Transcutaneous CO2 Monitoring: Alerting the Anesthesia Provider to Impending Respiratory Depression

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Objectives

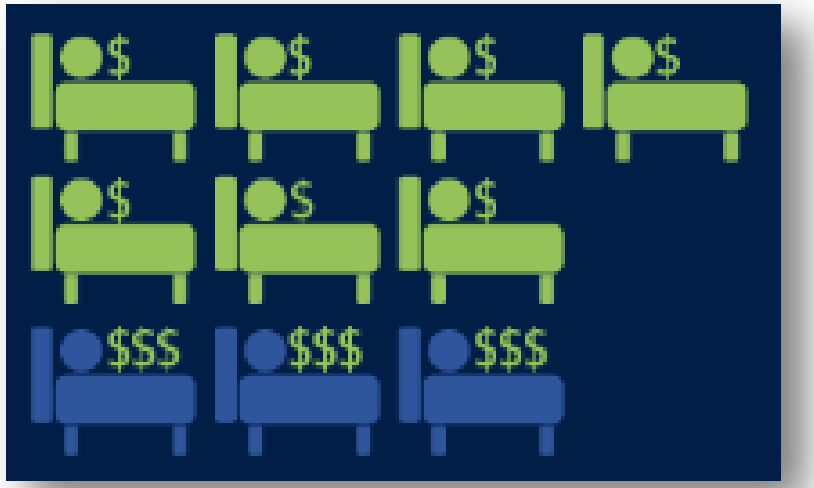
- Participants will be able to identify risk factors for respiratory depression in the perioperative patient
- Participants will review the current guidelines and literature supporting respiratory monitoring in the perioperative setting
- Participants will understand the accuracy of the transcutaneous CO2 monitoring technology
- Participants will be able to identify uses for the transcutaneous CO2 to monitor for respiratory depression in the intraoperative and postoperative period

U.S. Economic Burden: Inpatient Respiratory Failure

- Inpatient stays complicated by respiratory compromise (RC) surpassed $7 billion in 2007[1]

- RC originating on general wards **increase hospital length of stay (LOS) by 7 days** and **ICU LOS by 3 days** [2]

- RC will increase average hospital cost by an additional **+ $18,208** [2]



1. Canet J, Gallart L. Postoperative respiratory failure: pathogenesis, prediction, and prevention. Curr Opin Anaesthesiol. 2014;20(1):56-62.
2. Burt CC, Arrowsmith JE. Respiratory failure. Surgery (Oxford). 2009;27(11): 475-479.

Economic Burden: Postoperative Respiratory Failure

- Postoperative Pulmonary Complication: 70.3% of deaths[1]
- Nationally: 46,200 additional deaths[1]
- Additional ~9 days hospital LOS[2]
- Additional > $53,000 to hospital costs[2]
- 1/3 'Code Blue' due to respiratory arrest[3]

1) Linde-Zwirble WL, Bloom JD, Mecca RS. Postoperative pulmonary complications in the US 2008. Annual Meeting of the International Anesthesia Research Society. 2010: S142A.
2) Zhan C, Miller MR: Excess length of stay, charges, and mortality attributable to medical injuries during hospitalization. JAMA 2003; 290: 1868–1874
3) Fecho K, Freeman J, Smith FR, et al. In-hospital resuscitation: opioids and otherfactors influencing survival. Therapeutics and Clinical Risk Management 2009;5:961-8.

Respiratory Depression BEFORE Respiratory Failure

Definition of Respiratory Depression

- No standard definition
- Clinical
  - Bradypnea (RR 8-10)
  - Sedation (Richmond-Agitation Sedation Score)
  - Opioid antagonist administration
- Monitoring
  - Arterial blood gas
  - Hypoxemia (SpO_2 <85-90%, duration 30s-2min)
  - Hypercapnia (≥50mmHg or trend)

Ko S et al. Definitions of "respiratory depression" with intrathecal morphine postoperative analgesia: a review of the literature. Canadian Journal of Anesthesia 2003; 50: 679-88.

Risk of Respiratory Depression Postoperative Setting

- Incidence of critical respiratory events in the PACU between 0.8% and 6.9% [1]
- Incidence of respiratory depression 0.5-2% among post-operative patients (due to opioids)[2]

1) Karcz, M and Papdakos P. Respiratory complications in the postanesthesia care unit: A review of pathophysiological mechanisms Can J Respir Ther. 2013; 49:21–9
2) Dahan, A, Aarts L, Smith T. Incidence, Reversal, and Prevention of Opioid-induced Respiratory Depression Anesthesiology 2010; 112: 226-38.

Severity of the Problem Postoperative Opioids

- The Joint Commission's Opioid Related Sentinel Event Database (2004-2011)[1]
  - 47 % wrong dose medication errors
  - **29 % related to improper monitoring of the patient**
  - 11 % to other factors (ie. excessive dosing, medication interactions, adverse drug reactions)

- Anesthesia Closed Claims Database[2]
  - 97% of opioid related respiratory events were deemed **preventable with better monitoring**

1) https://www.jointcommission.org/assets/1/18/SEA_49_opioids_8_2_12_final.pdf
2) Lee LA et al. Postoperative Opioid-Induced Respiratory Depression. Anesthesiology 2015; 122: 659-65

Monitoring Choices

- Clinical (intermittent nursing checks)
  - Bradypnea (RR 8-10)
  - Sedation (Richmond-Agitation Sedation Score)
- Monitoring (intermittent or continuous)
  - Arterial blood gas
  - Impedance plethysmography
  - Pulse Oximetry- Hypoxemia (SpO_2 <85-90%, duration 30s-2min)
  - End tidal CO_2 /Transcutaneous CO_2- Hypercapnia (≥50mmHg or trend)

