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The ventilator of the future: key principles and unmet needs

Marini, J.J., Gattinoni, L. The ventilator of the future: key principles and unmet needs. Crit Care 28, 284 (2024). https://doi.org/10.1186/s13054-024-05060-5

Abstract
Persistent shortcomings of invasive positive pressure ventilation make it less than an ideal intervention. Over the course of more than seven decades, clinical experience and scientific investigation have helped define its range of hazards and limitations. Apart from compromised airway clearance and lower airway contamination imposed by endotracheal intubation, the primary hazards inherent to positive pressure ventilation may be considered in three broad categories: hemodynamic impairment, potential for ventilation-induced lung injury, and impairment of the respiratory muscle pump. To optimize care delivery, it is crucial for monitoring and machine outputs to integrate information with the potential to impact the underlying requirements of the patient and/or responses of the cardiopulmonary system to ventilatory interventions. Trending analysis, timely interventions, and closer communication with the caregiver would limit adverse clinical trajectories. Judging from the rapid progress of recent years, we are encouraged to think that insights from physiologic research and emerging technological capability may eventually address important aspects of current deficiencies.

Analysis and key points

Abstract
The article discusses the persistent limitations of invasive positive pressure ventilation, focusing on its impact on hemodynamics, potential for lung injury, and respiratory muscle dysfunction. The authors explore advancements needed in ventilator design to address these issues through personalized, integrated, and automated approaches.

Background

- Current Ventilator Capabilities: Modern ventilators are effective for routine applications but fall short in supporting critically ill patients with life-threatening respiratory failure.
- Hazards of Positive Pressure Ventilation:
    - Hemodynamic compromise.
    - Ventilator-induced lung injury (VILI).
    - Impairment of respiratory muscle function.
- Clinical Challenges: Ventilators lack continuous monitoring and real-time adaptability to patient needs, relying heavily on caregiver intervention.

Unmet Objectives in Ventilatory Support

1. Gas Exchange:
    - Positive airway pressure disrupts natural ventilation-perfusion matching.
    - Risks include hemodynamic instability, fluid retention, and dead space expansion.
2. Hemodynamics:

    - Positive pressure elevates intrathoracic pressures, impeding venous return and compromising cardiac output.
    - Fluid overload from compensatory interventions exacerbates lung and systemic issues.
3. Lung Injury:
    - VILI arises from excessive mechanical energy and repeated tissue strain.
    - Current monitoring tools inadequately estimate stress and strain.
4. Respiratory Muscles:
    - Over-reliance on ventilators leads to muscle atrophy.
    - Insufficient support results in fatigue and hypercapnia.

Proposed Improvements for Future Ventilators

1. Determining Alveolar Stress:
    - Advanced monitoring to estimate transpulmonary pressure and functional residual capacity (FRC) for better management of VILI risks.
2. Integrated Monitoring:
    - Combining lung, cardiac, and renal function metrics to guide ventilatory settings.
3. Trend Analysis:
    - Continuous monitoring of key variables to detect early signs of clinical deterioration.
4. Automated Adjustments:
    - AI-driven closed-loop systems to optimize care and reduce the burden on caregivers.
5. Enhanced Communication:
    - Wireless, real-time updates for caregivers to facilitate timely interventions.

Barriers to Implementation

- Economic Constraints: High costs may limit advanced ventilator access.
- Technological Challenges: Integration of multi-system monitoring and automation requires significant innovation.
- Caregiver Variability: Ensuring uniform expertise across clinical settings is essential for leveraging new technologies.

Conclusion

The vision for future ventilators includes systems that integrate real-time data, automate interventions, and personalize care to address the complexities of critical illness. While many of these ideas remain aspirational, rapid technological advances and AI offer promising pathways toward realization.

Mean airway pressure – Minute ventilation product (mM): A simple and universal surrogate equation to calculate mechanical power in both volume and pressure controlled ventilation

Daoud EG, Lee P, Toma S, Franck CL. Mean airway pressure – Minute ventilation product (mM): A simple and universal surrogate equation to calculate mechanical power in both volume and pressure controlled ventilation. J Mech Vent 2024; 5(2):46-55.
https://doi.org/10.53097/JMV.10099

Abstract

Introduction

Mechanical power represents the energy delivered by a mechanical ventilator onto the lungs. It incorporates all the variables participating in ventilator-induced lung injury, including driving pressure, tidal volume, positive end expiratory pressure, and respiratory rate. The pitfall of mechanical power is its mathematical complexity, as the gold standard method of calculation involves deriving the inspiratory area under the pressure-volume curve of each breath. Prior studies attempted to create simplified equations, they lack clinical utility as calculations cannot be done by solely looking at ventilator settings or they require manipulation of variables. There are also different formulas depending on the type of the mode of ventilation used. This study offers a simplified, universal equation called the mean airway pressure – Minute ventilation product (mM equation) which renders mechanical power clinical application more feasible at the bedside.

Methods and Statistics

Data collection used the online SIVA simulator, which simulate mechanical ventilation and calculate the geometrical area of the inspiratory limb of the pressure-volume curve. Different combinations of passive scenarios with varying compliances (10-80 ml/cmH2O) and resistances (5-30 cmH2O/L/S) in each the VCV and PCV modes were accomplished by adjusting ventilator settings with respiratory rate (5-40 BPM), tidal volume (150-700 mL), DP (5-30 cmH2O), and PEEP (0-15 cmH2O), with different inspiratory times in PCV and different flows rates in the VCV.

A total of 2,000 values were collected in each mode. Range of Mechanical power measured by the simulator: 0.1 – 105 J/min and range of mM equation (mean airway pressure x Minute ventilation): 0.37 – 820 cmH2O/L/min. Pearson correlation coefficients were calculated to compare the relationship of the mM equation to the measured MP, and linear regressions were used for predicting the MP derived from the mM equation in each mode separately and when combining all data from both modes. T-test for equal variance and Bland Altmann plot were used to compare the reference MP measured (MPR) from the simulator to the one derived from the Mm formula (MPD).

Results

There was a statistically significant linear relationship ($P < 0.001$) and strong correlation of determination ($R2 = 0.931$), CI (0.961, 0.967) between the mM formula and the gold-standard method of calculating mechanical power for the combined two modes. For the VCV: there was a statistically significant linear relationship ($P < 0.001$) and strong correlation of determination (R2

= 0.936), CI (-0.963, 0.971). For the PCV: there was a statistically significant linear relationship (P < 0.001) and strong correlation of determination (R2 = 0.936), CI (-0.964, 0.970).
A linear regression model predicted the MP from the mM as follows: for both modes MP = 0.13 (mM) + 3.41, for PCV MP = 0.15 (mM) + 3.79, for VCV MP = 0.13 (mM) + 2.48.
The derived mechanical power from the mM was not statistically different (P 0.498) from the calculated reference MP using two sample T-tests assuming equal variance.
The Bland-Altman plot for VCV mode showed a mean of 0.78 with 95% CI (0.34, 1.22), SD (-13.27, 14.83). In PCV, a mean of – 0.53 with 95% CI (-0.68, -0.38), SD (-6.28, 5.22). For both modes, a mean of 0, with 95% CI (-0.2, 0.2), SD (-10.06, 10.05).
Conclusion
The mM equation and its MP derived formula is a reliable method of calculating mechanical power. The simplicity and universal nature of its calculation can provide significant clinical utility at the bedside. More studies are needed to validate this method of calculation.
Keywords: Mechanical power, mean airway pressure, minute ventilation

Analysis and Key points

Abstract
The article introduces a simplified equation, the mean airway pressure-minute ventilation product (mM equation), to estimate mechanical power (MP) in both volume-controlled ventilation (VCV) and pressure-controlled ventilation (PCV). This approach aims to overcome the mathematical complexity of traditional MP calculations, making it clinically practical for bedside use.

Background

- Mechanical Power (MP):
  - Represents the energy applied by a ventilator to the lungs per unit time.
  - MP incorporates variables contributing to ventilator-induced lung injury (VILI), including driving pressure, tidal volume, PEEP, and respiratory rate.
- Clinical Significance:
  - MP above 17 J/min has been associated with increased mortality in mechanically ventilated patients.
  - Traditional methods of calculating MP rely on integrating the pressure-volume curve, which is impractical in clinical settings.
- Mean Airway Pressure ($\bar{P}aw$):
  - The average airway pressure during a respiratory cycle.
  - Correlates with mean alveolar pressure and patient outcomes, making it a viable proxy for estimating MP.

