SURGERY GRAND ROUNDS

Hypoxemia in the Surgical ICU
A Pragmatic Approach

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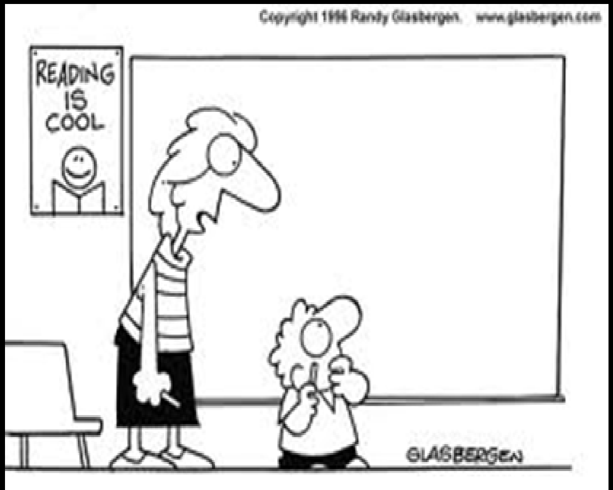
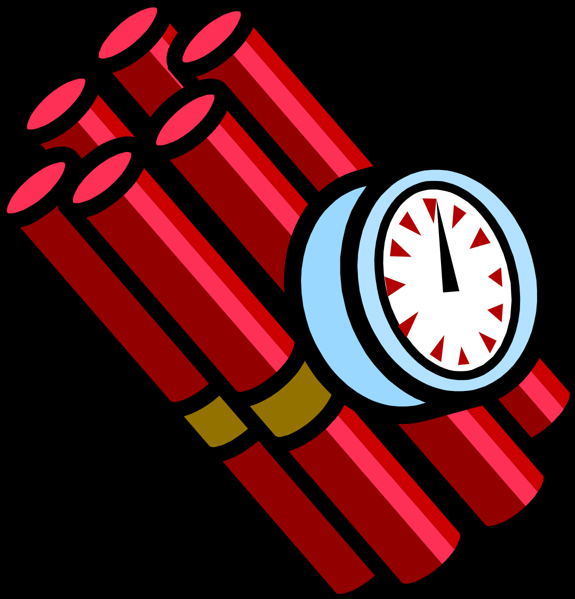
ROCKY MOUNTAIN REGIONAL TRAUMA CENTER
DENVER HEALTH
Level One Care for ALL

Overview

- **Mechanisms of Hypoxemia**
  Lets keep it as simple as ABC!
- **Detection of Hypoxemia**
  Will I know it When I see it?
- **Hypoxemia vs Hypoxia**
  Playing with fire or a clinical goal!
- **Hypoxic Events in the SICU**
  The clock is ticking!



"There aren't any icons to click. It's a chalk board."



Mechanisms of Hypoxemia

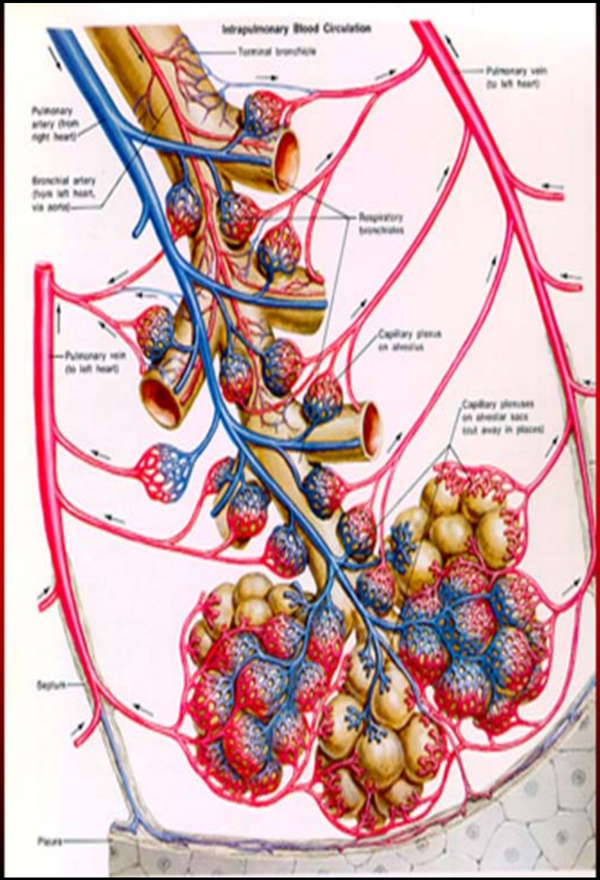
1) Low Inspired PO2

2) Hypoventilation

3) Ventilation/Perfusion mismatch

4) Right- to- Left Shunt

5) Diffusion defect



Low Inspired PiO_2/FIO_2 → Hypoxemia

Three variables determine Alveolar Po_2 : FIO_2, Pb, and $Paco_2$

- **Altitude**

- FiO_2= 0.21 everywhere

- Barometric pressure (Pb)

- **Seattle 760 mm Hg**
- **Denver 630 mm Hg**
- **Cheyenne 593 mm Hg**
- **Mt Everest 225 mm Hg**

