Assessment and Management of the Mechanically Ventilated Patient

Patient-Ventilator Dysynchrony in CMV-Volume

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Assessment of the Mechanically Ventilated Patient

- Resistance
- Compliance
- Gas Exchange
- Patient-Ventilator Synchrony
- Ventilator Rehabilitation / Discontinuation
- Pulmonary Hygiene
- Airway Management

Faculty Disclosures

- Clinical simulation & presentation author for IngMar Medical
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- Unless cited, the contents and conclusions of the following presentation are solely those of the speaker

Patient-Ventilator Dysynchrony

- Analyzed esophageal pressure waveforms of 11 patients (3 with COPD)
- 9 patients (82%) demonstrated ineffective efforts in 2-40% of all breaths
- 7 patients had substantial dysynchrony
  - Defined as $\geq$ 10% of breaths untriggered
- 10% failed efforts threshold (or index) was subsequently adopted by investigators as the indicator of substantial dysynchrony

Fabry, et al. Chest 1995;107(5):1387-1394
An analysis of desynchronization between the spontaneously breathing patient and ventilator during inspiratory pressure support

- 24 patients with various causes of acute respiratory failure on PSV with esophageal pressure measurements
- 13 patients (54%) demonstrated ineffective efforts
  - 30% of ARDS patients
  - 40% of surgical patients
  - 60% of COPD patients
  - 100% of COPD patients with C_{ST} > 88 ml/cmH_2O

Nava, et al. Eur Respir J 1997;10(1):177-183
Patient-ventilator interaction and inspiratory effort during pressure support ventilation in patients with different pathologies

- 20 patients with ALI who were ventilated using the ARDS network strategy
- Double-triggers occurred in 9.7% of all breaths at an average of 2.3/minute
- More than 3 double-triggered breaths/minute occurred in 33% of the study population
- More than 6 double-triggered breaths/minute for longer than 12 hours occurred in 45% of the patients

Pohlman, et al. Crit Care Med 2008;36(11):3019-3023
Excessive tidal volume from breath stacking during lung-protective ventilation for acute lung injury

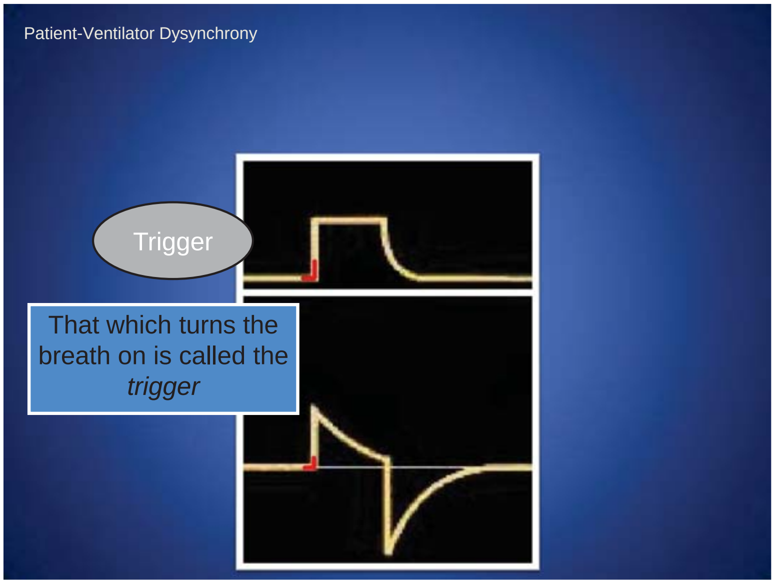
- 62 patients with acute respiratory failure on PSV and VC-CMV
  - PSV set to yield a V_T of 6-8 ml/kg and RR < 30 and cycle at 25%
  - VC-CMV set at V_T 6-8 ml/kg and flow of 60 L/m
- Pressure-time and flow-time graphics were analyzed by two blinded investigators
- Median of 2.1 dysynchronous breaths per minute
  - 85% were ineffective efforts
  - 13% were double-triggered breaths
  - Remainder were auto-triggering and delayed cycling
- 15 patients (24%) had a dysynchrony index > 10%

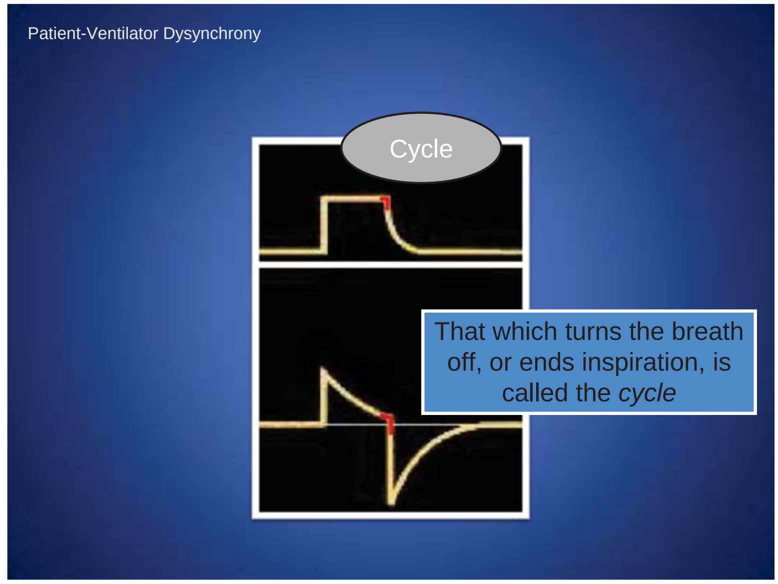
Thille, et al. Intensive Care Med 2006;32(10):1515-1522
Patient-ventilator synchrony during assisted mechanical ventilation

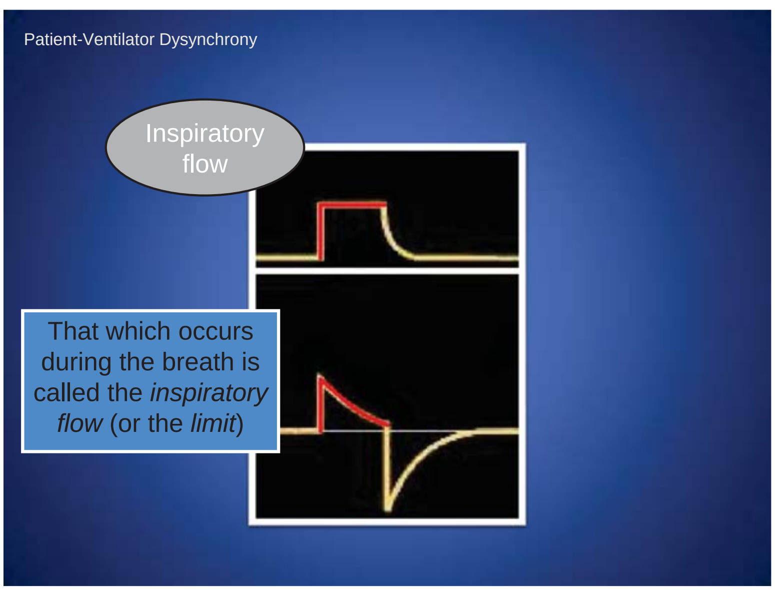
Patient-ventilator asychrony is common, and its prevalence depends on numerous factors, including…..patient population; type of asynchrony; ventilation mode and settings; and confounding factors (eg, state of wakefulness, sedation).

