Ventilator Waveforms

Explanations for questions 1-8 please refer to tables on next page

Table 1: from Hamilton Medical

Table 2: A Taxonomy for Patient-Ventilator Interactions and a Method to Read. Respir Care 2022;67(1):129–148.

1) C
2) C
3) B
4) B
5) A
6) B
7) A
8) A
9) A

The inspiratory pause shows loss of pressure, the P-V and the F-V curves shows loss of volume, all secondary to airleak (from ETT, Ventilator circuit, Broncho-pleural fistula)

10) B

The oscillations seen both during inspiration and expiration are usually secondary to fluids in the airways secondary to secretions or fluid condensation in the ventilator circuit
## Patient-ventilator asynchrony reference card

### Trigger asynchronies - during the beginning of inspiration

<table>
<thead>
<tr>
<th>Asynchrony</th>
<th>Description</th>
<th>On the waveform</th>
<th>Waveform example</th>
<th>Common possible causes</th>
</tr>
</thead>
</table>
| Delayed triggering    | The time interval between the patient's inspiratory effort and the delivery of a mechanical breath is increased | **Flow** waveform: Look for a longer-than-normal time interval between the positive deflection in flow and the delivery of ventilatory support. | ![Waveform example](https://via.placeholder.com/150) | Trigger threshold set too high  
Ventilator pneumatics  
Presence of AutoPEEP  
Low respiratory drive  
Weak inspiratory effort |
| Ineffective effort    | The patient's inspiratory effort fails to trigger the delivery of a mechanical breath | **Flow** waveform: Look for an abrupt change in the steepness of the waveform (decrease in expiratory flow or increase in inspiratory flow) that is not followed by ventilatory support. | ![Waveform example](https://via.placeholder.com/150) | Trigger threshold set too high  
Pressure support too high  
Set frequency and/or inspiratory time too high (in controlled modes)  
Tidal volume set too high  
Presence of AutoPEEP  
Low respiratory drive  
Weak inspiratory effort  
Sedation |
| Auto triggering       | A mechanical breath delivered without an inspiratory effort                  | **Pressure** waveform: Look for a delivered mechanical breath showing no drop in airway pressure at the beginning of the inspiratory phase. | ![Waveform example](https://via.placeholder.com/150) | Trigger threshold set too low  
Air leaks in the endotracheal tube cuff, ventilator circuit, or chest tube  
Flow oscillations (water or secession in the circuit, cardiac oscillations) |

### Flow asynchronies - during the gas delivery

<table>
<thead>
<tr>
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<th>Waveform example</th>
<th>Common possible causes</th>
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</thead>
</table>
| Flow asynchrony       | The delivered flow does not meet the patient's inspiratory flow demands     | **Pressure** waveform: Look for an upward concavity preceding the end of the mechanical breath. | ![Waveform example](https://via.placeholder.com/150) | Inappropriate selection of ventilation mode (more frequent in volume-controlled modes)  
High inspiratory effort  
In volume-controlled modes:  
Inappropriate flow settings  
In pressure-controlled modes:  
Inappropriate P-ramp settings |

