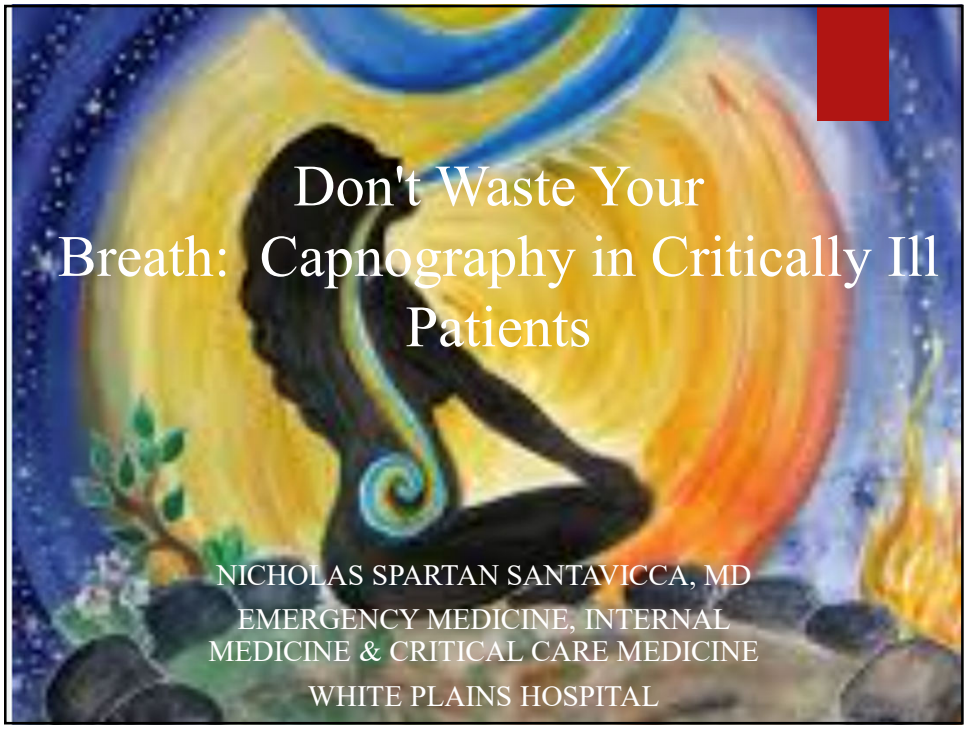
12th UMEM Critical Care Symposium
Wednesday, May 21, 2025
Presentation by Dr. Nicholas Santavicca



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Learning Points

- Capnography is determined by:
  - Metabolism
  - Cardiac output
  - Lung function
- Capnography in procedural sedation:
  - Decreases hypoxia
  - Decreases assisted ventilation
- Capnography for intubation:
  - Very specific
  - Waveform and value
  - Don't forget to use it!!

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Learning Points

- Capnography in cardiac arrest:
  - Low ETCO2 (< 10 mmHg) is ominous during cardiac arrest
    - Consider optimizing compressions (goal >20 mmHg)
  - Sudden, sustained increase in ETCO2 could represent ROSC
- Capnography for sepsis:
  - Noninvasive lactate
  - Low ETCO2 correlates with:
    - Sepsis/severe sepsis diagnosis
    - Acidosis
    - Higher lactate
    - Higher mortality
  - >5% increase during passive leg raise can predict fluid responsiveness

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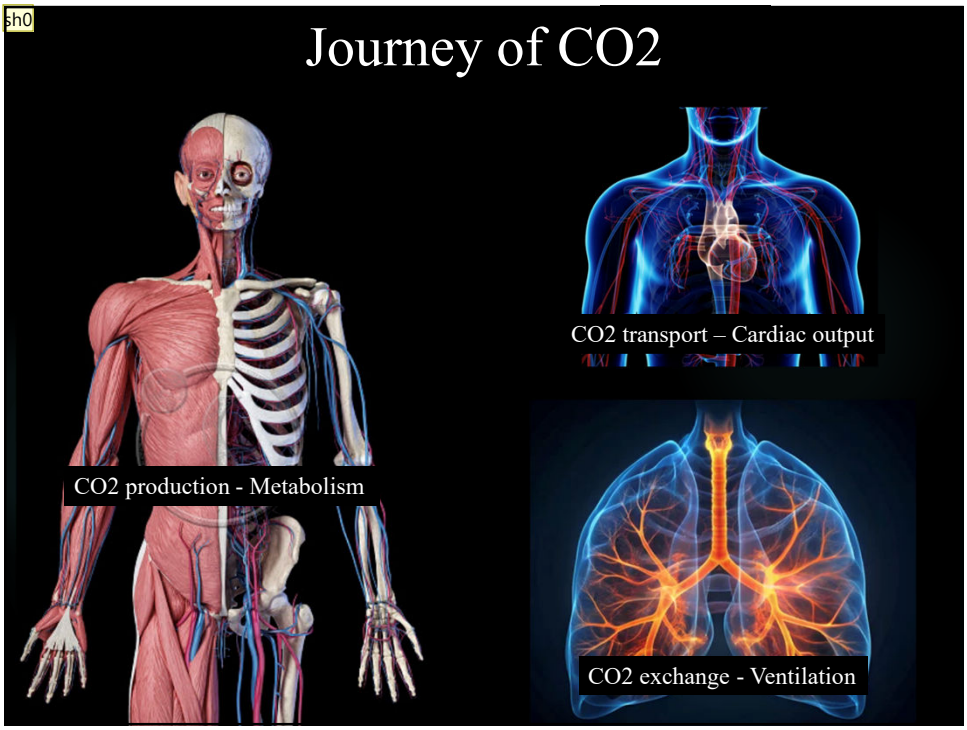
sh0
Journey of CO2
CO2 transport – Cardiac output
CO2 production - Metabolism
CO2 exchange - Ventilation