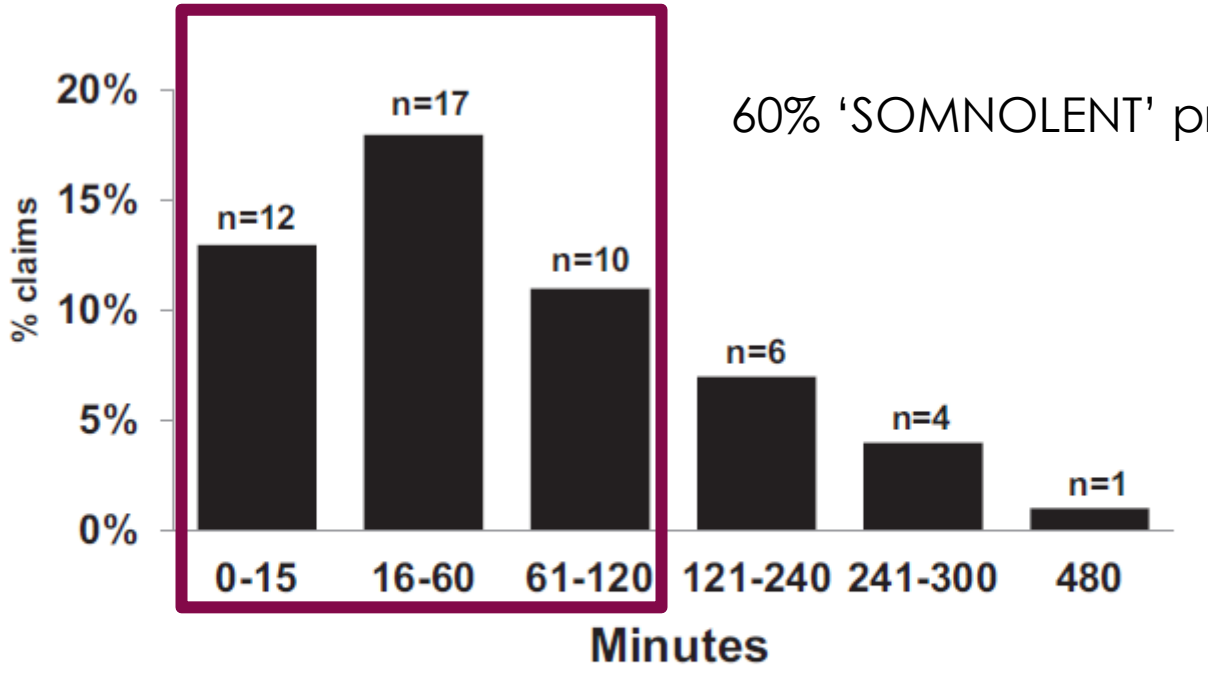
Nursing Assessments

Table 4. Monitoring Practices per Hospital Reported as Compliance to Every 2.5 Hours or Every 4.5 Hours During First 24 Hours of IV PCA Opioid Therapy (n = 287)

		Nurse-Abstracted EHR Data by Monitoring Parameter				
Hospital	Frequency of Patient Assessment	Pulse Oximetry, Respiratory Rate, and Sedation Score	Only Pulse Oximetry and Respiratory Rate	Pulse Oximetry	Respiratory Rate	Sedation Score
Hospital A	Every 2.5 h	0.0% (37)	10.8%	10.8%	10.8%	0.0%
	Every 4.5 h	2.7% (37)	29.7%	29.7%	32.4%	2.7%
Hospital B	Every 2.5 h	0.0% (29)	31.0%	34.5%	31.0%	0.0%
	Every 4.5 h	3.4% (29)	44.8%	48.3%	48.3%	3.4%
Hospital C	Every 2.5 h	6.5% (46)	15.2%	15.2%	21.7%	23.9%
	Every 4.5 h	30.4% (46)	50.0%	52.2%	60.9%	63.0%
Hospital D	Every 2.5 h	3.1% (32)	9.4%	9.4%	9.4%	6.3%
	Every 4.5 h	6.3% (32)	46.9%	50.0%	46.9%	9.4%
Hospital E (ICU)	Every 2.5 h	2.8% (36)	77.8%	83.3%	80.6%	5.6%
	Every 4.5 h	61.1% (36)	91.7%	94.4%	91.7%	61.1%
Hospital F (ICU)	Every 2.5 h	43.6% (39)	74.4%	76.9%	84.6%	48.7%
	Every 4.5 h	74.4% (39)	89.7%	92.3%	89.7%	76.9%
Hospital G	Every 2.5 h	5.9% (34)	20.6%	23.5%	23.5%	8.8%
	Every 4.5 h	17.6% (34)	61.8%	61.8%	64.7%	17.6%
Hospital H	Every 2.5 h	0.0% (34)	26.5%	26.5%	26.5%	0.0%
	Every 4.5 h	5.9% (34)	28.6%	29.4%	94.1%	23.5%
Total	Every 2.5 h	8.4% (287)	33.4%	35.2%	36.6%	12.9%
	Every 4.5 h	26.8% (287)	53.9%	56.1%	66.6%	34.8%

Jungquist CR et al. Avoiding Adverse Events Secondary to Opioid-Induced Respiratory Depression: Implications for Nurse Executives and Patient Safety- J Nurs Adm. 2016;46:87-94.

Timing of Respiratory Depression



60% 'SOMNOLENT' prior to event

Fig. 1. Time between last nursing check and discovery of opioid-induced respiratory depression (RD). Claims with unknown timing (n = 39) and not applicable (at home, n = 3) not shown.

Lee LA1, Caplan RA, Stephens LS, Posner KL, Terman GW, Voepel-Lewis T, Domino KB. Anesthesiology. 2015;122:659-65.

