KKH Children's Intensive Care Unit – Respiratory Therapy Clinical Practice Guidelines

Management of Conventional Invasive Mechanical Ventilation

A. Introduction

Invasive mechanical ventilation refers to the use of life-support technology to perform the work of breathing for patients who are unable to do so on their own via artificial airways such as endotracheal tubes (ETT) or tracheostomy tubes.

B. Aim

The overall goals of mechanical ventilation are:

- optimize gas exchange,
- reduce patient's work of breathing,
- improve patient comfort
- optimize patient-ventilator interaction and reduce patient-ventilator asynchrony
- minimizing ventilator-induced lung injury

C. Indications of Mechanical Ventilation

1) Respiratory failure—apnea/respiratory arrest, inadequate ventilation, inadequate oxygenation, chronic respiratory insufficiency
2) Cardiac insufficiency/shock—reduces work of breathing and reduces oxygen consumption
3) Neurologic dysfunction—central hypoventilation/frequent apnea, GCS < 8 and inability to protect airway

D. Initial Ventilator Settings

Initial Ventilator Settings	Infant (< 10kg)*	Pediatric (≥ 10kg and < 30 kg)*	Adult (≥ 30 kg)*
Mode	P-SIMV	P-SIMV	P-SIMV or V-SIMV
Respiratory Rate, RR (/min)	30 – 40	20 – 30	12 – 20
Inspiratory pressure, ΔP (cm H_2O)	Start at 1 – 2 cm H_2O above PEEP and adjust by 1 – 2 cm H_2O to achieve tidal volume target as indicated below		
Peak Inspiratory Pressure, PIP (cm H_2O)	≤ 28 – 32 cm H_2O for all patients		
Plateau Pressure, Pplat (cm H_2O)	≤ 28 – 32 cm H_2O for all patients		
Pressure Support, PS (cm H_2O)	Set at same level as or 1 – 2 cm H_2O below that of ΔP to achieve patient's comfort and target V_T ETT #3 - 3.5, PS ≥ 10; ETT #4 - 4.5, PS ≥ 8; ETT ≥ #5, PS ≥ 6		
Tidal volume, V_T (mL)	4 – 6 mL/ kg of PBW	6 – 8 mL/ kg of PBW	6 – 8 mL/ kg of PBW
	3-6 mL per kg of PBW for patients with Pediatric ARDS (PARDS) regardless of weight and age		
Inspiratory Time (seconds)	0.5 – 0.6	0.7 – 0.8	0.8 – 1.2
Inspiratory Trigger (L/min)	0.5 – 1.5	1.5 – 2	2 – 3
FIO_2	Start at 0.50 and adjust by 0.1 to achieve target SpO_2		
PEEP (cm H_2O)	Start at 5 cm H_2O for all patients. Adjust as needed and in accordance with the PEEP/FIO_2 table.		
*weight based on predicted body weight (PBW)			

Table of Predicted Body Weight and Height (Year 2000 HPB Growth Charts)		
Height (cm)	Predicted Body Weight, PBW (Kg)	
	Male	Female
50	3.4	3.25
55	4.5	4.4
60	6.0	5.75
65	7.25	6.8
70	8.25	8.0
75	9.2	8.9
80	10.25	10.0
85	11.4	11.0
90	12.5	12.1
95	13.75	13.5
100	15.0	14.8
110	18.25	18.0
120	22.85	22.5
130	28.0	26.8
140	34.9	33.9
150	42.6	42.1
160	51.0	50.7
170	59.8	57.8
180	68.0	62.7

E. Titration and Adjustment of Ventilator Settings

- **Prior to titrating of ventilator settings, discuss with managing ICU team regarding patient's diagnosis and goals of mechanical ventilation**
- **And during titration of ventilator settings, communicate with managing ICU team if any of the mechanical ventilation targets are not met**
- Check flow-time graph to ensure patient has adequate time for exhalation
- Ensure that $ETCO_2$ is within target range for patient.
- Obtain blood gas 30 – 60 mins after initiation of mechanical ventilation