➢ Alveolar O_2 **= 25 ~ mm Hg on Mt Everest**

The Mount Everest of the ICU

Potential Inadequate flow delivery

Room air entrainment

↓

Decreased FIO_2 Delivery

The Mount Everest of the ICU

Mechanical/Device Related Hypoxia

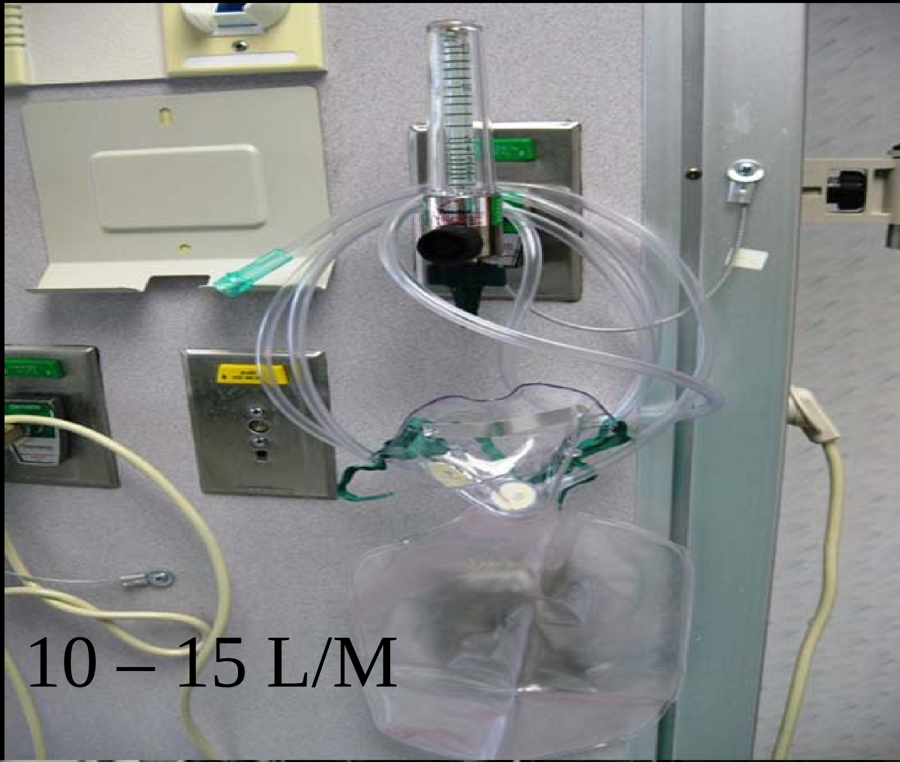
Normal Inspiratory flow
With spontaneous breathing
15 – 30 L/M

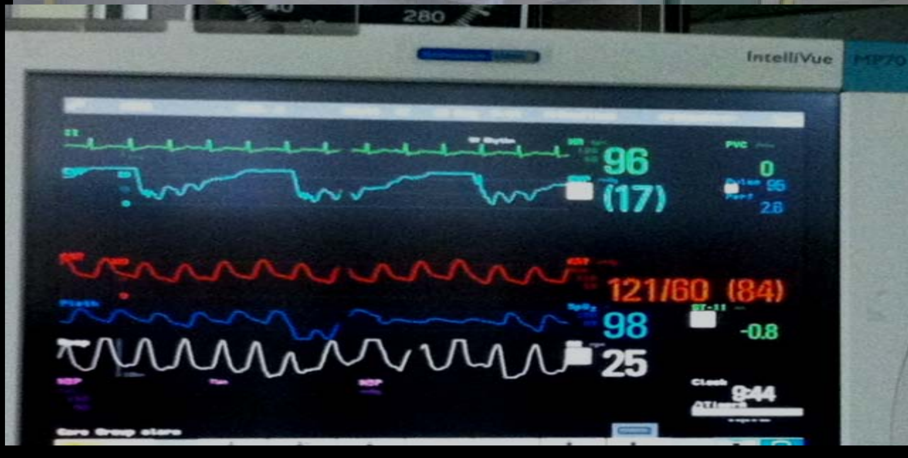
Poiseuille law
Raw =‘s L/r^4

Inspiratory flow with
Increased Raw
60 – 100 L/M

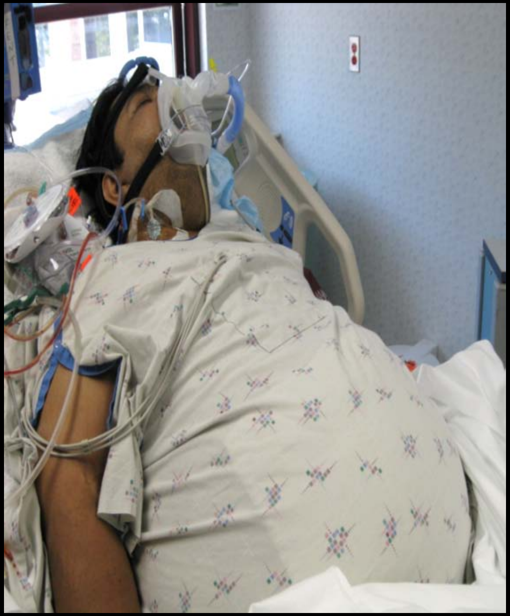
↓

Decreased FIO_2 Delivery





Alveolar Hypoventilation in the ICU



Brainstem respiratory depression

Peripheral neuropathy

Muscle weakness

Hypoxemia with a normal A-a gradient is a result hypoventilation!

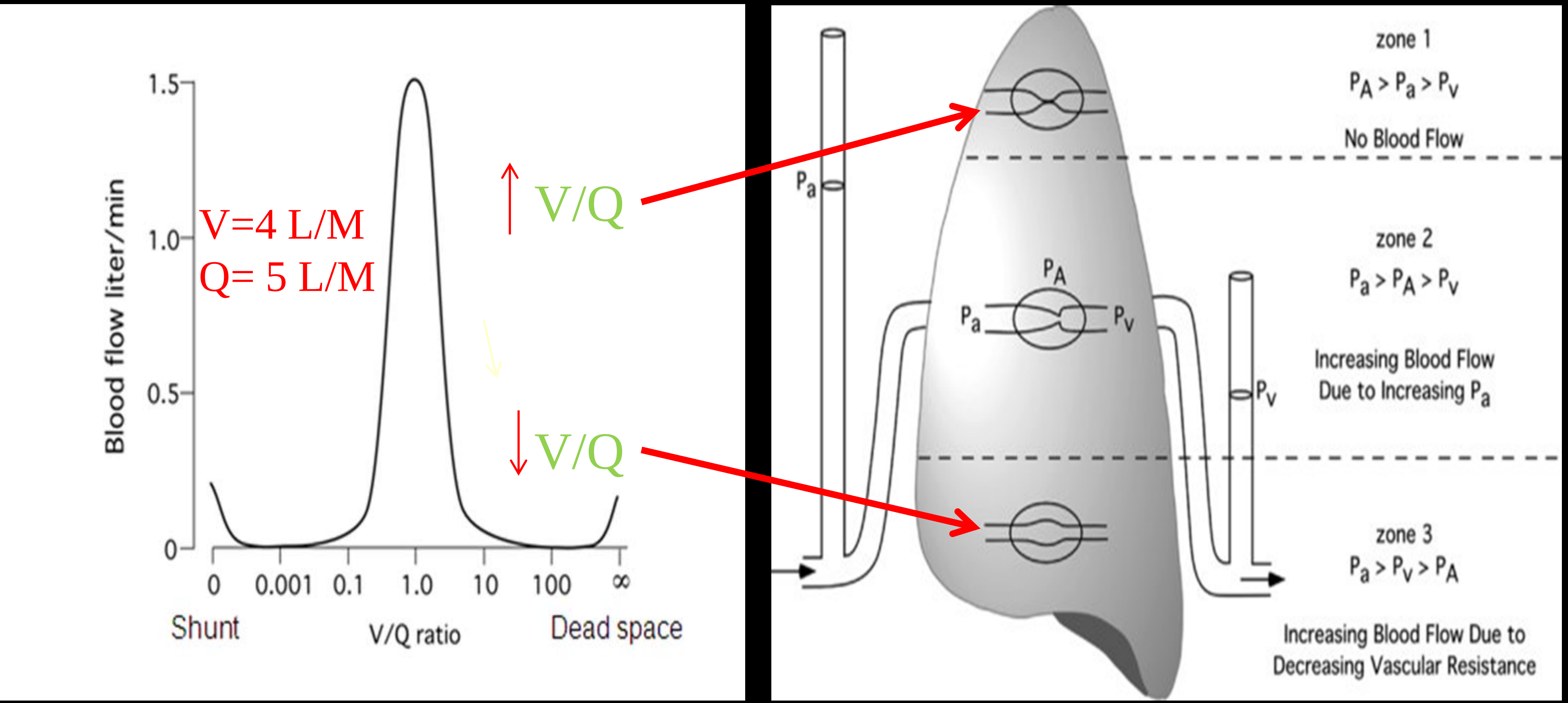
A-a gradient: Pb – H_2o vapor x FIO_2 - $PaCo_{2/}$ 0.8 – Pa0 $_2$