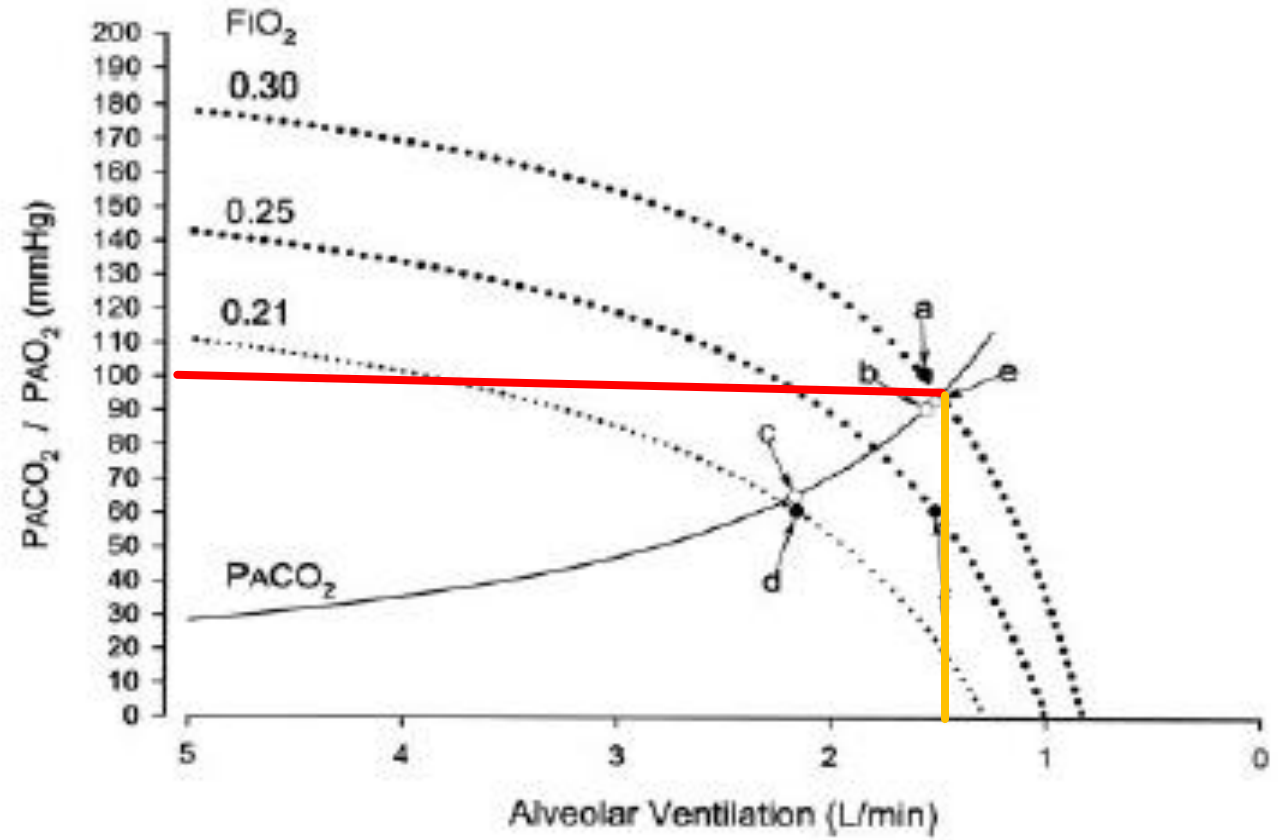
Timing of Respiratory Depression

- Observational study
- N= 833
- Noncardiac surgery
  - CPOX
  - q4-6 hour nursing spot-check for desaturation
- Overall 21% had average of >10 min/h SpO2<90%
- BUT 37% of cohort had SpO2<90% for over an hour

Sun Z et al. Postoperative Hypoxemia Is Common and Persistent: A Prospective Blinded Observational Study.Anesth Analg. 2015;121:709–715.

easy

Respiratory Depression on Oxygen



PAO2=(PB−PH2O)FiO2−(PaCO2÷R)

Fu ES et al. Supplemental oxygen impairs detection of hypoventilation by pulse oximetry. Chest. 2004;126(5):1552-8.Chest 2004;126:1552-8.

Pulse Oximetry and CO_2 Monitoring

- Continuous pulse oximetry inconclusive whether reduces rapid response team calls or mortality, trend toward reducing ICU transfers
- Continuous pulse oximetry is15X more likely to detect RD than nursing checks
- Capnography is 6X more likely to detect RD than pulse oximetry
- Clear that we should be monitoring oxygenation and ventilation

Lam, T et al. Continuous Pulse Oximetry and Capnography Monitoring for Postoperative Respiratory Depression and Adverse Events: A Systematic Review and Meta-analysis Anesthesia & Analgesia 2017;125: 2019–2029

ASA Guidelines

- Respiratory depression is …."Potentially preventable with improvements in monitoring of ventilation, and early response and intervention, particularly within the first 24 hours postoperatively."
- "The Task Force emphasizes that because ventilation and oxygenation are separate though related physiologic processes, monitoring oxygenation by **pulse oximetry is not a substitute for monitoring ventilatory function.“**

Practice Guidelines for the Prevention, Detection, and Management of Respiratory Depression Associated with Neuraxial Opioid Administration: An Updated Report by the American Society of Anesthesiologists Task Force on Neuraxial Opioids and the American Society of Regional Anesthesia and Pain Medicine. Anesthesiology 2016;124(3):535-552.

Opioid Route and Respiratory Depression

Table 2. Medication Factors Associated with Respiratory Depression

	n (%)
Routes of Opioid Therapy	
PCA only	17 (18)
Neuraxial only	16 (17)
Other only*	16 (17)
~~Multimodal†~~ Opioid via multiple routes	43 (47)
Continuous infusion of opioids	42 (46)
Interaction of opioid and nonopioid sedative medications	31 (34)
More than one physician prescribing (n = 91)	30 (33)
Excessive opioid dose	15 (16)

Lee LA, et al. Postoperative opioid-induced respiratory depression: a closed claims analysis. Anesthesiology. 2015;122:659-65.

