CENTER FOR BIOMEDICAL EQUIPMENT TESTING AND CALIBRATION

Comprehensive Reference of Lung and Ventilator Parameters

ICU & Mechanical Ventilation Clinical–Technical Guide

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A. Ventilation Parameters (CO_2 / Air Movement)

Abbrev	Parameter	One-liner	Normal Range
VT	Tidal Volume	Volume delivered per breath	6–8 mL/kg IBW
VTE	Expired Tidal Volume	Actual exhaled tidal volume	$\approx$ VT
VE	Minute Ventilation	VT $\times$ RR	5–8 L/min
ExpMinVol	Expiratory Minute Volume	Exhaled minute ventilation	5–8 L/min
RR	Respiratory Rate	Mandatory breaths per minute	12–20 /min
fTotal	Total RR	Machine + patient breaths	12–20 /min
$PaCO_2$	Arterial CO_2	Adequacy of ventilation	35–45 mmHg
$EtCO_2$	End-tidal CO_2	Alveolar CO_2 estimate	35–45 mmHg
VD/VT	Dead Space Fraction	Wasted ventilation	<0.3

B. Oxygenation Parameters

Abbrev	Parameter	One-liner	Normal Range
FiO_2	Inspired Oxygen Fraction	Oxygen delivered to patient	21%
PaO_2	Arterial Oxygen Pressure	Oxygenation status	80–100 mmHg
SaO_2	Arterial O_2 Saturation	Hemoglobin oxygen binding	95–100%
SpO_2	Pulse Oximetry	Peripheral O_2 saturation	95–100%
P/F Ratio	PaO_2/FiO_2	Lung efficiency index	>300

A–a Grad	Alveolar–Arterial Gradient	Gas exchange efficiency	<15–20 mmHg

C. Pressure Parameters

Abbrev	**Parameter**	**One-liner**	**Safe Range**
PIP / pPeak	Peak Inspiratory Pressure	Max airway pressure	<30–35 cmH_2O
Pplat	Plateau Pressure	Alveolar pressure	<30 cmH_2O
PEEP	Positive End-Expiratory Pressure	Prevents alveolar collapse	5 cmH_2O
Auto-PEEP	Intrinsic PEEP	Air trapping indicator	0
ΔP	Driving Pressure	Pplat − PEEP	<15 cmH_2O
MAP	Mean Airway Pressure	Average airway pressure	Mode-dependent

D. Lung Mechanics

Abbrev	**Parameter**	**One-liner**	**Normal Range**
C_{stat}	Static Compliance	Lung stiffness measurement	60–100 mL/cmH_2O
C_{dyn}	Dynamic Compliance	Lung + airway compliance	$<C_{stat}$
Raw	Airway Resistance	Opposition to airflow	5–10 $cmH_2O/L/s$
WOB	Work of Breathing	Energy to breathe	Minimal
τ	Time Constant	R × C (fill/empty speed)	<0.5 s

E. Flow and Timing Parameters

Abbrev	**Parameter**	**One-liner**	**Normal**
I:E	Inspiratory:Expiratory Ratio	Breath timing	1:2
Ti	Inspiratory Time	Duration of inspiration	0.8–1.2 s
Te	Expiratory Time	Duration of expiration	>Ti
Peak Flow	Inspiratory Flow	Gas delivery speed	40–60 L/min
Trigger	Trigger Sensitivity	Patient effort detection	–1 to –2 cmH_2O

F. Lung Volumes (Physiology)

Abbrev	**Volume**	**One-liner**	**Normal Value**
VT	Tidal Volume	Normal breath volume	∼500 mL

IRV	Inspiratory Reserve Volume	Extra inhalation volume	∼3000 mL
ERV	Expiratory Reserve Volume	Extra exhalation volume	∼1100 mL
RV	Residual Volume	Cannot be exhaled	∼1200 mL
FRC	Functional Residual Capacity	Oxygen reserve volume	∼2400 mL
VC	Vital Capacity	Maximum usable volume	∼4600 mL
TLC	Total Lung Capacity	Maximum lung volume	∼5800 mL

G. Acid–Base and Gas Exchange

Abbrev	Parameter	One-liner	Normal Range
pH	Blood pH	Acid–base balance	7.35–7.45
HCO_3^-	Bicarbonate	Metabolic buffer	22–26 mmol/L
BE	Base Excess	Metabolic deviation	–2 to +2
V/Q	Ventilation/Perfusion Ratio	Gas exchange efficiency	0.8–1

H. ASV / Hamilton Ventilator Parameters

Abbrev	Parameter	One-liner	Typical Range
ASV	Adaptive Support Ventilation	Closed-loop lung-protective mode	Auto-adjusted
%MinVol	Target Minute Volume	Percent of predicted VE	80–120%
IBW	Ideal Body Weight	Lung size estimation	Height-based
HPO	High Pressure Optimization	Pressure safety control	Automatic
LPO	Lung Protective Optimization	Normal ASV behavior	Automatic