630 – 47 x 0.21 ÷ 55/0.8 – 50 = 7mm Hg

+

+

Ventilation/Perfusion Relationships



↓Ventilation/Perfusion Ratio

Most common clinical cause for arterial hypoxemia !!

Settings:

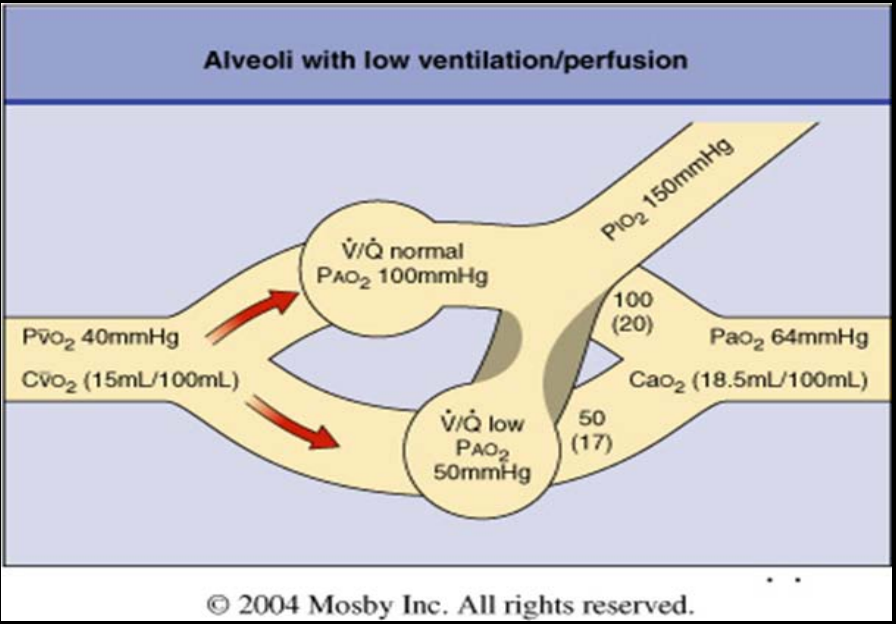
Atelectasis

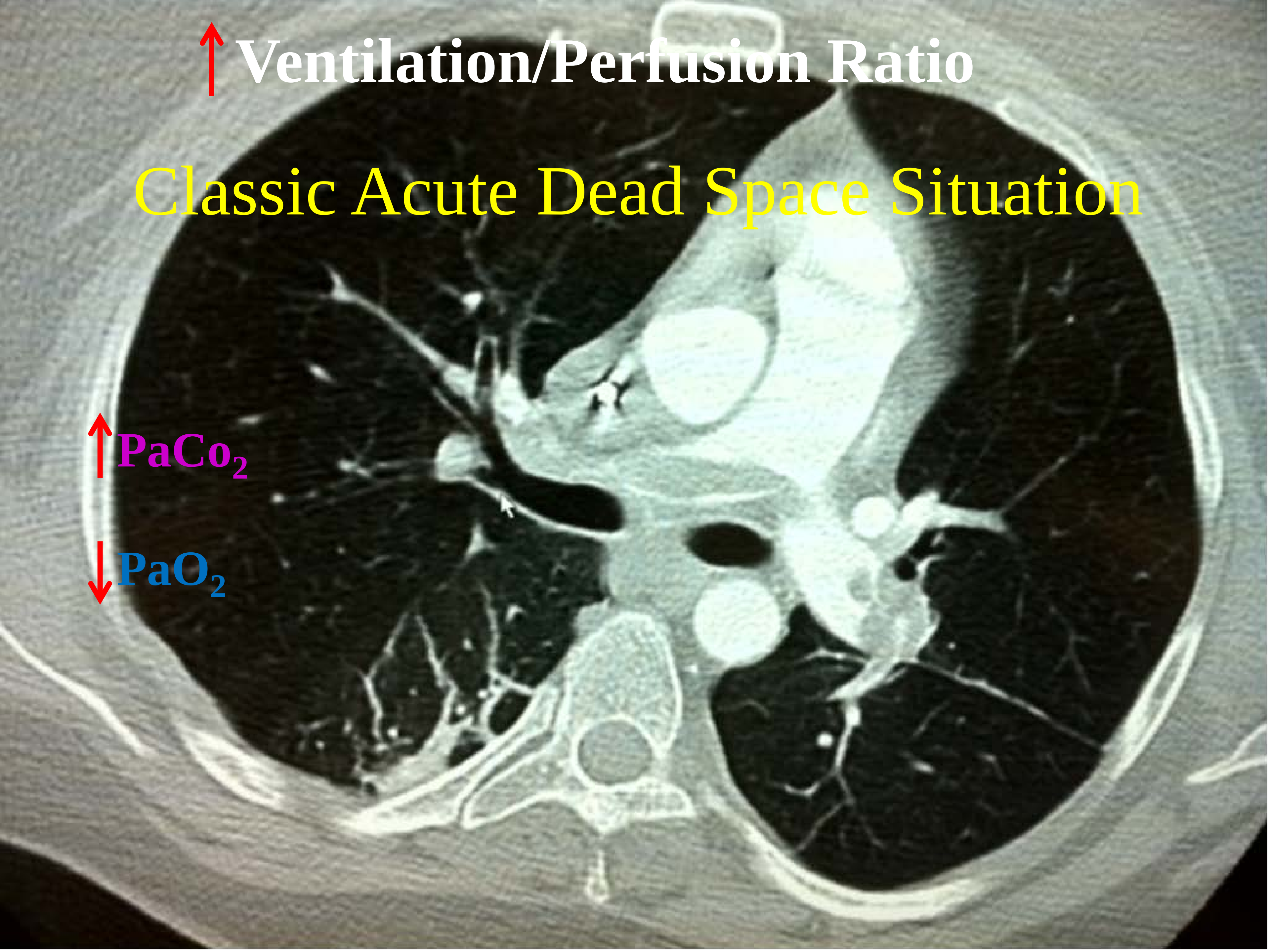
Bronchospasm

Partial airway obstruction

COPD

↓ V/Q ratio responds to supplemental O_2




↑ Ventilation/Perfusion Ratio
Classic Acute Dead Space Situation
↑ $PaCo_2$
↓ PaO_2

Right-to-Left Shunt

Physiologic shunt = ~ 3-5% of C.O.