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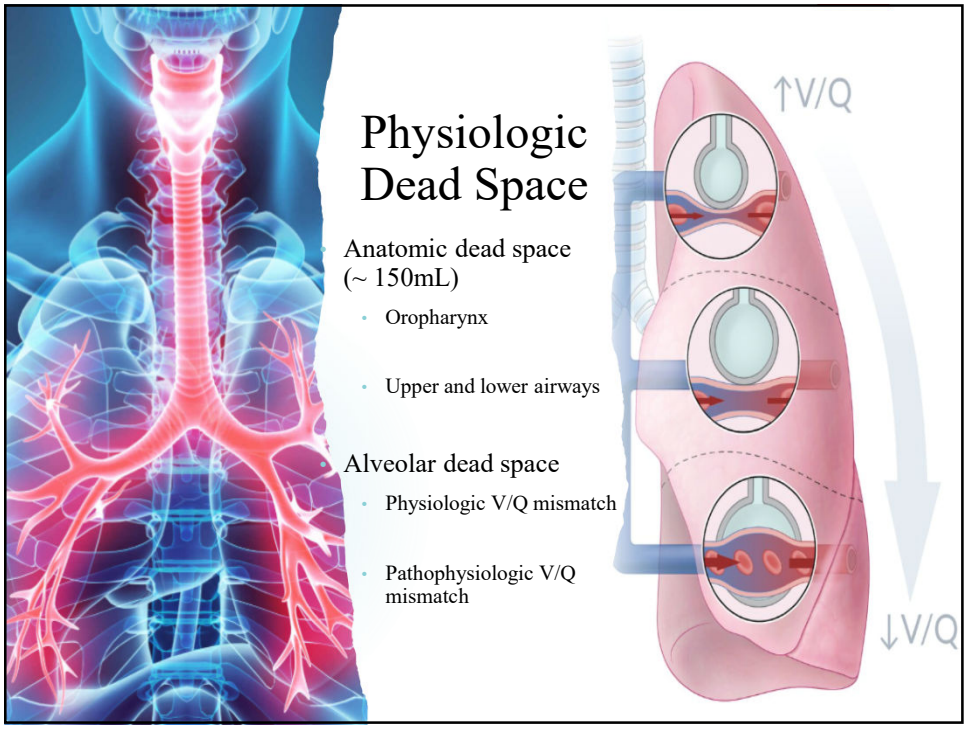
Physiologic Dead Space
Anatomic dead space (~ 150mL)
Oropharynx
Upper and lower airways
Alveolar dead space
Physiologic V/Q mismatch
Pathophysiologic V/Q mismatch
↑V/Q
↓V/Q

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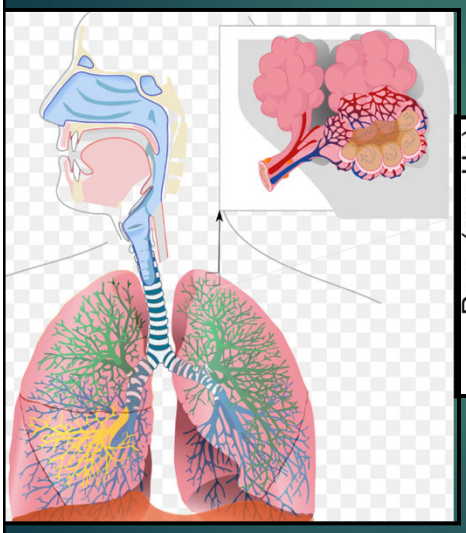
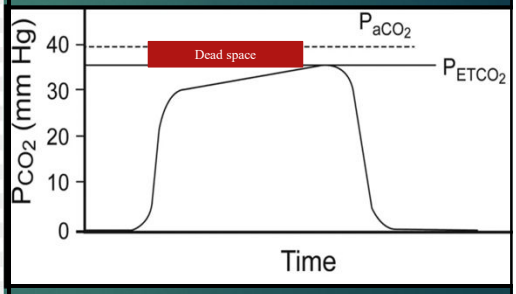
Slide 5

sh0 separate slide with text on what increases and decreases CO2 metabolism so there is a visual

shilpa.r.kolli@gmail.com, 2025-05-15T09:30:51.194

Dead Space and the CO2 Gap





Respir Care. 2016 Oct;61(10):1397-416

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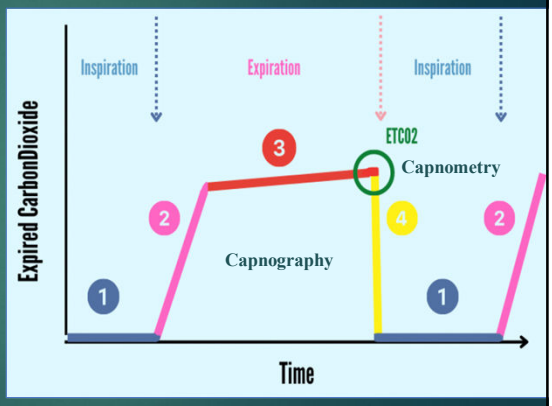
Waveform

1. Inspired air - baseline
2. Beginning of expiration
   - Anatomic dead space
3. Late expiration
   - Alveolar gas exchange
   - Max = ETCO2
4. Beginning of inspiration



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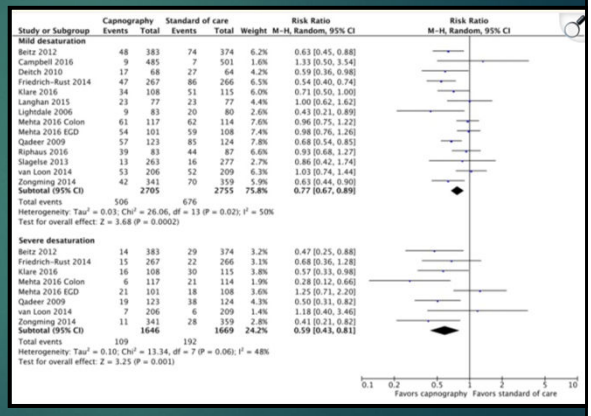
Procedural Sedation

- Meta-analysis
  - 13 studies
  - ED, outpatient clinics
- RR for mild desaturation 0.77
  - 30% reduction
- RR for severe desaturation 0.59
  - 40% reduction



BMJ Open. 2017 Jun 30; 7 (6):e013402

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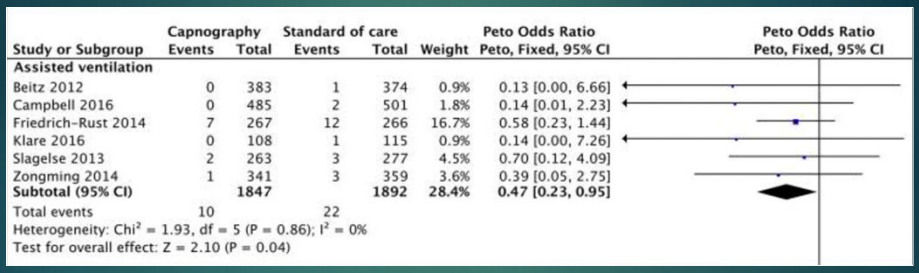
Procedural Sedation



Study or Subgroup	Capnography Events	Capnography Total	Standard of care Events	Standard of care Total	Weight	Peto Odds Ratio Peto, Fixed, 95% CI
Assisted ventilation						
Beitz 2012	0	383	1	374	0.9%	0.13 [0.00, 6.66]
Campbell 2016	0	485	2	501	1.8%	0.14 [0.01, 2.23]
Friedrich-Rust 2014	7	267	12	266	16.7%	0.58 [0.23, 1.44]
Klare 2016	0	108	1	115	0.9%	0.14 [0.00, 7.26]
Slagelse 2013	2	263	3	277	4.5%	0.70 [0.12, 4.09]
Zongming 2014	1	341	3	359	3.6%	0.39 [0.05, 2.75]
Subtotal (95% CI)		**1847**		**1892**	**28.4%**	**0.47 [0.23, 0.95]**
Total events	10		22			