Key High-Yield Rules

- $PaCO_2$ reflects ventilation
- PaO_2 reflects oxygenation
- High pressure and high volume cause lung injury
- PEEP maintains alveolar recruitment
- Increased resistance raises peak pressure
- Decreased compliance raises plateau pressure

I. Definitions and Calculation of Lung and Ventilator Parameters

Ventilation Parameters

VT (Tidal Volume) Volume of gas delivered to the lungs with each breath.
Calculation:

$$VT = \frac{Minute\ Ventilation}{Respiratory\ Rate}$$

VTE (Expired Tidal Volume) Actual volume of gas exhaled by the patient, used to detect leaks or compliance changes. *Measured directly by flow sensors during expiration.*

VE (Minute Ventilation) Total volume of gas inhaled or exhaled per minute.
Calculation:

$$VE = VT \times RR$$

ExpMinVol (Expiratory Minute Volume) Total volume exhaled per minute; reflects effective ventilation.
Calculation:

$$ExpMinVol = VTE \times fTotal$$

RR / fTotal (Respiratory Rate) Number of breaths per minute. *fTotal includes patient-triggered + machine breaths.*

$PaCO_2$ (Arterial Carbon Dioxide Pressure) Reflects adequacy of alveolar ventilation. *Inverse relationship with alveolar ventilation:*

$$PaCO_2 \propto \frac{CO_2\ Production}{Alveolar\ Ventilation}$$

$EtCO_2$ (End-Tidal CO_2) Partial pressure of CO_2 at end of expiration; approximates $PaCO_2$. *Measured using capnography.*

VD/VT (Dead Space Fraction) Fraction of each breath not participating in gas exchange.
Calculation (Bohr equation):

$$VD/VT = \frac{PaCO_2 - EtCO_2}{PaCO_2}$$

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Oxygenation Parameters

FiO_2 (Fraction of Inspired Oxygen) Percentage of oxygen delivered to the patient. *Set directly on ventilator.*

PaO_2 (Arterial Oxygen Pressure) Measures effectiveness of oxygen transfer from alveoli to blood. *Measured via arterial blood gas analysis.*

SaO_2 / SpO_2 Percentage of hemoglobin saturated with oxygen. *SaO_2 measured by ABG; SpO_2 by pulse oximetry.*

PaO_2/FiO_2 Ratio (P/F Ratio) Index of lung oxygenation efficiency.
Calculation:

$$P/F = \frac{PaO_2}{FiO_2}$$

A–a Gradient Difference between alveolar and arterial oxygen pressure.
Calculation:

$$A{-}a = PAO_2 - PaO_2$$

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Pressure Parameters

PIP / pPeak (Peak Inspiratory Pressure) Maximum airway pressure during inspiration. *Reflects resistance + compliance + flow.*

Pplat (Plateau Pressure) Pressure in alveoli when airflow is zero. *Measured during inspiratory hold maneuver.*

PEEP (Positive End-Expiratory Pressure) Pressure remaining in lungs at end expiration to prevent alveolar collapse. *Set on ventilator.*

Auto-PEEP (Intrinsic PEEP) Unintentional pressure due to incomplete exhalation. *Measured using expiratory hold.*

Driving Pressure (ΔP) Pressure applied to inflate the lung.
Calculation:

$$\Delta P = P_{plat} - PEEP$$

MAP (Mean Airway Pressure) Average airway pressure during respiratory cycle. *Calculated internally by ventilator based on waveform.*

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Lung Mechanics

Static Compliance ($\mathbf{C}_{stat}$) Elastic property of lungs during no-flow condition.
Calculation:

$$C_{stat} = \frac{VT}{P_{plat} - PEEP}$$

Dynamic Compliance ($\mathbf{C}_{dyn}$) Compliance during airflow.
Calculation:

$$C_{dyn} = \frac{VT}{PIP - PEEP}$$

Airway Resistance (Raw) Opposition to airflow in airways.
Calculation:

$$Raw = \frac{PIP - P_{plat}}{Flow}$$

Time Constant (τ) Time required for lung units to fill or empty.
Calculation:

$$\tau = Resistance \times Compliance$$

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Lung Volumes

FRC (Functional Residual Capacity) Volume remaining in lungs after normal expiration.
Calculation:

$$FRC = ERV + RV$$

VC (Vital Capacity) Maximum exhaled volume after full inspiration.
Calculation:

$$VC = VT + IRV + ERV$$

TLC (Total Lung Capacity) Maximum lung volume.
Calculation:

$$TLC = VC + RV$$

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Acid–Base Parameters

pH Measure of blood acidity or alkalinity.

