimate SBP
(2) overestimate DBP
(3) MAP relatively unaffected
(4) loss of details of arterial pressure oscillation e.g. lost dicrotic notch
N.B. Also note that excess damping can alter the natural frequency
N.B. Damping affects different harmonic to different extent → phase distortion

**Quantifying resonance and damping** *(source: Brandis – the physiology viva)*

Resonance and damping may be approximately quantified using the fast flush test

When the flush valve is squeezed → square pressure wave delivered → when let go of flush valve, the arterial line system will respond to the pressure wave as below

![Diagram showing pressure over time](image)

Frequency of oscillation following fast flush test → natural frequency
Amplitude of oscillation following fast flush test → can be used to calculate the damping coefficient

Quantifying damping with the following formula

\[ D = \sqrt{\frac{[\ln(D_2/D_1)]^2}{\pi^2 + [\ln(D_2/D_1)]^2}} \]

where,
D = damping coefficient
D_1 = amplitude of first oscillation after fast flush test
D_2 = amplitude of second oscillation after fast flush test

When \( D_2/D_1 \approx 7\% \) (i.e. small overshoot) → \( D \approx 0.64 \) (optimal damping)

Rough rule → **optimal damping** occurs when there are 2 oscillations following release of flush valve, where the amplitude of each oscillation is \(~7\%\) of previous oscillation

Advantages of **optimal damping**:
(1) amplitude distortion is minimised → < 2\% overshoot/undershoot at frequencies less than 2/3 natural frequency of arterial line setup
(2) phase distortion is minimised → same distortion for all harmonics
(3) maximal frequency response obtained → accuracy maintained up to 2/3 natural frequency. This accuracy range is better than at any other damping coefficients.
Examiner’s comments - 42% of candidates passed this question.

Basic material required to pass:
• **Description of the measurement system** was useful only if related to the following discussion
• **Definition of resonance and damping**
• **Explanation of their importance** and their effect on the timely measurement of the components of the blood pressure (systolic pressure, diastolic pressure, mean pressure)

Advanced material:
• **Quantification of the effects**

Common errors/omissions/unnecessary inclusions:
• Equations without definition of symbols
• Input frequency is not 0 – 40Hz!
• Natural resonant frequency is a property of the measuring system
• Details of transduction were not required
• “directionless relationships”; in a connected universe, everything influences everything else. To be of use, a relationship should include a direction of the effect, and a qualitative/quantitative indicator of the importance/magnitude

Organisational errors:
• Planning in the margins or on the back of the cover is a waste of time (headings can be used in the answer)
• Long lists of definitions before any factual content is a poor use of time (definitions should be embedded within the answer itself)