BASICS OF WAVEFORM INTERPRETATION
Objectives

• Identify graphic display options provided by mechanical ventilators.

• Describe how to use graphics to adjust the patient ventilator interface.

• Interpret ventilator graphics to identify problems during mechanical ventilation.
Introduction

Monitoring and analysis of graphic display of curves and loops during mechanical ventilation has become a useful way to determine not only how patients are being ventilated, but also a way to assess problems occurring during ventilation.
Uses of Flow, Volume, and Pressure Graphic Displays

- Confirm mode functions.
- Detect auto-PEEP.
- Determine patient-ventilator synchrony.
- Assess and adjust trigger levels.
- Measure the work of breathing.
- Adjust tidal volume and minimize overdistension.
- Assess the effect of bronchodilator administration.
- Detect equipment malfunctions.
- Determine appropriate PEEP level.
Uses of Flow, Volume, and Pressure Graphic Displays

- Evaluate adequacy of inspiratory time in pressure control ventilation.
- Detect the presence and rate of continuous leaks.
- Assess inspiratory termination criterion during pressure support ventilation.
- Determine appropriate rise ime.
Measured Variables

Flow
Pressure
Volume
Time
Most Commonly Used Waveforms ( Scalars )

- Pressure-Time
- Flow-Time
- Volume-Time
Pressure-Time Scalar

\[ P_{aw} \text{ cm H}_2\text{O} \]

-10

30

Mean Airway Pressure

Baseline

A

B

C

PIP

Sec

1 2 3 4 5 6
Pressure-Time Scalar

$P_{aw}$

cm H$_2$O

Sec

Volume Ventilation

Pressure Ventilation
Patient Triggering

\[ P_{aw} \text{ cmH}_2\text{O} \]

-10 0 10 20 30

1 2 3 4 5 6

Sec
Patient Triggering

Excessive patient effort
Time Triggering

Pressure does NOT drop below baseline.
Adequate Flow During Volume-Control Ventilation

![Graph showing pressure over time with adequate flow indicated.]
Inadequate Flow During Volume-Control Ventilation
Patient-Ventilator Synchrony
Volume Ventilator Delivering a Preset Flow and Volume

Adequate Flow

\[ P_{aw} \text{ cm H}_2\text{O} \]

-20

1 2 3 4 5 6

Sec
Patient-Ventilator Dyssynchrony

The Patient Outbreathing the Set Flow

\[ P_{aw} \text{ cm H}_2\text{O} \]

Air Starvation

-20

Sec
Inadequate Plateau Time

Inadequate plateau time

$P_{aw}$ cm H$_2$O

SEC
Plateau Time

- Adequate plateau time
- Inadequate plateau time

\[ P_{aw} \text{ cm H}_2\text{O} \]

SEC
Flow-Time Scalar

- Inspiration
- Exhalation
Flow-Time Scalar

- Inspiration
- Expiration

**V**

LPM

SEC

INSPARATION

EXHALATION
Flow-Time Scalar

Constant Flow Descending Ramp

Inspiration

INSP

EXH

SEC

LPM

V

-120

120

1 2 3 4 5 6

1 2 3 4 5 6
Flow-Time Scalar

\[ \dot{V} \]

LPM

120

-120

1 2 3 4 5 6

SEC

INSP

Expiration

Insp. Pause

EXH
Inspiratory Time ($T_i$)

Short    Normal    Long
Expiratory Flow and Changes in Expiratory Resistance
Higher Expiratory Flow and Decreased $T_E$: Lower Expiratory Resistance
Obstructed Lung

Delayed flow return to baseline.
Pressure-Time and Flow-Time Scalars

Volume Ventilation

Expiration

\[ \text{P}_{\text{aw}} \]
\[ \text{cm H}_2\text{O} \]

\[ \dot{V} \]
Pressure-Time and Flow-Time Scalars
Different Inspiratory Flow Patterns

Volume Ventilation

Expiration

Inspiration

\( P_{aw} \) cm H\(_2\)O

\( \dot{V} \)

Sec
Pressure-Time and Flow-Time Scalars

- Volume Ventilation
- Pressure Ventilation
- Inspiratory Time

Parameters:
- $P_{aw}$ (cm H$_2$O)
- $V$ (Volume)
Rise Time

How quickly set pressure is reached.
Flow Acceleration Percent Rise Time

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Minimal Pressure Overshoot

Slow rise                      Moderate rise               Fast rise

Pressure Relief

Time
Patient-Ventilator Synchrony

Volume Ventilation Delivering a Preset Flow and Volume

\( P_{aw} \)
\( \text{cmH}_2\text{O} \)

Adequate Flow
**Patient-Ventilator Dyssynchrony**

The Patient Is Outbreathing the Set Flow

![Graph showing air starvation](image)
If Inspiratory Flow Remains Constant, $T_I$ Increases: Could Cause Asynchrony

Longer $T_I$ than with square wave flow pattern.
Increased Inspiratory Flow: Decreased $T_I$
Detecting Auto-PEEP

Zero flow at end exhalation indicates equilibration of lung and circuit pressures.