- ✓ **Pulmonary shunt**

  Severe pneumonia

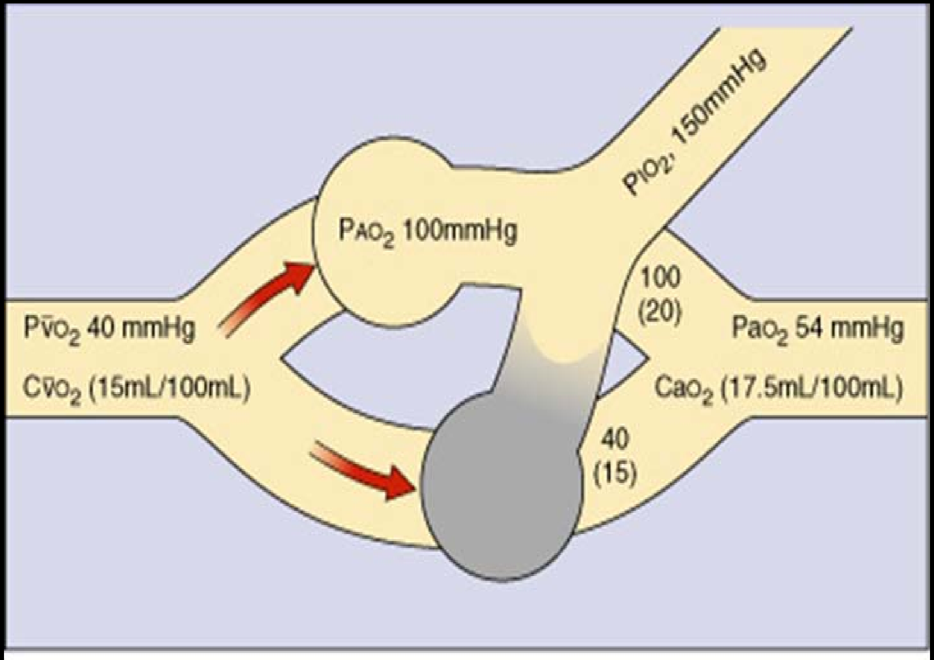
  ARDS

  Lobar collapse

  Reversal of H.P.V.

- ✓ **Extrapulmonary shunts** (atrial/ventricular/PDA)