Heterogeneity: $Chi^2 = 1.93$, $df = 5$ ($P = 0.86$); $I^2 = 0\%$
Test for overall effect: $Z = 2.10$ ($P = 0.04$)

Peto Odds Ratio
Peto, Fixed, 95% CI

BMJ Open. 2017 Jun 30; 7 (6):e013402

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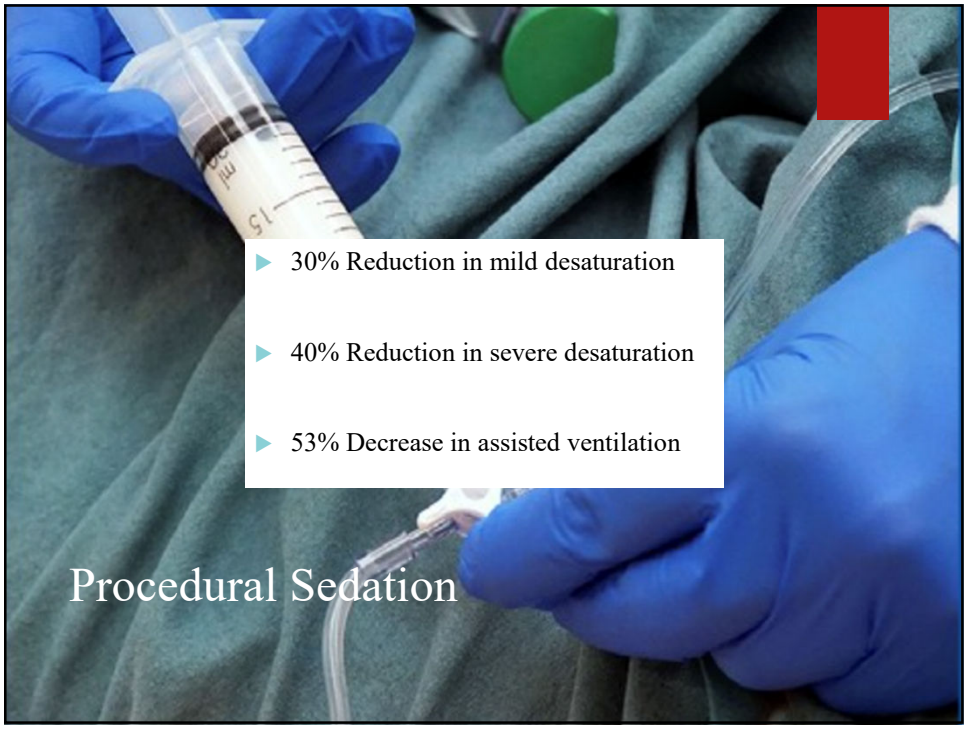

- 30% Reduction in mild desaturation
- 40% Reduction in severe desaturation
- 53% Decrease in assisted ventilation

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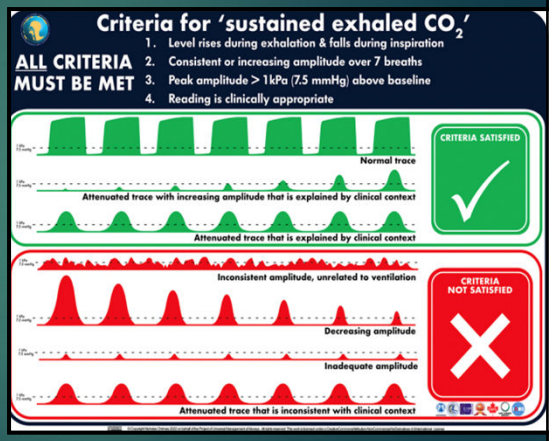
Airway Confirmation

- Waveform (capnography)
  - Squared off
  - Plateau
  - Consistent
- Value (capnometry)
  - Consistent
  - Increasing value



JACEP Open, Volume 4, Issue 3, e12951

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Airway Confirmation

- Missed intubation rates 5-10% (as high as 25%)
- EMS 20 year review – 0.3% esophageal intubation rate with ETCO2
- Prospective EMS trial – 0 vs. 23% esophageal intubations
- Grmec et al. - 345 prehospital intubations

Method	Sensitivity	Specificity
End-tidal CO_2 detecor	100%	100%
Esophageal detector device (EDD)	100%	93%
Auscultation	94%	86%

MA Wayne et al., Prehosp Emerg Care. 1999 Apr-Jun;3(2):107-9
Silvestri et al., Ann Emerg Med. 2005 May;45(5):497-503
Grmec et al., Intensive Care Med. 2002 Jun;28(6):701-4

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Fool's Gold?

- OHCA in 81 patients
  - 100% specificity when detectable after 5th breath
  - ETCO2 not detected in 26/72 correctly positioned tubes
    - Sensitivity 64%
- OHCA in 65 patients
  - 100% specificity
  - ETCO2 not detected in 26 correct intubations
    - Sensitivity 57%
- In a review of 4 studies
  - Predictive value for absent ETCO2 for misplaced ETT was 27%

Sandroni et al., Resuscitation 132 (2018) 73–77

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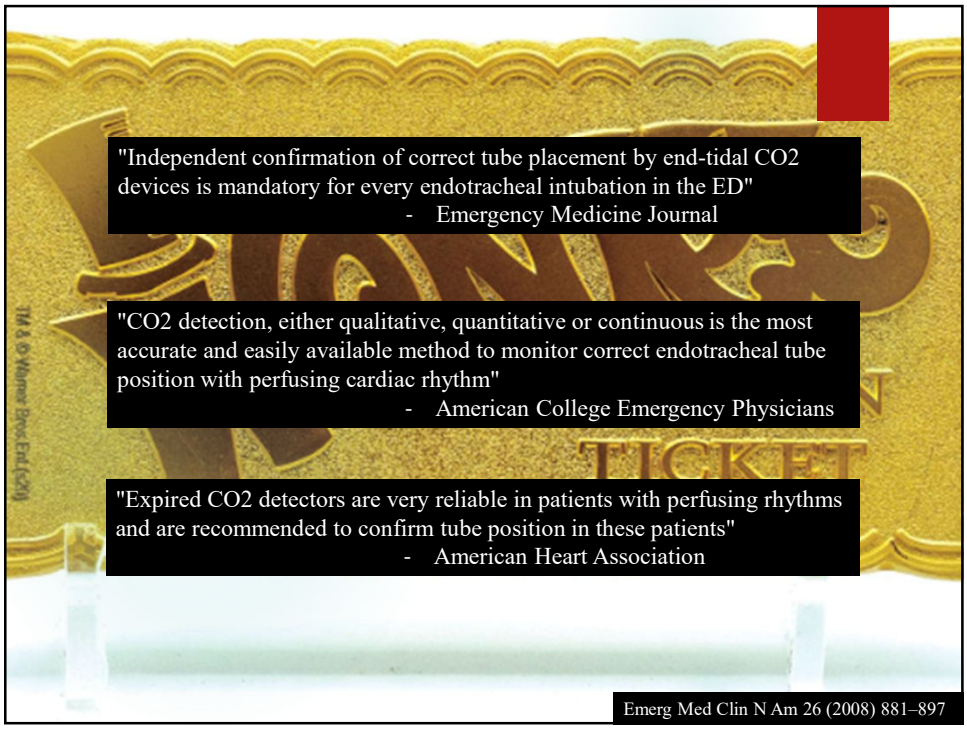

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No respect...