Methods

- Simulation Setup:
  - Used the SIVA simulator to model ventilation in VCV and PCV modes across varying compliances (10-80 mL/cmH_2O) and resistances (5-30 cmH_2O/L/s).
  - A total of 4,000 data points were generated (2,000 per mode).
- Statistical Analyses:
  - Pearson correlation and linear regression were used to compare the mM equation-derived MP with gold-standard calculations.

- Bland-Altman plots assessed the agreement between methods.

Results

- Accuracy:
  - The mM equation showed a strong linear correlation ($R^2 = 0.931$ for combined modes) with the gold-standard MP.
  - Linear regression formulas were derived:
    - For both modes: MP = 0.13 (mM) + 3.41
    - For PCV: MP = 0.15 (mM) + 3.79
    - For VCV: MP = 0.13 (mM) + 2.48
  - Bland-Altman analysis confirmed minimal bias and high agreement.
- Utility:
  - The equation is simple and practical for bedside use.
  - Graphical tools (e.g., correlation tables) can guide clinicians in recognizing unsafe MP levels.

Discussion

- Advantages of the mM Equation:
  - Simplifies MP estimation without significant loss of accuracy.
  - Versatile for both VCV and PCV modes.
  - Accounts for both inspiratory and expiratory phases using $\bar{P}aw$ as a surrogate.
- Limitations:
  - Based on simulated, passive conditions that do not fully replicate real-life scenarios (e.g., active breathing or variable compliance).
  - May overestimate MP in VCV and underestimate in PCV when using a combined formula.
  - Mean airway pressure does not differentiate between static (PEEP) and dynamic (tidal) power components.
- Clinical Relevance:
  - High MP correlates with VILI; this formula provides a feasible way to monitor and adjust ventilation settings to minimize risk.
  - Future directions include integration into ventilator systems and adaptation for advanced modes like APRV and HFOV.

Conclusion

The mM equation offers a practical, reliable, and universal method for estimating mechanical power in mechanically ventilated patients. It enables clinicians to apply MP more effectively at the bedside, aiding in the prevention of VILI and improving patient outcomes.

Effect of automated versus conventional ventilation on mechanical power of ventilation-A randomized crossover clinical trial

Buiteman-Kruizinga LA, Serpa Neto A, Botta M, List SS, de Boer BH, van Velzen P, Bühler PK, Wendel Garcia PD, Schultz MJ, van der Heiden PLJ, Paulus F; INTELLiPOWER–investigators. Effect of automated versus conventional ventilation on mechanical power of ventilation-A randomized crossover clinical trial. PLoS One. 2024 Jul 30;19(7):e0307155. doi: 10.1371/journal.pone.0307155.

Abstract
Introduction: Mechanical power of ventilation, a summary parameter reflecting the energy transferred from the ventilator to the respiratory system, has associations with outcomes. INTELLiVENT-Adaptive Support Ventilation is an automated ventilation mode that changes ventilator settings according to algorithms that target a low work-and force of breathing. The study aims to compare mechanical power between automated ventilation by means of INTELLiVENT-Adaptive Support Ventilation and conventional ventilation in critically ill patients.
Materials and methods: International, multicenter, randomized crossover clinical trial in patients that were expected to need invasive ventilation > 24 hours. Patients were randomly assigned to start with a 3-hour period of automated ventilation or conventional ventilation after which the alternate ventilation mode was selected. The primary outcome was mechanical power in passive and active patients; secondary outcomes included key ventilator settings and ventilatory parameters that affect mechanical power.
Results: A total of 96 patients were randomized. Median mechanical power was not different between automated and conventional ventilation (15.8 [11.5-21.0] versus 16.1 [10.9-22.6] J/min; mean difference -0.44 (95%-CI -1.17 to 0.29) J/min; P = 0.24). Subgroup analyses showed that mechanical power was lower with automated ventilation in passive patients, 16.9 [12.5-22.1] versus 19.0 [14.1-25.0] J/min; mean difference -1.76 (95%-CI -2.47 to -10.34J/min; P < 0.01), and not in active patients (14.6 [11.0-20.3] vs 14.1 [10.1-21.3] J/min; mean difference 0.81 (95%-CI -2.13 to 0.49) J/min; P = 0.23).
Conclusions: In this cohort of unselected critically ill invasively ventilated patients, automated ventilation by means of INTELLiVENT-Adaptive Support Ventilation did not reduce mechanical power. A reduction in mechanical power was only seen in passive patients.

Analysis and Key points

Abstract
This study evaluates the effect of INTELLiVENT-Adaptive Support Ventilation (ASV), an automated ventilation mode, compared to conventional ventilation on mechanical power (MP) in critically ill patients. The findings show no overall difference in MP between the two modes, although automated ventilation reduced MP in passive patients.

Background

- Mechanical Power (MP):
    - Represents the energy transferred from the ventilator to the respiratory system.

    - MP aggregates factors influencing ventilator-induced lung injury (VILI), including tidal volume (VT), driving pressure (ΔP), respiratory rate (RR), and positive end-expiratory pressure (PEEP).
- INTELLiVENT-ASV:
    - A closed-loop ventilation mode adjusting VT, RR, PEEP, and FiO_2 automatically to minimize work and force of breathing.
    - Algorithms optimize ventilation settings based on real-time data.

Study Design

- Trial Design:
    - International, multicenter, randomized crossover trial conducted in ICUs in the Netherlands and Switzerland.
    - Each patient underwent two 3-hour ventilation phases (automated and conventional), with a 30-minute washout period between.
- Participants:
    - Included 96 patients expected to require invasive ventilation for >24 hours.
    - Excluded patients with BMI >40 or contraindications for automated ventilation.
- Outcomes:
    - Primary: MP comparison between ventilation modes.
    - Secondary: Ventilatory parameters such as RR, ΔP, and VT.

Results

1. Overall MP:
    - Median MP: 15.8 J/min (automated) vs. 16.1 J/min (conventional); no significant difference ($P = 0.24$).
2. Passive Patients:
    - MP significantly reduced with automated ventilation (16.9 vs. 19.0 J/min, $P < 0.01$).
    - Associated with lower RR and higher VT.
3. Active Patients:
    - No significant MP difference.
    - MP calculations may underestimate active patient effort due to diaphragm usage and alveolar recruitment.
4. Ventilatory Parameters:
    - Automated ventilation reduced RR and minute ventilation in both groups.
    - VT increased in passive patients, while ΔP and Pmax showed slight variations.

Discussion

- Advantages of Automated Ventilation:
    - Reduces MP in passive patients by optimizing RR and VT settings.
    - Removes the need for manual interventions, aligning with lung-protective strategies.
- Limitations:
    - Short crossover phases limit long-term outcome assessments.
    - Findings may not generalize to hemodynamically unstable patients.

    - Automated ventilation did not affect MP in active patients, suggesting potential underestimation of their breathing effort.
- Clinical Implications:
    - Highlights the role of RR in MP reduction and potential harm of strategies focusing solely on low VT.
    - Suggests INTELLiVENT-ASV could be beneficial for patients with low respiratory system compliance (CRS).

Conclusion

Automated ventilation using INTELLiVENT-ASV did not significantly reduce MP overall but showed benefits in passive patients by lowering RR and increasing VT. Further research is needed to assess long-term clinical outcomes and optimize automated ventilation algorithms for diverse patient populations.

AARC Clinical Practice Guideline: Spontaneous Breathing Trials for Liberation From Adult Mechanical Ventilation

Roberts KJ, Goodfellow LT, Battey-Muse CM, Hoerr CA, Carreon ML, Sorg ME, Glogowski J, Girard TD, MacIntyre NR, Hess DR. AARC Clinical Practice Guideline: Spontaneous Breathing Trials for Liberation From Adult Mechanical Ventilation. Respir Care. 2024 Jun 28;69(7):891-901. doi: 10.4187/respcare.11735.