ASA Guidelines

Recommendations for Detection and Monitoring for Respiratory Depression

- Monitor all patients receiving neuraxial opioids for adequacy of ventilation (*e.g.*, respiratory rate, depth of respiration [assessed without disturbing a sleeping patient]), oxygenation (*e.g.*, pulse oximetry when appropriate), and level of consciousness.**
- Increased monitoring (*e.g.*, intensity, duration, or additional methods of monitoring) may be warranted for patients at increased risk of respiratory depression (*e.g.*, unstable medical condition, obesity, obstructive sleep apnea,†† concomitant administration of opioid analgesics or hypnotics by other routes, extremes of age).

Practice Guidelines for the Prevention, Detection, and Management of Respiratory Depression Associated with Neuraxial Opioid Administration: An Updated Report by the American Society of Anesthesiologists Task Force on Neuraxial Opioids and the American Society of Regional Anesthesia and Pain Medicine. Anesthesiology 2016;124(3):535-552.

Anesthesia Patient Safety Foundation

- **Carbon dioxide monitoring is required based upon the level of sedation**, moderate or deep, and is irrespective of the location or type of anesthesia used. We would make an argument that a **similar degree of monitoring should be maintained in the postoperative environment** where most patients are still in a sedated state, especially in patients at high-risk for respiratory compromise.

- Capnography or other **monitoring** modalities that measure **the adequacy of ventilation** and airflow is indicated when supplemental oxygen is needed to maintain acceptable oxygen saturations.

- Monitoring continuous **oxygenation and ventilation** from a central location (telemetry or comparable technologies) is desirable. This information needs to be reliably transmitted to the healthcare professional caring for the patient at the bedside.

APSF Newsletter 2011 and 2016

The Joint Commission

- Recommendation: Create and implement policies and procedures for the ongoing clinical monitoring of patients receiving opioid therapy by performing serial assessments of the **quality and adequacy of respiration** …Staff should be educated not to rely on pulse oximetry alone…. especially when supplemental oxygen is being used

https://www.jointcommission.org/assets/1/18/SEA_49_opioids_8_2_12_final.pdf

Challenge 4 | Failure to Rescue: Monitoring Opioid-Induced Respiratory Depression

- THE PATIENT SAFETY MOVEMENT FOUNDATION NON-PROFIT HAS WORKED WITH GLOBAL MEDICAL EXPERTS TO CREATE FREE EVIDENCE-BASED RESOURCES, CALLED ACTIONABLE PATIENT SAFETY SOLUTIONS OR APSS, TO HELP HOSPITALS ADDRESS THE LEADING CAUSES OF PREVENTABLE HARM IN HOSPITALS, INCLUDING FAILURE TO RESCUE.
- DOWNLOAD THE FREE APSS AT PATIENTSAFETYMOVEMENT.ORG/APSS

"As a result of the changes, Baylor University Medical Center went from 40 monthly rapid response team activations a month to 3, and these are early calls! Due to the continuous monitoring of patients, staff are warned early enough to identify and treat patients, preventing costly return to ICU stays. It has saved the hospital money and more importantly kept patients' safe."

Dr. Michael A.E. Ramsay MD, FRCA Chairman, Department of Anesthesiology and Pain Management at Baylor University Medical Center

The Joint Commission

When pulse oximetry or capnography is used, it should be used continuously rather than intermittently

https://www.jointcommission.org/assets/1/18/SEA_49_opioids_8_2_12_final.pdf

Monitoring Guidelines

Organization	ASA	APSF	ASPMN	JC
Continuous SpO2 for patient at risk for RC	X	X	X	X
Continuous capnography for patients at risk for RC		X	X	X
Continuous monitoring by telemetry may be used	X	X		

ASA = American Society of Anesthesiologists
APSF = Anesthesia Patient Safety Foundation
ASPMN = American Society for Pain Management Nursing
JC= Joint Commission

Risk Factors for Respiratory Depression

- Obstructive Sleep Apnea
- Morbid Obesity (BMI ≥ 40kg/m^2)
- Snoring
- Age
- Opioid Naive
- Post Surgery
- General Anesthesia
- Cardiac/Pulmonary Co-morbidities
- Concomitant Sedating Drugs
- Smoker

Characteristics of patients who are at higher risk for oversedation and respiratory depression

- Sleep apnea or sleep disorder diagnosis[5,6,19]
- Morbid obesity with high risk of sleep apnea[5,6]
- Snoring[5,6]
- Older age; risk is
  - 2.8 times higher for individuals aged 61-70
  - 5.4 times higher for age 71-80
  - 8.7 times higher for those over age 80[5,12,20]
- No recent opioid use[6,21]
- Post-surgery, particularly if upper abdominal or thoracic surgery[5,22]
- Increased opioid dose requirement[6] or opioid habituation
- Longer length of time receiving general anesthesia during surgery[5,23]
- Receiving other sedating drugs, such as benzodiazepines, antihistamines, diphenhydramine, sedatives, or other central nervous system depressants[5,6,8,12]
- Preexisting pulmonary or cardiac disease or dysfunction or major organ failure[5,6]
- Thoracic or other surgical incisions that may impair breathing[5,6]
- Smoker[5,6]

https://www.jointcommission.org/assets/1/18/SEA_49_opioids_8_2_12_final.pdf

Validated OSA Questionnaire's

STOP-BANG Sleep Apnea Questionnaire

Chung F et al Anesthesiology 2008 and BJA 2012

STOP		
Do you **S**NORE loudly (louder than talking or loud enough to be heard through closed doors)?	Yes	No
Do you often feel **T**IRED, fatigued, or sleepy during daytime?	Yes	No
Has anyone **O**BSERVED you stop breathing during your sleep?	Yes	No
Do you have or are you being treated for high blood **P**RESSURE?	Yes	No