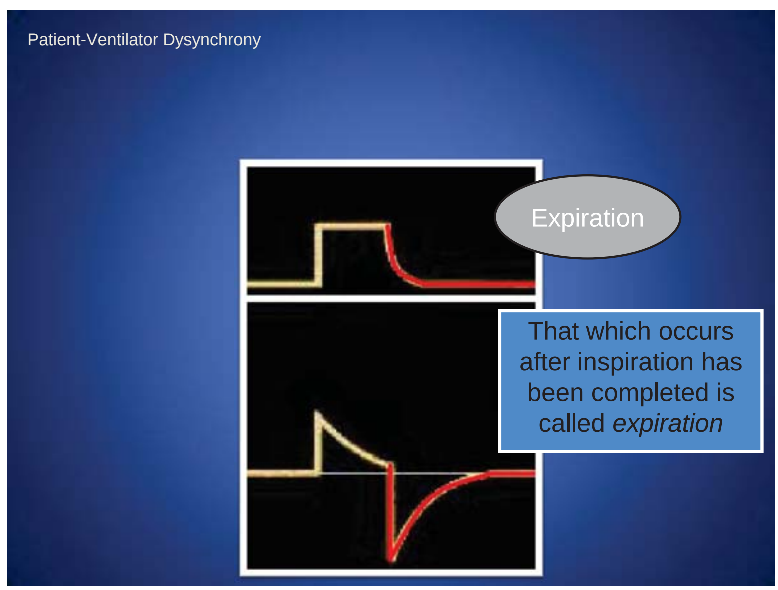
Patient-ventilator asynchrony (may possibly be) associated with adverse (outcomes), including increased/wasted WOB, discomfort, increased need for sedation, confusion during the weaning process, prolonged mechanical ventilation, longer ICU and hospital stay, and possibly higher mortality

Epstein, Scott. Resp Care 2011;56(1):33.
How often does patient-ventilator asynchrony occur and what are the consequences?


Patient-Ventilator Dysynchrony
Trigger
That which turns the breath on is called the *trigger*


Patient-Ventilator Dysynchrony
Cycle
That which turns the breath off, or ends inspiration, is called the *cycle*


Patient-Ventilator Dysynchrony
Inspiratory flow
That which occurs during the breath is called the *inspiratory flow* (or the *limit*)


Patient-Ventilator Dysynchrony
Expiration
That which occurs after inspiration has been completed is called *expiration*

Patient-Ventilator Dysynchrony

Inspiratory dysynchrony

Cycle dysynchrony

Trigger dysynchrony

Expiratory dysynchrony

Continuous Spontaneous Ventilation

Trigger dysynchrony

Inspiratory dysynchrony

Cycle dysynchrony

Expiratory dysynchrony

CSV Pressure Support

CSV Volume-Targeted Pressure

Continuous Mandatory Ventilation

CMV Volume

CMV Pressure

CMV Volume-Targeted Pressure

Trigger dysynchrony

Inspiratory dysynchrony

Cycle dysynchrony

Expiratory dysynchrony

Patient-Ventilator Dysynchrony

CMV Volume

Trigger dysynchrony

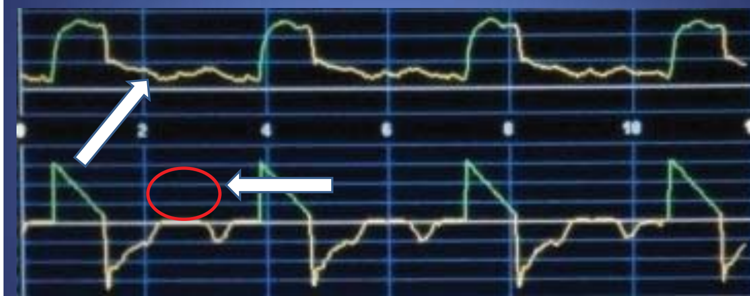
Ineffective trigger

Trigger Dysynchrony

- Ineffective trigger
  - Most common form of dysynchrony in which the patient's inspiratory effort fails to trigger the ventilator and is not rewarded with a breath
  - Also called:
    - Ineffective efforts
    - Untriggered breaths

Trigger Dysynchrony

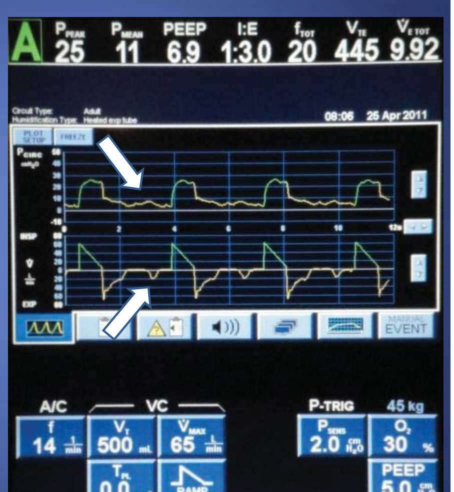
Recognizing ineffective efforts



- When the patient begins the inspiratory effort, the pressure decreases slightly
- The ventilator doesn't detect the drop in pressure to initiate an assisted breath, detectable by a lack of inspiratory flow

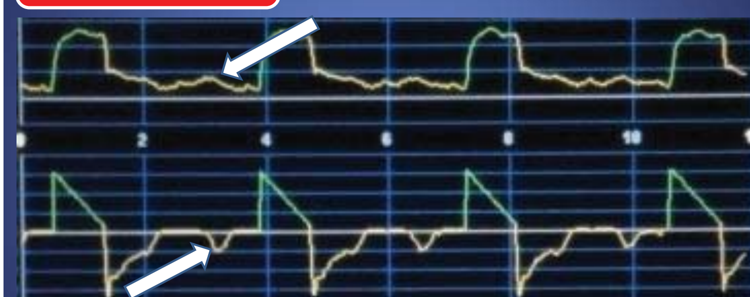
Trigger Dysynchrony

Recognizing ineffective efforts



Trigger Dysynchrony

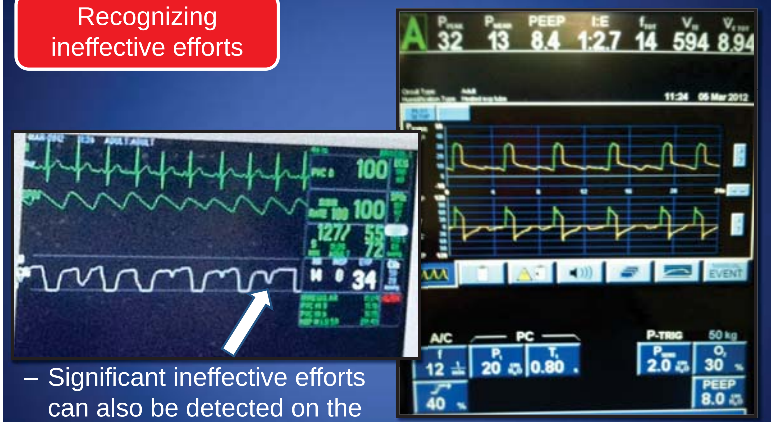
Recognizing ineffective efforts



- When the patient finishes the inspiratory effort and effectively exhales out, the pressure begins to increase
- Flow exits the patient's lung and travels towards the expiratory valve, observed on the expiratory arm of the flow-time scalar