Note: There can still be pressure in the lung behind airways that are completely obstructed.
Detecting Auto-PEEP

The transition from expiratory to inspiratory occurs without the expiratory flow returning to zero.
Volume-Time Scalar

800 ml

VT

Inspiration

SEC

1 2 3 4 5 6
Volume-Time Scalar

Expiration

800 ml

\( V_T \)
Typical Volume-Time Scalar

A = inspiratory volume
B = expiratory volume

$V_T$ (Liters) vs. SECONDS

I-Time

E-Time
Leaks

A = exhalation that does not return to zero
Setting Appropriate $T_I$

![Graph showing tidal volume ($V_T$) and ventilation rate ($\dot{V}$) over time in seconds (SEC). The graph indicates a tidal volume of 450 ml at 1 second and a ventilation rate around 120 LPM at the same time.]
Setting Appropriate $T_I$

- $V_T$ values: 600 ml, 450 ml, 500 ml
- LPM values: 120 LPM, -120 LPM

Lost $V_T$
Loops

• Pressure-Volume Loops

• Flow-Volume Loops
Pressure-Volume Loop
Mandatory Breath

\[ P_{aw} \text{ cm H}_2\text{O} \]

\[ V_T \text{ LITERS} \]

Inspiration
Mandatory Breath

\[ P_{aw} \text{ cm H}_2\text{O} \]

\[ V_T \text{ LITERS} \]

Expiration

Inspiration

Counterclockwise
Spontaneous Breath

Inspiration

P_{aw} (cm H_{2}O)

V_{T} (LITERS)

Clockwise
Spontaneous Breath

Inspiration

Expiration

$P_{aw}$

cm H$_2$O

$V_T$

LITERS

Clockwise

-60  -40  -20  0  20  40  60

0  0.2  0.4  0.6
Work of Breathing
Patient-Triggered Breath

Paw (cm H₂O)

Vₜ (LITERS)

-60 -40 -20 0 20 40 60

0.2 0.4 0.6

Patient-Triggered Breath
Patient-Triggered Breath

\[ P_{aw} \text{ cm H}_2\text{O} \]

\[ V_T \text{ LITERS} \]

-60 -40 -20 0 20 40 60

Inspiration
Patient-Triggered Breath

Paw (cm H₂O)

VT (LITERS)

Expiration

Inspiration

Clockwise to Counterclockwise
Pressure-Volume Loop Changes
Changes in Compliances

Indicates a drop in compliance (higher pressure for the same volume).
Overdistension

A = inspiratory pressure
B = upper inflection point
C = lower inflection point
Lung Overdistension

Duck bill (beak)
Flow-Volume Loops
Volume Control
ETT or Circuit Leaks
Obstructive Pattern
Bronchodilator Response

BEFORE

INSPIRATION

EXHALATION

V
LPS

V
LPS
Bronchodilator Response

BEFORE

AFTER

Worse

INSPIRATION

EXHALATION
Bronchodilator Response

**BEFORE**

**AFTER**

**Worse**

**Better**

**INSPIRATION**

**EXHALATION**
Remember!

Waveforms and loops are graphical representation of the data generated by the ventilator.

Typical Tracings
- Pressure-time,
- Flow-time,
- Volume -time

Loops
- Pressure-Volume
- Flow-Volume

Assessment of pressure, flow and volume waveforms is a critical tool in the management of the mechanically ventilated patient.
Volume-Controlled Ventilation
Pressure support breath
No return to baseline

Air trapping
Inspiration

Flow

Volume

Expiration

Normal

Abnormal
\[ \dot{V}_{CO_2} \]

\[ \dot{V}_A = \dot{V}_E - \dot{V}_D \]

\[ \dot{V}_T \]

\[ f \]

\[ T_i \]

\[ T_E \]