### Termination asynchronies - during the end of inspiration

<table>
<thead>
<tr>
<th>Asynchrony</th>
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<th>On the waveform</th>
<th>Waveform example</th>
<th>Common possible causes</th>
</tr>
</thead>
</table>
| Double triggering     | Two (or more) mechanical breaths are delivered during one single inspiratory effort | **Flow** waveform: Look for two assisted breaths without expiration between them or with an expiration interval of less than half of the mean inspiratory time (often visually displayed as a waveform with two inspiratory peaks). | ![Waveform example](https://via.placeholder.com/150) | Cycling criteria (ETS) set too high  
Pressure support too low  
P-ramp too short  
Flow starvation  
High respiratory drive  
Time constant too short  
Double triggering can be an effect of and/or promoted by reverse triggering or early cycling |
| Early cycling         | The duration of the mechanical breath is shorter than the duration of the patient's inspiratory effort | **Flow** waveform: Look for a small bump at the beginning of expiration (after peak expiratory flow) followed by an abrupt initial reversal in the expiratory flow. | ![Waveform example](https://via.placeholder.com/150) | In pressure support ventilation:  
Cycling criteria (ETS) set too high  
Low levels of ventilator pressure support  
Time constant too short  
In time-cycled ventilation:  
Short inspiratory time |
| Delayed cycling       | The duration of the mechanical breath is longer than the duration of the patient's inspiratory effort | **Flow** waveform: Look for a change in the slope of the inspiratory flow: a fast decrease followed by an exponential (less steep) decline. | ![Waveform example](https://via.placeholder.com/150) | In pressure support ventilation:  
Cycling criteria (ETS) set too low  
Pressure support too high  
P-ramp too long  
In pressure control ventilation:  
Cycling criteria (ETS) set too low  
Inspiratory time too long  
In volume control ventilation:  
Low flow  
Long inspiratory time  
High tidal volume |
<table>
<thead>
<tr>
<th>Phase</th>
<th>Patient-Ventilator Interactions Taxonomy</th>
<th>Other Names in Literature</th>
<th>Definition</th>
<th>What to Look for</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trigger</td>
<td>Normal</td>
<td>Reverse trigger, Early inflation</td>
<td>The beginning of a patient effort triggers inspiration within an acceptable timeframe (eg, 100 ms⁻¹).</td>
<td>Immediate elevation of pressure above baseline after patient trigger signal.</td>
</tr>
<tr>
<td></td>
<td>Early</td>
<td>Trigger delay, Late inflation</td>
<td>When a machine-triggered inspiration precedes patient effort. Patient effort may occur at any phase of inspiration or early expiration (to differentiate from failed trigger).</td>
<td>Machine breath followed by evidence of $P_{max}$.</td>
</tr>
<tr>
<td></td>
<td>False</td>
<td>Auto trigger, Auto cycling</td>
<td>A nonpatient (eg, non-$P_{max}$) signal triggers inspiration.</td>
<td>Airway pressure drops below baseline or flow crosses, $&gt;100$ ms before triggering breath.</td>
</tr>
<tr>
<td>Failed</td>
<td>Ineffective triggering, Ineffective effort, Missed trigger, Wasted efforts</td>
<td>When a patient signal (eg, $P_{max}$) fails to trigger inspiration.</td>
<td>Airway pressure drops below baseline or flow moves toward baseline without triggering a machine breath.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Inspiration Normal</td>
<td>Passive (no inspiratory effort)</td>
<td>No major evidence of $P_{max}$ during inspiration; breath may be patient triggered, but $P_{max}$ does not deform expected waveform.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Work shifting</td>
<td>Flow starvation, Flow asynchrony, Flow limited, Insufficient flow</td>
<td>Some portion of the total work is done by the ventilator and some by the patient. Severe work shifting occurs when the inspiratory pressure drops below the baseline (PEEP).</td>
<td>Work shifting: flow or pressure waveform deformations consistent with $P_{max}$. If airway pressure during inspiration drops below baseline, this is consistent with severe work shifting. When pressure is above baseline, it is likely clinically acceptable.</td>
</tr>
<tr>
<td>Cycle</td>
<td>Normal</td>
<td>Inspiration ends within an acceptable time after $P_{max}$ peaks.</td>
<td>Flow is deformed by presence of $P_{max}$. Transition from inspiratory to expiratory flow occurs without evidence of end-inspiratory zero flow or evidence of inspiratory $P_{max}$ during early exhalation.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Early</td>
<td>Premature cycling, Premature ventilator-terminated breath, Premature termination, Short cycling</td>
<td>When inspiration ends before the end of patient effort ($P_{max}$ peak).</td>
<td>Early expiratory flow demonstrates evidence of inspiratory effort ($P_{max}$); flow waveform is deviated toward baseline.</td>
</tr>
<tr>
<td></td>
<td>Late</td>
<td>Prolonged cycling, Delayed cycling, Runaway phenomena, Delayed termination</td>
<td>When the inspiration cycles after the end of patient effort (delay after the $P_{max}$ peak).</td>
<td>In a patient with inspiratory $P_{max}$, the end-inspiratory flow demonstrates zero flow with or without concomitant increase in airway pressure.</td>
</tr>
<tr>
<td>Expiration</td>
<td>Normal</td>
<td>Passive (no expiratory effort)</td>
<td>Exponential decay of the flow waveform.</td>
<td>The flow waveform moves away from baseline.</td>
</tr>
<tr>
<td>Expiratory work</td>
<td>None</td>
<td>Evidence of increased expiratory flow compared to passive expiration.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>