Trigger Dysynchrony

Recognizing ineffective efforts

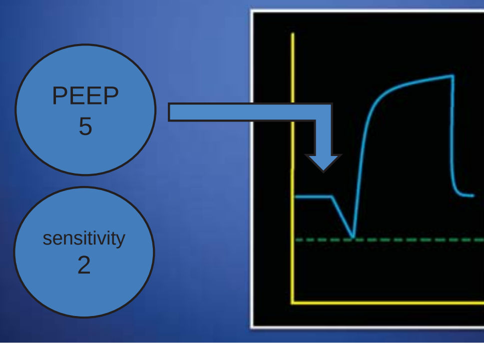


– Significant ineffective efforts can also be detected on the capnograph

Trigger Dysynchrony

Correcting ineffective efforts

- The ventilator's trigger mechanism is mathematically / numerically based on the actual PEEP setting and that sensitivity which is set



Trigger Dysynchrony

Clinical implications of ineffective efforts

– Ineffective efforts result in an increased work of breathing on the patient's behalf
  – This is due to the patient's employment of muscles of inspiration to expand the thoracic cage in an effort to initiate a breath

– Ineffective efforts can also result in a phenomenon of breathlessness and agitation because of the undelivered breath

Trigger Dysynchrony

Correcting ineffective efforts

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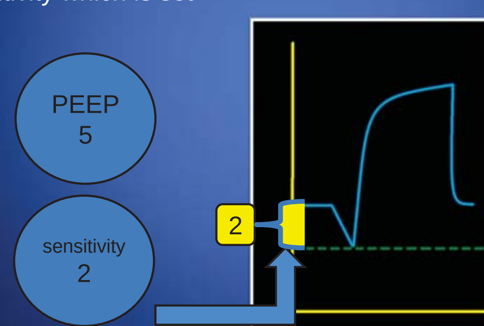


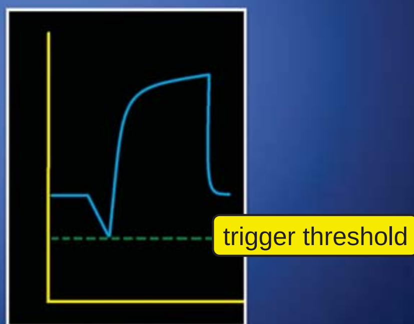
Trigger Dysynchrony

Correcting ineffective efforts

- The ventilator's trigger mechanism is mathematically / numerically based on the actual PEEP setting and that sensitivity which is set

PEEP
5

sensitivity
2



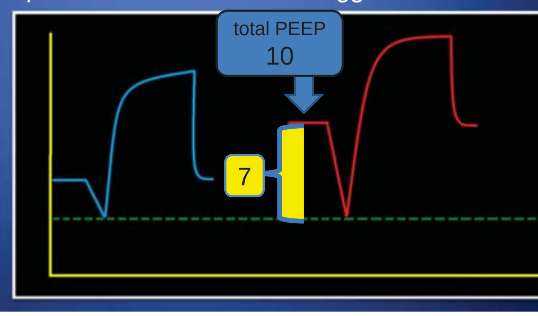
Trigger Dysynchrony

Correcting ineffective efforts

- Ineffective efforts often come in the presence of unintentional PEEP or auto-PEEP because the ventilator "does not know about the auto-PEEP" and still requires the patient to alter the pressure to the "pre-auto-PEEP levels" to trigger a breath

PEEP
5

sensitivity
2



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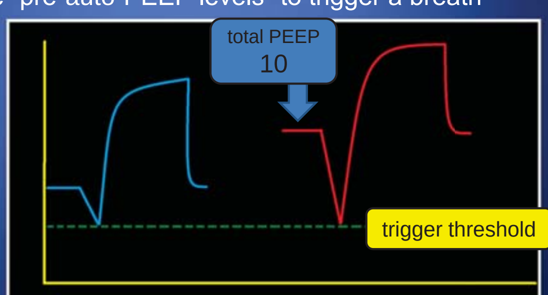
PEEP
5

sensitivity
2



Trigger Dysynchrony

Correcting ineffective efforts

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PEEP
5

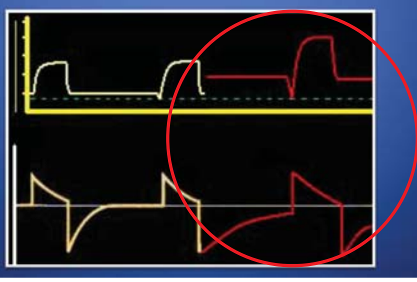
Flow-trigger
2

- Ineffective efforts occur when utilizing a flow trigger much the same way except…..
  - If there is no drop in pressure when the patient initiates the inspiratory effort then there will not be any flow taken from the bias flow in the circuit

Trigger Dysynchrony

Correcting ineffective efforts

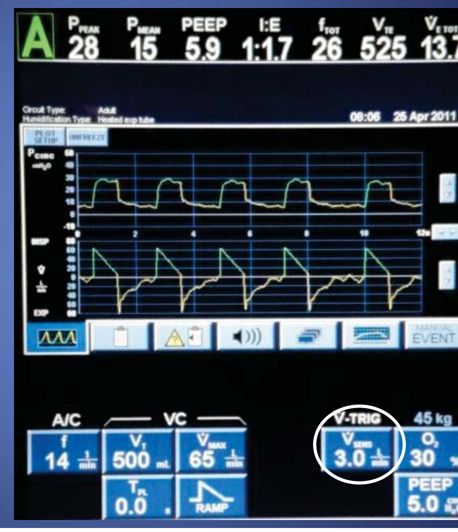
1) If ineffective efforts are due to air trapping and the development of auto-PEEP, then the cause of air trapping (obstruction to expiratory flow or inappropriate ventilator settings) must be identified and corrected



Trigger Dysynchrony

Correcting ineffective efforts

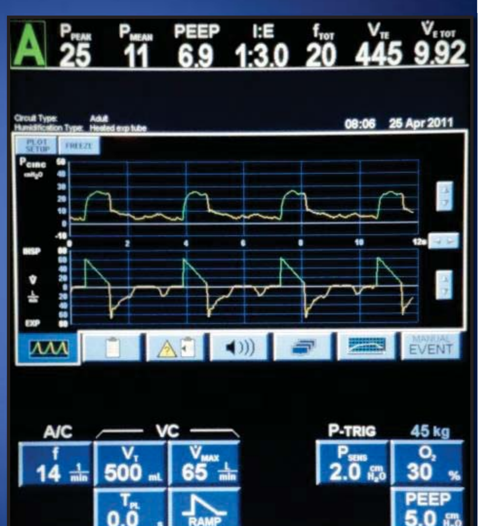
2) Correcting ineffective efforts due to inappropriate trigger setting



Trigger Dysynchrony

Correcting ineffective efforts

2) Correcting ineffective efforts due to inappropriate trigger setting



Patient-Ventilator Dysynchrony

CMV Volume

Trigger dysynchrony

Auto-trigger

Trigger Dysynchrony

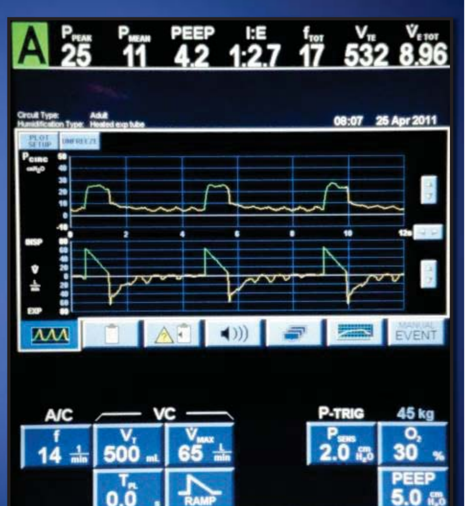
- Auto-triggering
  - An unscheduled or unintended machine-delivered breath that occurs in the absence of respiratory muscle contraction (by way of neural stimulation)
  - Etiologies include
    - Cardiac oscillation
    - Hiccups
    - Leaks in the circuit
    - Water in the circuit

