Respiratory domain-Ventilator Modelling Use Cases

Author: Grant Forrest grant.forrest@scata.org.uk

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Background

At the zoom meeting on 25th March 2021, Grant agreed to describe some clinical scenarios to inform the ventilator modelling process. Four cases are described with the intention of covering different care settings and patient demographics.
US English spelling is used for consistency.

1. Respiratory unit (acute medical care)
2. Pediatric surgical and anesthetic care
3. Adult surgical and anesthetic care
4. Critical Care

Each scenario could be extended with deterioration of clinical condition and escalation of care e.g. from ward level to high dependency to critical care.
Links to resources are included where possible. Please feel free to edit and annotate.

Use Case 1

Setting: Primary Care/Respiratory Unit

A 77 year-old attends the community health centre with a 2-day history of worsening shortness of breath on a background of mild COPD. Initial clinical findings:

- Bilateral inspiratory rhonchi and expiratory wheeze on auscultation
- Vital signs: pulse 103, SpO_2 86% on air, respiratory rate 28 with some use of accessory muscles, fever 38.3 degC.

Admission to a respiratory unit follows and treatment begins:

- Supplemental oxygen by mask to maintain SpO_2 > 94%
- Upright position
- Empirical antimicrobial therapy

Bedside non-invasive monitoring - ECG, NIBP, SpO_2, respiratory rate
EWS (early warning scoring)
Working diagnosis: Community Acquired Pneumonia
Relevant elements for modelling:

- Drug Administration: oxygen
- Observations - vital signs, clinical and radiological assessments
- Interventions - in this use case the breathing system is:
    - Venturi Mask - given the history of mild COPD, the type is adjusted to achieve satisfactory SpO_2 observations with the minimal inspired FiO_2, starting in this case with the WHITE (28%) venturi nozzle.

Use Case 2

Setting

- Secondary Care (Children's Hospital)
    - Operating Room
    - Post-anesthesia Care Unit (PACU)

A three year-old child (15Kg) is having surgery to insert grommets. They are anesthetized in the operating room using:

- Inhalational technique ('gas induction')
- Inspired gas mixture of oxygen and sevoflurane
- The breathing system is a Mapleson F t-piece with an open-ended 500ml reservoir bag on the expiratory limb.
- After induction, a size 2 LMA (laryngeal mask airway) is inserted and the child breathes an inspired mixture of sevoflurane 3%, oxygen 50%, set using the digital flow meters on the anesthetic machine.
    - The machine will adjust the flow of medical air into the inspired gas mixture so that the carrier gas (nitrogen) makes up the remaining percentage of the mixture.
- At the end of the procedure, the child is transferred to the PACU, the LMA is removed and a simple paediatric oxygen mask fitted with a flow rate of 6L/minute for as long as it is tolerated.

Relevant elements for modelling:

- Drug Administration: oxygen, anesthetic agent, medical air
- Observations - vital signs, capnography, anesthetic agent
- Interventions - in this use case the breathing system is:
    - T-piece with a reservoir bag of suitable volume
    - Simple oxygen mask (non-venturi) in PACU

Use Case 3

Setting

- Secondary Care Hospital
    - Operating Room
    - PACU
    - Surgical Ward

A 55 year-old is undergoing elective laparoscopic cholecystectomy.
Anesthetic technique:

- Pre-oxygenation with 100% oxygen using a tight-fitting clear disposable mask attached to a Circle breathing system.
- Intravenous induction and administration of a muscle relaxant
- Tracheal intubation with a size 7.0 cuffed endotracheal tube
- Controlled mandatory ventilation (CMV) with oxygen (FiO_2 50%) , sevoflurane and medical air
- Ventilator set to
    - Frequency 12 breaths/min
    - Tidal Volume 500ml
    - I:E ratio 1:3
    - Positive end-expiratory pressure (PEEP) 5 cmH_2O[1]
    - Pressure limit = 30 cmH_2O
- Circle system has an HME (disposable Heat and Moisture Exchanger) fitted on the expiratory limb.
- A number of other settings are available on the ventilator. These are left at their default values:
    - Trigger
    - Inspiratory pause Tip:Tinsp

After the procedure, the patient is extubated in the PACU and a simple c-circuit bag and mask system is used until normal spontaneous breathing is confirmed. Further supplemental oxygen is given by a simple variable flow-rate disposable oxygen mask at 5L/min.
The patient is discharged to the surgical ward with a prescription for oxygen at 2L/min for 4 hours, administered via nasal cannulae.
Relevant elements for modelling:

- Drug Administration: oxygen, anesthetic agent, medical air
- Observations - vital signs, capnography, anesthetic agent, pressure, flow, **ventilator variables** and alarm settings.
- Interventions - in this use case the breathing system is:
    - Circuit/Circle with soda lime absorber and HME (pre-op and intraop)
    - Mapleson C-circuit (mask and reservoir bag)
    - Simple variable-flow oxygen mask (non-venturi) in PACU
    - Nasal cannulae in Surgical Ward

Notes

1. The SI unit of pressure is the HectoPascal (hPa) and this is used in the technical manuals and documentation for ventilators. In clinical practice, the unit cmH_2O (centimeters of water) is still in regular use. 1 hPa = 1 mbar = 1.01972 cmH_2O

Use Case 4

Setting

- Critical Care

A 60 year old is admitted to critical care from the respiratory unit. They have viral pneumonia with deteriorating oxygenation and respiratory distress. They are anesthetized and given a muscle relaxant. A size 8.0 cuffed endotracheal tube is placed and connected to a circle breathing system, attached to a ventilator. The ventilator is set as follows:

- Mode: Pressure Control
- Inspiratory Pressure: 25 cmH_2O
- Pressure Limit: 50 cmH_2O
- I:E Ratio: 1:1 initially then attempt inverse ratio 2:1 guided by arterial blood gases (ABGs)
- Frequency: 12 breaths/min
- Initial FiO_2 50%
- PEEP: 10 cmH_2O

The breathing system has active humidification and filtering.
Modelling the recovery from acute lung injury/ARDS might include:

- Weaning modes e.g. pressure support or SIMV
- Positioning e.g. proning
- Tracheostomy as both a procedure and an airway device
- Non-invasive ventilation in the later stages of recovery

It might be a useful scoping exercise to get some test data exported from a real ventilator. This would likely include all the alarm conditions and ranges which may be out of scope but are important in clinical safety.