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A Novel Approach to Optimized Ventilation Strategies in Patients with Atrial Fibrillation: A Subgroup Analysis of the Ablate-by-LAWT-Study

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Abstract

Background: High-frequency ventilation remains largely unutilized in critically ill patients and existing literature does not demonstrate clinical benefit. Patients with atrial fibrillation (AF) included in the Ablate-by-LAWT-study underwent a specialized anesthesiologic protocol using higher-frequency (45-55/min), low-tidal volume (3.5-4 ml/kg ideal body weight) ventilation (HFLTV). Heart failure (HF) and post-capillary pulmonary hypertension (pcPH) are common in this population. Whereas conventional ventilation can increase intrathoracic pressure, HFLTV may offer both procedural and cardiorespiratory advantages.

This analysis aims to investigate hemodynamic and respiratory effects of higher-frequency, lower tidal volume ventilation in comparison to conventional volume-controlled ventilation and to evaluate potential benefits for patients with or at risk for HF, pcPH and right ventricular (RV) dysfunction.

Methods: 12 patients undergoing the HFLTV anesthesiology protocol were included in an analysis of left atrial pressure (LAP), blood gas and hemodynamic parameters, focusing on temporal progression of systolic LAP, partial arterial pressure of oxygen (PaO_2) and carbon dioxide ($PaCO_2$), and cardiac index (CI).

Results: Systolic LAP decreased significantly after initiation of HFLTV [-3.33, 95% CI (-5.61 - 1.06)], while global respiratory function (PaO_2, $PaCO_2$) remained stable. CI [-0.8, 95% CI (-1.092 – -0.448)] and heart rate [-9.0, 95% CI (-15.306 – -2.723)] increased, indicating improved hemodynamic performance without compromising oxygenation or carbon dioxide elimination.

Conclusion: Using higher frequencies in mechanical ventilation has a significant impact on systolic LAP and CI. It suggests potential for stabilizing hemodynamics in critically ill patients with atrial fibrillation, post-capillary pulmonary hypertension, heart failure and right ventricular dysfunction undergoing general anesthesia. Randomized controlled trials are warranted for further investigation.

Trial registration: The Ablate-by-LAWT-study was registered at ClinicalTrials.gov (January 2020, ID: NCT04218604).

Background

Ventilation in critically ill patients and lung-protective strategies remain a subject of ongoing debate, particularly regarding positive end-expiratory pressure (PEEP) and tidal volume (TV). The application of lower tidal volumes can reduce alveolar inflammation and prevent postoperative pulmonary complications – an effect that appears to be primarily attributable to TV reduction rather than the application of PEEP. [1, 2] Positive-pressure ventilation inevitably affects intrathoracic pressure and cardiac function. [3] While pulmonary effects of conventional positive-pressure ventilation have been extensively investigated, its implications on cardiac pathophysiology have not been integrated into ventilatory protocol.

Age-related decline in respiratory compliance results in an increase of susceptibility to barotrauma and volutrauma, both of which are associated with a higher risk of pulmonary complications. [4, 5] Pressure-driven ventilation can further affect age-related cardiac conditions – such as diastolic dysfunction, pulmonary hypertension (PH), and right ventricular failure – by decreasing right (RV) and left ventricular (LV) preload, LV afterload and increasing RV afterload. [6] Implementations for clinical practice and possible benefits of alternative, particularly lung-protective, ventilation strategies remain insufficiently evaluated.

The multicentric Ablate-by-LAWT-study investigated personalized protocol for paroxysmal atrial fibrillation ablation depending on local left atrial wall thickness (LAWT). [7] Following study protocol, patients underwent general anesthesia and a higher-frequency, low-tidal volume ventilation (HFLTV). High-frequency ventilation (HFV) can provide procedural advantages during ablation and is associated with a reduced cardiac-pressure burden and airway pressure, as well as minimized mechanical strain and stress on alveoli. [3, 8–10] However, due to procedural complexity, the need for specialized staff training, and a lack of conclusive evidence of clinical benefit, high-frequency ventilation remains largely unused in routine practice. [9]