Trigger Dysynchrony

Recognizing auto-triggering

Trigger Dysynchrony

Recognizing auto-triggering



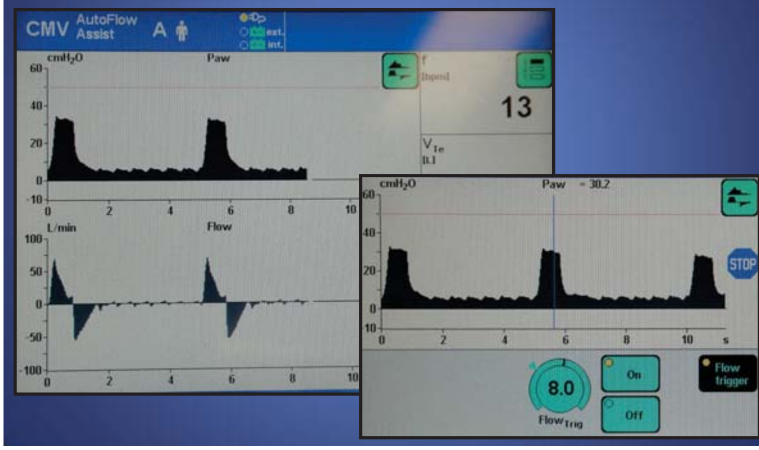
Trigger Dysynchrony

Clinical implications of auto-triggeirng

– Auto-triggering can result in a respiratory alkalosis due to the delivery of undesired or unnecessary ventilation

Trigger Dysynchrony

Correcting auto-triggering



CMV Volume

Trigger dysynchrony

– Ineffective efforts

1) Correct air-trapping

2) Adjust the triggering mechanism

– Auto-triggering

1) Adjust the triggering mechanism

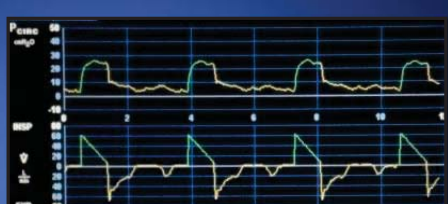
– Double-triggering

Not a trigger dysynchrony, but actually a cycle dysynchrony and will be covered in that section

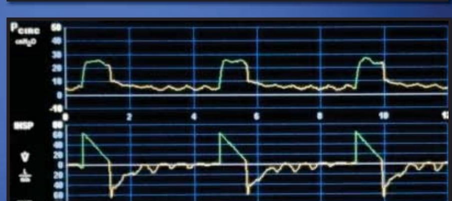
CMV Volume

Trigger dysynchrony

– Ineffective efforts



– Auto-triggering



Patient-Ventilator Dysynchrony

CMV Volume

Inspiratory dysynchrony

Inadequate flow

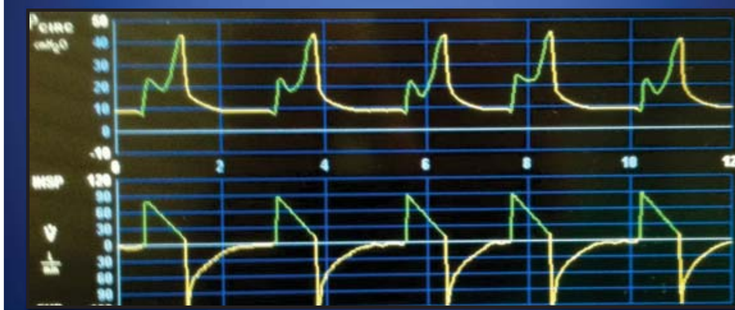
Inspiratory Dysynchrony

Recognizing inadequate flow

- There should be a linear rise in the peak pressure that nearly plateaus, forming a nearly square pressure waveform

Inspiratory Dysynchrony

Clinical implications of inadequate flow



Inspiratory Dysynchrony

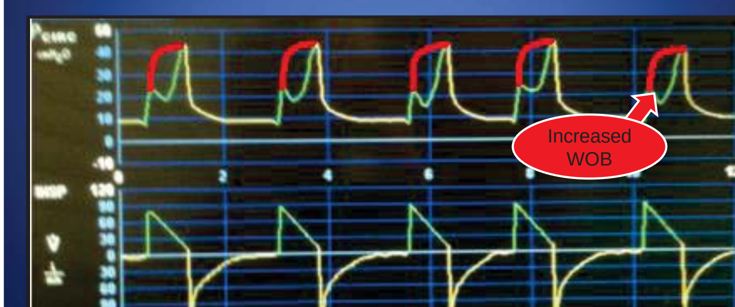
Recognizing inadequate flow

- The non-linear rise in pressure indicates that a higher initial peak flow is needed to keep pace with the patient's initial flow demands

Inspiratory Dysynchrony

Clinical implications of inadequate flow

- The clinical implication of continued inadequate flow is an increased WOB (the area under the reference curve)



- In addition, there is an phenomenon of breathlessness

Inspiratory Dysynchrony

Correcting inadequate flow

- If inadequate flow is recognized while using CMV Volume, it is corrected by increasing the peak inspiratory flow rate (on a ventilator with set peak flow)

Patient-Ventilator Dysynchrony

CMV Volume

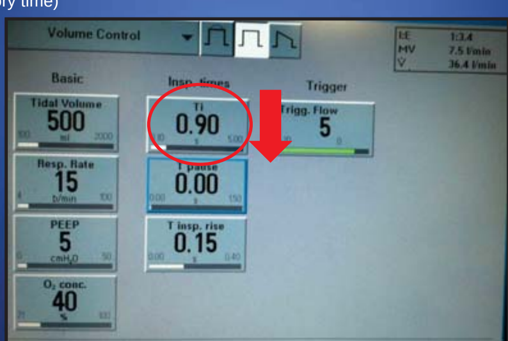
Inspiratory dysynchrony

Excessive flow

Inspiratory Dysynchrony

Correcting inadequate flow

- If inadequate flow is recognized while using CMV Volume, it is corrected by decreasing the inspiratory time (on a ventilator with set inspiratory time)



Inspiratory Dysynchrony

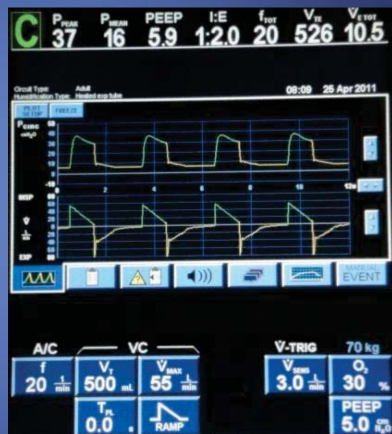
Recognizing excessive flow

- Excessive flow
  - The peak inspiratory flow can also be set too high with regards to a patient's demand
- If the peak inspiratory flow is set too high with regards to a patient's demand, there is spike observed on the left side of an individual pressure-time scalar

