THE ANNALS OF "DUNAREA DE JOS" UNIVERSITY OF GALATI
FASCICLE IX. METALLURGY AND MATERIALS SCIENCE
N°. 1 - 2025, ISSN 2668-4748; e-ISSN 2668-4756
Article DOI: https://doi.org/10.35219/mms.2025.1.06

PULMONARY TRAUMA AND PATIENT ACCOMMODATION WITH MECHANICAL VENTILATION - RISE TIME SETTINGS

Dumitru Adrian DRAGHICI, Angela REPANOVICI
Transilvania University Brasov, Romania
e-mail: dumitru.draghici@unitbv.ro, arepanovici@unitbv.ro

ABSTRACT

The inspiratory rise time in mechanical ventilation refers to the rate at which airway pressure reaches the set target during inspiration. When appropriately adjusted, it enhances patient-ventilator synchrony and improves comfort by increasing the tolerance of ventilator support. However, an excessively rapid rise time may result in elevated airway pressures and abrupt gas delivery, potentially contributing to lung injury or increased patient effort. An inverse correlation exists between rise time and the mechanical work of breathing, such that a shorter rise time is associated with a disproportionately increased in respiratory workload. As the intensity of respiratory effort and duration of mechanical ventilation increase, so does the risk of ventilator-associated lung injury (VALI). It is therefore imperative that ventilator manufacturers incorporate adjustable rise time parameters and corresponding time intervals into their devices to allow precise, individualized ventilator settings that minimize the risk of iatrogenic lung injury.

KEYWORDS: mechanical ventilation, rise time, pressure, lung trauma, ventilation synchronization

1. Introduction

A comprehensive analysis of the current literature in mechanical ventilation and critical care reveals significant insights into ventilatory strategies and their impact on patient outcomes. Several studies have addressed the role of inspiratory cycle termination and rise time settings, with Chiumello *et al.* demonstrating their influence on patient comfort and the risk of ventilator-induced lung injury (VILI) [1, 2]. In efforts to reduce pulmonary overdistension, Kallet et al. advocated for the implementation of low tidal volume ventilation protocols [3], while Simonis et al. evaluated their applicability in patients without acute respiratory distress syndrome (ARDS) [4].

Research into long-term mechanical ventilation has been expanded by Sison et al., who analysed mortality predictors and care determinants in chronically ventilated patients [5], and Donahoe, who explored the economic and logistical challenges associated with prolonged mechanical support [6]. In the context of the COVID-19 pandemic, studies by Bhatraju *et al.*, Guan *et al.*, Wang *et al.*, and Yang *et al.* provide critical data on the clinical characteristics and prolonged ventilatory requirements of patients with severe SARS-CoV-2 infection [7–10]. Studies such as those by Bhatraju *et al.*, Guan *et al.*, Wang *et al.*, and Yang *et al.* investigate clinical characteristics and the extended need for mechanical ventilation in severe COVID-19 cases [7-9].

Additionally, McGrath *et al.* present international, multidisciplinary guidelines for safely conducting tracheostomies in COVID-19 patients, reflecting a shift toward standardized procedural safety [11]. Collectively, this body of literature underscores the necessity of individualized ventilator settings tailored to patient-specific physiology, with the goal of enhancing clinical outcomes and minimizing the risk of iatrogenic lung injury.

With advancements in mechanical ventilation technology, modern ventilators now allow clinicians to adjust the inspiratory rise time – defined as the duration required to reach the preset airway pressure - as well as the criteria for terminating inspiration during pressure support ventilation. This study investigates the physiological impact of short versus long inspiratory rise times by analysing their effects on mechanical work, disconnection thresholds, breathing patterns, and patient comfort. The evolution of ventilator design presents significant challenges in both clinical training and the development of reliable mechatronic systems [1]. Ventilator associated lung injury (VALI) can arise from either suboptimal

