Describe the respiratory and cardiovascular effects of applying 10 cm of PEEP (positive end-expiratory pressure) to a healthy mechanically ventilated adult.

PPV
Physiological effects of positive pressure ventilation are mostly related to the increased mean airway pressure. This is a function of:

- Ventilation mode
- Tidal volume and peak (and plateau) airway pressure
- Respiratory rate
- I:E ratio
- **PEEP**

PEEP has a much larger effect than the other factors.

- **PEEP** is defined as a positive airway pressure at the end of expiration
- **PEEP** is distinct from positive airway pressure (which is not confined to a phase of the respiratory cycle) and CPAP (which is a mode of ventilation)
- iPEEP refers to intrinsic PEEP, auto PEEP or dynamic hyperinflation
- iPEEP is PEEP generated by the patient, and occurs when expiration stops before the lung volume reaches **FRC**.
  - Application of external PEEP may limit the generation of iPEEP by maintaining airway patency in late expiration
- Intrinsic PEEP can occur in patients with lung disease when they fail to fully expire, resulting in ‘gas trapping’ within the lungs and an increase in intrathoracic pressure

Respiratory Effects

- Decreased work of breathing
  - Decreased VO$_2$
    - More important when work of breathing is high.
- Alteration in anatomical/apparatus dead space
  - Intubation typically reduces dead space, as the additional apparatus dead space is of smaller volume than the anatomical dead space it replaces
  - Non-invasive ventilation masks cause a large increase in dead space
- Increases lung volume (and FRC, for PEEP) by an amount proportional to the compliance of the system
  - Improves oxygenation via alveolar recruitment
  - Improves lung compliance via alveolar recruitment, reducing work of breathing
- May Increase V/Q mismatch
  - Elevated airway pressures may increase the proportion of West Zone 1 physiology and alveolar dead space
    - In healthy lungs an increase in the VD / VT ratio is seen when PEEP exceeds 10-15cmH$_2$O.
  - ↓CO ⇒ ↓pulmonary perfusion
- Reduces airway resistance
  - Airway resistance decreases as lung volume increases.
- Lung water
  - Transfer of oedema fluid to the interstitium
- Permeability
  - Increased permeability to DTPA tracer molecules have been documented. Some evidence of biotrauma due to high airway pressures causing bacterial & cytokine translocation
- Barotrauma

Cardiovascular Effects

*In the Normal Heart:*

- RV –
• Preload: reduction in preload due to positive intrathoracic pressure (ITP) reducing venous return
• Afterload: PVR (RV Afterload)
  o If lung volume is lower than FRC, then PVR will reduce as PEEP stretches open extra-alveolar vessels
    ▪ Alveolar recruitment will reduce hypoxic-pulmonary vasoconstriction, further reducing PVR
  o If lung volume is higher than FRC, then PVR will increase as PEEP compresses alveolar vessels
  o Therefore, PEEP has variable effects on RV afterload depending on how it changes lung volume with respect to FRC
• LV –
  • Preload (LVEDV):
    o [initial]: ↑LVEDV as ↑ed blood squeezed from pulmon vessels into heart
    o [Soon]: reduction in preload due to:
      ▪ ↓VR from body ⇒ ↓LVEDV
      ▪ further ↓LVEDV via RV bulging into LV due to septal shift (ventricular interdependence)
      ▪ ↑Pulmon vasc resistance (PVR) ⇒
        ▪ ↓flow thru vascular bed ⇒ ↓LVEDV
        ▪ ↑RV afterload ⇒ ↓RV output ⇒ ↓LVEDV reduction in RV preload.
  • Afterload:
    o Reduction in afterload due to reduction in transmural pressure
    o (as per Laplace, T = PTM x r / u, where PTM = intraventricular pressure – intrapleural pressure, r = radius and u = wall thickness).
    o Some increase in afterload as positive ITP is also transmitted to aorta
    o But overall effect is a reduction in afterload
    o [low vent pressures] ↓↓afterload will balance ↓preload ⇒ preserved CO
    o [higher pressures] ↓↓preload will dominate ⇒ ↓CO
  • These changes are:
    o More marked with increasing PEEP
    o More marked in hypovolaemia - Changes reversed with volume expansion.
    o More marked in autonomic neuropathy
    o Less severe with poor lung compliance
    Reduced compliance greatly reduces the effect of PEEP and IPPV on the vasculature, as the change in intrapleural pressure is reduced.
• Reduction in MAP
  MAP decreases as PEEP increases.
• Changes to oxygen flux
  PEEP will tend to improve PO₂ whilst reducing CO.

In the CCF heart: (Can be skipped in this particular question, as our patient is a healthy adult)
• RV -
  o preload – reduction in preload may push the heart to a more favourable part of the Starling curve (as myocytes no longer overstretched).
  o Afterload - PVR may improve if underinflated lungs are pushed to a more favourable part of the PVR/lung volume curve, hence afterload may decrease
• LV –
  o reduction in preload due to reduction in RV preload.
  o Reduction in afterload as above reduces myocardial oxygen demand and also may push the overstretched LV to a better point on the Starling curve
End-Organ Effects

- Renal:
  - ↓CO & ↑renal venous pressure
    - → Reduced renal blood flow → Reduced GFR → Reduced urine output
    - → Reduced atrial stretch and ANP release → Increased ADH → Fluid retention
    - → Oedema

- Hepatic:
  - Reduced hepatic blood flow due to:
    - Increased CVP and decreased CO lowering the pressure gradient for hepatic flow
      - May result in circulation only intermittently throughout the cardiac cycle
    - Hepatocyte dysfunction

- Haematological:
  - Neutrophil sequestration in the compressed pulmonary vasculature

- CNS:
  - ↓VR ⇒ ↑CVP ⇒ ↑ICP

Examiner Comments:
29% of candidates passed this question.
This topic has been asked previously. It was expected candidates could detail the impact of PEEP on a variety of respiratory parameters such as lung volume, dead space, arterial pO2 and intrapleural pressure. The cardiovascular consequences are well described including the effect on cardiac output, blood pressure and oxygen delivery. The physiological impact of lower levels PEEP in a young healthy person is different to that often seen in the critically ill and this was not appreciated by most candidates.