Inspiratory Dysynchrony

Clinical implications of excessive flow

- Excessive flow will cause preferential distribution of volume predominantly to independent lung zones or areas of least resistance



Inspiratory Dysynchrony

Correcting excessive flow

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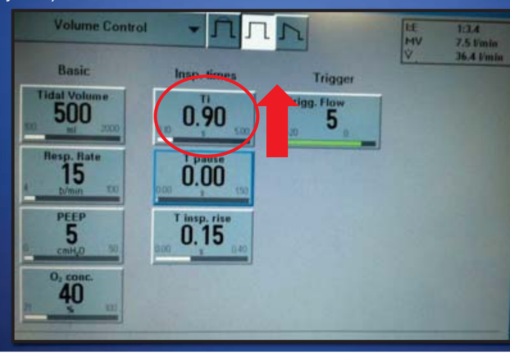

Inspiratory Dysynchrony

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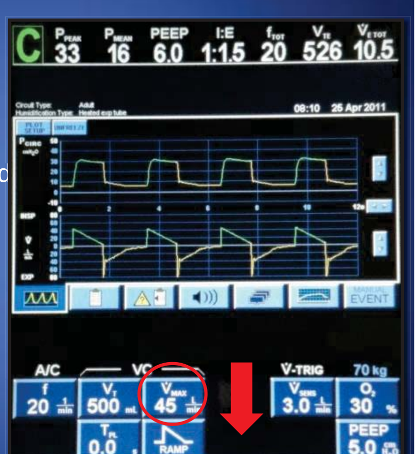
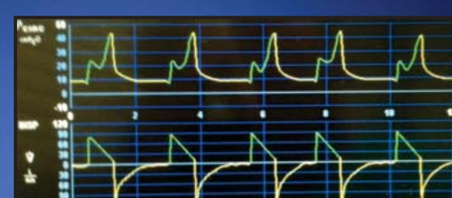


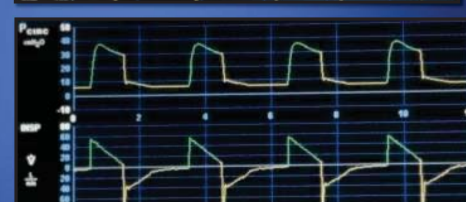
CMV Volume

Inspiratory dysynchrony

- Inadequate flow



- Excessive flow



CMV Volume

Inspiratory dysynchrony

- Inadequate flow

1) Increase inspiratory flow

2) Decrease inspiratory time

- Excessive flow

1) Decrease inspiratory flow

2) Increase inspiratory time

Cycle Dysynchrony

Recognizing premature cycling

- Premature cycling or "double-triggering"
  - Caused by a dysynchrony between the patient's neural inspiratory time and the ventilator's inspiratory time
    1. The ventilator has cycled the inspiratory phase (delivered the set volume)
    2. However, the patient continues to inspire and expand their thoracic cage
    3. The pressure / flow in the circuit is thereby decreased and an additional breath is triggered without exhaling the previous

Patient-Ventilator Dysynchrony

CMV Volume

Cycle dysynchrony

Premature cycling

Cycle Dysynchrony

Recognizing premature cycling

- In addition to the graphical presentation used to identify premature cycling, the exhaled V_T will read 0 ml for the breaths that were not exhaled followed by a "doubled volume"

Cycle Dysynchrony

Recognizing premature cycling

- In addition to the graphical presentation used to identify premature cycling, the exhaled V_T will read 0 ml for the breaths that were not exhaled followed by a “doubled volume”

Cycle Dysynchrony

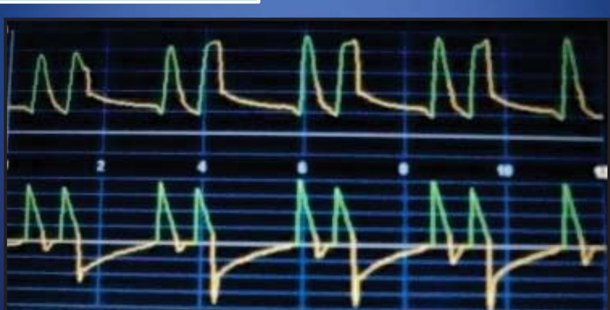
Recognizing premature cycling

moderate cycle dysynchrony

Cycle Dysynchrony

Recognizing premature cycling

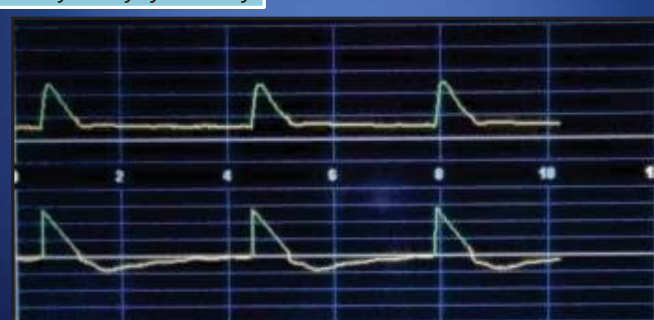
severe cycle dysynchrony

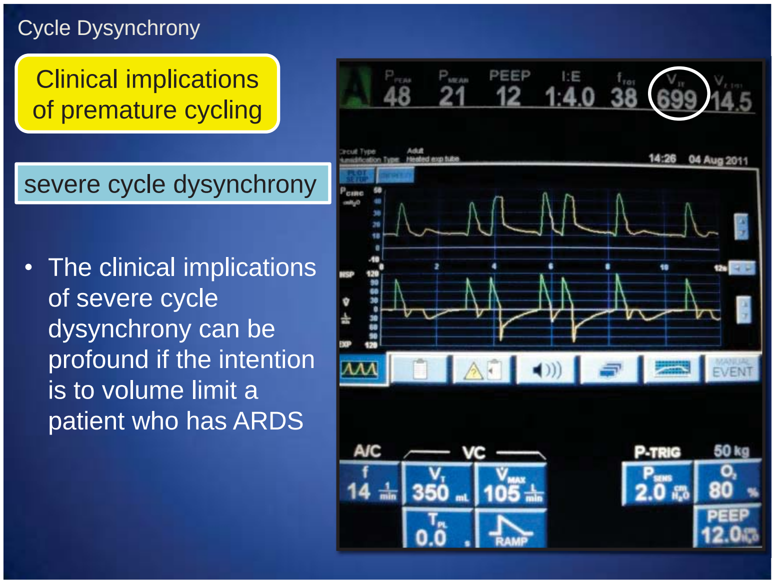
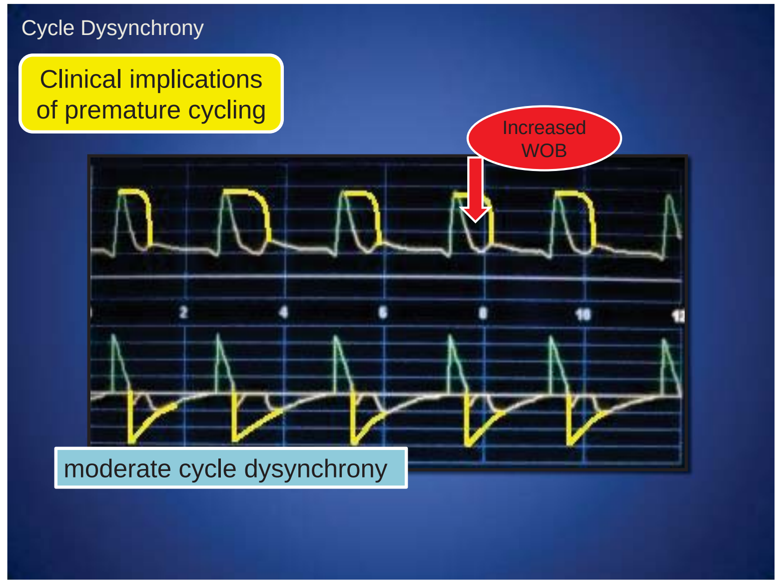
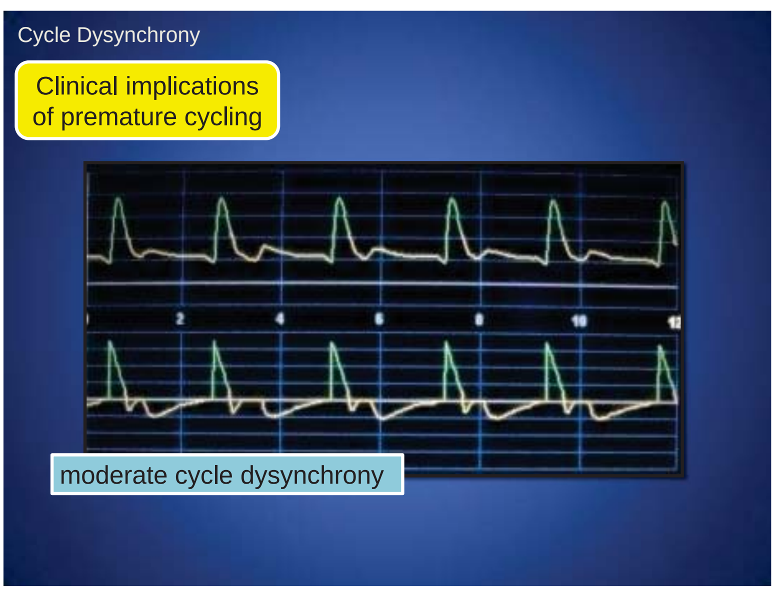