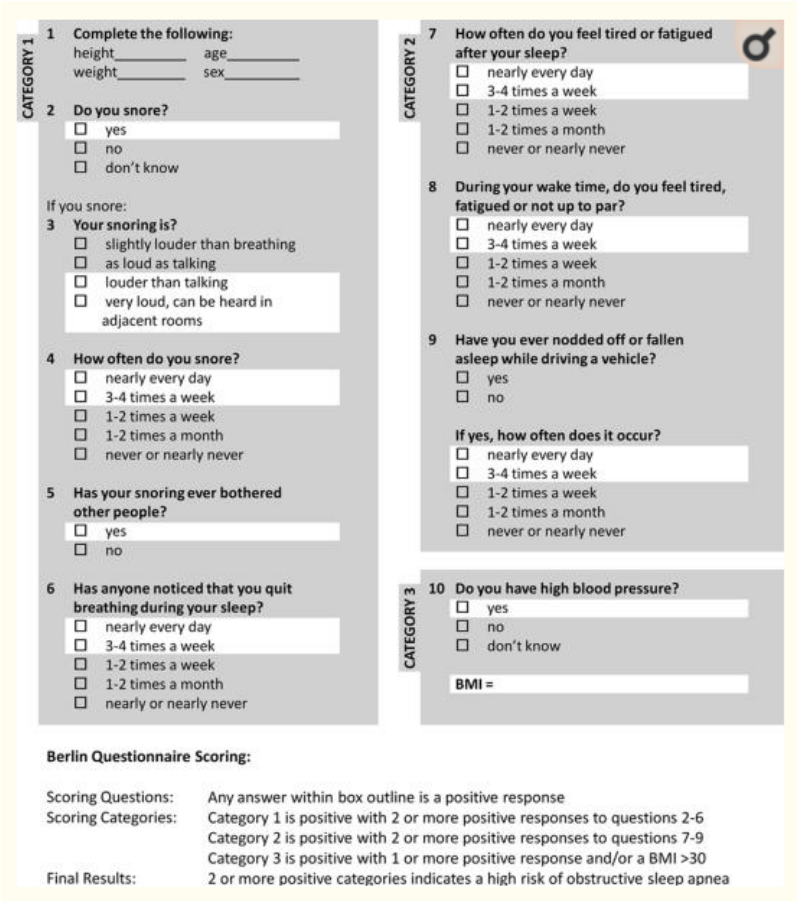
BANG		
BMI more than 35kg/m2?	Yes	No
AGE over 50 years old?	Yes	No
NECK circumference > 16 inches (40cm)?	Yes	No
GENDER: Male?	Yes	No

TOTAL SCORE		

High risk of OSA: Yes 5 - 8

Intermediate risk of OSA: Yes 3 - 4

Low risk of OSA: Yes 0 - 2



CATEGORY 1

1 **Complete the following:**
height_____ age_____
weight_____ sex_____

2 **Do you snore?**
- ☐ yes
- ☐ no
- ☐ don't know

If you snore:

3 **Your snoring is?**
- ☐ slightly louder than breathing
- ☐ as loud as talking
- ☐ louder than talking
- ☐ very loud, can be heard in adjacent rooms

4 **How often do you snore?**
- ☐ nearly every day
- ☐ 3-4 times a week
- ☐ 1-2 times a week
- ☐ 1-2 times a month
- ☐ never or nearly never

5 **Has your snoring ever bothered other people?**
- ☐ yes
- ☐ no

6 **Has anyone noticed that you quit breathing during your sleep?**
- ☐ nearly every day
- ☐ 3-4 times a week
- ☐ 1-2 times a week
- ☐ 1-2 times a month
- ☐ nearly or nearly never

CATEGORY 2

7 **How often do you feel tired or fatigued after your sleep?**
- ☐ nearly every day
- ☐ 3-4 times a week
- ☐ 1-2 times a week
- ☐ 1-2 times a month
- ☐ never or nearly never

8 **During your wake time, do you feel tired, fatigued or not up to par?**
- ☐ nearly every day
- ☐ 3-4 times a week
- ☐ 1-2 times a week
- ☐ 1-2 times a month
- ☐ never or nearly never

9 **Have you ever nodded off or fallen asleep while driving a vehicle?**
- ☐ yes
- ☐ no

If yes, how often does it occur?
- ☐ nearly every day
- ☐ 3-4 times a week
- ☐ 1-2 times a week
- ☐ 1-2 times a month
- ☐ never or nearly never

CATEGORY 3

10 **Do you have high blood pressure?**
- ☐ yes
- ☐ no
- ☐ don't know

BMI =

Berlin Questionnaire Scoring:

Scoring Questions:	Any answer within box outline is a positive response
Scoring Categories:	Category 1 is positive with 2 or more positive responses to questions 2-6
	Category 2 is positive with 2 or more positive responses to questions 7-9
	Category 3 is positive with 1 or more positive response and/or a BMI >30
Final Results:	2 or more positive categories indicates a high risk of obstructive sleep apnea

Perioperative Risk Factors for Respiratory Depression

Table 2. Medication Factors Associated with Respiratory Depression

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Lee LA, et al. Postoperative opioid-induced respiratory depression: a closed claims analysis. Anesthesiology. 2015;122:659-65.