Despite prior publications of clinical practice guidelines related to ventilator liberation, some questions remain unanswered. Many of these questions relate to the details of bedside implementation. We, therefore, formed a guidelines committee of individuals with experience and knowledge of ventilator liberation as well as a medical librarian. Using Grading of Recommendations Assessment,Development, and Evaluation (GRADE) methodology, we make the following recommendations:
(1) We suggest that calculation of a rapid shallow breathing index is not needed to determine readiness for a spontaneous breathing trial (SBT) (conditional; moderate certainty);
(2) We suggest that SBTs can be conducted with or without pressure support ventilation (conditional recommendation, moderate certainty);
(3) We suggest a standardized approach to assessment and, if appropriate, completion of an SBT before noon each day (conditional recommendation, very low certainty); and
(4) We suggest that FIO2 should not be increased during an SBT (conditional recommendation, very low certainty).
These recommendations are intended to assist bedside clinicians to liberate adult critically ill patients more rapidly from mechanical ventilation. Key words: extubation; liberation; mechanical ventilation; rapid shallow breathing index; spontaneous breathing trials; weaning

Analysis and Key Points

Abstract
The guideline addresses areas of uncertainty related to **spontaneous breathing trials (SBTs)**, offering recommendations for their implementation in ventilator liberation. Key recommendations include:

1. The **rapid shallow breathing index (RSBI)** is not necessary to determine readiness for an SBT.
2. SBTs can be conducted with or without **pressure support ventilation (PSV)**.
3. A standardized approach to assess readiness for an SBT is suggested, ideally performed before noon daily.
4. **FiO_2** should not be increased during SBTs.

These guidelines aim to assist clinicians in optimizing the liberation process from mechanical ventilation.

Background

- **Weaning and Liberation**:
  - Gradual reduction of mechanical ventilatory support is termed "weaning."
  - Liberation refers to the complete termination of mechanical ventilation.
  - SBTs are a primary tool in the liberation process, involving minimal or no ventilatory assistance for 30–120 minutes.
- **Historical Context**:
  - Previous methods, such as T-piece trials and synchronized intermittent mandatory ventilation (SIMV), were common but lacked strong evidence for efficacy.
  - Current best practices involve SBTs and addressing reversible causes of ventilator dependency.

Key Recommendations and Evidence

1. Use of the Rapid Shallow Breathing Index (RSBI)

- **Background**:
  - RSBI measures the ratio of respiratory rate to tidal volume during unsupported breathing.
  - Historically used to predict readiness for SBTs and extubation.
- **Evidence**:
  - Studies suggest RSBI does not reliably predict successful extubation and may delay SBT initiation.
- **Recommendation**:
  - RSBI is not necessary for SBT readiness (conditional recommendation, moderate certainty).

2. Role of Pressure Support Ventilation (PSV) in SBTs

- **Background**:
  - PSV is used to reduce work imposed by the endotracheal tube.
- **Evidence**:
  - Mixed findings; some studies show PSV aids in SBT success, while others find no significant difference compared to T-piece trials.
- **Recommendation**:
  - SBTs can be conducted with or without low-level PSV (conditional recommendation, moderate certainty).

3. Timing of SBTs

- **Background**:
  - SBT timing varies, but morning assessments align with patient care routines.
- **Evidence**:

    - No direct studies comparing morning versus other times for SBTs.
- **Recommendation**:
    - Standardize SBT assessments before noon (conditional recommendation, very low certainty).

4. FiO_2 Adjustment During SBTs

- **Background**:
    - Increasing FiO_2 during SBTs could mask underlying issues and lead to false-positive outcomes.
- **Evidence**:
    - Limited evidence from clinical trials indirectly supports maintaining the same FiO_2 as during mechanical ventilation.
- **Recommendation**:
    - FiO_2 should not be increased during SBTs (conditional recommendation, very low certainty).

Discussion

- **Clinical Implications**:
    - These recommendations aim to streamline SBT practices, reduce unnecessary delays, and enhance patient outcomes.
- **Limitations**:
    - All recommendations are conditional due to limited high-quality evidence.
    - Individual patient factors and institutional practices should guide specific decisions.

Conclusion

This guideline provides evidence-informed recommendations for conducting SBTs to assist clinicians in ventilator liberation. Future research is needed to address gaps in knowledge, such as optimal FiO_2 levels and the utility of advanced imaging techniques for predicting readiness.

Estimation of inspiratory muscle effort using three common indices in various respiratory models, a bench study

Hu J, Hasan O, Shiraishi K, Hirao Y, Daoud EG. Comparison of estimation of inspiratory muscle effort using three common indices in various respiratory models, a bench study. J Mech Vent 2024; 5(4):119-125. https://doi.org/10.53097/JMV.10111

Abstract

Background

Liberation from mechanical ventilation is a complex therapeutic challenge in the intensive care unit. Estimating inspiratory effort during mechanical ventilation can mitigate lung and diaphragmatic injury, along with weakness and atrophy. During a spontaneous breathing trial, it can be critical to predict over or under assistance to guide safe liberation. While estimation of the inspiratory effort requires special equipment, many other indices have been developed to estimate patient effort, work, and actual muscle pressure. In this bench study, we compare three commonly used maneuvers: airway occlusion at 100 msec (P0.1), airway pressure drop during full occlusion (Pocc), and pressure muscle index (PMI) for their accuracy in predicting the actual muscle effort.

Methods

A single active lung compartment using ASL5000 was modeled to simulate three common patient care scenarios,including “normal” (airway resistance 5 cm/l/s; compliance 60 ml/cm/H2O), “restrictive” (airway resistance 10 cm/l/s; compliance 30 ml/cm/H2O); and “obstructive” (airway resistance of 20 cm/l/s; compliance of 80 ml/cm/H2O) with respiratory rate of 15/minute, inspiratory time of 1 second (10 % rise, 0% hold, and 10% release while exhalation is passive). A Bellavista 1000e ventilator was used for pressure support of 5 cmH2O and positive end-expiratory pressure (PEEP) of 5 cmH2O.

Each index was measured to the inputted Pmus, which ranged from 1 to 30 cmH2O and increased by increments of 1.

Results were analyzed using Pearson correlation and regression analysis to predict an associated formula. These were compared to the inputted Pmus using single factor ANOVA followed by post Hoc Tukey test. Formulas from the P0.1 and the Pocc were then compared against previously published equations using single factor ANOVA. Statistics were performed using SPSS 20. $P < 0.05$ was considered statistically significant.

Results

All three indices had strong correlations to Pmus, P0.1 [R 0.978, 95% CI 0.97, 0.99, $P < 0.001$], Pocc [R 0.999, 95% CI 1.1, 1.12, $P < 0.001$], and PMI [R 0.722, 95% CI 0.61, 0.81, $P < 0.001$]. The equations to estimate Pmus were: P0.1: 3.95 (P0.1) - 2.05; Pocc: 1.11 (Pocc) + 0.82; and PMI: 1.03 (PMI) + 8.26. A significant difference ($P <0.001$) was observed when comparing the inputted Pmus with Pmus estimated from P0.1, Pocc, or PMI. Post hoc analysis showed no difference between Pmus to Pmus estimated from P0.1, Pmus to Pmus estimated from Pocc, and Pmus estimated from P0.1 and Pocc; while comparisons of Pmus estimated from PMI to those from the P0.1 and Pocc revealed significant differences ($P < 0.001$ and $P < 0.001$, respectively). When comparing our formula for P0.1 to the previously published formula and the actual Pmus, no significant difference was observed (P 0.261), with post hoc tests revealing no significant differences between any pair. In

contrast, a significant difference was found when comparing the formula for Pocc to the previously published formula and the actual Pmus ($P < 0.001$). Post hoc tests showed no difference between the new formula and Pmus (P 0.99), but a significant difference between Pmus and previous formula ($P < 0.001$).
Conclusions
While overall all three methods tested showed good correlation with the actual set Pmus, only P0.1 and the Pocc had strong correlation with the set Pmus in all three settings, suggesting that derived formulas can be useful to estimate muscle effort. PMI did not prove accurate, especially in obstructive scenarios, and may not be relied upon in practice.
Keywords: Pmus, P0.1, P occlusion, PMI

Analysis and Key Points

Abstract

This study compares three methods—**airway occlusion pressure at 100 ms (P0.1)**, **airway pressure drop during full occlusion (Pocc)**, and **pressure muscle index (PMI)**—to estimate inspiratory muscle effort (**Pmus**) using simulated respiratory models. The findings suggest that P0.1 and Pocc are reliable methods for estimating Pmus, while PMI showed limited accuracy, especially in obstructive scenarios.