HCO_3^- (Bicarbonate) Metabolic buffer regulating pH. *Calculated using Henderson–Hasselbalch equation.*

Base Excess (BE) Amount of acid or base needed to normalize pH. *Derived from ABG analysis.*

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ASV / Hamilton Parameters

IBW (Ideal Body Weight) Estimated lung size based on height.
Calculation (male):

$$IBW = 50 + 2.3 \times (\textit{height in inches} - 60)$$

Calculation (female):

$$IBW = 45.5 + 2.3 \times (\textit{height in inches} - 60)$$

%MinVol Target minute ventilation as percentage of predicted value. *Calculated internally using IBW and metabolic model.*

HPO / LPO Safety algorithms adjusting pressures and volumes to protect lungs. *Automatically controlled by ventilator.*

J. Additional Monitoring and Derived Parameters

This section describes additional lung, ventilation, and hemodynamic parameters commonly displayed on modern ventilators and patient monitors. These parameters are especially important for biomedical equipment testing, validation, and calibration, as many of them are derived from multiple sensors.

Rinsp (Inspiratory Airway Resistance)

Definition: Inspiratory airway resistance represents the opposition to airflow during inspiration, mainly within the airways, endotracheal tube, and breathing circuit.

Physiological Significance: An increase in Rinsp indicates airway narrowing, secretions, tube obstruction, or high inspiratory flow.

Calculation:

$$R_{insp} = \frac{PIP - P_{plat}}{Inspiratory\ Flow}$$

Biomedical Relevance: Rinsp accuracy depends on precise pressure and flow sensor calibration. Circuit configuration and flow settings significantly affect measured values.

$PetCO_2$ (End-Tidal Carbon Dioxide Pressure)

Definition: $PetCO_2$ is the partial pressure of carbon dioxide measured at the end of expiration.

Physiological Significance: $PetCO_2$ reflects the effectiveness of ventilation and pulmonary perfusion and closely approximates arterial $PaCO_2$ in healthy lungs.

Normal Range: 35–45 mmHg

Measurement Method: Measured using mainstream or sidestream capnography.

Biomedical Relevance: Accurate capnography calibration is essential. Sampling line leaks, moisture, or sensor drift may lead to falsely low readings.

PVI (Pleth Variability Index)

Definition: Pleth Variability Index is a non-invasive parameter derived from pulse oximetry that quantifies respiratory-induced variations in the plethysmographic waveform.

Physiological Significance: PVI is used as an indicator of fluid responsiveness in mechanically ventilated patients.

Calculation Principle: PVI is calculated from the dynamic changes in perfusion index (PI) over the respiratory cycle.

Biomedical Relevance: PVI accuracy depends on stable pulse oximetry signals, correct sensor placement, and proper signal processing.

fControl (Controlled Respiratory Rate)

Definition: fControl represents the number of breaths per minute delivered entirely by the ventilator without patient initiation.

Clinical Meaning: A high fControl indicates full ventilator dependence, typically seen in sedated or paralyzed patients.

Biomedical Relevance: Trigger sensitivity calibration is critical. Faulty triggering can falsely elevate the controlled breath count.

fSpont (Spontaneous Respiratory Rate)

Definition: fSpont is the number of breaths initiated by the patient per minute.

Clinical Meaning: It reflects patient respiratory drive, comfort, and readiness for ventilator weaning.

Biomedical Relevance: Flow and pressure trigger accuracy directly affect fSpont detection. Poor calibration can lead to missed or false spontaneous breath identification.

RSB / RSBI (Rapid Shallow Breathing Index)

Definition: RSB measures the efficiency of spontaneous breathing and is widely used as a predictor of weaning success.

Calculation:

$$RSB = \frac{Respiratory\ Rate}{Tidal\ Volume\ (L)}$$

Interpretation:

- RSB $<$ 105: Likely successful weaning
- RSB $>$ 105: High risk of weaning failure

Biomedical Relevance: Accurate measurement of respiratory rate and tidal volume is essential, as small sensor errors significantly affect RSB values.

fCO_2 (CO_2 Elimination Frequency)

Definition: fCO_2 represents the rate or frequency of carbon dioxide elimination derived from respiratory rate and capnography data.

Physiological Significance: It provides a trend of ventilation adequacy and CO_2 clearance over time.

Biomedical Relevance: fCO_2 accuracy depends on synchronized flow and $CO_2 sensortiming.Anydelayorr$

Key Biomedical Takeaway

Many advanced ventilator parameters are **derived values**, not directly measured quantities. Their accuracy relies on the correct calibration, synchronization, and performance of multiple sensors. Errors in a single sensor can propagate across multiple displayed parameters, potentially misleading clinical decisions.