Pulse Oximetry and CO_2 Monitoring

Table 4. Advantages and Disadvantages of Continuous Pulse Oximetry and Continuous Capnography Monitoring

Continuous Pulse Oximetry Monitoring		Continuous Capnography Monitoring	

Transcutaneous CO_2 Monitor

Lam, T et al. Continuous Pulse Oximetry and Capnography Monitoring for Postoperative Respiratory Depression and Adverse Events: A Systematic Review and Meta-analysis Anesthesia & Analgesia 2017;125: 2019–2029

LIFE IN THE FASTLANE

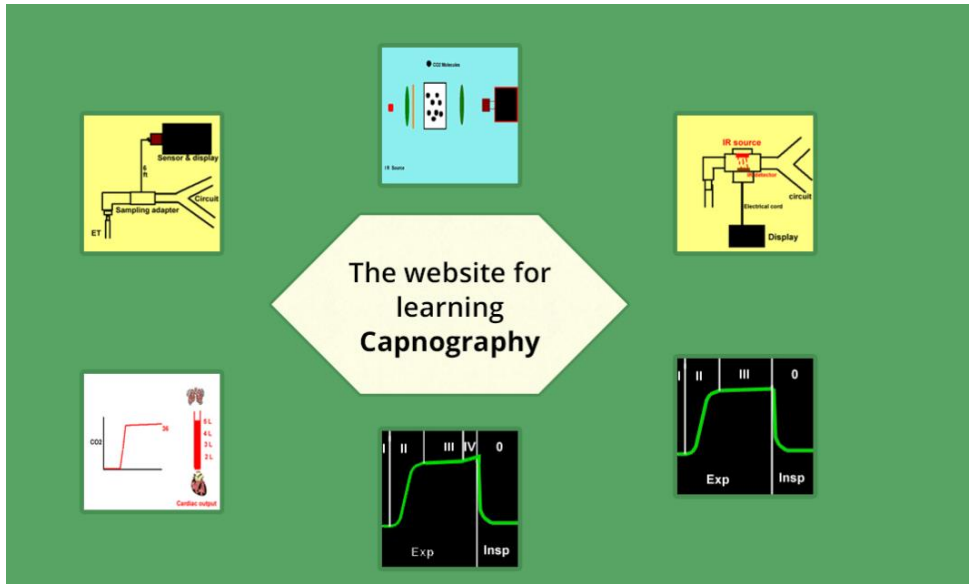
Home | Critical Care Compendium | **Capnography Waveform Interpretation**

Capnography Waveform Interpretation

by Chris Nickson, Last updated May 24, 2016

OVERVIEW

- Capnography waveform interpretation can be used for diagnosis and ventilator-trouble shooting
- The CO2 waveform can be analyzed for 5 characteristics:
  - –Height
  - –Frequency
  - –Rhythm
  - –Baseline
  - –Shape



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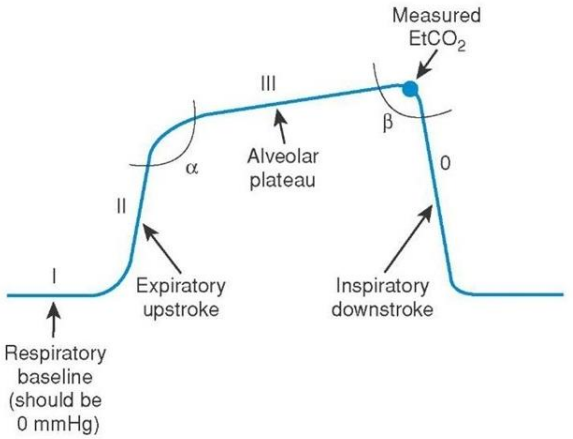
HOME >> PATIENT CARE >> HOW TO READ AND INTERPRET END-TIDAL CAPNOGRAPHY WAVEFORMS

How to Read and Interpret End-Tidal Capnography Waveforms

Tue, Aug 1, 2017 | By Rommie L. Duckworth, LP



EMS Products > EMS Capnography > Articles

Picture from http://what-when-how.com/wp-content/uploads/2012/04/tmp2A92_thumb221.jpg

The Practical Medic
with Bob Sullivan

5 things to know about capnography

Understand the importance of monitoring end-tidal carbon dioxide and the valuable information it provides for patient assessment and treatment

Apr 27, 2015

Ventilation/Perfusion Mismatch

- Arterial CO_2 can rise without a rise in $EtCO_2$
- BOTH
  - Physiologic dead space= (PaCO2-PexpCO2)/PaCO2
    - % Tidal volume not contributing to gas exchange
    - Ventilated but underperfused parts of the lung
  - Shunt (has to be >50% to contribute to hypercapnia)
    - Perfused but underventilated

Wagner PD. Causes of a high physiological dead space in critically ill patients. Crit Care. 2008; 12: 148.