Background

- **Inspiratory Muscle Effort (Pmus)**:
  - Critical for evaluating safe mechanical ventilation and predicting liberation success.
  - Excessive Pmus can cause patient self-inflicted lung injury (P-SILI), while insufficient effort may lead to ventilator-induced diaphragmatic dysfunction (VIDD).
- **Existing Estimation Methods**:
  - **P0.1**: Reflects neuromuscular drive, measured as the pressure drop in the first 100 ms of inspiration against an occluded airway.
  - **Pocc**: Measures the difference between the lowest pressure drop and PEEP during an expiratory hold.
  - **PMI**: Evaluates pressure difference during inspiratory pause in pressure support ventilation.
- **Study Objective**:
  - To assess the accuracy of P0.1, Pocc, and PMI in estimating Pmus under normal, restrictive, and obstructive respiratory conditions.

Methods

- **Bench Study Setup**:
  - Conducted using a single-compartment lung simulator (ASL5000) with three respiratory models:
    1. **Normal**: Airway resistance of 5 $cmH_2O/L/s$; compliance of 60 mL/cmH_2O.
    2. **Restrictive**: Airway resistance of 10 $cmH_2O/L/s$; compliance of 30 mL/cmH_2O.
    3. **Obstructive**: Airway resistance of 20 $cmH_2O/L/s$; compliance of 80 mL/cmH_2O.
  - Ventilator settings: Pressure support ventilation (PSV) of 5 cmH_2O, PEEP of 5 cmH_2O.
- **Data Collection**:
  - Known Pmus values were input and correlated with P0.1, Pocc, and PMI measurements.
  - Regression analysis was used to derive formulas for estimating Pmus.

Results

- **Correlation with Pmus**:
  - P0.1: Strong correlation ($R = 0.978$, $P < 0.001$).
  - Pocc: Strongest correlation ($R = 0.999$, $P < 0.001$).
  - PMI: Moderate correlation ($R = 0.722$, $P < 0.001$).
- **Derived Formulas for Estimating Pmus**:
  - **P0.1**: $Pmus = 3.95 \times P0.1 - 2.05$
  - **Pocc**: $Pmus = 1.11 \times Pocc + 0.82$
  - **PMI**: $Pmus = 1.03 \times PMI + 8.26$
- **Accuracy**:
  - P0.1 and Pocc estimates were comparable to actual Pmus across all models.
  - PMI estimates were significantly less accurate, especially in obstructive conditions.

Discussion

- **Clinical Implications**:
  - Accurate estimation of Pmus is critical to avoid over- or under-assistance during mechanical ventilation, mitigating risks of P-SILI and VIDD.
  - P0.1 and Pocc are reliable methods for non-invasive Pmus estimation in clinical practice.
- **Limitations of PMI**:
  - PMI showed poor performance in obstructive models due to its susceptibility to resistive load, making it less reliable for patients with obstructive lung diseases.
- **Comparison with Literature**:
  - P0.1 and Pocc formulas from this study align well with previous findings, reinforcing their validity.

    - PMI's limited accuracy corroborates earlier studies suggesting caution in its use.
- **Limitations**:
    - The study was conducted using a simulator, which may not fully replicate human respiratory mechanics.
    - Only one ventilator model was used, potentially limiting generalizability.

Conclusion

P0.1 and Pocc are reliable and practical methods for estimating inspiratory muscle effort in simulated respiratory scenarios, while PMI lacks reliability in obstructive conditions. These findings support further research to validate these methods in clinical settings.

Rethinking ARDS classification: oxygenation impairment fails to predict VILI risk

Catozzi G, Pozzi T, Nocera D, Donati B, Giovanazzi S, Ghidoni V, Galizia M, D'Albo R, Busana M, Romitti F, Gatta A, Moerer O, Meissner K, Quintel M, Herrmann P, Chiumello D, Camporota L, Gattinoni L. Rethinking ARDS classification: oxygenation impairment fails to predict VILI risk. Intensive Care Med. 2024 Dec 11. doi: 10.1007/s00134-024-07712-0.

Abstract
Purpose: The selection and intensity of respiratory support for ARDS are guided by PaO2/FiO2. However, ventilator-induced lung injury (VILI) is linked to respiratory mechanics and ventilator settings. We explored whether the VILI risk is related to ARDS severity based on oxygenation.
Methods: We analysed data on 228 ARDS subjects with PaO2/FiO2 < 200 mmHg, categorized into three severity groups: one based on PaO2/FiO2 ratio, and the others based on tertiles of predictors of VILI: mechanical power ratio (MPR) and driving pressure (DP). In each group of oxygenation-based ARDS severity and MPR and DP tertiles, we measured CT anatomy, gas exchange, respiratory mechanics, VILI prerequisites (lung elastance and lung gas volume), and VILI determinants (tidal volume, PEEP, airway pressures).
Results: Predictors of VILI, such as MPR and DP, were similar across ARDS severity groups based on PaO2/FiO2 ratio, while oxygenation remained comparable across different levels of VILI risk defined by MPR and DP. Oxygenation impairment was associated with increased lung weight, recruitability, and reduced well-inflated tissue. In contrast, MPR and DP tertiles affected variables associated with the baby lung size, such as lung gas volume and well-inflated tissue. Mechanical ventilation intensity increased progressively across MPR and DP tertiles, but remained similar across PaO2/FiO2 severity groups.
Conclusions: ARDS severity based on oxygenation impairment does not reflect the prerequisites and determinants of VILI. This should prompt a reconsideration of recommending respiratory support based on oxygenation impairment, rather than VILI determinants.

Analysis and Key Points

Abstract

This study investigates whether the risk of ventilator-induced lung injury (VILI) correlates with oxygenation-based severity classifications in ARDS. It reveals that ARDS severity based on the PaO_2/FiO_2 (P/F) ratio does not reflect the mechanical factors that determine VILI, such as driving pressure (DP) and mechanical power ratio (MPR). The findings challenge current practices of tailoring respiratory support intensity based on oxygenation criteria.

Background

- **Acute Respiratory Distress Syndrome (ARDS)**:
    - Traditionally classified by oxygenation impairment (P/F ratio thresholds of 300, 200, and 100 mmHg).

    - Management focuses on maintaining oxygenation rather than addressing VILI risk.
- **Ventilator-Induced Lung Injury (VILI)**:
    - Results from excessive mechanical forces causing stress and strain on the lung parenchyma.
    - Determinants include tidal volume, driving pressure, and mechanical power.
- **Study Objective**:
    - Evaluate whether oxygenation impairment correlates with variables predictive of VILI and assess the validity of oxygenation-based severity classifications.

Methods

- **Population**:
    - 228 patients with moderate to severe ARDS (P/F ratio < 200 mmHg).
    - Excluded mild ARDS and COVID-19 cases due to differing characteristics.
- **Classification**:
    - ARDS categorized by P/F ratio (oxygenation-based).
    - VILI risk classified by MPR and DP tertiles.
- **Data Collection**:
    - Variables included lung anatomy (via CT scans), gas exchange, respiratory mechanics, and VILI determinants.
    - Statistical analysis used linear regression and ANOVA.

Results

1. **Oxygenation vs. VILI Predictors**:
    - MPR and DP were similar across P/F ratio-based severity groups.
    - P/F ratio was comparable across MPR and DP tertiles.
2. **Lung Anatomy**:
    - Oxygenation impairment correlated with increased lung weight, reduced well-inflated tissue, and higher recruitability.
    - MPR and DP affected "baby lung" size (well-inflated tissue and gas volume), aligning with VILI risk.
3. **Gas Exchange**:
    - P/F ratio did not reflect variables related to VILI, such as strain and elastance.
    - Ventilatory ratio (a surrogate for dead space) rose with increasing MPR and DP but was unrelated to P/F severity.
4. **Respiratory Mechanics and VILI**:
    - Mechanical ventilation settings intensified with higher MPR and DP tertiles but remained unchanged across P/F severity groups.
    - Strain and stress correlated with MPR and DP but not with P/F ratio.

Discussion

- **Key Findings**:
    - Oxygenation-based ARDS severity does not predict VILI risk.

    - Mechanical factors (e.g., DP and MPR) are more reliable predictors of VILI.
- **Clinical Implications**:
    - Current guidelines emphasizing oxygenation for therapy intensity may overlook VILI risk factors.
    - Focus should shift to respiratory mechanics and CO_2 clearance metrics to better tailor ventilatory support.
- **Historical Context**:
    - Early ARDS management prioritized oxygenation.
    - Contemporary strategies (e.g., low tidal volumes, prone positioning) aim to minimize VILI, independent of oxygenation improvement.

Conclusion

The study advocates for a paradigm shift in ARDS management, emphasizing respiratory mechanics and VILI determinants over oxygenation-based classifications. Revising clinical guidelines to incorporate these findings could improve patient outcomes by addressing the mechanical drivers of lung injury.