- ✓ **Hepatopulmonary syndrome**

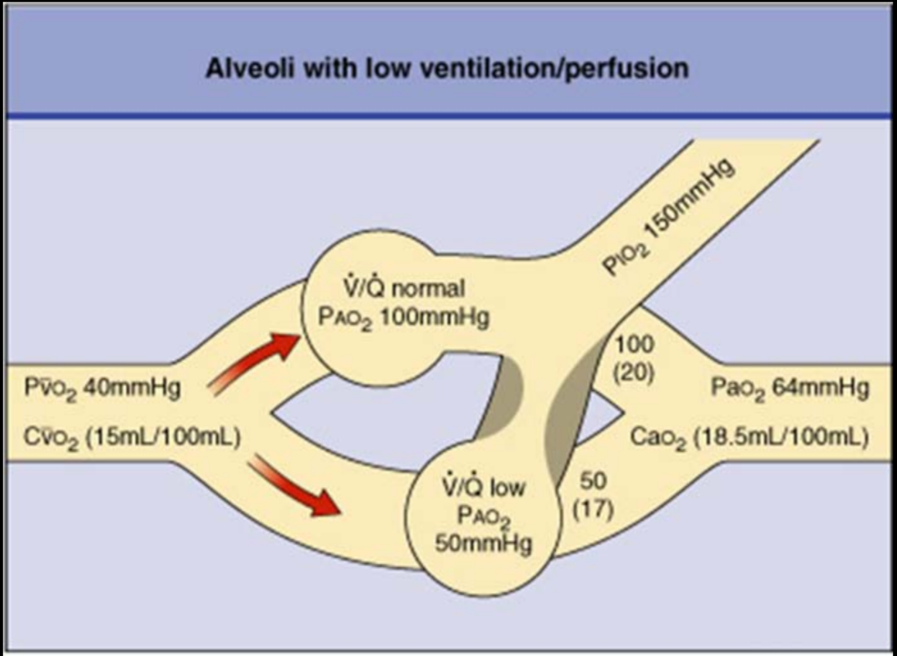


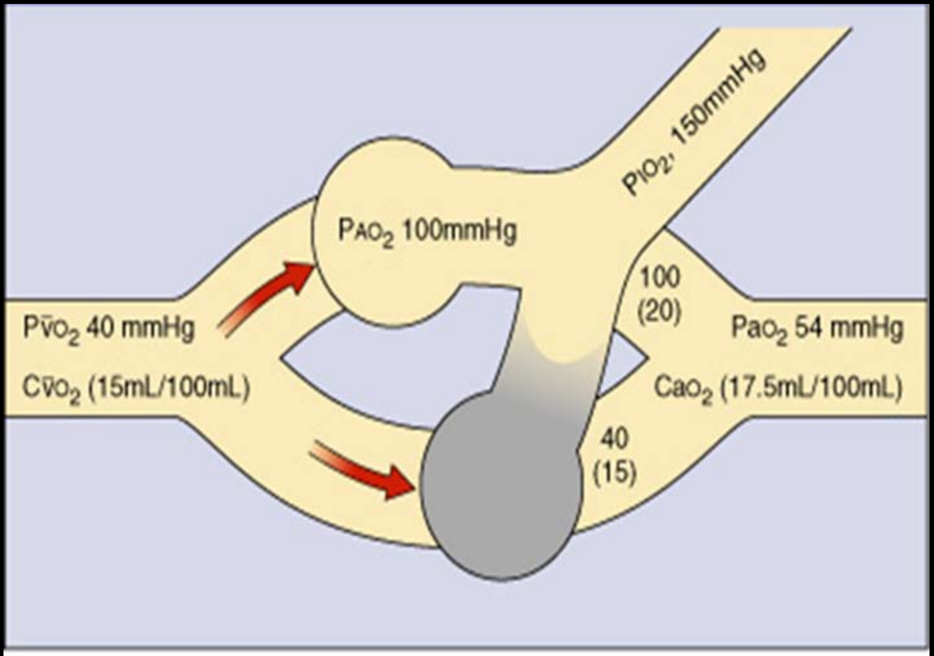
Perfusion without ventilation

Left – to – Right Qs/Qt does not respond to increased FIO_2

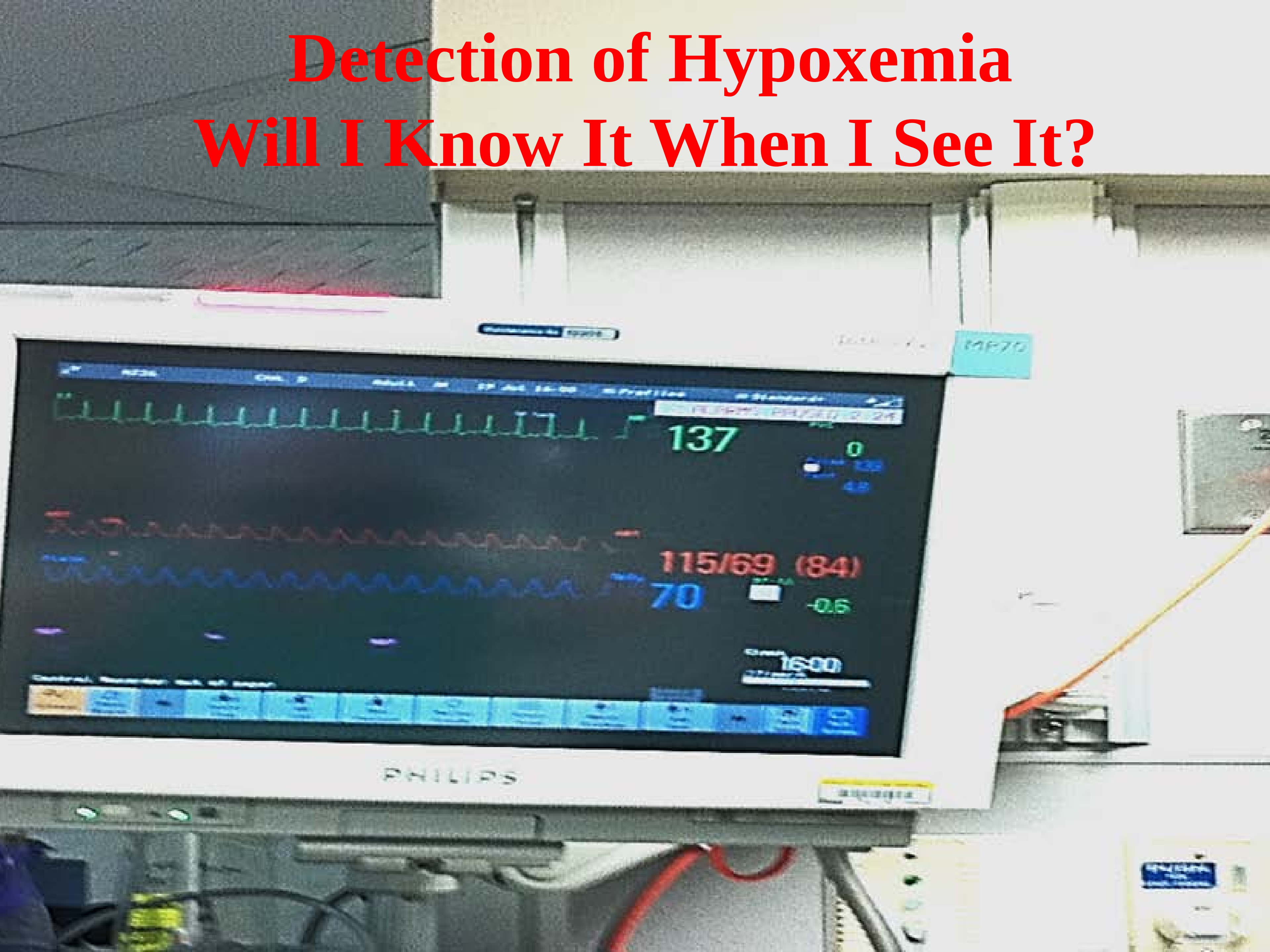
In Sum

- Mechanical/Device related exacerbation of hypoxemia is common
- Hypoventilation associated hypoxemia results in a normal A-a gradient
- V/Q Mismatch is the most common cause for hypoxemia
- Left – right – Qs/Qt does not respond to oxygen therapy





Detection of Hypoxemia
Will I Know It When I See It?



THE AMERICAN JOURNAL OF THE MEDICAL SCIENCES

JULY, 1947

ORIGINAL ARTICLES

THE UNRELIABILITY OF CYANOSIS IN THE RECOGNITION OF ARTERIAL ANOXEMIA*

By Julius H. Comroe, Jr., M.D.
and
Stella Botelho, A.B.
Philadelphia, Pennsylvania

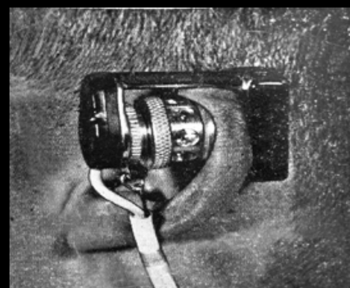
Table 1.—Percentages of Total Observations at Various Arterial Oxygen Saturation Levels Noted as Normal Color, Slight Cyanosis or Definite Cyanosis

Oximeter reading (arterial O_2 saturation)	No. observations at each arterial O_2 level			% observations reported: Normal color			Slight cyanosis			Definite cyanosis		
	Students	Staff	Total	Students (%)	Staff (%)	Total (%)	Students (%)	Staff (%)	Total (%)	Students (%)	Staff (%)	Total (%)
100–96 . . .	2865	808	3673	67	70	68	27	22	26	6	8	6
95–91 . . .	711	203	914	42	48	43	42	32	40	16	20	17
90–86 . . .	712	182	894	33	25	32	36	43	37	31	32	31
85–81 . . .	799	244	1043	15	10	14	36	37	37	49	53	49
80–76 . . .	418	76	494	10	4	10	43	29	40	47	67	50
75–71 . . .	139	47	186	4	0	3	25	15	22	71	85	75
Total . . .	5644	1560	7204									

Monitoring Oxygenation

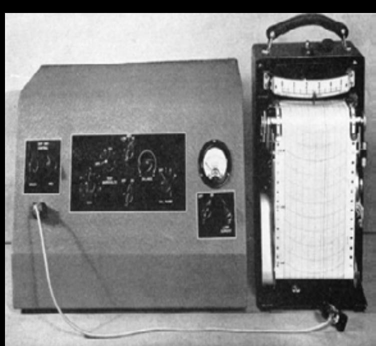
1930's

1941



1967*

1980-1990



1939*

1956

1978

2010

Anesthesiology
78:445–453, 1993

J. B. Lippincott Company, Philadelphia

Randomized Evaluation of Pulse Oximetry in 20,802 Patients: II.