Multiple Settings Where End Tidal CO_2 Monitoring is not Accurate

- Increased dead space ventilation

  Yamanaka MK et al, *Chest* 1987;92:832

- Critically ill adult ICU patients

  Hoffman RA et al, *Amer Rev Resp Dis*1989;140:1265

- Intraoperative care

  Wahaba RWM et al, *Can J Anaesth* 1996;43:862

- One-lung ventilation

  Yam PCI et al, *Br J Anaesth*1994;72:21

- Patient positioning

  Panard JL et al, *Anesth Analg*1992;75:506

  Grenier B et al, Anesth Analg 1999;88:43

- Type of ventilator affects accuracy of ETCO2 monitoring

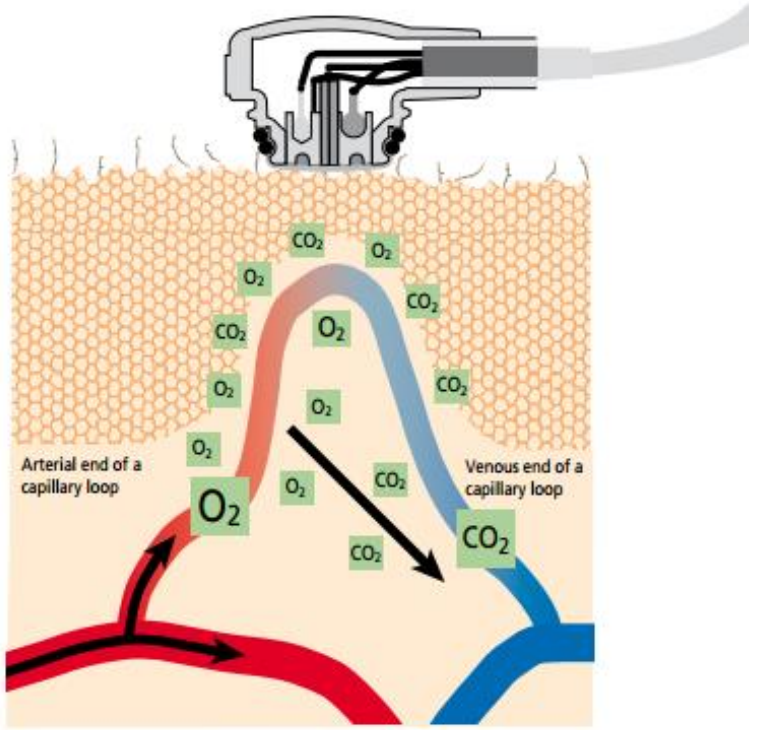
  Badgwell JM et al, *Anesthesiology*1987;66:405

Transcutaneous CO_2 Monitoring: What is it?

- Continuous monitoring
- Central Monitoring compatible
- Transcutaneous CO_2
- Pulse Oximetry

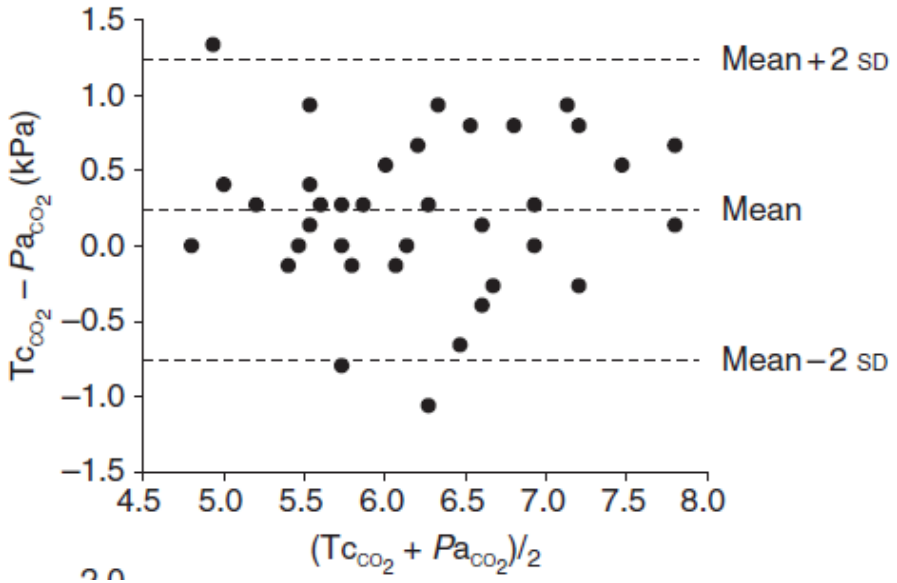
Transcutaneous CO_2 Monitoring: What is it?

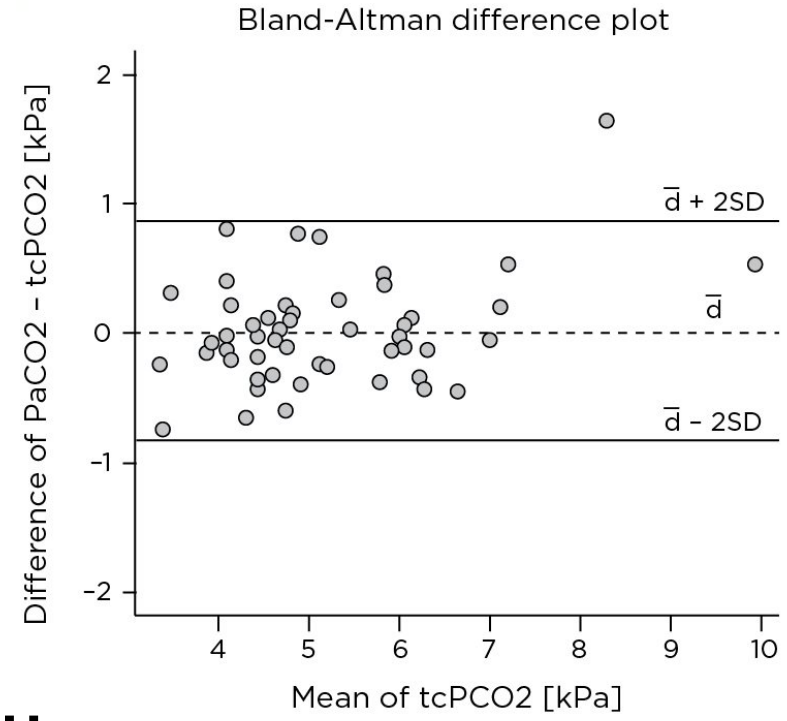
- Stow-Severinghaus type electrode-
  - Heated sensor
- Measures pH Δ- converts to CO_2 reading
- Accuracy $TcCO_2$ within 0-6mmHg [1,2,3]



1) De Oliveira et al. Br J Anaesth 2010; 104:774-8.
2) Reid et al. Can J Anaesth 1992; 39:31- 6.
3) Gancel et al. Intensive Care Med. 2011;37:348-51.