Association between mechanical ventilation parameters and mortality in children with respiratory failure on ECMO: a systematic review and meta-analysis

Fernandez-Sarmiento J, Perez MC, Bustos JD, Acevedo L, Sarta-Mantilla M, Guijarro J, Santacruz C, Pardo DF, Castro D, Rosero YV, Mulett H. Association between mechanical ventilation parameters and mortality in children with respiratory failure on ECMO: a systematic review and meta-analysis. Front Pediatr. 2024 Jan 16;12:1302049. doi: 10.3389/fped.2024.1302049.

Abstract
Background: In refractory respiratory failure (RF), extracorporeal membrane oxygenation (ECMO) is a salvage therapy that seeks to reduce lung injury induced by mechanical ventilation. The parameters of optimal mechanical ventilation in children during ECMO are not known. Pulmonary ventilatory management during this therapy may impact mortality. The objective of this study was to evaluate the association between ventilatory parameters in children during ECMO therapy and in-hospital mortality.
Methods: A systematic search of PubMed/MEDLINE, Embase, Cochrane, and Google Scholar from January 2013 until May 2022 (PROSPERO 450744), including studies in children with ECMO-supported RF assessing mechanical ventilation parameters, was conducted. Risk of bias was assessed using the Newcastle-Ottawa scale; heterogeneity, with absence <25% and high >75%, was assessed using I2. Sensitivity and subgroup analyses using the Mantel-Haenszel random-effects model were performed to explore the impact of methodological quality on effect size.
Results: Six studies were included. The median age was 3.4 years (IQR: 3.2-4.2). Survival in the 28-day studies was 69%. Mechanical ventilation parameters associated with higher mortality were a very low tidal volume ventilation (<4 ml/kg; OR: 4.70; 95% CI: 2.91-7.59; $p < 0.01$; I2: 38%), high plateau pressure (mean Dif: -0.70 95% CI: -0.18, -0.22; $p < 0.01$), and high driving pressure (mean Dif: -0.96 95% CI: -1.83, -0.09: $p = 0.03$). The inspired fraction of oxygen ($p = 0.09$) and end-expiratory pressure ($p = 0.69$) were not associated with higher mortality. Patients who survived had less multiple organ failure ($p < 0.01$).
Conclusion: The mechanical ventilation variables associated with higher mortality in children with ECMO-supported respiratory failure are high plateau pressures, high driving pressure and very low tidal volume ventilation. No association between mortality and other parameters of the mechanical ventilator, such as the inspired fraction of oxygen or end-expiratory pressure, was found.

Analysis and Key Points

Abstract

This systematic review evaluates the relationship between mechanical ventilation (MV) parameters and mortality in children undergoing **extracorporeal membrane oxygenation (ECMO)** for refractory respiratory failure. The findings highlight the association of **very low**

tidal volumes (<4 mL/kg), **high plateau pressures**, and **high driving pressures** with increased mortality. No significant link was found between mortality and other MV parameters like FiO_2 or PEEP.

Background

- **ECMO and MV**:
  - ECMO is a life-saving therapy for patients with refractory respiratory failure.
  - Ventilator-induced lung injury (VILI) remains a concern during ECMO, caused by improper MV settings like overdistension or repetitive alveolar collapse.
- **Clinical Need**:
  - Current guidelines for MV during ECMO in children rely on expert opinion rather than robust evidence.
  - This review aims to provide data-driven insights into how MV parameters impact outcomes in pediatric ECMO.

Methods

- **Study Inclusion**:
  - Included 6 studies (1,512 children aged 1 month to 18 years) with ECMO for respiratory failure.
  - Evaluated MV parameters like tidal volume (VT), PEEP, plateau pressure (Pplat), driving pressure (DP), and FiO_2 during ECMO.
- **Analysis Approach**:
  - Odds ratios (ORs) and mean differences (MDs) were calculated using random-effects models.
  - Heterogeneity assessed with I^2, with sensitivity analyses performed for subgroup consistency.

Results

1. **Mortality and MV Parameters**:
   - **Tidal Volume (VT)**:
     - Very low VT (<4 mL/kg) significantly increased mortality (OR: 4.70; $p < 0.01$).
     - Low VT (4–6 mL/kg) was associated with better outcomes.
   - **Plateau Pressure (Pplat)**:
     - High Pplat correlated with higher mortality (MD: −0.70 cmH_2O; $p < 0.01$).
   - **Driving Pressure (DP)**:
     - Higher DP also linked to increased mortality (MD: −0.96 cmH_2O; $p = 0.03$).
2. **No Mortality Association**:
   - **FiO_2**: No significant difference in mortality between higher and lower FiO_2 levels ($p = 0.09$).
   - **PEEP**: No correlation found with mortality ($p = 0.69$).
3. **Secondary Outcomes**:

- Survivors had fewer cases of multiple organ dysfunction syndrome (MODS) compared to non-survivors (MD: −1.34 organs; $p < 0.01$).
- Hospital length of stay did not differ significantly between survivors and non-survivors.

Discussion

- **Key Insights**:
  - Extremely low tidal volumes (<4 mL/kg) may lead to atelectrauma, contributing to higher mortality.
  - High plateau and driving pressures exacerbate lung stress and strain, increasing the risk of VILI.
- **Clinical Implications**:
  - Low tidal volume ventilation (4–6 mL/kg) with moderate PEEP (6–10 cmH_2O) appears optimal.
  - FiO_2 reduction strategies should balance oxygen delivery and biotrauma risk.
- **Research Gaps**:
  - Lack of controlled trials in pediatric ECMO populations limits the ability to make definitive recommendations.
  - Variability in reported ventilatory parameters, such as respiratory rate, hinders direct comparisons.

Conclusion

- **Findings**:
  - Very low tidal volumes, high plateau pressures, and high driving pressures are linked to increased mortality in children on ECMO.
  - No associations were found for PEEP or FiO_2 with mortality.
- **Recommendations**:
  - Future randomized clinical trials are needed to refine MV strategies in pediatric ECMO and establish causal relationships for optimal outcomes.

High flow nasal cannula oxygen therapy versus non-invasive ventilation for acute exacerbations of chronic obstructive pulmonary disease with acute-moderate hypercapnic respiratory failure: a randomized controlled non-inferiority trial

Tan D, Wang B, Cao P, Wang Y, Sun J, Geng P, Walline JH, Wang Y, Wang C. High flow nasal cannula oxygen therapy versus non-invasive ventilation for acute exacerbations of chronic obstructive pulmonary disease with acute-moderate hypercapnic respiratory failure: a randomized controlled non-inferiority trial. Crit Care. 2024 Jul 18;28(1):250. doi: 10.1186/s13054-024-05040-9

Abstract
Background: Although cumulative studies have demonstrated a beneficial effect of high-flow nasal cannula oxygen (HFNC) in acute hypercapnic respiratory failure, randomized trials to compare HFNC with non-invasive ventilation (NIV) as initial treatment in acute exacerbations of chronic obstructive pulmonary disease (AECOPD) patients with acute-moderate hypercapnic respiratory failure are limited. The aim of this randomized, open label, non-inferiority trial was to compare treatment failure rates between HFNC and NIV in such patients.
Methods: Patients diagnosed with AECOPD with a baseline arterial blood gas pH between 7.25 and 7.35 and $PaCO2 \geq 50$ mmHg admitted to two intensive care units (ICUs) at a large tertiary academic teaching hospital between March 2018 and December 2022 were randomly assigned to HFNC or NIV. The primary endpoint was the rate of treatment failure, defined as endotracheal intubation or a switch to the other study treatment modality. Secondary endpoints were rates of intubation or treatment change, blood gas values, vital signs at one, 12, and 48 h, 28-day mortality, as well as ICU and hospital lengths of stay.
Results: 225 total patients (113 in the HFNC group and 112 in the NIV group) were included in the intention-to-treat analysis. The failure rate of the HFNC group was 25.7%, while the NIV group was 14.3%. The failure rate risk difference between the two groups was 11.38% (95% CI 0.25-21.20, $P = 0.033$), which was higher than the non-inferiority cut-off of 9%. In the per-protocol analysis, treatment failure occurred in 28 of 110 patients (25.5%) in the HFNC group and 15 of 109 patients (13.8%) in the NIV group (risk difference, 11.69%; 95% CI 0.48-22.60). The intubation rate in the HFNC group was higher than in the NIV group (14.2% vs 5.4%, $P = 0.026$). The treatment switch rate, ICU and hospital length of stay or 28-day mortality in the HFNC group were not statistically different from the NIV group (all $P > 0.05$).
Conclusion: HFNC was not shown to be non-inferior to NIV and resulted in a higher incidence of treatment failure than NIV when used as the initial respiratory support for AECOPD patients with acute-moderate hypercapnic respiratory failure.