Cycle Dysynchrony

Recognizing premature cycling

mild cycle dysynchrony




Cycle Dysynchrony
Clinical implications of premature cycling
severe cycle dysynchrony
• The clinical implications of severe cycle dysynchrony can be profound if the intention is to volume limit a patient who has ARDS
PEEP
I:E
48
21
12
1:4.0
38
699
14.5
14:26 04 Aug 2011
A/C
VC
P-TRIG
50 kg
14
350
105
2.0
80
0.0
RAMP
PEEP
12.0
MANUAL EVENT

Cycle Dysynchrony
Clinical implications of premature cycling
Increased WOB
moderate cycle dysynchrony

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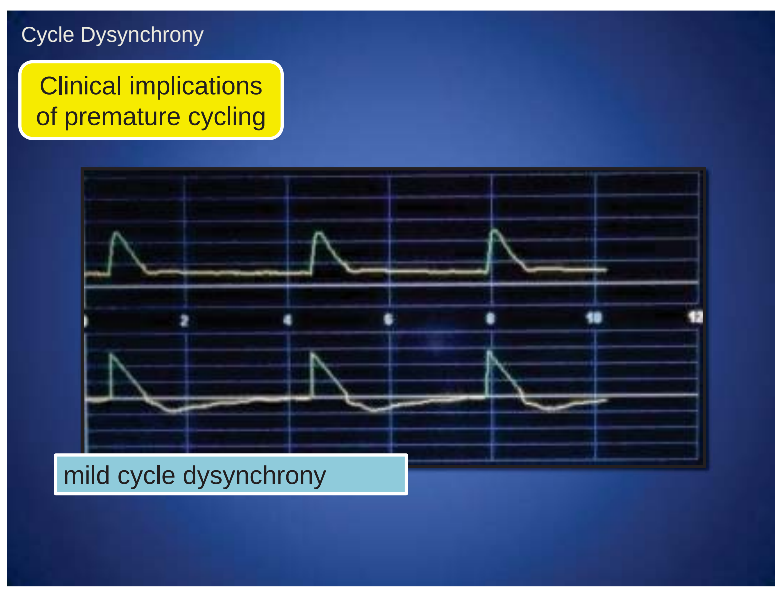
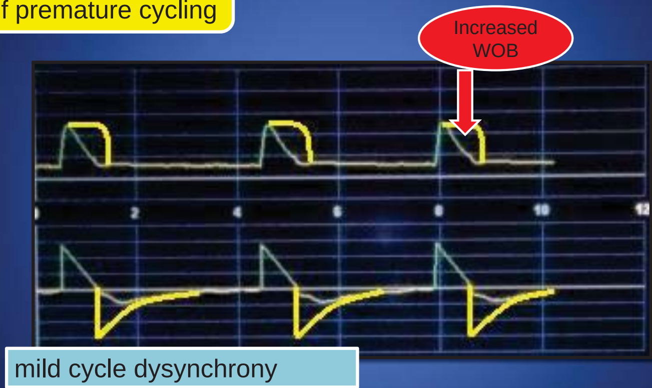

Cycle Dysynchrony
Clinical implications of premature cycling
mild cycle dysynchrony

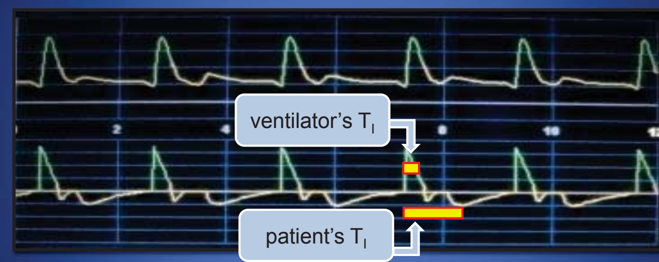
Cycle Dysynchrony

Clinical implications of premature cycling



Cycle Dysynchrony

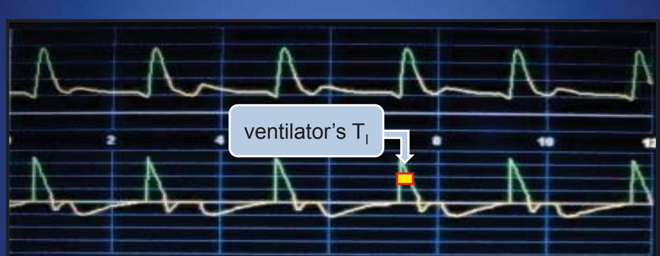
Correcting premature cycling



- The inherent problem in a cycle dysynchrony is that the ventilator's inspiratory time is shorter than the patient's inspiratory time

Cycle Dysynchrony

Correcting premature cycling



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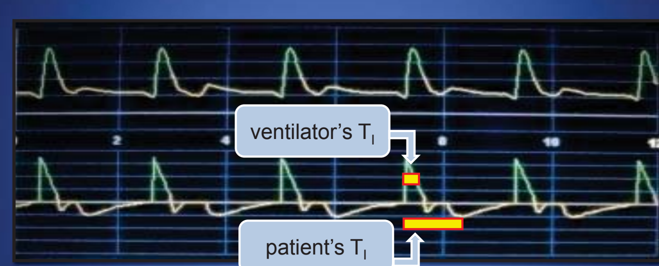
Cycle Dysynchrony

