Inspiratory Muscle Training in CICU/HD

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Introduction – The Impact of Mechanical Ventilation and Critical Illness

Invasive mechanical ventilation (MV) is a life-saving intervention that is commonly used in the intensive care unit (ICU) (1). Despite its benefits, MV can lead to respiratory muscle dysfunction, characterized by diaphragm atrophy and contractile dysfunction (2-4). This entity, known as ventilator-induced diaphragmatic dysfunction (VIDD), develops within 18 – 69 hours of initiating MV and can occur in 34 – 84% of critically ill children and adults in the ICU (5-11).

VIDD has been reported to be twice as prevalent as ICU-acquired weakness, with the severity of VIDD being directly proportional to the duration of MV (5, 12). Even with low levels of MV support, intrinsic diaphragm function may be suppressed, with no detectable diaphragmatic electrical activity (13). In contrast, providing insufficient MV support leads to respiratory fatigue (4, 9).

There are several suggested mechanisms for VIDD, which may be exacerbated by prolonged immobility, critical illness (e.g., sepsis, heart failure) and the use of neuromuscular blockade and steroids (Figure 1) (14).

VIDD has been associated with increased risks of nosocomial pneumonia, extubation failure, prolonged duration of MV, increased lengths of ICU and hospital stay, poorer functional outcomes and even increased mortality (2, 8, 15).

Making a clinical diagnosis of VIDD is especially challenging when the work of breathing is supported by MV and may only manifest as increased respiratory effort when MV is weaned. Hence, the diagnosis of VIDD requires a high index of suspicion.

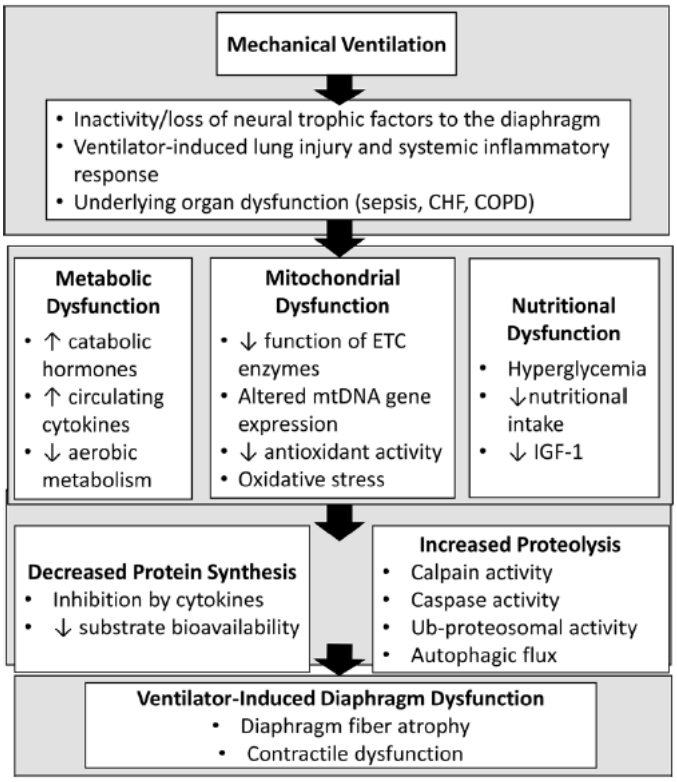


Figure 1: Suggested mechanisms for Ventilator-Induced Diaphragmatic Dysfunction

VIDD can be diagnosed by measuring maximal inspiratory pressure (MIP) or via diaphragm ultrasound, which can assess diaphragm excursion, diaphragm thickness and diaphragm thickening fraction (16, 17). Unfortunately, age-normative reference values and thresholds for these ultrasound parameters are not yet available in children.

Maximal Inspiratory Pressure

MIP is a quick, simple, non-invasive method of measuring global inspiratory muscle strength (representing the diaphragm and other inspiratory muscles). Measuring MIP requires patients to exhale completely to residual volume before performing a forceful inspiration against an occluded inspiratory valve. A manometer is used to indicate the magnitude of negative pressure generated by the inspiratory effort (18). Alternatively, MIP may be measured for patients on MV by performing an end-expiratory hold maneuver (19). However, this may yield a different MIP value as patients may only exhale to functional residual capacity before performing an inspiratory effort against the occluded inspiratory valve.