- 1000 EM surveys through 550 hospitals
  - 3:1 Colorimetry vs. Continuous capnography availability
  - 57% "rarely" or "never" used in non-arrest intubations
  - 700 of 6000 (12%) intubations used continuous capnography monitoring

Emerg Med J 2005;22:490–493

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100% Specificity.
right tracing, right placing
Sensitivity 40-60%
Misplaced endotracheal intubation predictive value is 27%
USE IT! USE IT! USE IT!
Intubation

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CARDIAC ARREST

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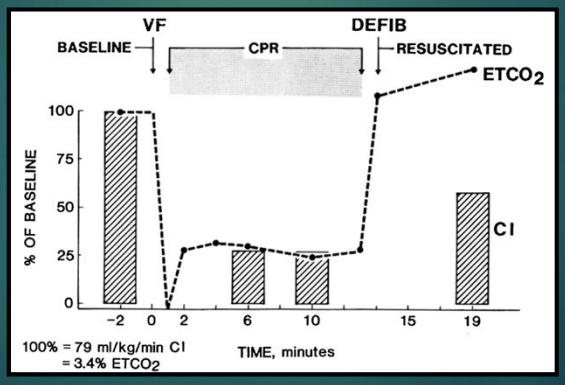
ETCO2 and CO

- ETCO2 increased once perfusion was restored
- CPR maintained certain % of ETCO2



Sandroni et al., Resuscitation 132 (2018) 73–77

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ETCO2 Early in Cardiac Arrest

- Low ETCO2 early = poor prognostic sign
  - 4% chance of ROSC
- ETCO2 > 10 mmHg @ 3min
  - OR 18.1 of ROSC
  - 31% obtained ROSC

Diagnostic characteristics of $ETCO_2$ >10 mmHg to predict ROSC.

	Value	95% CI
Sensitivity	0.95	0.89–0.98
Specificity	0.27	0.21–0.33
Positive predictive value	0.40	0.34–0.46
Negative predictive value	0.92	0.82–0.97

Poon et al., Resuscitation, 2016-05-01, Volume 102, Pages 80-84

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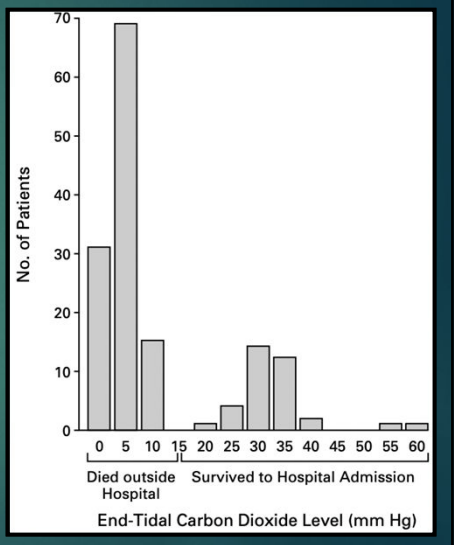
ETCO2 as Arrest Progresses

- Levine et al. - prospective observational OHCA
  - 150 patients
  - @ 20 minutes ACLS
    - Survivors - ETCO2 was 32.8 +/- 7.4 mmHg
    - Nonsurvivors – ETCO2 was 4.4 +/- 2.9 mmHg
- Sanders et al.
  - No one survived with an ETCO2 < 10 mmHg



Levine et al., N Engl J Med 1997;337:301–6.

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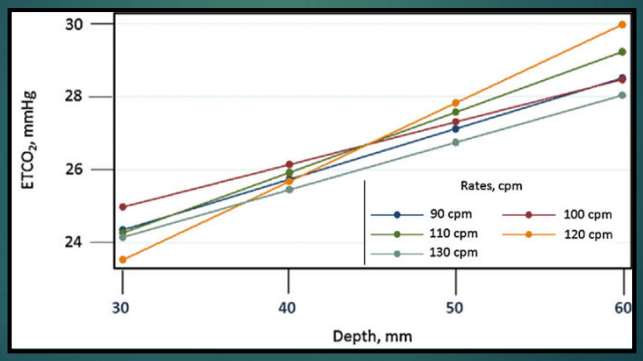
ETCO2 & Chest Compressions

- Sheik et al. - multicenter cohort study for IHCA and OHCA
  - Every increase 10mm CC depth ~ increase in ETCO2 1.4mmHg
  - CC rate increased ETCO2 > 120cpm



Resuscitation, 2015-04-01, Volume 89, Pages 149-154

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ETCO2 and ROSC

- Sudden changes in CO change ETCO2
  - Tissue perfusion --> CO2 production
  - Cardiac output transports CO2 to lungs for exchange

Diagnostic characteristics of $ETCO_2$ change indicating ROSC.

	$ETCO_2$ rise ≥10 mmHg	$ETCO_2$ rise ≥20 mmHg	$ETCO_2$ rise ≥10 mmHg and $ETCO_2$ value ≥40 mmHg	$ETCO_2$ rise ≥20 mmHg and $ETCO_2$ value ≥40 mmHg
Sensitivity, 95% CI	33% (22–47%)	20% (11–33%)	18% (10–31%)	15% (8–27%)
Specificity, 95% CI	97% (91–99%)	98% (93–100%)	98% (93–100%)	99% (95–100%)
Positive predictive value, 95% CI	83% (62–95%)	86% (56–97%)	85% (54–97%)	90% (54–99%)
Negative predictive value, 95% CI	74% (66–81%)	71% (63–77%)	70% (63–77%)	70% (62–76%)
Positive likelihood ratio, 95% CI	9.8 (3.5–27.5)	11.8 (2.7–51)	10.8 (2.5–47.2)	17.7 (2.3–136.5)
Negative likelihood ratio, 95% CI	0.7 (0.6–0.8)	0.8 (0.7–0.9)	0.8 (0.7–0.9)	0.9 (0.8–1)

LC Tat et al. , Resuscitation 104 (2016) 53–58

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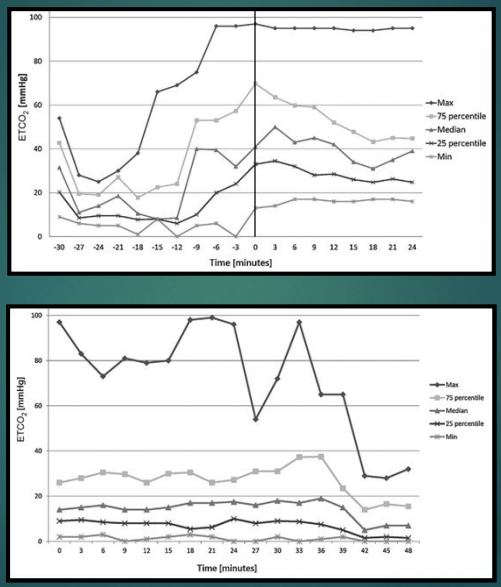
ETCO2 and ROSC