Heart failure (HF) is prevalent in up to 15% of patients undergoing atrial fibrillation (AF) ablation. AF is associated with an increased risk of pulmonary hypertension (PH), the development of which represents an unfavorable clinical turning point and has been reported in up to 46.6% of HF-patients. [11–14] Elevated left atrial pressure (LAP), resulting from increased tidal volume or attenuated pulmonary compliance, may lead to or exacerbate PH and further impair right ventricular performance. [3, 15, 16] A systematic review reported favorable outcomes with high-frequency ventilation during atrial fibrillation ablation but emphasized the need for further research to clarify its clinical impact. [8]

This analysis comprises 12 patients enrolled in the Ablate-by-LAWT-study and aims to evaluate hemodynamic and ventilatory responses to higher-frequency and low-tidal ventilation in comparison to conventional volume-controlled ventilation with particular attention to its implications for critical patients with HF, PH or RV dysfunction. [7]

Methods

Ethics and patient selection: The Ablate-by-LAWT-study complied with the Declaration of Helsinki, and the Ethic Committee of the Medical Faculty of the Ruhr University Bochum approved the study protocol (Registration Number: 2020-715). All patients were ≥ 18 years old, presented with an indication for paroxysmal atrial fibrillation ablation and reported signed informed consent. In 12 study-patients undergoing PAF-ablation at Heart- and Diabetes-Center North Rhine-Westphalia, invasive LAP-measurement and corresponding data was additionally assessed.

Anesthesiologic protocol and data collection: Following the Ablate-by-LAWT-study-protocol, patients underwent a 10-minute recruitment using volume-controlled ventilation (VCV) with a tidal volume of 8 ml/kg ideal body weight (IBW) and a respiratory rate of 12-15/min, followed by initiation of higher-

frequency (45-55/min) and low-tidal (3.5-4 ml/kgIBW) ventilation (HFLTV). During ablation, left atrial pressure (LAP) was measured intracardially. Relevant parameters – including heart rate (HR), mean arterial pressure (MAP), cardiac index (CI), partial arterial pressure of oxygen and carbon dioxide (PaO2, PaCO2) – were assessed at baseline, after intubation and 10-minute-recruitment, 5, 30, 60 and 90 minutes after initiation and 5 minutes after discontinuation of HFLTV, after extubation and in the recovery room.

Analysis: Using R©, baseline characteristics, including age and sex, mean length of anesthesia, intervention and HFLTV, were assessed. [17] Changes in LAP, cardiac index, PaO_2 and $PaCO_2$ were evaluated and significance of LAP-differences were investigated via t-test.

Results

Mean age was 61.83 years, 41.67% of patients were female. Mean duration of HFLTV was 85.67 minutes. Nine of ten patients with available data on left ventricular ejection fraction (LVEF) had an LVEF of at least 50%. Demographic data and duration of anesthesia, intervention and cumulative duration of higher-frequency, low-tidal ventilation is described in Table 1.

Table 1: Baseline demographic and interventional data

	Overall	
Variable	**12**	
Female sex (%)	5	(41.67)
Age (years, mean (SD))	61.83	(7.42)
Dur. anesthesia (minutes, mean (SD))	134.67	(27.57)
Dur. intervention (minutes, mean (SD))	97.00	(16.13)
Dur. HFLTV (minutes, mean (SD))	85.67	(12.15)

Systolic left atrial pressure (sLAP) is significantly lower during higher-frequency low-tidal ventilation (HFLTV), while diastolic LAP did not change significantly (Table 2, Figure 1).

Table 2: Left atrial pressure (LAP) under volume-controlled ventilation (VCV) and higher-frequency, low-tidal ventilation (HFLTV), mean differences and t-test

	VCV	**HFLTV**	**MD (95% CI)**	***p***
LAP (systolic, mean ± SD)	16.67 ± 6.02	13.33 ± 4.23	-3.33 (-5.61 – -1.06)	**0.008**
LAP (diastolic, mean ± SD)	5.08 ± 3.87	6.67 ± 4.1	1.58 (-0.72 – 3.89)	0.159

In comparison with volume-controlled ventilation (VCV), higher-frequency, low-tidal ventilation (HFLTV) resulted in a significant increase in heart rate, mean arterial pressure and cardiac index (Table 3, Figure 2). HFLTV had no significant effect on oxygenation or carbon dioxide elimination (Table 3, Figure 3).