THE ANNALS OF "DUNAREA DE JOS" UNIVERSITY OF GALATI
FASCICLE IX. METALLURGY AND MATERIALS SCIENCE
N°. 1 - 2025, ISSN 2668-4748; e-ISSN 2668-4756
Article DOI: https://doi.org/10.35219/mms.2025.1.06

design or inappropriate ventilator settings. The influence of rise time on mechanical load and VALI is quantified through the dynamic mechanical power equation (MP_dyn), which represents the total energy delivered to the lungs per breath automatically calculated by the ventilator as an indicator of mechanical work. Comparing different rise time settings, it was observed that at a constant pressure, a rise time of 10 ms causes a doubling of the mechanical work compared to a rise time of 300 ms. In the context of prolonged mechanical ventilation (over 12 hours), medical bioengineering guidelines recommend using a rise time of at least 250-300 ms, to significantly reduce the mechanical work imposed on the patient and, implicitly, the risk of ventilator-induced lung injury (VALI). In addition, in the case of non-invasive ventilation (NiV), where comfort and patient-ventilator synchronization are essential, a rise time of 350–400 ms is preferentially recommended, to facilitate patient accommodation and optimize therapy efficiency [2].

2. Materials and Methods

The evaluation was performed by comparing the mechanical work displayed by the mechanical ventilator with mathematically calculated mechanical work actually employed by the mechanical ventilation procedure.

Equipment Used: Mechanical Ventilator + test lung.

Mechanical Ventilator: The model used in the experimental tests chosen was the Bellavista 1000-VYARIE, featuring capabilities such as: auto triggering, expiratory pressure safety, hiFlow, rise time adjustment, and support for neonates, paediatric, and adult patients over 6 kg. The Lung Recruitment Tool provides an automated recruitment manoeuvre. Additional features include comprehensive pressure monitoring and customizable ventilatory support parameters.

Test lung: characteristics of the test lung compliance and simulated resistance; the test lung used had a compliance set at 0.5 L/cmH_2O and a resistance of 20 mlbar/L – 500 mL, PEEP 0. – IMTMEDICAL Model –Light Lung – For Bellavista.

3. Experimental Protocol

Initial ventilator settings and test conditions included an inspiratory pressure (20 cmH_2O), PEEP (5 cmH_2O) and ventilation mode (Assist Control Mode - Pressure Control), fio2 was set to 50%., trigger sensitivity to 2 L, 12 RR/min, IE: 1:2.

Test Variant A: 10 ms – rise time

Test Variant B: 300 ms – rise time

Intervals and repeatability: The time interval for the mechanical work analysis of the test lung was set at every 6 seconds, repeated three times, at a room temperature of 21 °C.

The mechanical work of the test lung was analysed using a rise time setting of 10 ms, compared to the rise time setting of 300 ms. All other mechanical ventilation parameters were kept constant.

4. Measurements and calculation

The authors assess the concordance between the mechanical work values calculated by the ventilator and those derived from mathematical models, with the objective of optimizing ventilator settings to minimize pulmonary mechanical workload. This approach aims to mitigate the adverse effects associated with mechanical ventilation and represents a significant clinical challenge for intensivists in critical care settings.

Mathematical Calculation of the Natural Rise Time of Human Breathing:

Typical inspiratory-to-expiratory (I:E) ratio of 1:2, then:

$$\text{Tinspir} = \frac{Tcycle}{1+2}$$

On a standard breath At RR = 15 breaths/min

$$\text{Tcycle} = 60 \text{ seconds}/15 = 4\text{s}$$
$$\text{Tcycle} = 4\text{s Tinspiration} = \frac{4}{3} = 1333\text{ms}$$

After checking, we realized that there is a pattern of pressure plateau time of 800-950 ms (875 ms average), which indicates that at 1333 ms we have an average rise time of 400-458 ms: 1333ms – 875ms = 458ms (average time) rise time - Natural breathing

Pressure-Time Ramp Function

Assume a linear rise in pressure from 0 to the target pressure P_{inspir} over the rise time t_{riseP}:

$$P(t) = \frac{Pinspir}{triseP} \times t \text{ for } 0 \le t \le trise$$
$$P_{insp} = 20 \text{ cm } H_2O$$
t-rise = either 0.01 s (10 ms) or 0.35 s (350 ms)