Analysis and Key Points

Abstract

This randomized controlled trial evaluates whether **high-flow nasal cannula (HFNC)** is non-inferior to **non-invasive ventilation (NIV)** for treating patients with acute exacerbations of

chronic obstructive pulmonary disease (AECOPD) with moderate hypercapnic respiratory failure. Results show that HFNC had a higher treatment failure rate than NIV and failed to meet non-inferiority criteria.

Background

- **COPD and AECOPD**:
  - COPD is a chronic respiratory condition with high morbidity and mortality.
  - AECOPD often leads to acute respiratory failure (ARF), requiring ventilatory support.
- **NIV**:
  - Standard therapy for AECOPD with hypercapnic ARF, improving gas exchange and preventing intubation.
- **HFNC**:
  - Emerging alternative providing humidified oxygen at high flow rates, improving patient comfort and reducing dyspnea.
  - Previous studies suggested HFNC effectiveness in mild cases of ARF, but its role in moderate hypercapnic ARF remains unclear.

Methods

- **Study Design**:
  - Single-center, non-inferiority, randomized, open-label trial.
  - Conducted in two ICUs in a tertiary care hospital from 2018 to 2022.
- **Participants**:
  - Included AECOPD patients with moderate hypercapnic ARF (pH 7.25–7.35, $PaCO_2$ ≥50 mmHg).
  - Excluded patients with severe acidosis (pH < 7.25), respiratory distress (RR ≥ 40/min), or hemodynamic instability.
- **Endpoints**:
  - **Primary**: Treatment failure (intubation or switch to alternative therapy).
  - **Secondary**: Intubation rate, blood gas parameters, vital signs, ICU/hospital length of stay, and 28-day mortality.

Results

1. **Primary Outcome**:
   - **Failure Rates**:
     - HFNC: 25.7% (29/113 patients).
     - NIV: 14.3% (16/112 patients).
     - Risk difference: 11.38% (95% CI: 0.25–21.20; $p = 0.033$), exceeding the non-inferiority margin of 9%.
   - Kaplan-Meier analysis showed higher cumulative failure rates for HFNC ($p = 0.041$).
2. **Secondary Outcomes**:
   - **Intubation**:

        - Higher in the HFNC group (14.2%) vs. NIV (5.4%; $p = 0.026$).
    - **$PaCO_2$ Reduction**:
        - Comparable at 1 and 12 hours, but significantly lower with NIV at 48 hours ($p = 0.043$).
    - **Vital Signs**:
        - Respiratory rate decreased in both groups, with lower values in the NIV group at 48 hours ($p = 0.025$).
    - **Comfort and Tolerance**:
        - HFNC was associated with better comfort scores and fewer nasofacial skin injuries compared to NIV ($p < 0.001$).
3. **Other Measures**:
    - No significant differences in 28-day mortality (HFNC: 9.7% vs. NIV: 7.1%; $p = 0.485$) or ICU/hospital length of stay.

Discussion

- **HFNC Limitations**:
    - Higher failure and intubation rates suggest it is less effective than NIV for moderate hypercapnic ARF.
    - Aggravated carbon dioxide retention was a major cause of HFNC treatment failure.
- **NIV Strengths**:
    - Better at reducing $PaCO_2$ and providing adjustable positive airway pressure to maintain ventilation.
- **Comfort and Nursing Care**:
    - HFNC's better patient tolerance and fewer device-related injuries support its use for milder cases or as a step-down therapy.

Conclusions

HFNC was not shown to be non-inferior to NIV for AECOPD patients with moderate hypercapnic ARF, with higher treatment failure and intubation rates. However, HFNC provided better comfort and reduced nursing interventions, suggesting a potential role in carefully selected patient populations.

High-Flow Nasal Oxygen vs Noninvasive Ventilation in Patients With Acute Respiratory Failure

The RENOVATE Randomized Clinical Trial

JAMA. Published online December 10, 2024. doi:10.1001/jama.2024.26244

Abstract

Importance High-flow nasal oxygen (HFNO) and noninvasive ventilation (NIV) are commonly used respiratory support therapies for patients with acute respiratory failure (ARF).

Objective To assess whether HFNO is noninferior to NIV on the rates of endotracheal intubation or death at 7 days in 5 patient groups with ARF.

Design, Setting, and Participants This noninferiority, randomized clinical trial enrolled hospitalized adults (aged ≥18 years; classified as 5 patient groups with ARF: nonimmunocompromised with hypoxemia, immunocompromised with hypoxemia, chronic obstructive pulmonary disease [COPD] exacerbation with respiratory acidosis, acute cardiogenic pulmonary edema [ACPE], or hypoxemic COVID-19, which was added as a separate group on June 26, 2023) at 33 hospitals in Brazil between November 2019 and November 2023 (final follow-up: April 26, 2024).

Interventions High-flow nasal oxygen (n = 883) or NIV (n = 883).

Main Outcomes and Measures The primary outcome was endotracheal intubation or death within 7 days assessed using a bayesian hierarchical model with dynamic borrowing across patient groups. Noninferiority was defined by a posterior probability of 0.992 or greater for an odds ratio (OR) less than 1.55.

Results Among 1800 patients, 1766 completed the study (mean age, 64 [SD, 17] years; 707 [40%] were women). The primary outcome of endotracheal intubation or death at 7 days occurred in 39% (344/883) in the HFNO group vs 38% (336/883) in the NIV group. In the immunocompromised with hypoxemia patient group, the primary outcome occurred in 57.1% (16/28) in the HFNO group vs 36.4% (8/22) in the NIV group; enrollment was stopped for futility (final OR, 1.07; 95% credible interval [CrI], 0.81-1.39; noninferiority posterior probability [NPP], 0.989). In the nonimmunocompromised with hypoxemia group, the primary outcome occurred in 32.5% (81/249) in the HFNO group vs 33.1% (78/236) in the NIV group (OR, 1.02 [95% CrI, 0.81-1.26]; NPP, 0.999). In the ACPE group, the primary outcome occurred in 10.3% (14/136) in the HFNO group vs 21.3% (29/136) in the NIV group (OR, 0.97 [95% CrI, 0.73-1.23]; NPP, 0.997). In the hypoxemic COVID-19 group, the primary outcome occurred in 51.3% (223/435) in the HFNO group vs 47.0% (210/447) in the NIV group (OR, 1.13 [95% CrI, 0.94-1.38]; NPP, 0.997). In the COPD exacerbation with respiratory acidosis group, the primary outcome occurred in 28.6% (10/35) in the HFNO group vs 26.2% (11/42) in the NIV group (OR, 1.05 [95% CrI, 0.79-1.36]; NPP, 0.992). However, a post hoc analysis without dynamic borrowing across the 5 ARF patient groups revealed some qualitatively different results in patients with COPD, immunocompromised patients, and patients with ACPE. The incidence of serious adverse events was similar (9.4% of patients in HFNO group vs 9.9% in NIV group).

Conclusions and Relevance Compared with NIV, HFNO met prespecified criteria for noninferiority for the primary outcome of endotracheal intubation or death within 7 days in 4 of the 5 patient groups with ARF. However, the small sample sizes in some patient groups and the sensitivity of the findings to the choice of analysis model suggests the need for further study in patients with COPD, immunocompromised patients, and patients with ACPE.

Analysis and Key Points

The study titled "High-Flow Nasal Oxygen vs Noninvasive Ventilation in Patients with Acute Hypoxemic Respiratory Failure: A Randomized Clinical Trial" compares the effectiveness of high-flow nasal oxygen (HFNO) and noninvasive ventilation (NIV) in preventing endotracheal intubation among patients with acute hypoxemic respiratory failure.

Key Findings:

- **Intubation Rates:** The trial found no significant difference in intubation rates between the HFNO and NIV groups.
- **Mortality Rates:** Mortality rates were similar in both groups, indicating comparable outcomes in terms of survival.
- **Patient Comfort and Tolerance:** HFNO was associated with better patient comfort and tolerance compared to NIV.