Table 3: Heart rate (HR), mean arterial pressure (MAP), cardiac index (CI), partial arterial pressure of oxygen (PaO_2) and carbon dioxide ($PaCO_2$) during volume-controlled (VCV) and higher-frequency, low-tidal ventilation (HFLTV), mean differences and t-test

	VCV	**HFLTV**	**MD**	**95 % CI**	***p***
HR (mean ± SD)	52.1 ± 8.5	61.1 ± 13.1	9.0	(2.7 – 15.3)	**0.007**
MAP (mean ± SD)	71.7 ± 7.2	83.4 ± 10.7	11.7	(6.4 – 17.0	**< 0.001**
CI (mean ± SD)	1.8 ± 0.4	2.6 ± 0.8	0.8	(0.5 – 1.1)	**< 0.0001**
PaO_2 (mean ± SD)	157.4 ± 92.2	112.1 ± 36.6	-45.3	(-104.5 – 13.8)	0.121
$PaCO_2$ (mean ± SD)	35.7 ± 4.5	34.3 ± 9.8	-1.4	(-5.3 – 2.4)	0.450

Discussion

This subgroup analysis provides first evidence for clinically relevant benefits associated with higher-frequency, low-tidal-volume ventilation (HFLTV) in patients at risk for heart-failure (HF), post-capillary pulmonary hypertension (pcPH) and right ventricular (RV) dysfunction.

Compared with conventional volume-controlled ventilation (VCV), HFLTV was associated with significantly higher cardiac index, mean arterial pressure and heart rate, indicating hemodynamic improvement likely attributable to lower intrathoracic pressure. In addition, systolic left atrial pressure (sLAP) – a surrogate of pulmonary arterial pressure a parameter reflecting right ventricular afterload – decreased significantly. Importantly, oxygenation and carbon dioxide elimination were not impaired during HFLTV, indicating that effective ventilation was maintained while preserving, or possibly improving, hemodynamic stability.

Previous studies have largely focused on broad patient populations but have not provided substantial evidence supporting a clinical benefit of higher-frequency ventilation, especially not on hemodynamic stability or cardio-pulmonary complications in high-risk-patients. A study of 20 patients undergoing coronary artery bypass grafting compared tidal volumes of 4–10 ml/kgIBW across varying thoracic compliance and demonstrated that intrathoracic pressure increases with higher tidal volumes and reduced respiratory compliance. [3] In an analysis of 1.822 patients undergoing AF-ablation, high-frequency jet ventilation (HFJV) was compared with conventional mechanical ventilation. While HFJV was associated with longer length-of-stay and a higher incidence of periprocedural abnormalities, including disturbances in carbon dioxide homeostasis, it also conferred procedural advantages, notably improved catheter stability and reduced arrhythmia recurrence. [18] Another study involving 46 patients

undergoing image-guided lung tumor ablation reported reduced technical difficulty during HFJV and unaffected complication rates. [19] Our analysis investigated 12 patients undergoing AF-ablation and HFLTV, representing a novel approach compared with previously published studies. Though patient characteristics may be similar, the applied ventilatory strategies differ substantially.

Our findings extend previous observations by demonstrating favorable hemodynamic effects of HFLTV without compromising respiratory efficacy. Moreover, HFLTV may enhance right ventricular performance, which is frequently compromised prior to and during cardiac interventions. [20, 21]

This study presents strengths and limitations. Although the cohort was small and consisted of a pre-selected population enrolled in the Ablate-by-LAWT study, it provides valuable insights into interventionally assessed left atrial pressure as well as associated respiratory and hemodynamic changes. [7] The observed effects highlight the physiological relevance of mechanical ventilation strategies and underscore the need for further prospective investigation, including randomized controlled trials evaluating ventilation-related hemodynamic effects in patient populations presenting with HF, RV dysfunction and PH undergoing general anesthesia.

Conclusion

For patients with atrial fibrillation undergoing catheter ablation, HFLTV presents a compelling or even superior alternative to conventional ventilation strategies. HFLTV was associated with improved hemodynamic status while preserving ventilatory efficacy and offering procedural advantages, underscoring its potential benefit in patients at risk of developing heart failure, right ventricular dysfunction or post-capillary pulmonary hypertension. Further randomized controlled trials in patients with heart failure, pulmonary hypertension and RV-dysfunction are warranted.