LC Tat et al., Resuscitation 104 (2016) 53–58

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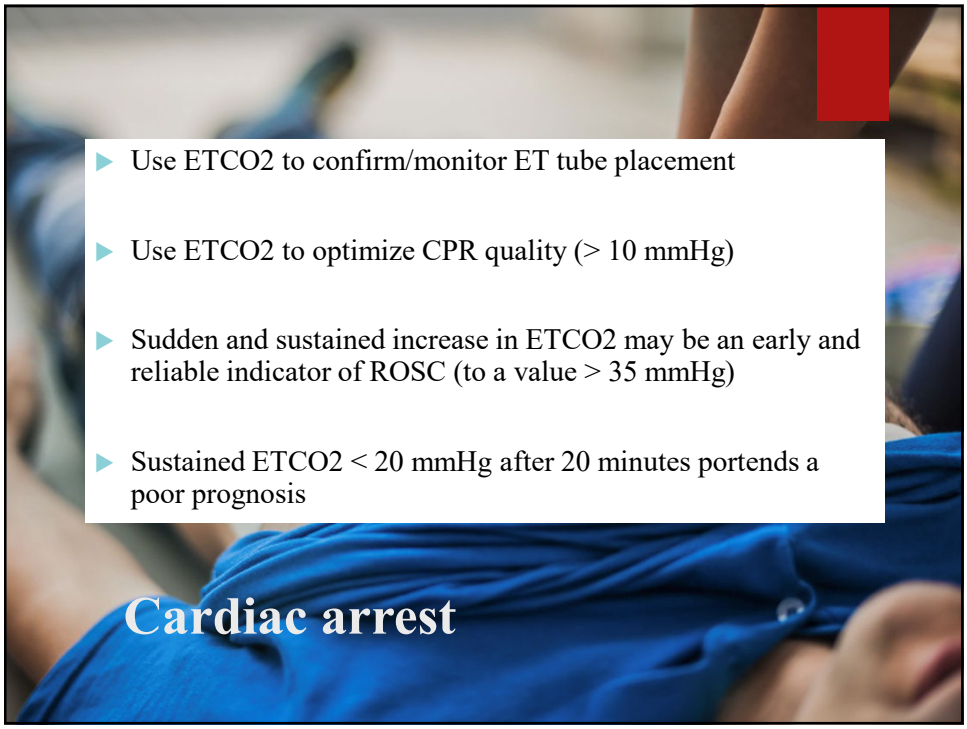
Use ETCO2 to confirm/monitor ET tube placement
Use ETCO2 to optimize CPR quality (> 10 mmHg)
Sudden and sustained increase in ETCO2 may be an early and reliable indicator of ROSC (to a value > 35 mmHg)
Sustained ETCO2 < 20 mmHg after 20 minutes portends a poor prognosis
Cardiac arrest

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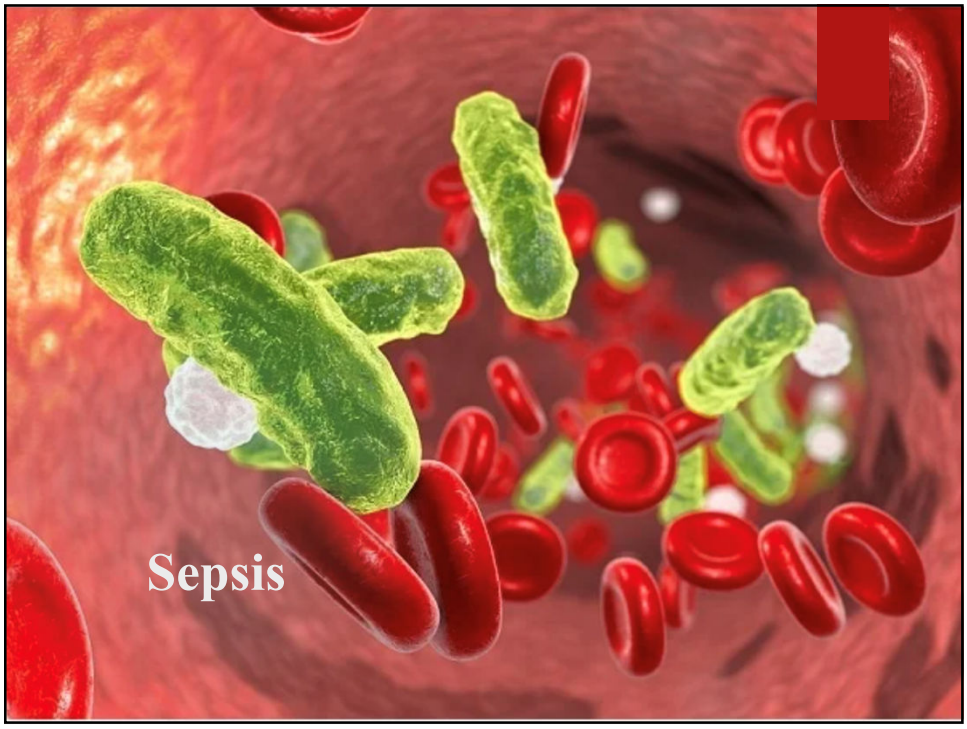
Sepsis

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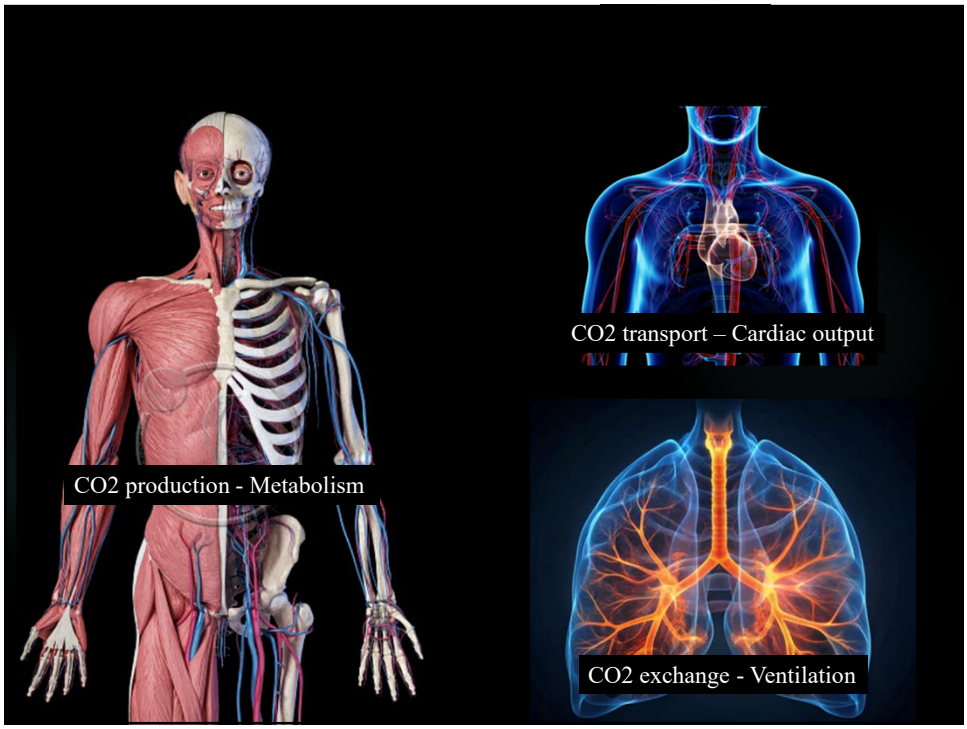