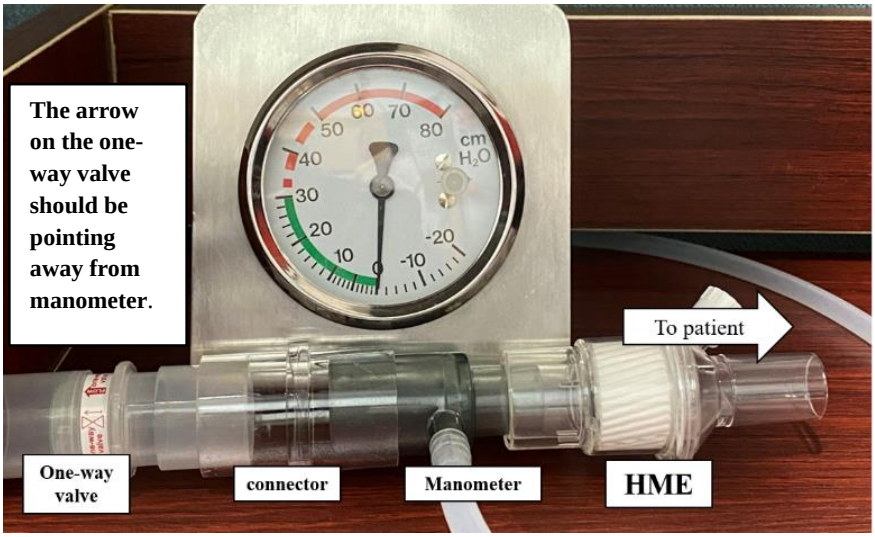
Ideally, MIP should be performed in a patient who can obey instructions. Hence, when attempting to measure MIP in a young child, measurements can be affected by variable extents of exhalation and a less forceful inspiratory effort. **An MIP of less than 30cmH_2O has been proposed as a significant risk factor for extubation failure** in both adults and children and is also associated with increased one-year mortality in adults (20-22).

Measuring MIP

Figure 2: Setting up an MIP measurement circuit.

Equipment required:

1) Manometer
2) One-way valve
3) Heat and moisture exchanger (HME)



For Intubated/Tracheostomy Patients	For Non-Intubated Patients
• Suction ETT/tracheostomy 10-15 mins prior • Ensure ETT/tracheostomy is cuffed and/or air leak is < 20% • Consider hyper-oxygenating patient for 5 mins by increasing FiO_2 by 10% from baseline • Connect MIP measurement circuit to ETT/tracheostomy • Instruct patient to exhale fully and slowly, followed by inhaling forcefully	• Apply nose clips and prepare MIP measurement circuit • Instruct patient to seal lips around the HME • Instruct the patient to exhale fully and slowly, following by inhaling forcefully
General Instructions	
• For patients who can obey instructions, use the manometer to provide visual feedback and to improve patient performance • Monitor patient for discomfort, desaturation, or bradycardia • Repeat 3 times (aim for <10% variability) – taking the best value • Perform MIP measurements up to a maximum of 5 times in one setting. If further testing is required, allow sufficient rest before repeating	

ETT: Endotracheal tube, HME: Heat and moisture exchanger, MIP: Maximal inspiratory pressure.

Inspiratory Muscle Training

Inspiratory muscle training (IMT) is a form of respiratory rehabilitation used to improve the strength or endurance of inspiratory respiratory muscles through the application of a set resistance or pressure load (14, 23). The goal of IMT is to oppose diaphragm inactivity and to improve muscle fibre activation and contractile force (14).

