

Ventilatory management for cardiogenic pulmonary edema



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Cardiogenic PE

Non-cardiogenic PE

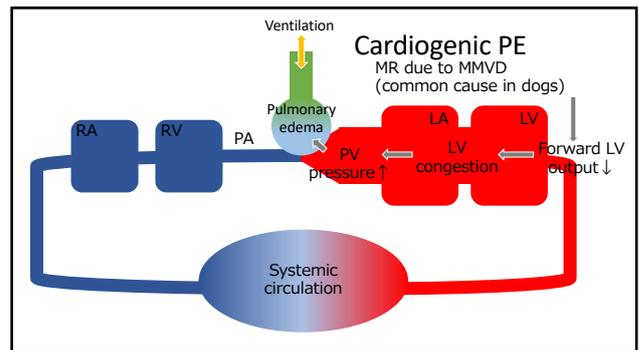
ventilatory techniques are the same for
 both conditions

※ Note that some content may overlap with the previous speaker.

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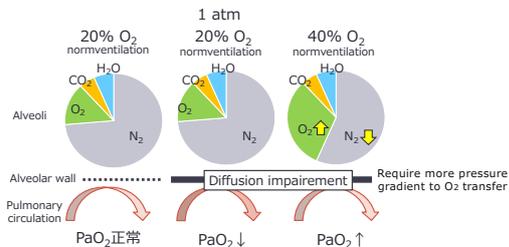
Why is Mechanical Ventilation (MV) required?

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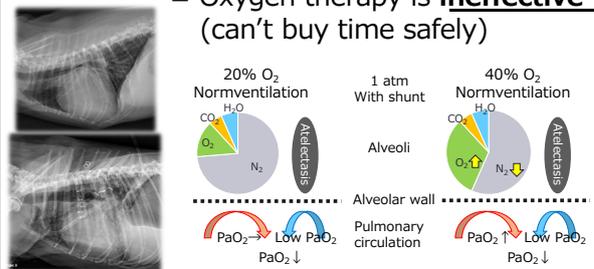
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Early stage: **Diffusion impairment**
 = Oxygen therapy is effective (buy time safely)



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Severe cases: **R-L shunt flow ↑**
 = Oxygen therapy is **ineffective**
 (can't buy time safely)



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Conventional oxygen therapy is insufficient

→ **Mechanical Ventilation**

- or High-Flow Nasal Oxygen Therapy ?
- Requires specialized equipment and high oxygen consumption (10-60 L/min)
 - Limited report in veterinary medicine
- Whitney et al. Front Vet Sci 2023;10:1070881.

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When to consider MV? (my opinion)

- Under oxygen therapy
 - **Persistent hypoxemia**
Target: PaO₂ >60 mmHg, SpO₂ >90%
 - **Respiratory distress doesn't improve**
 - **Altered consciousness**
Brain highly sensitive to hypoxia
- Auscultation of crackles or pink foamy sputum
→ Strongly suspect atelectasis ↑ (= shunt ↑)



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Informed consent for MV

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Cardiogenic PE vs non-Cardiogenic PE

- Higher weaned of MV: 66% vs 35%
- Higher survival to discharge: 54% vs 26%
- Shorter ventilation duration:
14 (1-48) hr vs 24 (2-132) hr
- Lower surviving rate >2 month: 54% vs 100%

Oppenheimer N et al. JVECC 2022;32:769-776.

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Considerations for MV (my opinion)

- High cost
- A lot of staff
- Just **buying time** for primary cardiac treatment
- Most cases are severe PE (include a poor prognosis)
- Responders are usually weaned **within 12-48 hr**
(generally, tend of improvement over time)
- Long-term prognosis depends on
response to continued cardiac therapy

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Anesthetic management
during MV

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Anesthetic induction

Similar to normal induction

- Propofol or Alfaxalone to effect IV
+/- opioids or Midazolam
sometimes use Ketamine with Propofol (ketofol)
- Emergency: Propofol alone for rapid intubation
- If possible, pulse oximetry & oxygen supply (flow-by or mask) during induction.