Abbreviations

AF	Atrial fibrillation
CI	Cardiac index
CI	Confidence interval
HF	Heart failure
HFLTV	Higher-frequency, low-tidal ventilation
HFV	High-frequency ventilation
LAP	Left atrial pressure
LAWT	Left atrial wall thickness
PaCO2	Partial arterial pressure of oxygen
PaO2	Partial arterial pressure of carbon dioxide
pcPH	Post-capillary pulmonary hypertension
PEEP	Positive end-expiratory pressure
RV	Right ventricular
SD	Standard deviation
TV	Tidal volume
VCV	Volume-controlled ventilation

Declarations

Ethics approval and consent to participate: The study complied with the Declaration of Helsinki, and the local ethic committees approved the study protocol (Registration Number: 2020-715). All participants included in the study provided written informed consent.

Consent for publication: Not applicable.

Availability of data and materials: The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests: The authors declare that they have no competing interests.

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Writing - Review & Editing; GF: Writing - Review & Editing; PS: Writing - Review & Editing, Resources; VVD: Conceptualization, Writing - Review & Editing, Supervision, Project administration.

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Figures

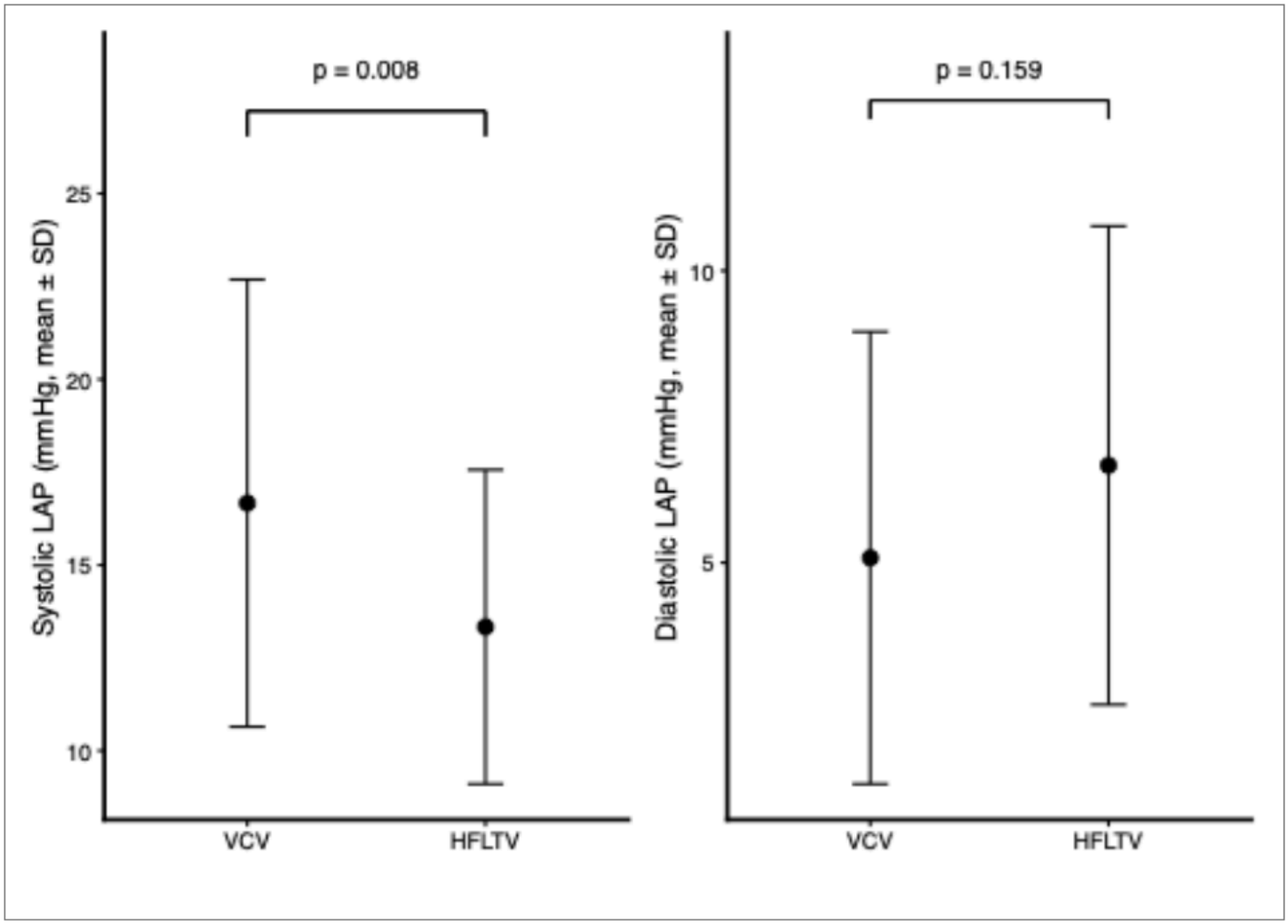


Figure 1

Changes in systolic and diastolic left atrial pressure during volume-controlled (VCV) and higher-frequency low-tidal (HFLTV) ventilation