Transcutaneous CO2 Monitoring: Accuracy





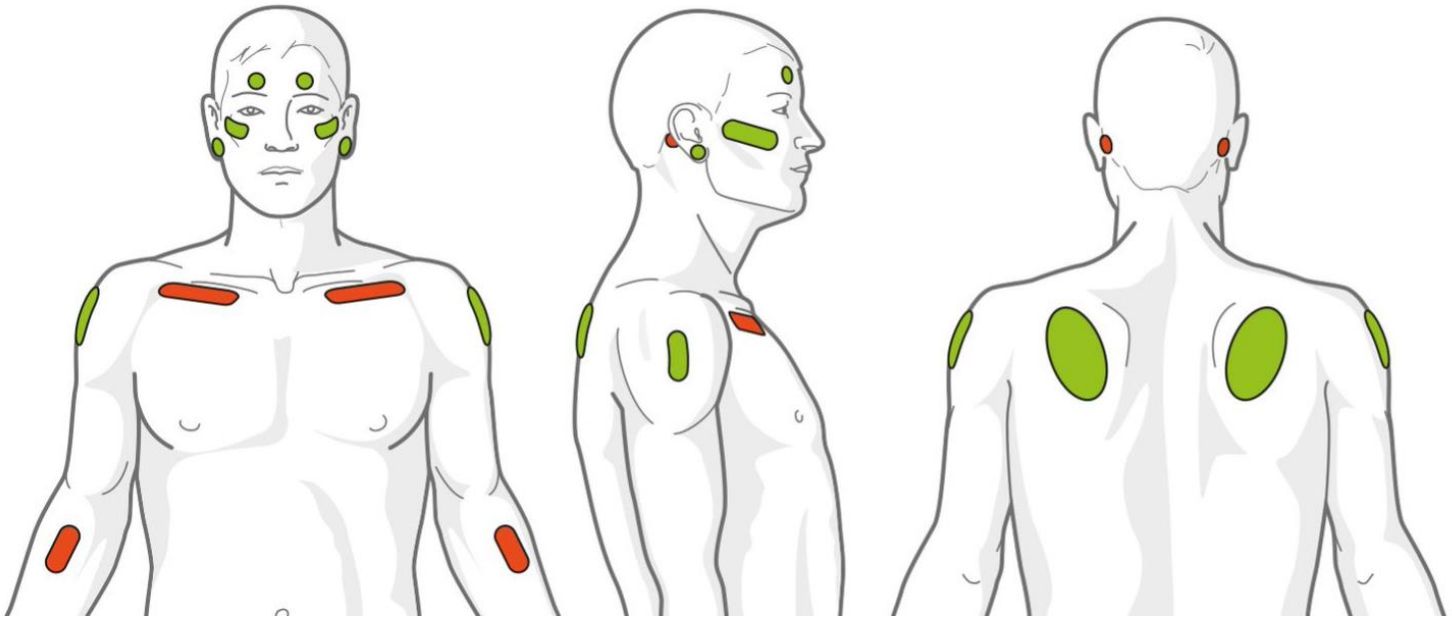
1 kPa = 7.5 mmHg

DeOliveira et al. British Journal of Anaesthesia 2010; 104: 774-8.

Chhajed et al. Scand J Clin Lab Invest 2012; 72:340-2.

Transcutaneous CO2 Monitoring Sites

= multisite attachment ring



PCO2/SpO2/PR

PCO2

Transcutaneous CO2 Monitoring vs Capnography

- Easy, easy, easy
- Quantitative CO_2 measurement
- Independent of tidal volume
- Pulse oximetry built in
- Less patient aggravation

Transcutaneous CO_2 Monitoring is Accurate for ….

…Intrahospital transport of critically ill and ventilated adults

Hinkelbein J, et al. Accuracy and precision of three different methods to determine Pco2 (Paco2 vs. Petco2 vs. Ptcco2) during interhospital ground transport of critically ill and ventilated adults. J Trauma 2008; 65: 10–8

…One lung ventilation

Cox P & Tobias J. *Noninvasive monitoring of $PaCO_2$ during one-lung ventilation and minimal access surgery in adults: End-tidal versus transcutaneous techniques* 2007; 3:.

Choi H et al. A Comparison of Transcutaneous and End-tidal Measurements of CO2 in One Lung Ventilation. *Korean J Anesthesiol 2008; 54:* 129–33.

…Spontaneously breathing nonintubated ICU patients admitted for acute respiratory failure

Lermuzeaux, M et al. (2016). Superiority of transcutaneous CO2 over end-tidal CO2 measurement for monitoring respiratory failure in nonintubated patients: A pilot study. *J Crit Care 2016; 31:* 150–6

…. Morbidly obese patients to detect perioperative hypercapnia

Soto, RG, Davis, M, & Faulkner MJ. A comparison of the incidence of hypercapnea in non-obese and morbidly obese peri-operative patients using the SenTec transcutaneous pCO2 monitor. *J Clin Monit Comput 2014; 28:* 293-8

...Laparoscopic radical gastrectomy or radical proctectomy under general anesthesia

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Transcutaneous CO2 Monitoring: Use in Perioperative Setting

- Monitor Sedation Cases
- Monitor General Anesthesia for 'Nontraditional Cases'
  - High Frequency Jet Ventilation
  - High Frequency Oscillation
  - One Lung Ventilation
  - Prolonged apneic phases
- Monitor High Risk Patients
  - PACU
  - Risk Factors for Respiratory Depression
    - OSA, Obesity, Co-morbidities, etc.
  - Postoperative Surgical Floors
    - Systemic or neuraxial opioids

Summary

- The safety and economic burden of respiratory failure is high in the perioperative setting.
- Continuous pulse oximetry and respiratory monitoring can increase identification of respiratory depression and is recommended by multiple national organizations.
- Patients should be screened for risk factors for respiratory depression and those at high risk should have continuous monitoring for both oxygenation and ventilation.
- Transcutaneous carbon dioxide monitoring provides continuous oxygenation and ventilatory monitoring that is more convenient and for the patient and healthcare providers and more accurate than capnography.