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Anesthetic maintenance

Similar to normal maintenance

- Inhalation (Iso or Sev): When using an anesthetic machine
- Propofol-TIVA: 0.1-0.3mg/kg/min (avoid in cats)
- Alfaxalone-TIVA: Can use in dogs & cats
Risk of emergency delirium during recovery
- +/- opioids or Midazolam
e.g. Fentanyl 5-10 mcg/kg/hr, Midazolam 0.2-0.5 mg/kg/hr
- Avoid alpha-2, if possible



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Muscle relaxant (requires some specialized knowledge)

- Only Rocuronium in Japan (0.5 mg/kg IV ?)
- Suppress asynchrony between spontaneous breathing and MV
- Useful immediately after the induction of MV (not essential)
- Cautions:
 - Difficult to assess the depth of anesthesia (can immobilize even while awake)
 - Consideration of reversal before weaning (how to monitor, antagonize?)



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Basic strategy of MV

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Considerations for MV setting

- Just **buying time** for cardiac treatment
- Goals:
 - Maintain **minimum oxygenation** (SpO₂ 90-95%)
※ not to normalize oxygenation and ventilation
 - Avoid **Ventilator-induced Lung Injury (VILI)**

Lung protective strategy

- PEEP
- Inspired oxygen concentration ↓
- Tidal volume ↓
- Permissive hypercapnia

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Common cause of VILI

- **Volutrauma**
Excessive tidal volume
→ Overdistended alveoli
- **Atelectrauma**
Functional residual capacity ↓ (**Atelectatic alveoli**)
→ Repeated alveolar collapse & re-expansion

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Laplace's law

$$P = 2T / r$$

P: pressure, T: tension in the wall, r: radius

$P \uparrow, r \downarrow$
= distended alveoli ↓

$T \uparrow$ = surfactant ↓
→ More prone to collapse (PE lung)

Atelectrauma

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Normal lung

PE lung

Inspiration

Normal alveoli expand evenly

Normal alveoli over-expand

Collapsed alveoli difficult to expand

Volutrauma

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Lung protective ① minimize alveoli collapse (prevent Atelectrauma, Volutrauma)

- **PEEP** (not high PEEP)
- **Lower inspired oxygen concentration**
 - Prevention of absorption atelectasis
 - Protective effect against oxidative injury
- Avoid ZEEP, if possible

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Lung protective ② restrict tidal volume (prevent Volutrauma)

- Human: 6-8 mL/kg
- Dogs & Cats
 - 6-8mL/kg (probably not enough)
 - Around 10 mL/kg**
 - Due to large anatomical & mechanical dead space
 - Breed variations especially in dogs (sometimes, ≥15 mL/kg)

Donati et al. J Vet Sci 2019;20:e21.

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Lung protective ③ Permissive hypercapnia

- Collapsed alveoli & restrict tidal volume
 - Permit for PaCO_2 ($\approx \text{EtCO}_2$) ↑
 - Avoid excessive increase in minute ventilation
- Allow **PaCO_2 50-60 mmHg** especially immediately after induction

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Lung protective + alpha

- Lung stress due to transpulmonary pressure pressure difference between airway & pleural space
- Respiratory distress + MV → Lung injury

Control spontaneous breathing with muscle relaxants, if required

Spontaneous breathing

Ventilation

Ventilation

Transpulmonary pressure: 15

Transpulmonary pressure: 10

※Respiratory distress improves naturally as lung recovers

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Initial settings (my opinion)

- PCV or VCV
- Inspired oxygen concentration: 100%
- Tidal volume: around 10 mL/kg
 PCV: PIP 15 cmH₂O (above PEEP 10 cmH₂O)
- PEEP: 5 cmH₂O
- Respiratory rate: 20-30 bpm, I/E 1:2

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PCV

- Suitable even for small animals
- Lower risk of sudden increasing in PIP
- Better synchrony with spontaneous breathing?
- Easy to maintain lung expansion?
- Tidal volume monitor is essential
- More difficult to detect leaks
- Check pulmonary graphics

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VCV

- Can measure peak pressure & plateau pressure
- Easy to detect leaks
- The opposite of the merit of PCV

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Common trouble during MV

- Leaks
- Airway resistance ↑
- Pulmonary compliance ↓
- Asynchrony with spontaneous breathing

Pulmonary graphics are useful

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Initial goal (relatively easy)

Induction

PCV or VCV

Reduced the inspired oxygen concentration to 30-40% as long as SpO₂ can maintained around 90-95%

PEEP 3-5 cmH₂O

Inspired oxygen 100% → 30-40%

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Next goal (relatively difficult)

Gradually switch

Assist or Support Ventilation

Stable

Weaning

PCV or VCV

PEEP 3-5 cmH₂O

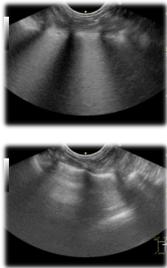
Inspired oxygen 30-40%

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Parameters reflecting improvement

- Pulmonary compliance ↑
- P/F ratio ↑ (Arterial blood gas)
- B-line ↓ (Lung ultrasound)

Useful as objective indicator, but the parameters depend on the MV settings.