IMT has been reported to be an effective, low-cost intervention that can improve MIP and reduce the duration of MV in critically ill adults (14, 23, 24). In children, IMT has been used mainly in patients with neuromuscular disease, with few case reports and series exploring the role of IMT after congenital heart surgery (25-29). Despite the paucity of studies and heterogeneous methods of implementing IMT, some studies report promising results for the role of IMT in children with VIDD.

Inclusion and Exclusion Criteria for IMT

Patient Type	Inclusion Criteria	Exclusion Criteria
All Patients	• MV > 7 days OR clinical concerns of respiratory muscle weakness • MIP ≤ 30 cmH_2O • Alert, cooperative and spontaneously breathing* • Not in respiratory distress (RR not > 30% higher than age norm) • If on respiratory support: PEEP ≤ 8 cmH_2O^ AND able to tolerate removal of support for > 1 min without desaturating to SpO_2 < 90%	• Haemodynamic instability (arrhythmia, decompensated heart failure) • Pulmonary hypertension, PARDS, pulmonary haemorrhage, pneumothorax of any size, moderate to large pleural effusions, unstable asthma, bullae or unrepaired trachea-esophageal fistulae • Severe restrictive lung disease from severe kyphoscoliosis or severe chest wall contractures or within 12 months of lung surgery • Severe osteopenia or rib fractures • Poor prognosis or anticipated fatal outcome
Intubated	• ETT leak < 20% • FiO_2 ≤ 0.60	
Tracheostomy	• Tracheostomy leak < 20%: Ideally using cuffed tube, non-fenestrated inner cannula, or capping of tracheostomy with fenestrated inner cannula# • FiO_2 ≤ 0.60 or 8L/min O_2	
Non-intubated	• Able to create lip seal around IMT or HME mouth piece • O_2 supplementation < 8L/min	
General Precautions		
• Care should be taken in children with cardiac disease. Forceful inspiratory efforts against an occluded inspiratory valve may generate significant negative intrathoracic pressures, which can transiently increase left ventricular afterload, myocardial oxygen consumption, pulmonary blood flow and pulmonary pressure (27). • **Age < 5 years of age is a *relative contra-indication***: Performing IMT in young children who do not understand may be emotionally traumatic as they may perceive the experience of IMT as a feeling of suffocation. If a young child is markedly uncomfortable during IMT, we strongly encourage cessation of training.		

HME: Heat and moisture exchanger, IMT: Inspiratory muscle training, MIP: Maximal inspiratory pressure, MV: Mechanical ventilation, PEEP: Positive end-expiratory pressure.

**Excessive sedation and delirium are significant barriers to performing IMT (30).*
^Several centers permit disconnection from MV to perform manual hyperinflation for adults and children receiving PEEP ≤ 10cmH_2O (31-32). IMT protocols in adults recommend that IMT may be performed for patients receiving PEEP ≤ 10cmH_2O (20, 23).
#If the patient can tolerate capping of the tracheostomy (with a fenestrated inner cannula), oral IMT can be performed (provided good lip seal can be achieved around the device) (Figure 9).

Threshold Inspiratory Muscle Training Device

The threshold IMT device is an inspiratory pressure trainer used to train inspiratory muscle strength and endurance with an adjustable resistance ranging from 9 to 41 cmH_2O.