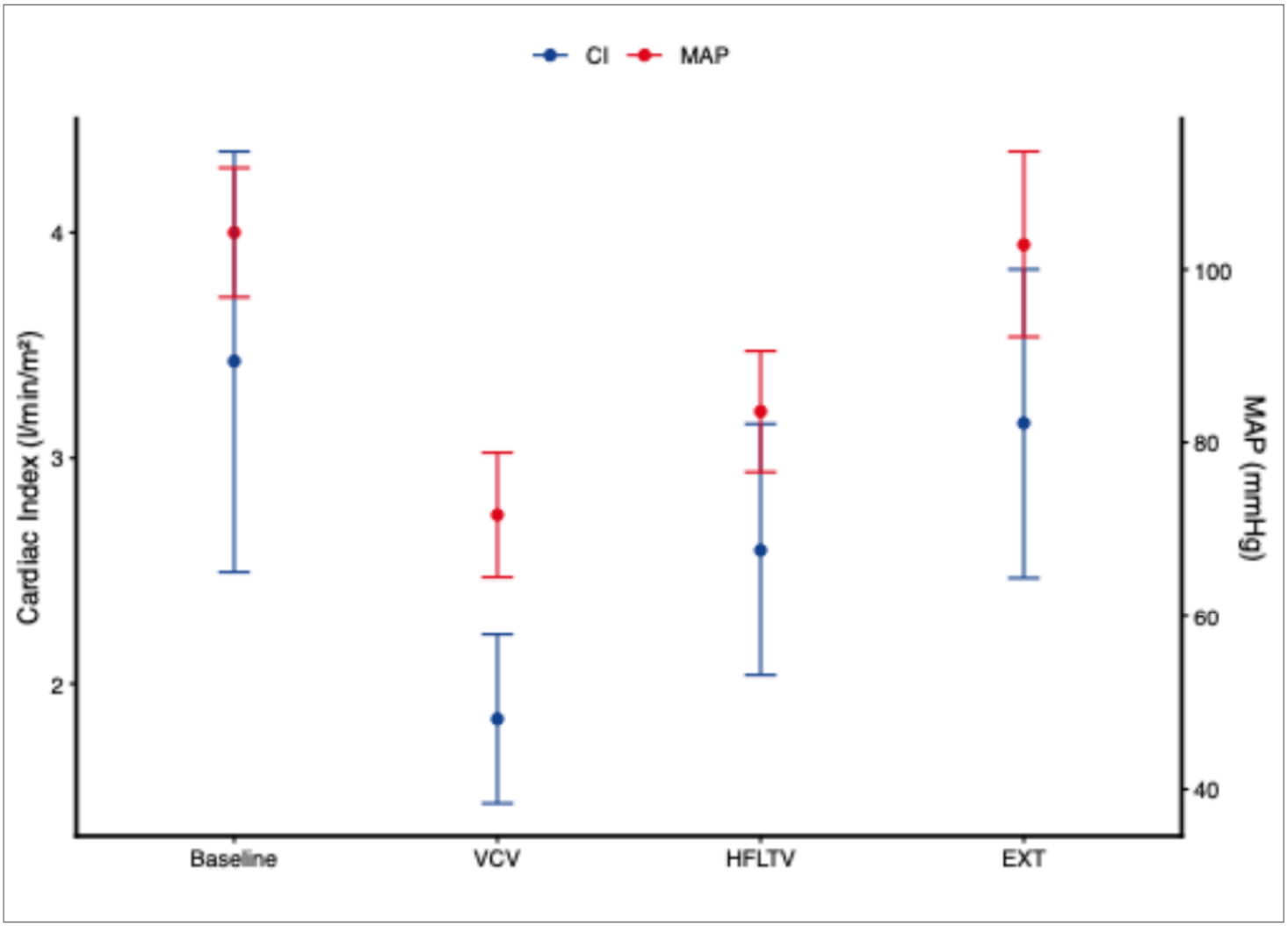


Figure 2

Cardiac index (CI) and mean arterial pressure at baseline, during volume-controlled ventilation (VCV), during higher-frequency, low-tidal ventilation (HFLTV) and after extubation