Correcting premature cycling

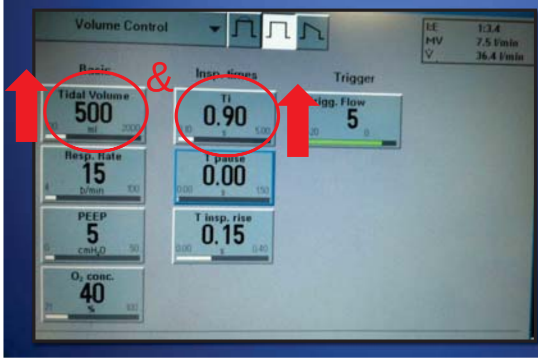


- To correct the problem, the ventilator's inspiratory time needs to be lengthened to match the patient's neural inspiratory time
- In CMV Volume, the flow can be decreased OR
- In CMV Volume, the volume can be increased (on a ventilator with set peak flow)

Cycle Dysynchrony

Correcting premature cycling

- To correct premature cycling on a ventilator with a set inspiratory time, <u>the volume AND the inspiratory time</u> should be increased



- If the inspiratory time alone is increased and volume left constant, the inspiratory flow would decrease (and possibly result in inspiratory dysynchrony

Cycle Dysynchrony

Recognizing delayed cycling

- The cycling criteria (delivered volume) produces an inspiratory time that is longer than the patients neural inspiratory time
  - The patient begins to exhale against an incoming volume delivery and a pressure spike is created at the end of inspiration

Patient-Ventilator Dysynchrony

CMV Volume

Cycle dysynchrony

Delayed cycling

Cycle Dysynchrony

Clinical implications of delayed cycling

- A patient exhaling against a significant positive pressure, in this case the peak inspiratory pressure, will incur a work of breathing

Cycle Dysynchrony

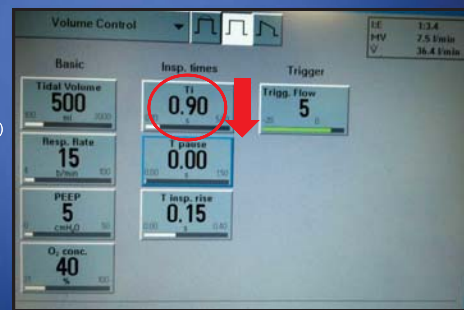
Correcting delayed cycling

- To correct delayed cycling the ventilator's inspiratory time must be shortened to match the patient's inspiratory time
- In CMV Volume, the inspiratory flow can be increased

Cycle Dysynchrony

Correcting delayed cycling

- To correct delayed cycling the ventilator's inspiratory time must be shortened to match the patient's inspiratory time
- In CMV Volume, the inspiratory time can be decreased (on a ventilator with set inspiratory time)



Cycle Dysynchrony

Correcting delayed cycling

- To correct delayed cycling the ventilator's inspiratory time must be shortened to match the patient's inspiratory time
- In CMV Volume, the inspiratory flow can be increased (on a ventilator with set peak flow)

Cycle Dysynchrony

Correcting delayed cycling

- To correct delayed cycling the ventilator's inspiratory time must be shortened to match the patient's inspiratory time
- In CMV Volume, the inspiratory flow can be increased

OR

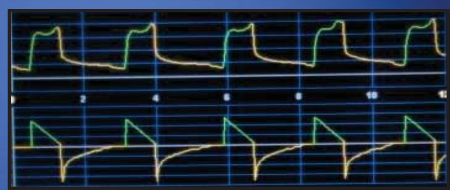
- In CMV Volume, the tidal volume may be decreased (on a ventilator with set peak flow)

CMV Volume

Cycle dysynchrony

- Premature cycling

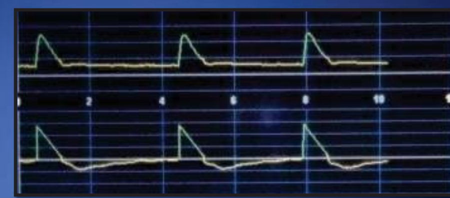
- Delayed cycling



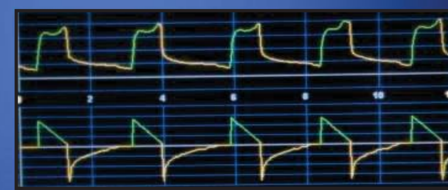
CMV Volume

Cycle dysynchrony

- Premature cycling



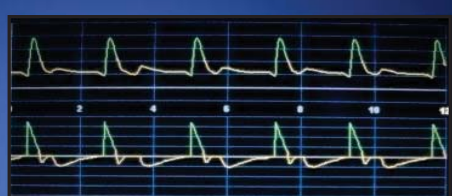
- Delayed cycling



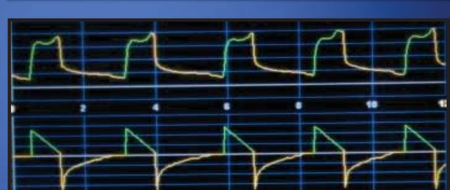
CMV Volume

Cycle dysynchrony

- Premature cycling



- Delayed cycling



CMV Volume

Cycle dysynchrony

- Premature cycling

1) Increase volume

2) Decrease inspiratory flow

- Delayed cycling

1) Decrease inspiratory flow

2) Increase inspiratory time

Patient-Ventilator Dysynchrony

CMV Volume

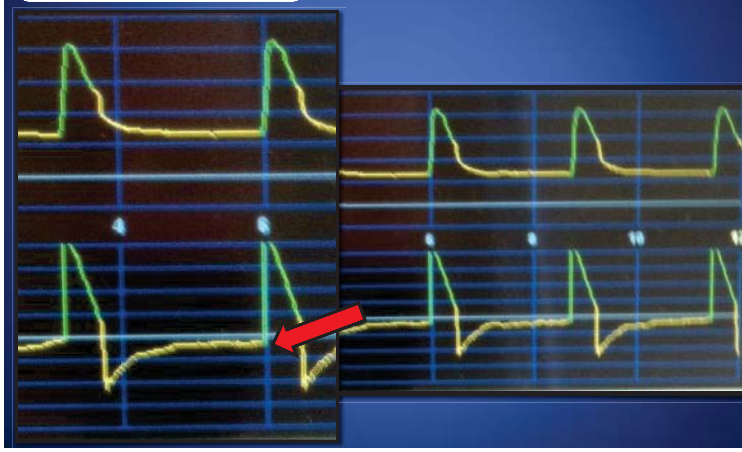
Expiratory dysynchrony

Air-trapping

Expiratory Dysynchrony

Recognizing air-trapping/auto-PEEP

- If expiratory flow does not return to baseline, air-trapping is present



Expiratory Dysynchrony

Recognizing air-trapping/auto-PEEP

- An expiratory hold can be performed to measure auto-PEEP
- Air-trapping or auto-PEEP can be difficult to measure quantitatively in the clinical setting

Expiratory Dysynchrony

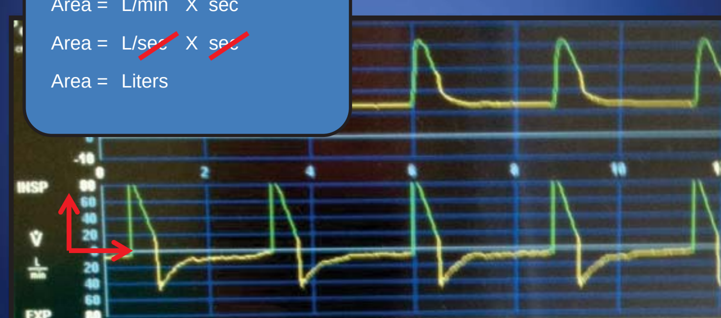
Recognizing air-trapping/auto-PEEP

- If the area under the expiratory flow curve is less than that of the inspiratory flow, then a degree of air trapping is present