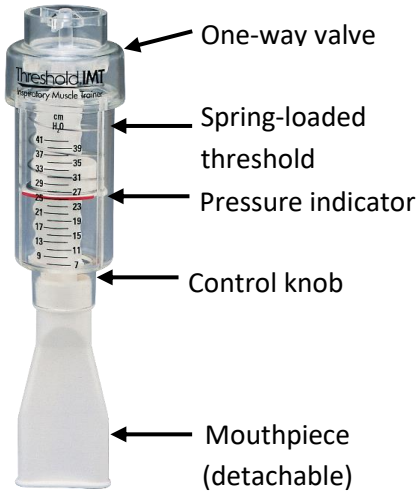


Figure 3: Components of the IMT device

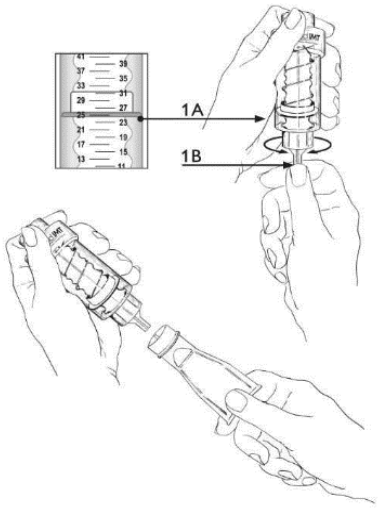


Figure 4: Adjusting the resistance

To adjust the resistance level: Insert the mouthpiece onto the device and turn the control knob to align the red edge of the resistance indicator to the desired setting for training.

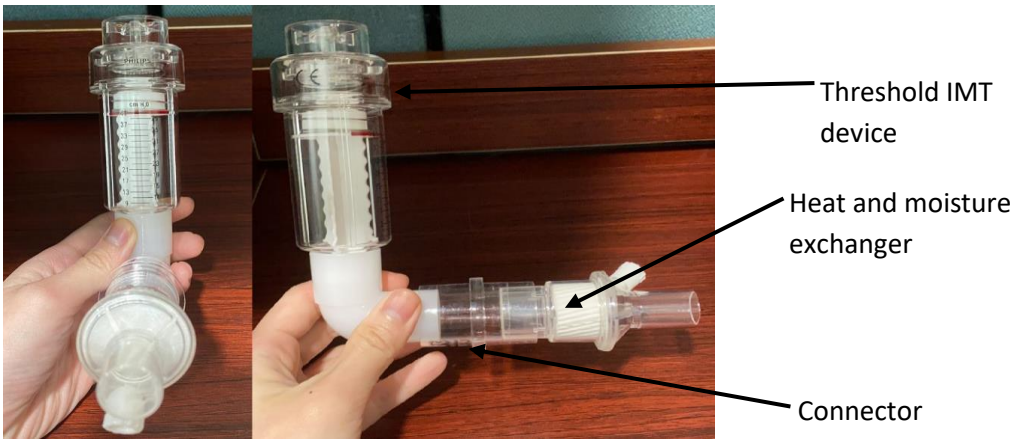


Figure 5: IMT device setup for intubated or tracheostomy patients

- When IMT is performed correctly, a “whoosh” sound should be heard.
- If insufficient inspiratory force is applied and the valve opens partially for less than 1 second, a “moo” sound might be heard.
    - If possible, instruct the patient to breathe harder over 1 second
    - Otherwise, consider reducing the set resistance level

Whoosh

Moo

Device Care

- Clean the IMT device mouthpiece/interface and any attachments used with 70% isopropyl alcohol wipes on a daily basis.
- If washing is necessary (e.g., chamber is moist), flush clear water through both ends of the device and any attachments used. Shake out excess water and allow to air dry completely on a dry paper towel before the next session. Do not boil or heat.

Instructions for Inspiratory Muscle Training

General Instructions	
• Assess patient suitability (Check Inclusion / Exclusion criteria) • Explain the rationale of IMT to patient/caregivers and seek consent. Caregiver presence during IMT is encouraged • Provide threshold IMT device to the patient and label it with the patient's sticker • Measure baseline MIP and re-assess once a week. If MIP measurements are not accurate, use the set resistance level that the patient can achieve as a guide of the patients' progress • If the patient is also planned for other rehabilitation sessions or spontaneous breathing trials, aim to schedule IMT sessions earlier in the day to avoid patient exhaustion • For intubated/tracheostomy patients, consider using a cuffed ETT/tracheostomy or for fenestrated tracheostomies: change to a non-fenestrated inner cannula or cap the tracheostomy if patient is able to tolerate it, so as to facilitate leak < 20% • After each session, return the patient to their previous level of respiratory support and clean the device	
For patients with severe weakness	**For patients < 5 years old**
• If the patient is unable to tolerate the minimum resistance level of 9 cmH_2O, consider starting IMT training without the threshold device, using the resistance from the ETT/tracheostomy tube to spontaneously breathe without ventilator support • Progress to the IMT device when the patient is stronger	• If the child does not understand the concept of IMT, consider starting by allowing the child to breathe through the ETT/tracheostomy for 1-2 minutes, while monitoring the patient • To ease the transition, consider using party blowing toys or a whistle to engage the child • If the child remains uncomfortable after repeated attempts, consider ceasing IMT