1) <u>Oxygenation</u>
   - Determined primarily by PEEP and FIO_2
   - Also influenced by inspiratory time and inspiratory pressure (components of mean airway pressure)
   - If arterial blood gases are available, ensure PaO_2 are within target range for patients
     - For cardiac patients, target SpO_2
     - For patients with PARDS, employ permissive hypoxemia and keep PaO_2 55 – 65
     - For all other patients, keep PaO_2 70 – 90 mmHg or as per PaO_2 target stated by ICU team
   - SpO_2 targets:
     - For patients with underlying chronic lung disease, target SpO_2 to that of their baseline and keep $\leq$ 97%
     - For patients with PARDS, target SpO_2 based on the severity of PARDS
     - For cardiac patients with uncorrected cyanotic heart disease, and cardiac patients with BT shunt or univentricular physiology, target SpO_2 75 – 85 % or as per SpO_2 target indicated by ICU team
     - For cardiac patients with corrected biventricular physiology or non-cyanotic heart condition, target SpO_2 92 – 97% or as per SpO_2 target indicated by ICU team
     - For all other patients, target SpO_2 92 – 97%

Severity of PARDS based on OI/OSI			
PARDS Severity	Mild	Moderate	Severe
OI	> 4 OI ≤ 8	> 8 OI ≤ 16	> 16
OSI	> 5 OSI ≤ 7.5	> 7.5 OSI ≤ 12.3	> 12.3
SpO_2 targets	92 – 97%	88 – 92%	88 – 92%
- OI = (Mean airway pressure) x (FIO_2/PaO_2 x 100) - OSI = (Mean airway pressure) x (FIO_2/SpO_2 x100) and adjusting FIO_2 to maintain SpO_2 88 – 97% for calculation of OSI when PaO_2 is not available for calculation of OI			

- Adjust PEEP and FIO_2 based on the PEEP/FIO_2 table below

PEEP/FIO_2 table							
FIO_2	0.3 – 0.4	0.4 – 0.5	0.5 – 0.6	0.7	0.8	0.9	1.0
PEEP	5	8	10	10 – 14	14	14 – 18	18

2) Ventilation

- Determined primarily by minute volume (= RR x V_T)
    - When RR is increased to improve ventilation, check flow-time graph on ventilator to ensure that expiratory flow returns to zero and that patient has adequate time for exhalation. With increase in RR, a decrease in inspiratory time may be needed to ensure patient has adequate time for exhalation
    - When V_T is increased to improve ventilation, ensure that the measured V_T is not more than 8 mL/kg of PBW and that PIP is < 30 cm H_2O to minimize ventilator-induced lung injury
    - Acceptable total measured RR for patient

Age	RR
< 1 year	30 – 40/min
1 – 5 years	25 – 30/min
5 – 12 years	20 – 25/min
> 12 years	12 – 20/min

- If blood gases are available, ensure pH is within target range for patient
    - For patients with PARDS, employ permissive hypercapnia and keep pH 7.15 – 7.30 to avoid excessive and toxic ventilator settings and to minimize ventilator-induced lung injury
    - For all other patients, keep normal pH 7.35 – 7.45 or as per pH target indicated by ICU team
- Ensure $PaCO_2$/ $ETCO_2$ is within target range for patient. Note the trend for $ETCO_2$ and the difference between $ETCO_2$ and $PaCO_2$ to assess patient's ventilation and perfusion status.
    - For patients on permissive hypercapnia and patients with underlying chronic lung disease, keep $PaCO_2$ > 45 mmHg
    - All other patients, keep normal range of $PaCO_2$ 35 – 45 mmHg and $ETCO_2$ of 33 – 43 mmHg or as per target indicated by ICU team

Titrating Oxygenation		
	PaO_2 or SpO_2 < target	PaO_2 or SpO_2 > target
FIO_2	Increase FIO_2 by 0.05 to 0.1 every 5 – 10 mins to achieve PaO_2/SpO_2 target	Decrease FIO_2 by 0.05 to 0.1 and not more often than every 30 mins

PEEP (cm H_2O)	Increase PEEP by 1-2 cm H_2O if FIO_2 > 0.6 and unable to achieve PaO_2/SpO_2 target	Maintain current PEEP level and do not decrease if FIO_2 > 0.6. Decrease PEEP by 1 cm H_2O when FIO_2 < 0.4 to 0.5. Do not decrease more often than every 4 – 6 hours
When decreasing settings, do not make more than 2 alterations at any one time. May consider adjusting ΔP to improve oxygenation while ensuring that V_T is within target and acceptable range.		