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When to switch the ventilation mode

Respiratory distress subsides

- Reduced respiratory rate (spontaneous breathing)
- Reduced insp/exp effort

→ Becomes easier to synchronize with assisted/support ventilation



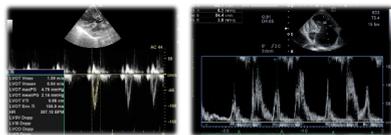
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When it does not go well: Check circulation

Echocardiogram: heart disease is improved?

- Forward LV output : VTI
- LA pressure : E-wave velocity
- End-diastolic intraventricular volume

SV = Forward output + MR




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Weaning criteria (my opinion)

- Resolved respiratory distress
 - Spontaneous respiratory rate: around 20-30 bpm
 - No insp/exp effort
- P/F ratio >300
- Improved pulmonary edema (lung ultrasound)

Before initiating weaning
 → Check pharyngeal secretions, then reduce anesthetics
 Antagonize muscle relaxants, as needed (sugammadex)
 Gradually reduce the ventilatory support (e.g. PIP)

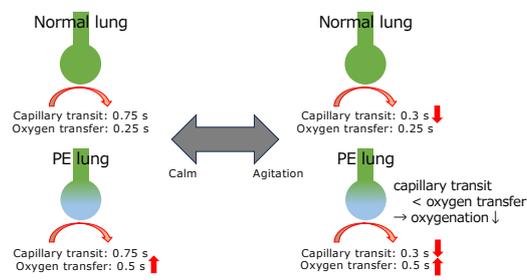
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Post-ventilation Care (After weaning)

- Continue cardiac treatment
- **Avoid agitation** sedation (as needed)
 - butorphanol 0.1-0.2 mg/kg
 - ± acepromazine 0.01-0.02 mg/kg IV
- Monitor changes in **breathing pattern & rate**

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Why is agitation undesirable?



The diagram shows four scenarios of oxygen transfer:

- Normal lung, Calm:** Capillary transit: 0.75 s, Oxygen transfer: 0.25 s
- Normal lung, Agitation:** Capillary transit: 0.3 s ↓, Oxygen transfer: 0.25 s
- PE lung, Calm:** Capillary transit: 0.75 s ↑, Oxygen transfer: 0.5 s ↑
- PE lung, Agitation:** capillary transit < oxygen transfer → oxygenation ↓, Capillary transit: 0.3 s ↓, Oxygen transfer: 0.5 s ↓

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Patient Care during MV = prevent **Infection**

e.g. Ventilator associated pneumonia
(VAP)

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- Wear gloves for all patient care/handling at all times
- Sterile breathing circuit
- Airway humidification
- Tongue care: Water & glycerin q2hr
- Oropharyngeal care: Suctioning followed by water & chlorhexidine q4hr
- Eye care: Artificial tears and lubricant alternating q2hr
- Evaluation of corneal ulceration: Fluorescein staining q24hr
- Airway suctioning q4hr
- Cuff pressure monitoring (20-25 mmHg) q4hr
- Repositioning (sternal, right lateral, left lateral) q4hr as possible
- Passive range of motion q4hr
- Tube exchange: As needed. Avoid routine exchange
Laura et al. JVECC 2022;32:376-385.

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In our hospital (short-term MV)

Handwashing, disinfection & glove use

- Use sterile breathing circuit & artificial nose
- Oropharyngeal suction q4-6hr
- Mouth & oropharyngeal care: Water & chlorhexidine q4-6hr
- Eye care: Ophthalmic ointment q6hr
- Airway suction: Close suction technique, as needed
- Cuff pressure monitoring: As needed
- Repositioning (sternal, right lateral, left lateral): Not adequately performed
- Range of motion: Not adequately performed
- Tube exchange: As needed (not usually performed)

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Questions ?



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