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ETCO2 Identifying Sepsis and Severe Sepsis

- Prospective cohort study (2016)
  - 183 prehospital protocol compliant patients
    - >2 SIRS
    - ETCO2 < 25mmHg
  - 147 prehospital protocol noncompliant patients
    - Did not meet SIRS criteria or ETCO2 > 25mmHg

Hunter et al., American Journal of Emergency Medicine 34 (2016) 813–819

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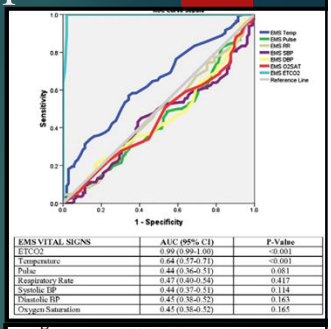
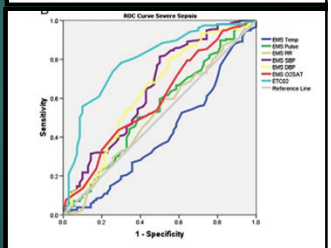
ETCO2 Identifying Sepsis and Severe Sepsis

- ETCO2 differed
  - 33 mmHg in protocol noncompliant
  - 20 mmHg in protocol compliant
- Protocol compliant patients
  - More likely to be admitted to hospital and ICU
  - Higher sepsis diagnosis (78% v 43%)
    - AUC 0.99
  - Higher severe sepsis diagnosis (47% v 7%)
    - AUC 0.80



EMS VITAL SIGNS	AUC (95% CI)	P-Value
ETCO2	0.99 (0.99-1.00)	<0.001
Temperature	0.64 (0.57-0.71)	<0.001
Pulse	0.44 (0.36-0.51)	0.081
Respiratory Rate	0.47 (0.40-0.54)	0.417
Systolic BP	0.44 (0.37-0.51)	0.114
Diastolic BP	0.45 (0.38-0.52)	0.163
Oxygen Saturation	0.45 (0.38-0.52)	0.165



EMS VITAL SIGNS	AUC (95% CI)	P-Value
ETCO2	0.80 (0.73-0.86)	<0.001
Temperature	0.41 (0.33-0.49)	0.029
Pulse	0.54 (0.46-0.63)	0.309
Respiratory Rate	0.52 (0.43-0.60)	0.690
Systolic BP	0.65 (0.57-0.73)	<0.001
Diastolic BP	0.64 (0.55-0.72)	0.001
Oxygen Saturation	0.59 (0.52-0.68)	0.024

Hunter et al., American Journal of Emergency Medicine 34 (2016) 813–819

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ETCO2 Identifying Sepsis and Severe Sepsis

- Retrospective cohort study (2018)
  - 289 patients
- Prehospital assessment "sepsis alert"
  - Suspected infection
  - QSOFA >2
  - ETCO2 < 25mmHg
- Severe sepsis:
  - Higher ICU admission
  - Higher mortality
  - Higher lactate
  - Lower HCO2
  - LOWER ETCO2 !!!

	Sepsis N=203	Severe sepsis N=86	Total N=289	P value
Age (n=289)	69 (SD18)	74 (SD15)	70 (SD17)	0.034
Gender (female) (n=289)	108 (53%)	41 (48%)	149 (52%)	0.440
Admitted (n=287)	193 (96%)	85 (100%)	278 (97%)	0.062
Admitted to ICU (n=285)	49 (25%)	50 (59%)	99 (35%)	<0.001
Hospital mortality (n=288)	9 (5%)	16 (19%)	25 (9%)	<0.001
Admitting diagnosis (n=287)				
Abdominal/GI	14 (7%)	2 (2%)	16 (6%)	
Altered mental status	19 (10%)	6 (7%)	25 (9%)	
Cardiac/vascular	3 (2%)	1 (1%)	4 (1%)	
Respiratory	35 (17%)	8 (9%)	43 (15%)	0.009
Infection	85 (42%)	60 (70%)	145 (52%)	
Neurologic	3 (2%)	0 (0)	3 (1%)	
Metabolic/endocrine	9 (5%)	2 (2%)	11 (4%)	
Renal/urinary	26 (13%)	4 (5%)	30 (11%)	
Other	7 (4%)	3 (4%)	10 (4%)	
At least 2 SIRS criteria	187 (93%)	84 (98%)	271 (94%)	0.108
qSOFA score				
0	12 (6%)	2 (2%)	14 (5%)	
1	84 (41%)	17 (20%)	101 (35%)	<0.001
2	94 (46%)	40 (47%)	134 (46%)	
3	13 (6%)	27 (31%)	40 (14%)	
$ETCO_2$ [95% CI]	28 [27-29]	19 [18-22]]	25 [24-16]	<0.001
Lactate (n=228)	1.9 [1.8-2.1]	5.4 [4.8-6.2]	3.2 [2.8-3.5]	<0.001
HCO_3 (n=259)	24 [23-24]	20 [19-22]	23 [22-23]	<0.001

Hunter et al., West J Emerg Med. 2018 May;19(3):446-451.