Titrating Ventilation		
	$PaCO_2$ or $ETCO_2$ > target pH < target	$PaCO_2$ or $ETCO_2$ < target pH > target
Respiratory Rate, RR (/min)	Increase RR by 2 – 5/min and monitor $ETCO_2$. Ensure expiratory flow on flow-time graph returns to zero.	Decrease RR by 2 – 5/min and monitor $ETCO_2$.
Inspiratory pressure, ΔP (cm H_2O)	For pressure limited ventilation, increase ΔP by 1 – 2 cm H_2O and ensure that measured $V_T \leq$ 8 mL/kg PBW. Ensure that PS is increased by a similar amount. Monitor $ETCO_2$.	For pressure limited ventilation, decrease ΔP by 1 – 2 cm H_2O and ensure that measured $V_T \geq$ 4-6 mL/kg PBW. Ensure that PS is decreased by a similar amount. Monitor $ETCO_2$.
Tidal volume, V_T (mL)	For volume limited ventilation, increase set V_T by 1 mL/kg PBW but not more than 8 mL/kg PBW.	For volume limited ventilation, decrease set V_T by 1 mL/kg PBW

	Ensure that PIP does not exceed 30 cm H_2O. Monitor $ETCO_2$.	and ensure that measured $V_T \geq 4 – 6$ mL/kg PBW. Monitor $ETCO_2$.
	When decreasing settings, do not make more than 2 alterations at any one time.	

F. Weaning from Mechanical Ventilation

1) Clinical criteria to start weaning mechanical ventilator settings:
   - Resolution or improvement of the cause of respiratory failure
   - Hemodynamic stability; absence or progressive decrease of vasoactive drugs
   - Spontaneous respiratory effort
   - Discontinue muscle relaxants at least 12 hours
   - Chest x-rays do not show worsening lung disease
   - Correction of significant metabolic and electrolyte imbalances

2) Spontaneous Breathing Trial (SBT) Screening and Readiness Parameters
   - Screen patients daily between 6 – 10 am
   - Notify physician if patient meets the following criteria for spontaneous breathing trial. An order to hold feeds by the physician to be ordered if extubation is anticipated. Patient will need to be NBM for at least 4 hours prior to an elective extubation.
     i. No planned procedure with GA in next 24 hours
     ii. No increase in ventilator settings for the past 12 hours
     iii. No muscle relaxants for the past 12 hours for patients who have received continuous IV muscle relaxants for at least 24 hours
     iv. Spontaneous respirations within acceptable parameters
       - Exhaled $V_T \geq 4$ mL/kg and PIP ≤ 20 cm H_2O
       - PEEP ≤ 8
       - SpO_2 92-97% on $FIO_2 \leq 0.5$ in patients without congenital heart disease or patients with acyanotic heart defect

- $SpO_2 \geq 75\%$ on $FIO_2 \leq 0.4$ in patients with cyanotic congenital heart disease
- RR within target range for age

v. Acceptable blood gas and lactate of < 2 mmol/L within last 12 hours and with pH > 7.3

vi. Acceptable hemoglobin of ≥ 8 g/dL

vii. Low dose of sedatives and with adequate level of consciousness

- SBS sedation score of 0 – 2
- Patient to be able to follow commands. For patients who are unable to follow commands, there should be spontaneous eye opening and/or spontaneous limb movements
- The patient should not be on more than any 2 of the following sedatives concurrently at the following stipulated dosing. If the patient require more than 2 sedatives concurrently, discuss with the managing ICU team regarding suitability for SBT.
    - Midazolam infusion ≤ 2 mcg/kg/min
    - Morphine infusion ≤ 20 mcg/kg/hr
    - Fentanyl infusion ≤ 3 mcg/kg/hr
    - Ketamine infusion ≤ 10 mcg/kg/hr
    - Dexmedetomidine infusion ≤ 0.3 mcg/kg/hr

viii. Stable hemodynamically and with acceptable arterial blood pressure and heart rate

- 1 – 2 vasoactive drugs with no increase in rate for the last 12 hours
- Milrinone ≤ 0.5 mcg/kg/min
- Adrenaline ≤ 0.1 mcg/kg/min