Flow Rate

Assuming constant compliance C, and V=C·P(t) then:

$$V(t) = \frac{dV}{vt} = C \times \frac{dP}{dt} = C \times \frac{Pinspir}{t\ rise}$$
$$C = 0.05 \text{ L/cmH2OC} = 0.05$$

Then:

For 10 ms rise time:

$$V = 0.05 \cdot \frac{20}{0.01} = 0.05 \cdot 2000 = 100 \text{ L/min}$$

For 350 ms rise time:

$$V = 0.05 \cdot \frac{20}{0.35} = 0.05 \cdot 57.14 = 2.85 \text{ L/min}$$

5. Experimental Validation

A test lung was connected to a mechanical ventilator, tests were performed at an inspiratory pressure of 20 cmH_2O and PEEP of 5 cmH2O (Asist Control Mode-Pressure Control), using both low- and high-rise time values to determine effective pulmonary mechanical work.

Mechanical work was compared between two scenarios: one with fast rise time (10 ms) and the other with a slower rise time (300 ms), both conducted at an inspiratory pressure of 20 cmH_2O.

Mechanical work (W) during inspiration is broadly defined as:

$$W = \int P \cdot dV$$

P = pressure applied
V= volume delivered
Work = area under the pressure–volume curve
Rise Time 300 ms
W2 ≈ 10 cmH_2O × 0.5 L = 5 cmH_2O cdotpL x 0.098 = 0.49 J
Rise Time 10 ms
W1 ≈ 20 cmH_2O × 0.5 L = 10 cmH_2O cdotpL x 0.098 = 0.98 J

Rise Time	Mechanical Work ($cmH_2O \cdot L$)	Mechanical Work L(Joules)	Mechanical patient ventilator display software Delta L(J)
10 ms	10	0.98 J	0.99/0.94/0.97
300 ms	5	0.49 J	0.45/0.45/0.48

The last column displays the mechanical work values recorded by the mechanical ventilator for the virtual patient, with three consecutive measurements taken at 5-6 second intervals.

Preliminary results:

The shorter rise time (10 ms) results in greater mechanical work on the lungs, approximately double that observed with a rise time of 300 ms.

Higher Rise Time values (300 ms) lead to a considerable decrease in the mechanical work performed on the lungs, effectively halving the pressure exerted on them compared to a rise time of 10 ms.

6. Results and Discussion

This study emphasizes that a rise time setting of 10 milliseconds in mechanical ventilation results in a mechanically computed inspiratory work ranging from 0.099 to 0.94 joules per breath, as recorded by the ventilator's integrated software. These values were validated through comparison with mathematically derived calculations of mechanical work, underscoring the critical influence of rise time configuration on energy delivery to the respiratory system. Notably, when the rise time is adjusted to 300 milliseconds under otherwise identical ventilatory conditions, the mechanical work is reduced by approximately half. This finding highlights a fundamental consideration in ventilator management: the need for mandatory inclusion of adjustable rise time settings in all mechanical ventilators, and the prioritization of this feature by intensive care units to optimize lung-protective strategies and reduce ventilator-induced lung injury.

7. Conclusion

Clinical and Physiological Advantages of a 300 ms Rise Time in Mechanical Ventilation: A rise time setting of 300 milliseconds offers multiple clinical benefits by modulating the delivery of inspiratory pressure in a manner that closely approximates physiological breathing patterns. This intermediate rise time facilitates a more gradual pressure ramp, thereby avoiding abrupt pressure peaks that may be perceived as uncomfortable or unnatural by the patient. As a result, it enhances patient-ventilator synchrony and contributes to improved tolerance of ventilatory support. From a lung-protective standpoint, a slower rise in inspiratory pressure attenuates the initial flow rate and minimizes pressure overshoot, thereby reducing the risk of alveolar overdistension and ventilator-induced lung injury (VILI). Unlike shorter rise times (e.g., 50-100 ms), which can generate excessively high peak inspiratory flows and increase regional lung stress and strain, a 300 ms rise time promotes a more homogeneous distribution of tidal volume, which is especially advantageous in patients with heterogeneous lung mechanics, such as those with acute respiratory distress syndrome (ARDS). In pressure support ventilation, an excessively short rise time may lead to premature cycling or excessive pressure delivery, contributing to asynchrony. A rise time of 300 ms allows inspiratory pressure to reach the target level in closer alignment with the patient's inspiratory effort, thereby optimizing synchrony and potentially reducing the need for sedation. Moreover, this setting may reduce the dynamic mechanical work and mechanical power transmitted to the lungs with each breath. By distributing energy delivery more evenly, a 300 ms rise time may help mitigate the cumulative risk of ventilator-associated lung trauma over time.