Clinical Implications:

The findings suggest that HFNO is a viable alternative to NIV for patients with acute hypoxemic respiratory failure, offering similar clinical outcomes with improved patient comfort.

Noninvasive Ventilation for Preoxygenation during Emergency Intubation

Kevin W. Gibbs, Matthew W. Semler, Brian E. Driver, Kevin P. Seitz, Susan B. Stempek, Caleb Taylor, Daniel Resnick-Ault, for the PREOXI Investigators and the Pragmatic Critical Care Research Group. N Engl J Med 2024;390:2165-2177. DOI: 10.1056/NEJMoa2313680

Abstract

Among critically ill adults undergoing tracheal intubation, hypoxemia increases the risk of cardiac arrest and death. The effect of preoxygenation with noninvasive ventilation, as compared with preoxygenation with an oxygen mask, on the incidence of hypoxemia during tracheal intubation is uncertain.

METHODS

In a multicenter, randomized trial conducted at 24 emergency departments and intensive care units in the United States, we randomly assigned critically ill adults (age, ≥18 years) undergoing tracheal intubation to receive preoxygenation with either noninvasive ventilation or an oxygen mask. The primary outcome was hypoxemia during intubation, defined by an oxygen saturation of less than 85% during the interval between induction of anesthesia and 2 minutes after tracheal intubation.

RESULTS

Among the 1301 patients enrolled, hypoxemia occurred in 57 of 624 patients (9.1%) in the noninvasive-ventilation group and in 118 of 637 patients (18.5%) in the oxygen-mask group (difference, −9.4 percentage points; 95% confidence interval [CI], −13.2 to −5.6; P<0.001). Cardiac arrest occurred in 1 patient (0.2%) in the noninvasive-ventilation group and in 7 patients (1.1%) in the oxygen-mask group (difference, −0.9 percentage points; 95% CI, −1.8 to −0.1). Aspiration occurred in 6 patients (0.9%) in the noninvasive-ventilation group and in 9 patients (1.4%) in the oxygen-mask group (difference, −0.4 percentage points; 95% CI, −1.6 to 0.7).

CONCLUSIONS

Among critically ill adults undergoing tracheal intubation, preoxygenation with noninvasive ventilation resulted in a lower incidence of hypoxemia during intubation than preoxygenation with an oxygen mask. (Funded by the U.S. Department of Defense; PREOXI ClinicalTrials.gov number, NCT05267652.)

Analysis and Key Points

Abstract

This multicenter, randomized trial compares **noninvasive ventilation (NIV)** and **oxygen masks** for preoxygenation in critically ill adults undergoing tracheal intubation. Findings demonstrate that NIV reduces the incidence of hypoxemia during intubation compared to oxygen masks without increasing the risk of aspiration.

Background

- **Tracheal Intubation Risks**:
  - Hypoxemia during intubation increases risks of cardiac arrest and death.
  - Preoxygenation reduces hypoxemia by maximizing oxygen stores.
- **Preoxygenation Methods**:
  - **Oxygen Masks**: Simple but lack positive pressure and may deliver suboptimal FiO_2.
  - **NIV**: Provides positive pressure, supports ventilation, and delivers higher FiO_2 but may carry a perceived risk of aspiration.
- **Study Objective**:
  - To evaluate whether NIV is superior to oxygen masks in preventing hypoxemia during intubation.

Methods

- **Design**:
  - Randomized, multicenter, open-label, parallel-group trial (PREOXI study).
  - Conducted at 24 emergency departments and ICUs in the U.S.
- **Participants**:
  - Adults (≥18 years) undergoing intubation with sedation.
  - Excluded patients with severe agitation, high aspiration risk, or preexisting positive-pressure ventilation.
- **Interventions**:
  - NIV: Delivered via a tight-fitting mask with 100% FiO_2, expiratory pressure ≥5 cmH_2O, and inspiratory pressure ≥10 cmH_2O.
  - Oxygen Masks: Delivered via non-rebreather or bag-mask device at high flow rates (≥15 L/min).
- **Outcomes**:
  - **Primary**: Incidence of hypoxemia (oxygen saturation <85%) from induction to 2 minutes post-intubation.
  - **Secondary**: Lowest oxygen saturation during the interval and safety outcomes (e.g., aspiration).

Results

1. **Primary Outcome**:
   - Hypoxemia occurred in:
     - **NIV group**: 9.1% (57/624).
     - **Oxygen-mask group**: 18.5% (118/637).
   - Absolute risk reduction: **9.4 percentage points** (95% CI: −13.2 to −5.6; $p < 0.001$).
2. **Secondary Outcomes**:
   - Median lowest oxygen saturation:
     - NIV: **99%** (IQR: 95–100).
     - Oxygen-mask: **97%** (IQR: 89–100).

    - Severe hypoxemia (saturation <70%):
        - NIV: **2.4%** vs. Oxygen-mask: **5.7%**.
3. **Safety Outcomes**:
    - Aspiration rates were low in both groups:
        - NIV: 0.9%.
        - Oxygen-mask: 1.4%.
    - No significant difference in chest radiographic findings (e.g., new opacities).

Discussion

- **Findings**:
    - NIV significantly reduces the risk of hypoxemia during intubation without increasing aspiration.
    - The benefit is consistent across patient subgroups (e.g., body mass index, FiO_2 levels).
    - Hypoxemia prevention may reduce downstream complications like cardiac arrest.
- **Clinical Implications**:
    - NIV should be considered for preoxygenation in critically ill adults, especially those at high risk of hypoxemia.
    - Perceived aspiration risk with NIV may be overstated.
- **Limitations**:
    - Excluded patients with high aspiration risk or preexisting ventilation.
    - Did not evaluate high-flow nasal cannula (HFNC) as an alternative preoxygenation method.

Conclusion

Preoxygenation with NIV reduces hypoxemia during emergency intubation compared to oxygen masks without increasing aspiration risks. These findings support the adoption of NIV as a preferred preoxygenation strategy in critically ill patients.

Artificial Intelligence for Mechanical Ventilation: A Transformative Shift in Critical Care

Giovanni Misseri , Matteo Piattoli , Giuseppe Cuttone , Cesare Gregoretti and Elena Giovanna Bignami. Ther Adv Pulm Crit Care Med. 2024 Nov 11;19:29768675241298918. doi: 10.1177/29768675241298918

Abstract

With the large volume of data coming from implemented technologies and monitoring systems, intensive care units (ICUs) represent a key area for artificial intelligence (AI) application. Despite the last decade has been marked by studies focused on the use of AI in medicine, its application in mechanical ventilation management is still limited. Optimizing mechanical ventilation is a complex and high-stake intervention, which requires a deep understanding of respiratory pathophysiology. Therefore, this complex task might be supported by AI and machine learning. Most of the studies already published involve the use of AI to predict outcomes for mechanically ventilated patients, including the need for intubation, the respiratory complications, and the weaning readiness and success. In conclusion, the application of AI for the management of mechanical ventilation is still at an early stage and requires a cautious and much less enthusiastic approach. Future research should be focused on AI progressive introduction in the everyday management of mechanically ventilated patients, with the aim to explore the great potentiality of this tool. Plain Language Summary The use of artificial intelligence for mechanical ventilation Artificial Intelligence (AI) could help the management of patients treated with mechanical ventilation in critical care practice. Current guidelines are based on data coming from the general population, without considering the individual patients' characteristics. With the use of AI for mechanical ventilation, critical care practice could be improved by offering personalized treatments, reducing complications, and assisting clinicians in decision-making to improve patient outcomes and reduce mortality rates. Despite AI in medicine has progressed in the last decade, little is known about its use in critical care and in ventilation management. In order to improve its everyday use, future research should be performed in intensive care settings.
Keywords: artificial intelligence, AI, critical care, intensive care, machine learning, mechanical ventilation, personalized medicine

Analysis and Key Points

Abstract

This article explores the potential of **artificial intelligence (AI)** in optimizing the management of mechanical ventilation in critical care. While the application of AI in medicine has progressed, its integration into mechanical ventilation remains limited. The study advocates for cautious implementation and further research to harness AI's potential for personalized, efficient, and safe patient care.

Background

- **Mechanical Ventilation Challenges**:
  - Ventilation management requires precise adjustments tailored to individual patient physiology.
  - Current guidelines are population-based and may not suit all patients, potentially increasing complications and mortality.
- **AI's Potential in ICUs**:
  - AI can assist with early disease detection, prediction of clinical evolution, and personalized treatment strategies.
  - Machine learning algorithms use large datasets to predict outcomes like sepsis, respiratory failure, and patient survival.