Perioperative Events and Postoperative Complications

Table 1. Respiratory and Cardiovascular Events during Anesthesia

Event	Control (n = 10,490)		Oximetry (n = 10,312)		
	N	%	N	%	*P**
Respiratory					
[illegible]	[illegible]	0.4	[illegible]	7.9	<0.00001
Hypoventilation	[illegible]	0.4	[illegible]	1.2	<0.00001
Airway obstruction	29	0.3	44	0.4	NS
Laryngospasm	20	0.2	24	0.2	NS
Bronchospasm	66	0.6	85	0.8	NS
Aspiration (suspected)	10	0.1	13	0.1	NS
Difficulty with intubation	139	1.3	170	1.7	NS
Esophageal intubation	31	0.3	38	0.4	NS
Endobronchial intubation	5	0.05	27	0.3	<0.001
Reintubation	20	0.2	16	0.2	NS
Other	31	0.3	18	0.2	NS
Total no. of patients with 1 or more event(s)	[illegible]	3.3	[illegible]	11.2	<0.00001
Cardiovascular					
Hypotension	469	4.5	456	4.4	NS
Hypertension	224	2.1	216	2.1	NS
Hypovolemia	39	0.4	56	0.5	NS
Arrhythmia (all)	197	1.9	188	1.8	NS
Cardiac arrest with resuscitation	11	0.1	4	0.04	NS
Myocardial ischemia	[illegible]	0.2	[illegible]	0.1	<0.03
Other	14	0.1	10	0.1	NS
Total no. of patients with 1 or more event(s)	[illegible]	7.7	[illegible]	7.8	NS

* Chi-square test followed by stratification and logistic regression analyses to control for the known confounders.

Anesthesiology
78:445–453, 1993

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Randomized Evaluation of Pulse Oximetry in 20,802 Patients: II.

Perioperative Events and Postoperative Complications

Multi-institutional study: Denmark

✓ 19 – fold increase in the incidence of diagnosed hypoxemia in oximetry group

Intraoperative:

❑ Incidence of myocardial ischemia: Pulse Oximetry =12 Control = 26

✓ Pulse Oximetry group received more interventions while in the PACU

I. Increased use of supplemental O2
II. Increased use of supplemental O2 at discharge
III. Increased use of Narcan

Postoperative rate of complications :

❑ 10% vs 9.4%
❑ No difference in post-op complications of any kind
❑ Hospital stay 5 days both groups
❑ NO DIFFERENCE in MORTALITY!!

ABG’S: To Many, To Few or Just Right?

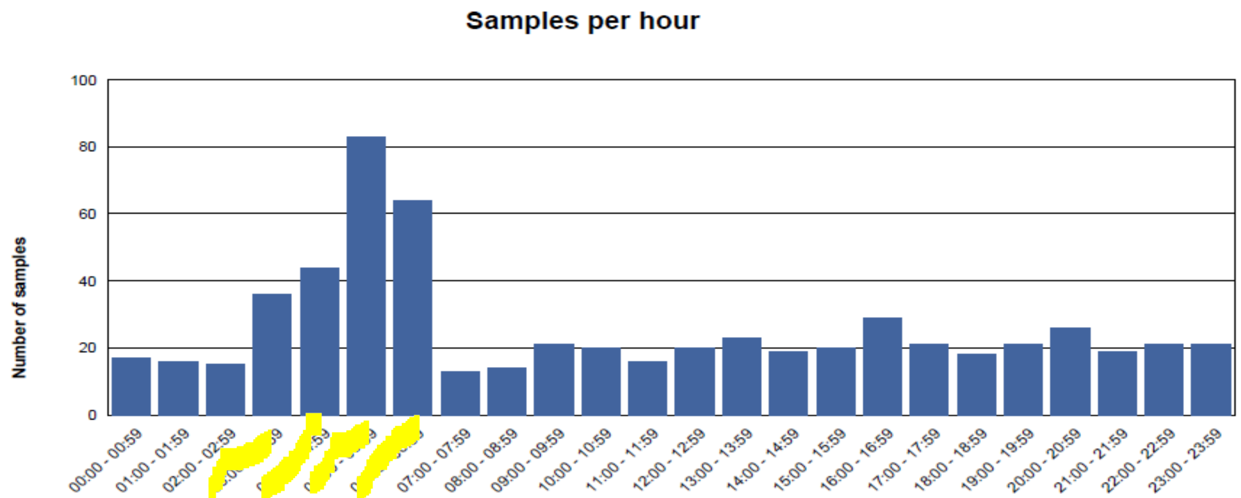
Denver Health Medical Center
777 Bannock Street
Denver, CO 80402

Print date: 9/7/2011

Sample Detail Graph

Match Criteria

Start date:	8/1/2011
End date:	8/31/2011
Analyzer:	ABL 2 (ABL820)



Spontaneous Blood-Gas Variability

Variation	PaO2	PaCO2
Mean	13 mm Hg	2-5 mm Hg
95th Percentile	± 18 mm Hg	±4 mm Hg
Range	2-37 mmHg	0-12 mm Hg

Represents variation over a 1-hour period in 26 ventilator dependent trauma patients who were clinically stable.

Hess D J Clin Monit 1992; 8:111

Hypoxemia vs Hypoxia
Playing with fire or a Clinical Goal?