Setting up the IMT device with patients

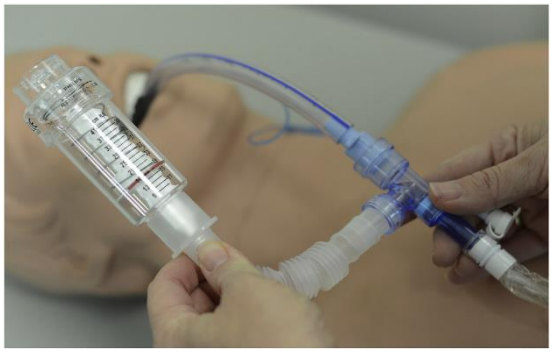


Figure 6: Connect IMT device to the ETT via an extension tubing with a T-connector and in-line suctioning tube

Figure 7: IMT device set up for patient with a tracheostomy (HME included)

Figure 8: Child using IMT with nose-clips applied (HME not included here)

Figure 9: IMT conducted orally, with tracheostomy capped, using fenestrated inner cannula (HME included)

Inspiratory Muscle Training Workflow

RESPIRATORY MUSCLE WEAKNESS?

- Assess Patient Suitability (Check Inclusion/Exclusion Criteria)
- Explain IMT to patient/caregiver & Provide IMT device (labelled with patient sticker) + HME
- If on respiratory support: PEEP ≤ 8 cmH_2O AND able to tolerate removal of support for > 1 min without desaturating to SpO_2 < 90%
- Perform suctioning / hyper-oxygenation as required
- Measure baseline MIP or re-assess once/week (Document in Procedure Note)

Intubated/Tracheostomy

- Aim for ETT/Tracheostomy leak < 20%
  - Cuffed tubes → Inflate cuff
  - Fenestrated tracheostomy → change to non-fenestrated inner cannula OR add on speaking valve/cap tracheostomy and proceed with oral IMT
- Connect IMT device + HME to patient
- Monitor patient during IMT

Non-intubated

- Apply nose clips
- Ensure adequate lip seal around HME mouthpiece
- Monitor patient during IMT

STRENGTH TRAINING

- Set IMT resistance level to ≥ 50% MIP
- **Training dosage:** 6 breaths/set. Inhale slowly and deeply. 7 sets/session. If caregiver competent, aim for 2-3 sessions/day, 5 days/week
- Monitor patient's comfort and technique
- If patient is not fatigued by the 6th breath, ↑ resistance level
- Rest 1 to 2 minutes between sets, restart respiratory support in between sets
- ↑ resistance level by 1 to 2 cmH_2O/day or as tolerated

Cease IMT training if:

1) **SpO2 < 90%**
2) **HR deviates by 20% from baseline**
3) **Patient develops respiratory distress**
4) **Patient becomes agitated or fretful**
5) **Patient requests to stop**

OR

Patient successfully extubated AND has good respiratory muscle function

Patient able to consistently perform strength training at the IMT device maximum resistance level (41 cmH_2O) and able to tolerate absence of respiratory support for 2 mins safely

ENDURANCE TRAINING

- Trial IMT resistance level of ≥ 30% MIP for 1 min to assess suitability
- **Training dosage:** Perform 2-minute sets with 1 to 2 minutes rest on respiratory support. 7 sets/session. 1 session/day. Aim for 5 days/week
- Monitor patient's comfort and technique
- Gradually ↑ set duration by 30 seconds or ↑ resistance by 1 to 2 cmH_2O/day
- Ideally, to achieve 30 minutes of cumulative training per day
- Aim for up to 8 weeks of training OR for patients with neuromuscular conditions, consider referral to Neuromuscular clinic and long-term training (e.g., 6 months) (25,26, 33)

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