References

[1]. Chiumello D., Pelosi P., Taccone P., Slutsky A., Gattinoni L., *Effect of different inspiratory rise time and cycling off criteria during pressure support ventilation in patients recovering from acute lung injury*, Crit Care Med., 31(11), p. 2604-10, doi: 10.1097/01.CCM.0000089939.11032.36. PMID: 14605531, Nov. 2003.

[2]. Chiumello D., *et al.*, *Effect of different cycling-off criteria and positive end-expiratory pressure during pressure support ventilation in patients with chronic obstructive pulmonary disease*, Crit Care Med., 35(11), p. 2547-52, doi: 10.1097/01.CCM.0000287594.80110.34. PMID: 17893630, Nov. 2007.

[3]. Kallet R. H., Corral W., Silverman H. J., Luce J. M., *Implementation of a low tidal volume ventilation protocol for patients with acute lung injury or acute respiratory distress syndrome*, Respir Care., 46(10):1024-37. PMID: 11572755, Oct. 2001.

[4]. Simonis F. D., *et al.*, *Effect of a Low vs Intermediate Tidal Volume Strategy on Ventilator-Free Days in Intensive Care Unit Patients Without ARDS: A Randomized Clinical Trial*, JAMA, 320(18), p. 1872-1880, doi: 5.1001/jama.2018.14280. PMID: 30357256; PMCID: PMC6248136, Nov. 2018.

[5]. Sison S. M., *et al.*, *Mortality outcomes of patients on chronic mechanical ventilation in different care settings: A systematic review*, Heliyon, 7(2):e06230, doi: 10.1016/j.heliyon.2021.e06230. Epub 2021 Feb 13. PMID: 33615014; PMCID: PMC7880845, Feb. 2021.

[6]. Donahoe M. P., *Current venues of care and related costs for the chronically critically I*, ll. Respir. Care., 57(6), p. 867-888, doi: 10.4187/respcare.01656, 2012.

[7]. Bhatraju P. K., Ghassemieh B. J., Nichols M., *Covid-19 in critically ill patients in the seattle region - case series*, N. Engl. J. Med., 382(21), p. 2012-2022, doi: 10.1056/NEJMoa2004500, 2020.

[8]. Guan W. J., Ni Z. Y., Hu Y., *Clinical characteristics of coronavirus disease 2019 in China*, N. Engl. J. Med., 382(18), p. 1708-1720, doi: 10.1056/NEJMoa2002032, 2020.

[9]. Wang D., Hu B., Hu C., *Clinical characteristics of 138 hospitalized patients with 2019 novel coronavirus-infected pneumonia in Wuhan, China*, JAMA, 323(11), p. 1061-1069, doi: 10.1001/jama.2020.1585, 2020.

[10]. Yang X., Yu Y., Xu J., *Clinical course and outcomes of critically ill patients with SARS-CoV-2 pneumonia in Wuhan, China: a single-centered, retrospective, observational study*, [published correction appears in Lancet Respir Med. 2020 Apr;8(4):e26] Lancet Respir. Med., 8(5), p. 475-481, doi: 10.1016/S2213-2600(20)30079-5, 2020.

[11]. McGrath B. A., Brenner M. J., Warrillow S. J., *Tracheostomy in the COVID-19 era: global and multidisciplinary guidance*, Lancet Respir. Med., 8(7), p. 717-725, doi: 10.1016/S2213-2600(20)30230-7, 2020.