Definitions of Severe Hypoxemia

1967
Cyanosis refractory to oxygen therapy
Lancet Saturday 12 August 1967

1974
ARF is usually defined on the basis of alterations in ABG compositions, an arterial Po_2 < 50 mm Hg and/or an arterial Pco_2 > 50 mm Hg Thomas Petty

1988
PaO_2 /Fio_2 ratio < 299
Murray LIS , AM REV RESP DIS

2000
P/F ratio < 300 ALI , <200 ARDS
ARDS Net

2009
CESAR trial
Murray Score > 3.0

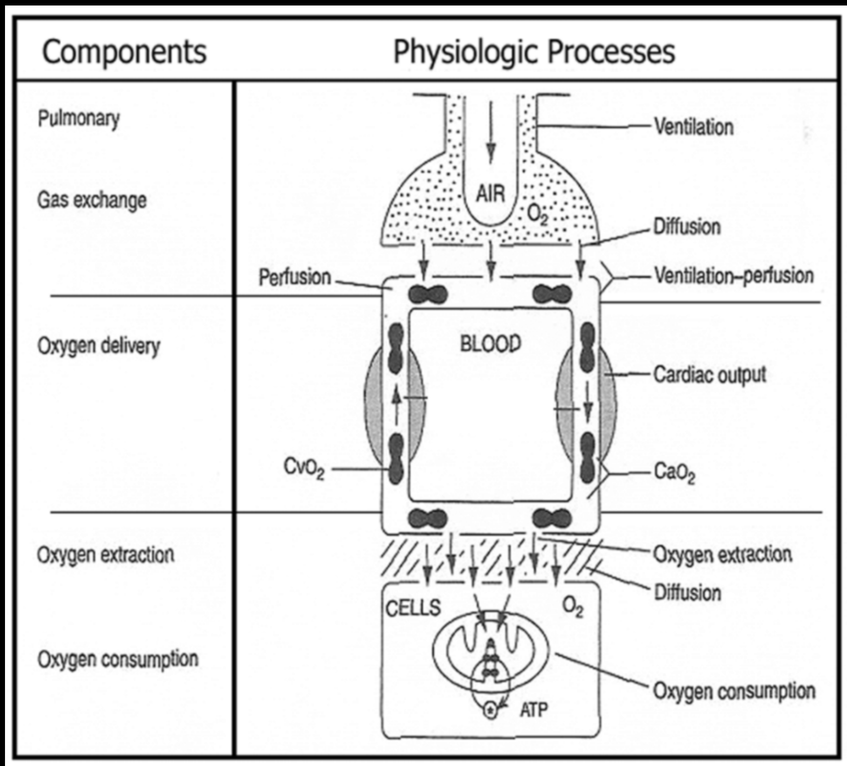
The nurse reminds you every 10 mins that the patients pulse-ox is 88%!!

The nurse says they need you in room 20 NOW!

Tissue Oxygenation

Inadequate oxygen carrying capacity
Anemic hypoxia
Inadequate oxygen transport
Stagnant hypoxia
Inadequate peripheral Oxygen Extraction
Cytopathic hypoxia

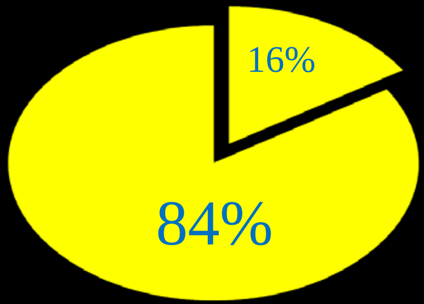
→ Inadequate oxygen saturation
Hypoxic hypoxia,



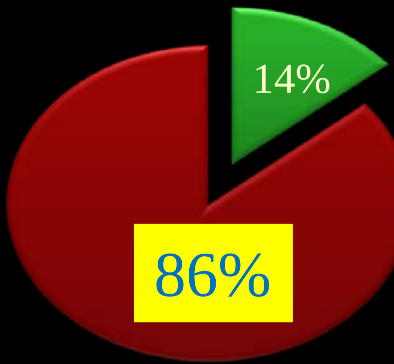
Why do ARDS Patients Die??

Death from ARDS

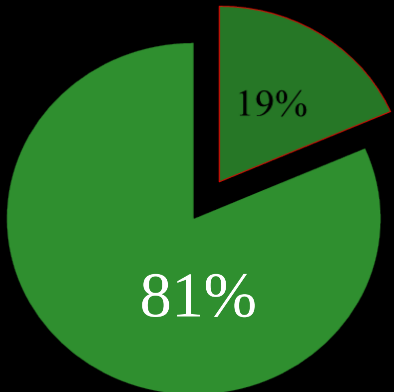
1981-82 (n=32)



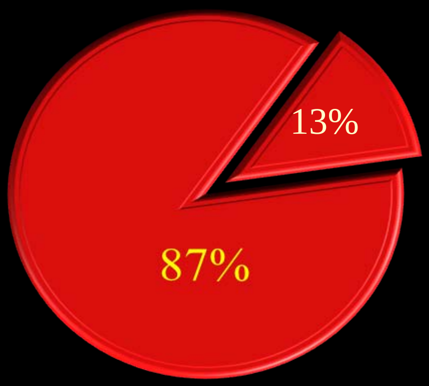
1990 (n=57)



1994 (n= 32)

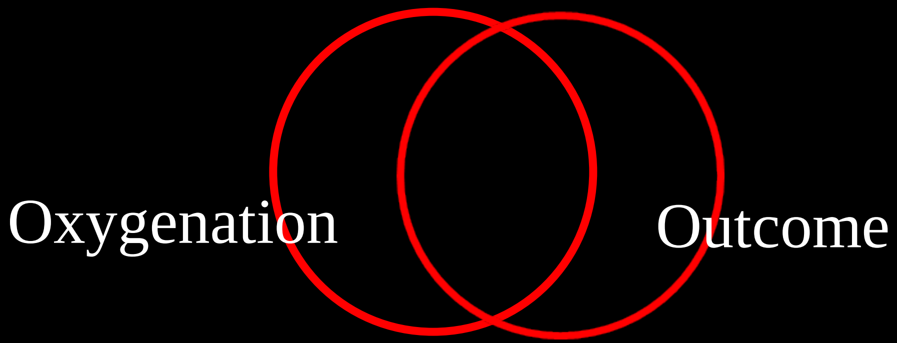


1998 (n=75)



Elements in the Management of ARDS

1. Oxygenation of arterial blood
2. Support of ventilation
3. Treatment of the inciting event
4. Monitoring patient
5. Prevention, recognition and treatment of complications



ALI/ARDS (Pao_2/Fio_2) Strategies 1980-2011

- ✓ Alternate modes of ventilation- HFOV, APRV, Bi-Level
- ✓ Neuromuscular blockade
- ✓ PEEP trials
- ✓ Nitric oxide
- ✓ ECLS
- ✓ Liquid ventilation
- ✓ Prone positioning
- ✓ Lung recruitment maneuvers

NO proven benefit in survival!!

What works and what are we afraid of?