Age	Heart Rate
< 1 year	110 – 160/min
1 – 5 years	95 – 140/min
5 – 12 years	80 – 120/min
> 12 years	60 – 100/min

Age	Systolic blood pressure (SBP)
< 1 month	> 60 mmHg
1 month to 1 year	> 70 mmHg
> 1 year	SBP > 70 + (age in years x 2) mmHg

ix. Adequate cough, gag and secretions management
   - Suction not more often than every 2 hours unless otherwise agreed by ICU team

x. Ensure that there is presence of endotracheal tube leak of at least 10% with PIP at 20 – 25 cm H_2O
   - In the absence of leak for patients who are intubated for > 1 week, consider dexamethasone

3) <u>SBT Settings</u>

A. Non-cardiac patients:

- If patient fulfils the above SBT readiness criteria, proceed to perform an SBT with the following ventilator settings for a duration of 2 hours:
  i. Mode: Pressure Support Ventilation (Spont)
  ii. Current FIO_2 level and ensure ≤ 0.50
  iii. Current PEEP level and ensure ≤ 6 cm H_2O
     - For patients with baseline already on ventilator support, PEEP should not be set less than their baseline value during SBT
  iv. Pressure Support (PS) level

ETT Size (ID in mm)	Initial PS setting
3 – 3.5	10 cm H_2O
4 – 4.5	8 cm H_2O
≥ 5	6 cm H_2O
May titrate to a PS of 5 cm H_2O if patient tolerates initial PS setting for 1 hour.	

B. Cardiac patients:

- Complete SBT with PS based on ETT size for 1 hour as per criteria in (A). If patient tolerates this 1 hour of SBT, to then proceed to decrease PS to 0 for the next 1 hour. Obtain an ABG at the end of 1 hour of SBT with PS = 0.

4) <u>Unacceptable Parameters during SBT</u>

- SBT to be terminated immediately if patient displayed any of the following at any point during the SBT:
  - i. Desaturation
    - SpO_2 < 92% in patients without congenital heart disease or patients with acyanotic heart defect
    - SpO_2 decrease by > 5% from baseline in patients with cyanotic congential heart disease
  - ii. RR increased above normal range
  - iii. Exhaled V_T < 4 mL/kg
  - iv. Respiratory distress indicated by accessory muscle use, diaphoresis, nasal flaring
  - v. Hemodynamic compromise
    - HR ± 20% from baseline
    - BP ± 20% from baseline

vi. Patient went into apnea with ventilator backup ventilation

vii. $ETCO_2$ > 55 mm Hg or increase by 10 mm Hg or by 20% from baseline

5) Post-SBT

- If patient fails SBT, place patient back on previous ventilator settings and screen again the next day. Inform ICU team and restart feeds if it was placed on hold for the SBT.
- If patient passes SBT,
  i. Obtain blood gas
  ii. Inform ICU team of patient readiness for extubation, set time for extubation and decide on post-extubation respiratory support level.
  iii. Inform RN to hold feeds if not already done so.
  iv. An order must be entered into the electronic medical record for extubation.
  v. If order for extubation is not given, to document reason (e.g. upcoming surgery or procedure such as MRI, no provider available to monitor extubation, excessive suctioning, ICU team preference) in the electronic medical record. Place patient back to previous ventilator settings.

6) Extubation Procedure

- Ensure that order for extubation has been entered into patient's electronic medical record.
- Ensure that patient has been NBM at least 4 hours prior to extubation
- Gather all necessary equipment needed for extubation
  - Suction equipment
  - Manual resuscitator with the appropriate size face mask
  - Appropriate oxygen delivery devices to maintain target SpO_2
  - If patient's baseline is on home ventilatory support, gather the needed equipment and set up the ventilator to ensure that the settings are not lower than patient's baseline settings

    - For patient with high risk of developing post extubation stridor, consider extubating patient directly to HFNC or NIV
- Suction endotracheal tube (ETT), oral cavity and nostrils, and deflate endotracheal tube cuff is using a cuffed tube
- Suction/aspirate NGT to empty the stomach
- Disconnect patient from the ventilator and attach manual resuscitator to ETT
- Remove ETT plaster
- Provide patient with a positive pressure breath from the manual resuscitator, instruct patient to take a deep breath and proceed to extubate patient
- Place patient on the appropriate oxygen delivery devices or ventilatory support to maintain target SpO_2
- Monitor patient for signs and symptoms of respiratory distress
- Obtain blood gas 30 – 60 minutes post extubation