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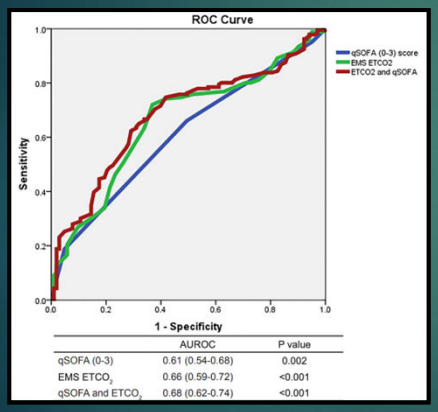
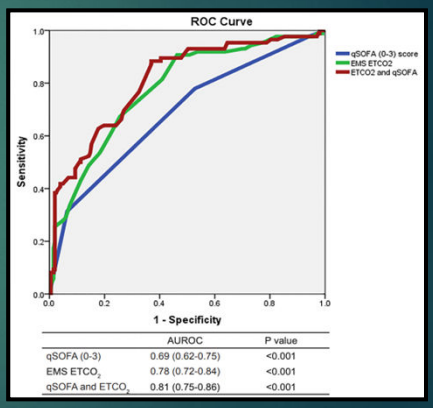
ETCO2 Identifying Sepsis and Severe Sepsis

AUC Sepsis



AUC Severe Sepsis



Hunter et al., West J Emerg Med. 2018 May;19(3):446-451

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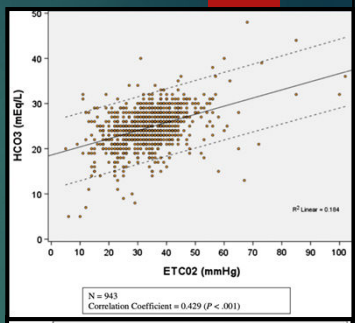
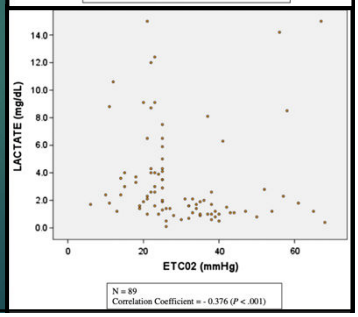
ETCO2 Correlation with Lactate and Acidosis

- Retrospective cohort (2014)
  - 1048 patients
    - 4% died (40)
- ETCO2 with pre-hospital vitals
- ETCO2 survivors – 34 mmHg
- ETCO2 nonsurvivors = 24 mmHg





Hunter et al., American Journal of Emergency Medicine 32 (2014) 160–165

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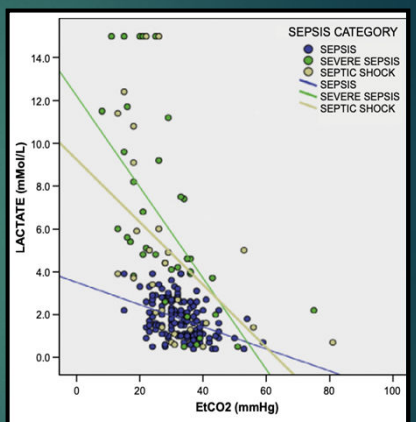
ETCO2 Correlation with Lactate and Acidosis

- Observational study (2013)
  - 201 patients with suspected sepsis
- ETCO2 measured with lactate early in resuscitation
- Nonsurviving patients had higher lactates and lower ETCO2 levels



	Correlation Coefficient ETCO2-Lactate	P-Value
Sepsis	-0.421	<0.001
Severe Sepsis	-0.597	<0.001
Septic Shock	-0.482	0.011

Hunter et al., American Journal of Emergency Medicine (2013) 31, 64–71

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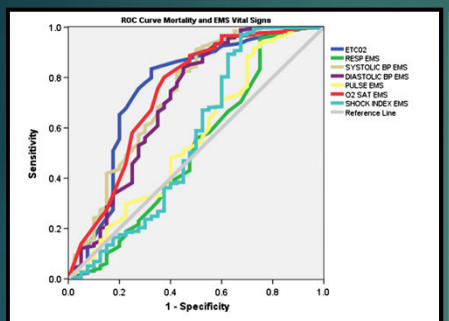
ETCO2 and Mortality

Hunter 2014

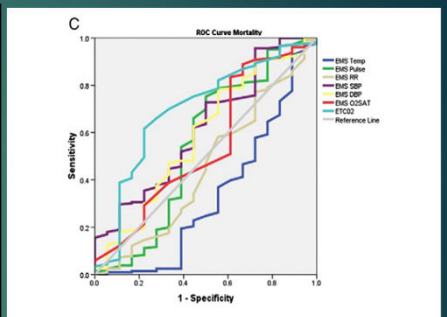


EMS VITAL SIGNS	AUC (95% CI)	*P*-Value
ETCO2	0.76 (0.66-0.85)	< .001
Respiratory Rate	0.52 (0.41-0.63)	.691
Systolic BP	0.73 (0.64-0.83)	< .001
Diastolic BP	0.71 (0.61-0.81)	< .001
Pulse	0.56 (0.46-0.66)	.210
Oxygen Saturation	0.74 (0.64-0.83)	< .001
Shock Index	0.56 (0.44-0.68)	.209

Retrospective cohort of 1048 patients

ETCO2 in survivors was 34 mmHg
ETCO2 in nonsurvivors was 24 mmHg

Hunter 2016



EMS VITAL SIGNS	AUC (95% CI)	P-Value
ETCO2	0.70 (0.57-0.83)	0.005
Temperature	0.31 (0.18-0.48)	0.018
Pulse	0.55 (0.38-0.72)	0.478
Respiratory Rate	0.45 (0.30-0.60)	0.490
Systolic BP	0.62 (0.48-0.76)	0.089
Diastolic BP	0.59 (0.44-0.74)	0.217
Oxygen Saturation	0.55 (0.40-0.70)	0.497

Protocol compliant patients had higher mortality (11% v 5%)

Hunter et al., American Journal of Emergency Medicine 32 (2014) 160–165
Hunter et al., American Journal of Emergency Medicine 34 (2016) 813–819

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ETCO2 and Mortality

- Observational study
  - 201 patients with suspected sepsis
- 3 significant predictors of mortality
  - Mechanical ventilation (OR 16.4)
  - Pressors (OR 16.4)
  - Abnormal ETCO2 (OR 6.48)

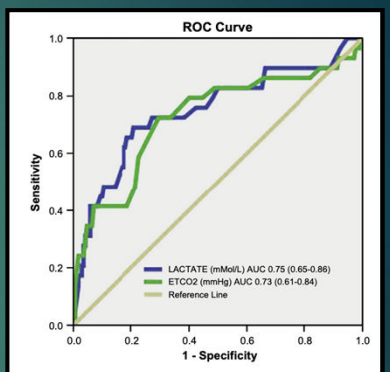

Fig. 2 Receiver operating characteristic curves for predicting mortality in all patients.