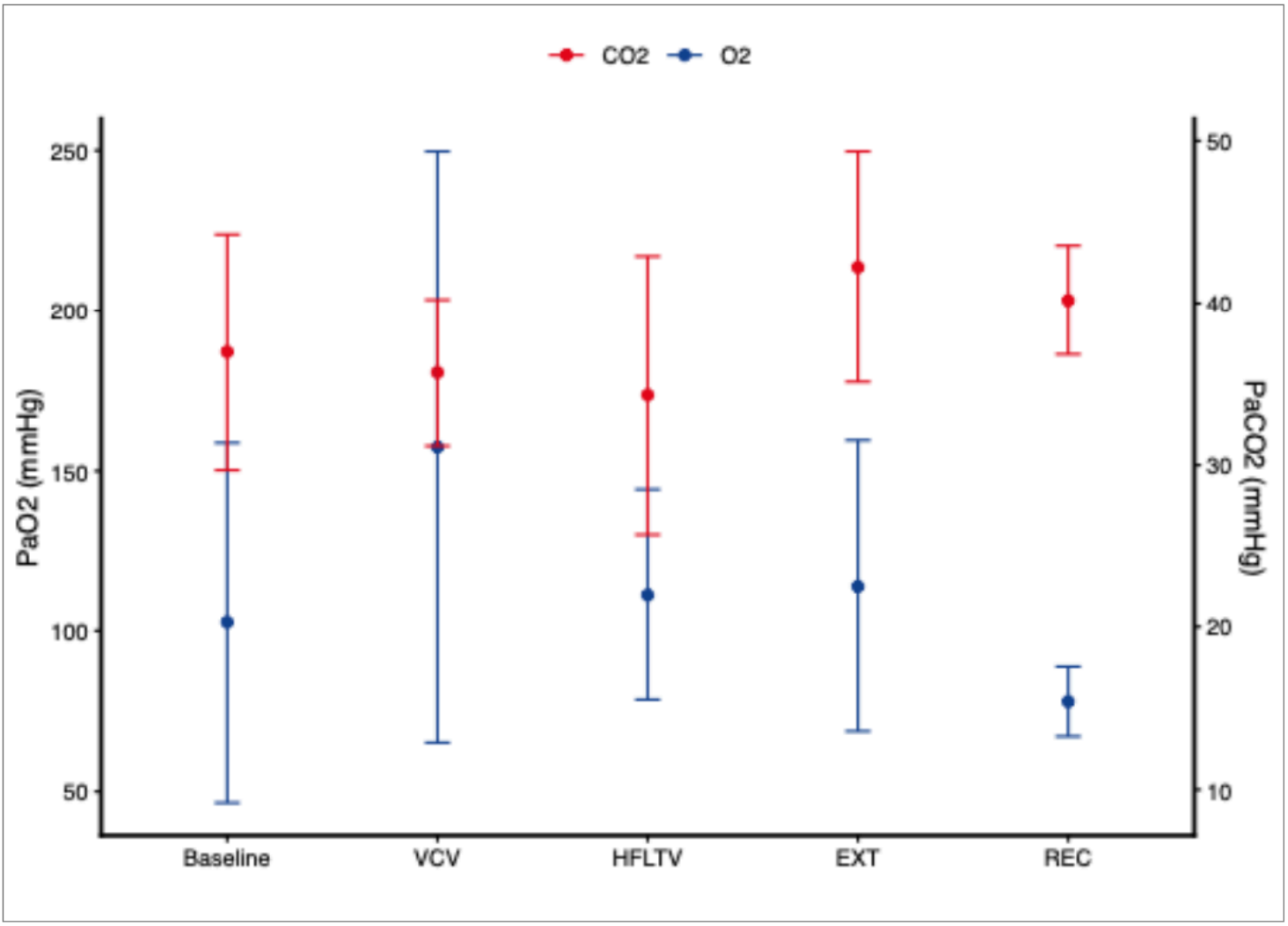


Figure 3

Partial arterial pressure of oxygen (PaO2) and carbon dioxide (PaCO2) at baseline, during volume-controlled ventilation (VCV), during higher-frequency, low-tidal ventilation (HFLTV), after extubation and in the recovery room