7) <u>Post Extubation</u>
    - If patient develop post extubation stridor
        - Consider nebulised adrenaline
        - Consider dexamethasone
        - Consider trial of NIV
        - Increase NIV settings if patient is already on NIV
        - Re-intubation
    - If patient not already on ventilatory support developed respiratory distress post extubation
        - Consider High Flow Nasal Cannula (HFNC)
        - Consider NIV
        - Re-intubation
    - If patient already on ventilatory support developed respiratory distress post extubation
        - Consider increase in ventilator settings
        - Re-intubation
        -

References

1. 2010 National Pediatric CSN. Pediatric Intensive Care Clinical Practice Guildeline https://www.health.gov.fj/wp-content/uploads/2014/05/Ventilation-Guidelines-for-PICU_Oct-2010.pdf

2. https://paws.augusta.edu/pub/respiratory/Documents/pediatric_protocol/PICUventilatorWeaningProtocol.pdf

3. Velenzuela J, Araneda P, Cruces P. Weaning from Mechanical Ventilation in Paediatrics. State of the Art. Arch Bronchoneumol. 2014;50(3):105-112.

4. Kraweic C, Carl D, Stetter C, Kong L, Ceneviva GD, Thomas NJ. Challenges with implementation of a respiratory therapist-driven protocol of spontaneous breathing trials in the pediatric ICU. Respir Care 2017;62(10):1233-1240.

5. Abu-Sultaneh S, Hole AJ, Tori AJ, Benneyworth BD, Lutfi R, Mastropietro CW. An interprofessional quality improvement initiative to standardize pediatric extubation readiness assessment. Pediatr Crit Care Med 2017;18:e463-e471.

6. The Pediatric Acute Lung Injury Consensus Conference Group. Pediatric acute respiratory distress syndrome: consensus recommendations from the Pediatric Acute Lung Injury Consensus Conference. Pediatr Crit Care Med 2015;16(5):428-439.

7. Kneyber MCJ, de Luca D, Calderini E, Jarreau P-H, Javouhey E, Lopez-Herce J, et. al. Recommendations for mechanical ventilation of critically ill children from the Pediatric Mechanical Ventilation Consensus Conference (PEMVECC). Intensive Care Med 2017;43:1764-1780.

8. Tan HL, Ma YJ, Aguilan AB, Goh CY, Wong JCK, Ang LSU, Kirk AHP, Loh TF, Mok YH, Wong JJM. Respiratory Therapist-Driven Extubation Readiness Testing in a Single Pediatric ICU. Respir Care 2022;67(7):833-841

9. Loberger JM, Jones RM, Prabhakaran P. A respiratory therapist–driven pathway improves timeliness of extubation readiness assessment in a single PICU. Pediatr Crit Care Med 2020;21(8):e513-e521.

10. Abu-Sultaneh S, Iyer NP, Fernández A, Gaies M, González-Dambrauskas S, Hotz JC, Kneyber MCJ, López-Fernández YM, Rotta AT, Werho DK, Baranwal AK, Blackwood B, Craven HJ, Curley MAQ, Essouri S, Fioretto JR, Hartmann SMM, Jouvet P, Korang SK, Rafferty GF, Ramnarayan P, Rose L, Tume LN, Whipple EC, Wong JJM, Emeriaud G, Mastropietro CW, Napolitano N, Newth CJL, Khemani RG. Executive Summary: International Clinical Practice Guidelines for Pediatric Ventilator Liberation, A Pediatric Acute Lung Injury and Sepsis Investigators (PALISI) Network Document. Am J Respir Crit Care Med. 2023 Jan 1;207(1):17-28

11. Iyer NP, López-Fernández YM, González-Dambrauskas S, Baranwal AK, Hotz JC, Zhu M, Zhang Y, Craven HJ, Whipple EC, Abu-Sultaneh S, Khemani RG. A Network Meta-analysis of Dexamethasone for Preventing Postextubation Upper Airway Obstruction in Children. Ann Am Thorac Soc. 2023 Jan;20(1)