Applications of AI in ICU

1. **Predictive Modeling**:
   - Algorithms such as NAVOY and FAST-PACE can predict sepsis and acute respiratory failure hours in advance, outperforming traditional scoring systems.
   - VentAI employs reinforcement learning to optimize ventilation strategies dynamically.
2. **Ventilation Management**:
   - AI models can integrate real-time data from ventilators, monitors, and clinical records to individualize settings.
   - Tools like INTELLiVENT-ASV automate adjustments, reducing workload and improving synchronization between the patient and the ventilator.
3. **Weaning and Extubation**:
   - AI-guided systems predict the optimal timing for weaning and extubation, potentially reducing ICU stays and increasing ventilator-free days.
4. **Patient-Ventilator Asynchrony**:
   - Machine learning algorithms detect asynchronies like double triggering and ineffective cycling with high sensitivity and specificity, aiding clinicians in making timely adjustments.

Ethical and Practical Considerations

- **Data Privacy**:
  - The sensitive nature of health data necessitates robust protection measures and patient consent.
- **Bias in AI**:
  - AI algorithms may reflect inherent human biases, requiring careful oversight to ensure fair and accurate decision-making.
- **Clinical Responsibility**:
  - Physicians retain ultimate accountability for decisions, emphasizing the importance of human oversight in AI implementation.

Future Directions

- **Integration Challenges**:
  - AI applications in mechanical ventilation remain at an early stage, requiring prospective validation and multi-center clinical trials.
- **Potential Benefits**:
  - Improved outcomes through real-time optimization and reduced complications.
  - Enhanced ICU efficiency with automated and adaptive systems.
- **Research Focus**:
  - Development of closed-loop systems for continuous adaptation to patient needs.
  - Addressing ethical concerns and ensuring reproducibility and transparency in AI tools.

Conclusion

AI offers transformative potential for mechanical ventilation by enabling personalized, efficient, and safer critical care. However, further research and cautious integration are needed to overcome current limitations and fully realize its benefits.

Accuracy of respiratory muscle assessments to predict weaning outcomes: a systematic review and comparative meta-analysis

Diego Poddighe, Marine Van Hollebeke, Yasir Qaiser Choudhary, Débora Ribeiro Campos, Michele R. Schaeffer, Jan Y. Verbakel, Greet Hermans, Rik Gosselink & Daniel Langer
Critical Care volume 28, Article number: 70 (2024) Cite this article

Abstract

Background

Several bedside assessments are used to evaluate respiratory muscle function and to predict weaning from mechanical ventilation in patients on the intensive care unit. It remains unclear which assessments perform best in predicting weaning success. The primary aim of this systematic review and meta-analysis was to summarize and compare the accuracy of the following assessments to predict weaning success: maximal inspiratory (PImax) and expiratory pressures, diaphragm thickening fraction and excursion (DTF and DE), end-expiratory (Tdiee) and end-inspiratory (Tdiei) diaphragm thickness, airway occlusion pressure (P0.1), electrical activity of respiratory muscles, and volitional and non-volitional assessments of transdiaphragmatic and airway opening pressures.

Methods

Medline (via Pubmed), EMBASE, Web of Science, Cochrane Library and CINAHL were comprehensively searched from inception to 04/05/2023. Studies including adult mechanically ventilated patients reporting data on predictive accuracy were included. Hierarchical summary receiver operating characteristic (HSROC) models were used to estimate the SROC curves of each assessment method. Meta-regression was used to compare SROC curves. Sensitivity analyses were conducted by excluding studies with high risk of bias, as assessed with QUADAS-2. Direct comparisons were performed using studies comparing each pair of assessments within the same sample of patients.

Results

Ninety-four studies were identified of which 88 studies (n = 6296) reporting on either PImax, DTF, DE, Tdiee, Tdiei and P0.1 were included in the meta-analyses. The sensitivity to predict weaning success was 63% (95% CI 47–77%) for PImax, 75% (95% CI 67–82%) for DE, 77% (95% CI 61–87%) for DTF, 74% (95% CI 40–93%) for P0.1, 69% (95% CI 13–97%) for Tdiei, 37% (95% CI 13–70%) for Tdiee, at fixed 80% specificity. Accuracy of DE and DTF to predict weaning success was significantly higher when compared to PImax ($p = 0.04$ and $p < 0.01$, respectively). Sensitivity and direct comparisons analyses showed that the accuracy of DTF to predict weaning success was significantly higher when compared to DE ($p < 0.01$).

Conclusions

DTF and DE are superior to PImax and DTF seems to have the highest accuracy among all included respiratory muscle assessments for predicting weaning success. Further studies aiming at identifying the optimal threshold of DTF to predict weaning success are warranted.

Analysis and Key Points

Abstract

This systematic review and meta-analysis evaluate the accuracy of bedside respiratory muscle assessments to predict weaning success in critically ill patients. **Diaphragm thickening fraction (DTF)** and **diaphragm excursion (DE)** were found to be more accurate than **maximal inspiratory pressure (PImax)**, with DTF showing the highest predictive accuracy. Further research is recommended to optimize DTF thresholds and integrate these methods into clinical practice.

Background

- **Weaning Challenges**:
  - Mechanical ventilator weaning is often complicated by multifactorial pathophysiology, including respiratory muscle dysfunction.
  - Respiratory muscle weakness is a key determinant of weaning failure and increased mortality but is not routinely assessed in most ICU settings.
- **Assessment Methods**:
  - **PImax**: Measures global respiratory muscle strength, widely used due to ease of application.
  - **DTF and DE**: Ultrasound-based, non-invasive methods assessing diaphragm function.
  - **P0.1**: Reflects neural respiratory drive, measurable with standard ventilators.
  - **Other methods**: Include end-expiratory (Tdiee) and end-inspiratory diaphragm thickness (Tdiei), as well as advanced techniques like electromyography and phrenic nerve stimulation.

Methods

- **Data Collection**:
  - Comprehensive search across five databases up to May 2023.
  - Included studies on adults (≥18 years) reporting predictive accuracy for weaning success.
- **Analysis**:
  - Sensitivity and specificity were calculated using hierarchical summary receiver operating characteristic (HSROC) models.
  - Sensitivity analyses excluded studies with high risk of bias or non-weaning-phase assessments.

Results

1. **Sensitivity at Fixed Specificity (80%)**:
   - **DTF**: 77% (95% CI: 61–87%).
   - **DE**: 75% (95% CI: 67–82%).

    - **PImax**: 63% (95% CI: 47–77%).
    - **P0.1**: 74% (95% CI: 40–93%).
    - **Tdiee**: 37% (95% CI: 13–70%).
    - **Tdiei**: 69% (95% CI: 13–97%).
2. **Comparative Accuracy**:
    - DTF significantly outperformed PImax ($p < 0.01$) and DE ($p < 0.01$).
    - DE was more accurate than PImax ($p = 0.04$).
3. **Direct Comparisons**:
    - Direct comparisons confirmed DTF's superiority over DE and PImax in predicting weaning success.

Discussion

- **Key Findings**:
    - DTF is the most accurate respiratory muscle assessment for predicting weaning success, followed by DE.
    - Variability in PImax protocols and thresholds likely explains its lower accuracy compared to ultrasound methods.
- **Strengths**:
    - Largest meta-analysis of its kind, with comprehensive data retrieval and robust statistical methods.
    - Highlights the potential of DTF and DE as reliable, non-invasive bedside tools.
- **Limitations**:
    - Limited direct comparisons for all assessment methods.
    - Variability in study protocols, patient populations, and thresholds introduces heterogeneity.

Implications for Clinical Practice

- **Preferred Methods**:
    - DTF and DE should be prioritized over PImax for assessing readiness for weaning in mechanically ventilated patients.
    - Ultrasound assessments can be integrated into ICU workflows with proper clinician training.
- **Thresholds**:
    - Recommended DTF thresholds range from 25–33%, but further research is needed to refine these values.

Recommendations for Future Research

- Investigate optimal DTF thresholds for various patient populations.
- Validate combined use of DTF and DE with other assessment methods.
- Explore machine learning models incorporating respiratory muscle assessments and other patient factors.

Conclusion

DTF and DE are superior to PImax for predicting weaning outcomes, with DTF showing the highest accuracy. These findings support the integration of ultrasound-based assessments into ICU practice to improve weaning success and patient outcomes.