Area = L/min X sec

Area = L/~~sec~~ X ~~sec~~

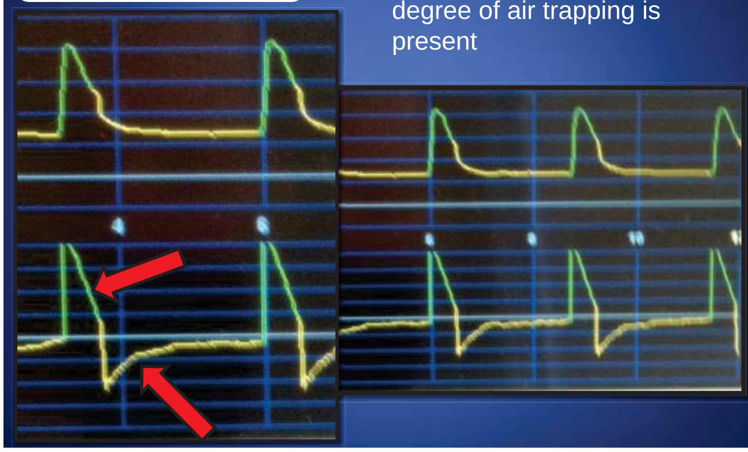
Area = Liters



Expiratory Dysynchrony

Recognizing air-trapping/auto-PEEP

- If the area under the expiratory flow curve is less than that of the inspiratory flow, then a degree of air trapping is present



Expiratory Dysynchrony

Correcting air-trapping/auto-PEEP

– To correct auto-PEEP the expiratory time must be lengthened

1. Expiratory time can be increased indirectly by decreasing the T_I in the appropriate manner dependent on the mode of ventilation
2. Expiratory time can be increased directly by decreasing the respiratory rate
   – If the patient is assisting above the set respiratory rate then pharmacological means may be necessary
3. If excessive expiratory time is required due to obstructed expiratory flow, then bronchodilator therapy should also be instituted

Expiratory Dysynchrony

Clinical implications of air-trapping/auto-PEEP

– Air-trapping / auto-PEEP can cause an

1) Increased work of breathing due to ineffective triggering
2) Decreased cardiac output and blood pressure

Expiratory Dysynchrony

Correcting air-trapping/auto-PEEP

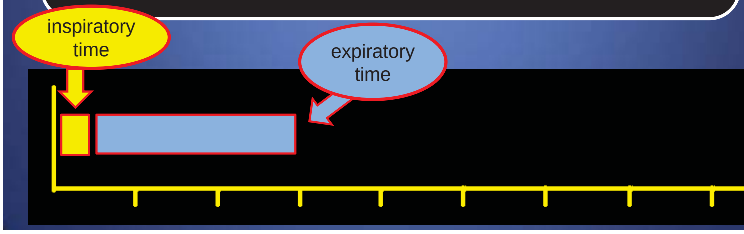
1) Decrease the inspiratory time
   - Increase the inspiratory flow
   - Decrease the tidal volume

RR 20
V_T 500
flow 60

$TCT = 60/RR = 3$ sec

$T_I = \frac{V_T}{flow} = \frac{.5\ L}{1\ L/sec} = 0.5$ sec

$T_E = TCT - T_I = 3 - .5 = 2.5$ sec



Expiratory Dysynchrony

Correcting air-trapping/auto-PEEP

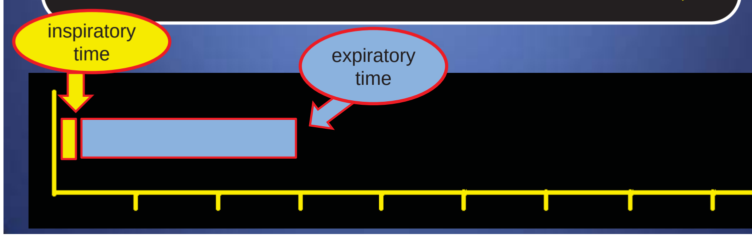
1) Decrease the inspiratory time
   - Increase the inspiratory flow
   - Decrease the tidal volume

RR 20
V_T 500
flow ↑90

TCT
3 sec

T_I = $\frac{.5\text{ L}}{1.5\text{ L/sec}}$ = 0.33 sec

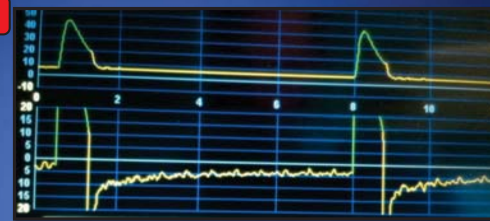
T_E
3 - .33 = 2.67 sec



CMV Volume

Expiratory dysynchrony

- Air-trapping / auto PEEP



Expiratory Dysynchrony

Correcting air-trapping/auto-PEEP

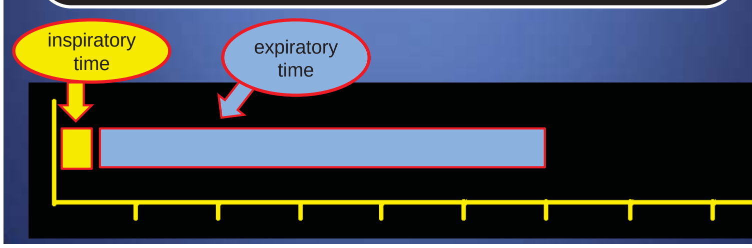
2) Increase the expiratory time
   - Decrease the respiratory rate

RR ↓10
V_T .5
flow 60

TCT
60/RR
6 sec

T_I 0.5 sec

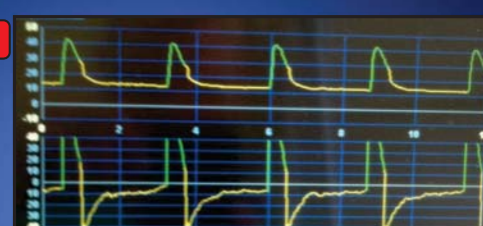
T_E =
6 - .5
= 5.5 sec



CMV Volume

Expiratory dysynchrony

- Air-trapping / auto PEEP



CMV Volume

Expiratory dysynchrony

- Air-trapping / auto PEEP

1) Decrease respiratory rate
2) Increase inspiratory flow / decrease inspiratory time
3) Decrease tidal volume

Patient-Ventilator Dysynchrony

TRIGGER DYSYNCHRONY	INSPIRATORY FLOW DYSYNCHRONY	CYCLE DYSYNCHRONY	EXPIRATORY DYSYNCHRONY
<u>All modes</u> • Ineffective efforts • Auto-triggering	*<u>VC mode</u>* • Inadequate flow • Excessive flow *<u>PC or PS mode</u>* • Inadequate flow / pressure • Excessive flow / pressure *<u>V-T PC mode</u>* • Inadequate flow / pressure	*<u>VC mode</u>* • Premature cycling • Delayed cycling *<u>PC or V-T PC mode</u>* • Premature cycling • Delayed cycling *<u>PS mode</u>* • Premature cycling • Delayed cycling	<u>All modes</u> • Auto-PEEP