	$ETCO_2$ AUC (95% CI)	Lactate AUC (95% CI)
Sepsis categories		
Suspected sepsis	0.60 (0.37-0.83)	0.61 (0.36-0.87)
Severe sepsis	0.67 (0.46-0.88)	0.69 (0.48-0.89)
Septic shock	0.78 (0.59-0.96)	0.74 (0.55-0.93)
Intubation		
Intubated	0.77 (0.60-0.94)	0.82 (0.68-0.96)
Not intubated	0.72 (0.56-0.88)	0.64 (0.46-0.82)

Hunter et al., American Journal of Emergency Medicine (2013) 31, 64–71

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Fluid Responsiveness

- With similar ventilation and metabolism, changes in cardiac output change ETCO2
- Passive leg raise (PLR)
- Need a way to monitor effectiveness

Monge García et al. Annals of Intensive Care 2012, 2:9

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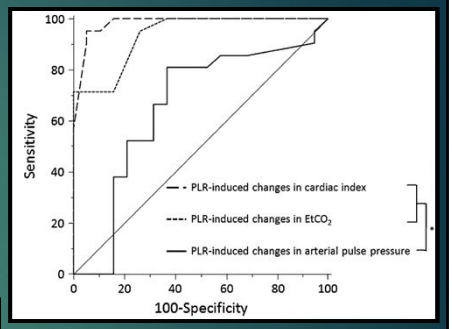
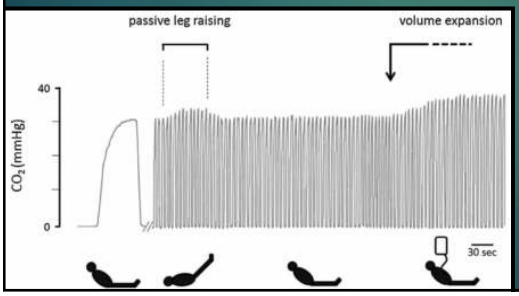
ETCO2 and Fluid Responsiveness

- Prospective study
  - 65 patients
- CO increasing by 15% considered responders
  - ETCO2 increased by 5% during PLR = sensitivity 71% and specificity 100%
  - Changes within 1 minute





Monge García et al. Annals of Intensive Care 2012, 2:9

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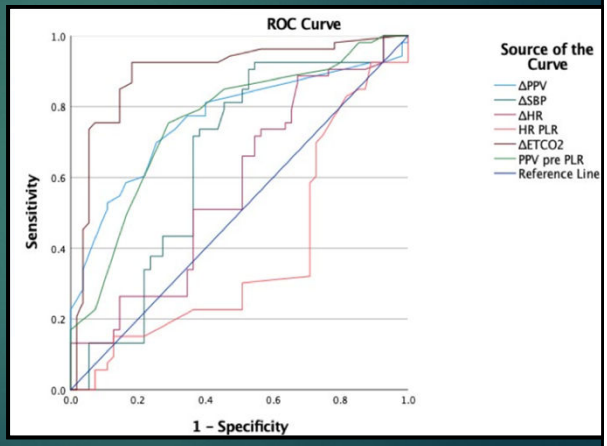
ETCO2 and Fluid Responsiveness

- Prospective observational study in Turkish ICU
  - 108 patients
  - 15% increase in CO from PLR = responder
- Change in ETCO2 indicated fluid responsiveness
  - Change 4% = sensitivity 85%, specificity 86%
  - Change in 5% = sensitivity 77%, specificity 99.3%
  - AUC 0.89



Ozkarakas et al., Ulus Travma Acil Cerrahi Derg 2024;30(2):90-96

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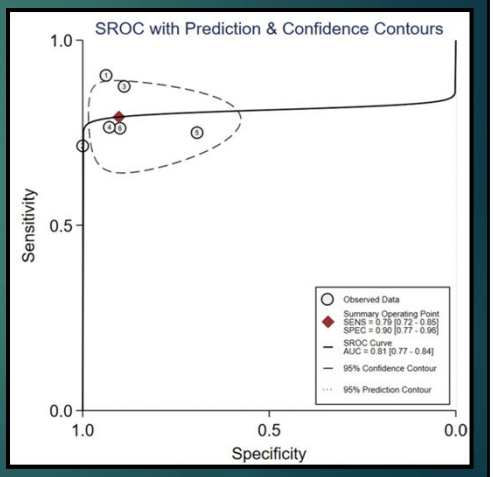
ETCO2 and Fluid Responsiveness

- Meta-analysis
  - 6 studies
  - 298 patients
- Pooled sensitivity 0.79
- Pooled specificity 0.90
- AUC 0.81



Huang et al. Critical Care (2022) 26:20

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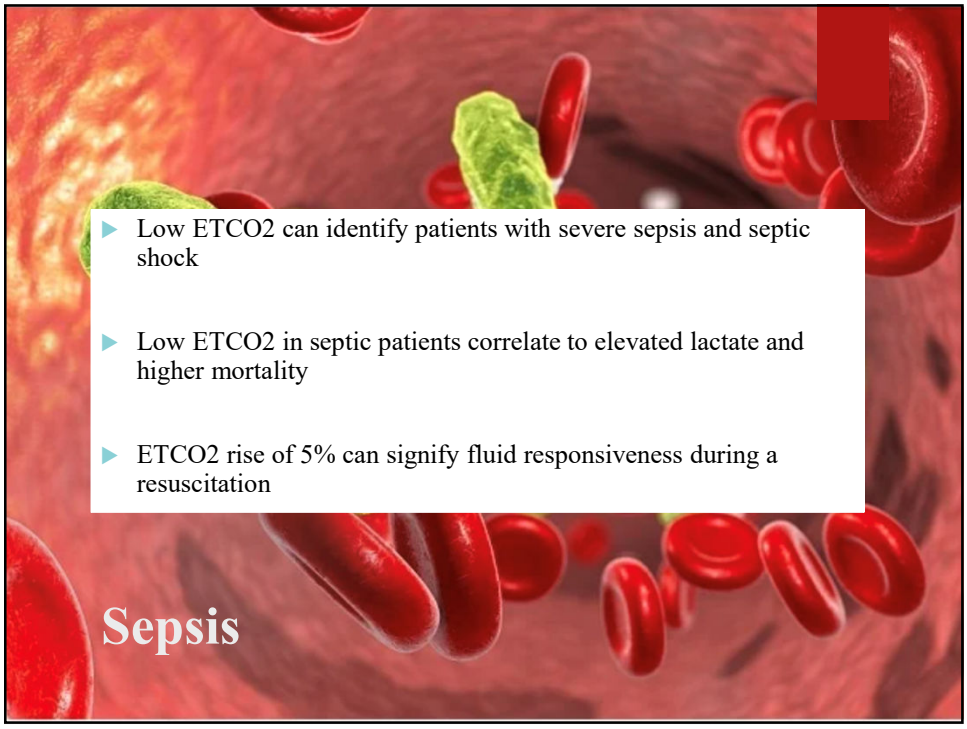

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Learning Points

- Capnography is determined by:
  - Metabolism
  - Cardiac output
  - Lung function
- Capnography in procedural sedation:
  - Decreases hypoxia
  - Decreases assisted ventilation
- Capnography for intubation:
  - Very specific
  - Waveform and value
  - Don't forget to use it!!

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Learning Points

- Capnography in cardiac arrest:
  - Low ETCO2 (< 10 mmHg) is ominous during cardiac arrest
    - Consider optimizing compressions (goal >20 mmHg)
  - Sudden, sustained increase in ETCO2 could represent ROSC
- Capnography for sepsis:
  - Noninvasive lactate
  - Low ETCO2 correlates with:
    - Sepsis/severe sepsis diagnosis
    - Acidosis
    - Higher lactate
    - Higher mortality
  - >5% increase during passive leg raise can predict fluid responsiveness

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