LPV

- Low tidal volumes
- plateau pressures < 30
- Moderate PEEP
- A/C with volume

Oxygenation goals

✓ **Pao_2 55-80- SPo2 88-95%**

ARDS Net NEJM May 4 2000

Why is there no consensus then in ordinary patient management?

FIO2 /PEEP tolerance varies
PaO_2 ,Pulse oximetry/SVO2 values that triggers an intervention differs

The “acceptable” level of arterial oxygenation varies from patient to patient and even for a given patient shift to shift!

Permissive Hypoxemia??

Managing Oxygenation: Questioning Assumptions and Moving Toward Permissive Hypoxemia
Respiratory Care July [illegible]1 Vol 46 No 7

CHEST

Official publication of the American College of Chest Physicians

CHEST ONLINE

Permissive Hypoxemia : Is It Time To Change Our Approach?

Mohamed Abdelsalam

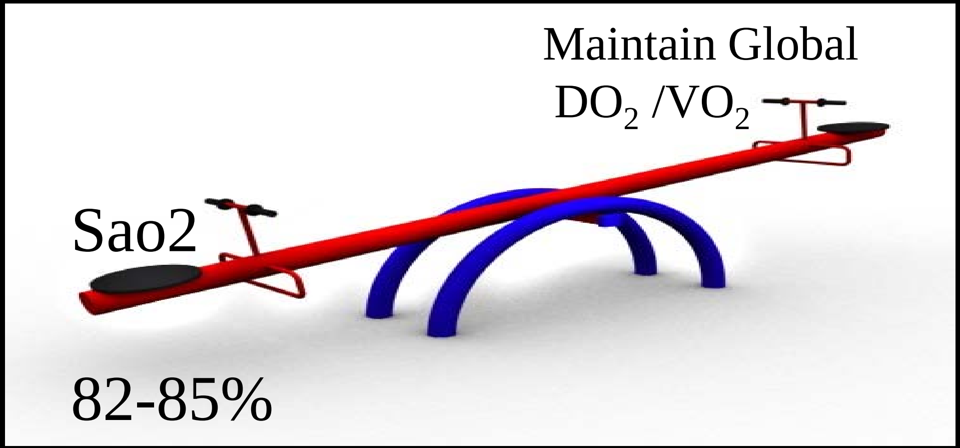
Chest [illegible];129;210-211
DOI 10.1378/chest.129.1.210

‘The overall goal of permissive hypoxemia as a lung-protective strategy, is to minimize the detrimental pulmonary and systemic effects of high ventilatory support (by accepting a relatively low arterial oxygen saturation)while maintaining adequate Do_2 by optimizing cardiac output.”

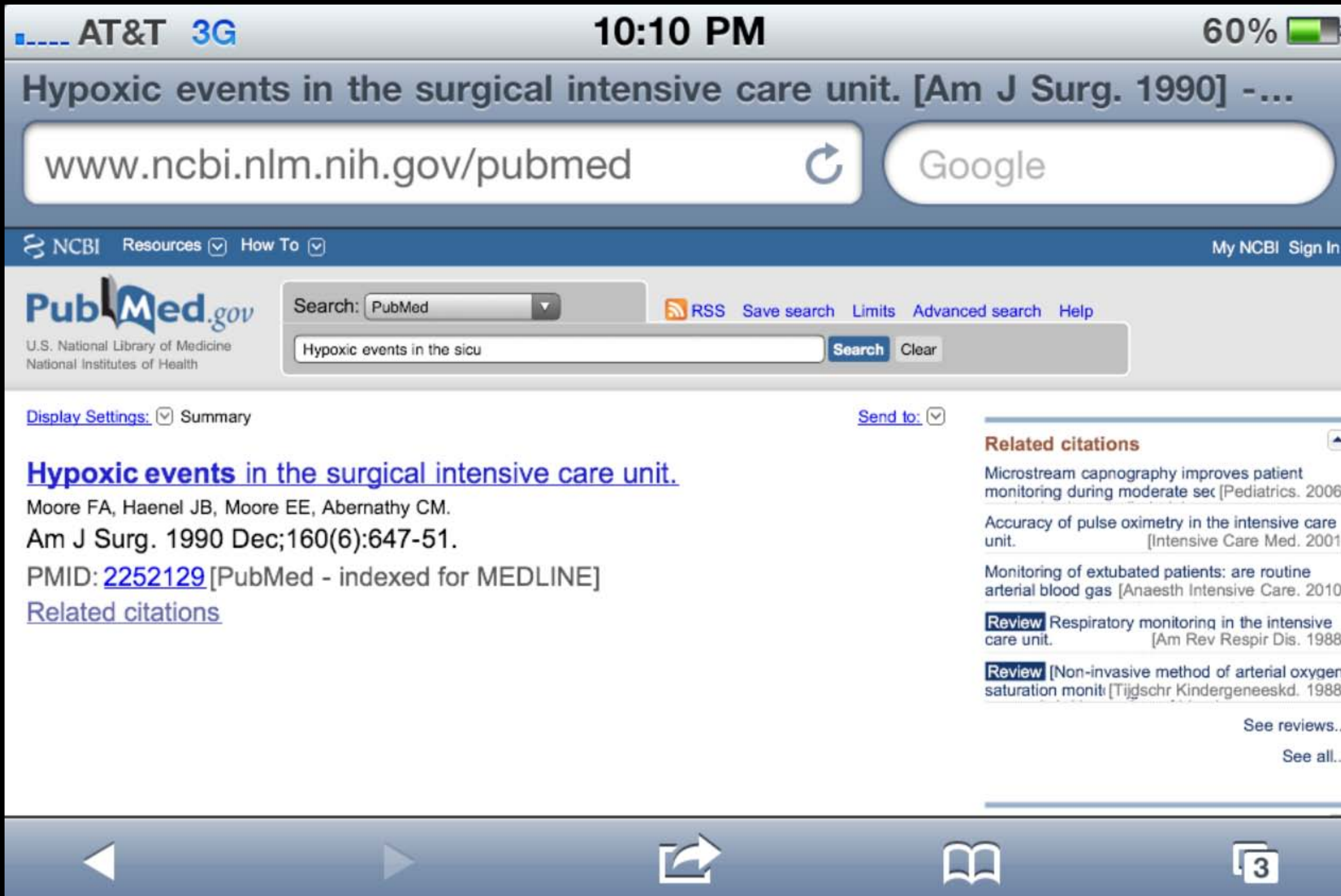
Goal-Directed Therapy for Severely Hypoxic Patients With Acute Respiratory Distress Syndrome: Permissive Hypoxemia

Mohamed Abdelsalam MD and Ira M Cheifetz MD FAARC

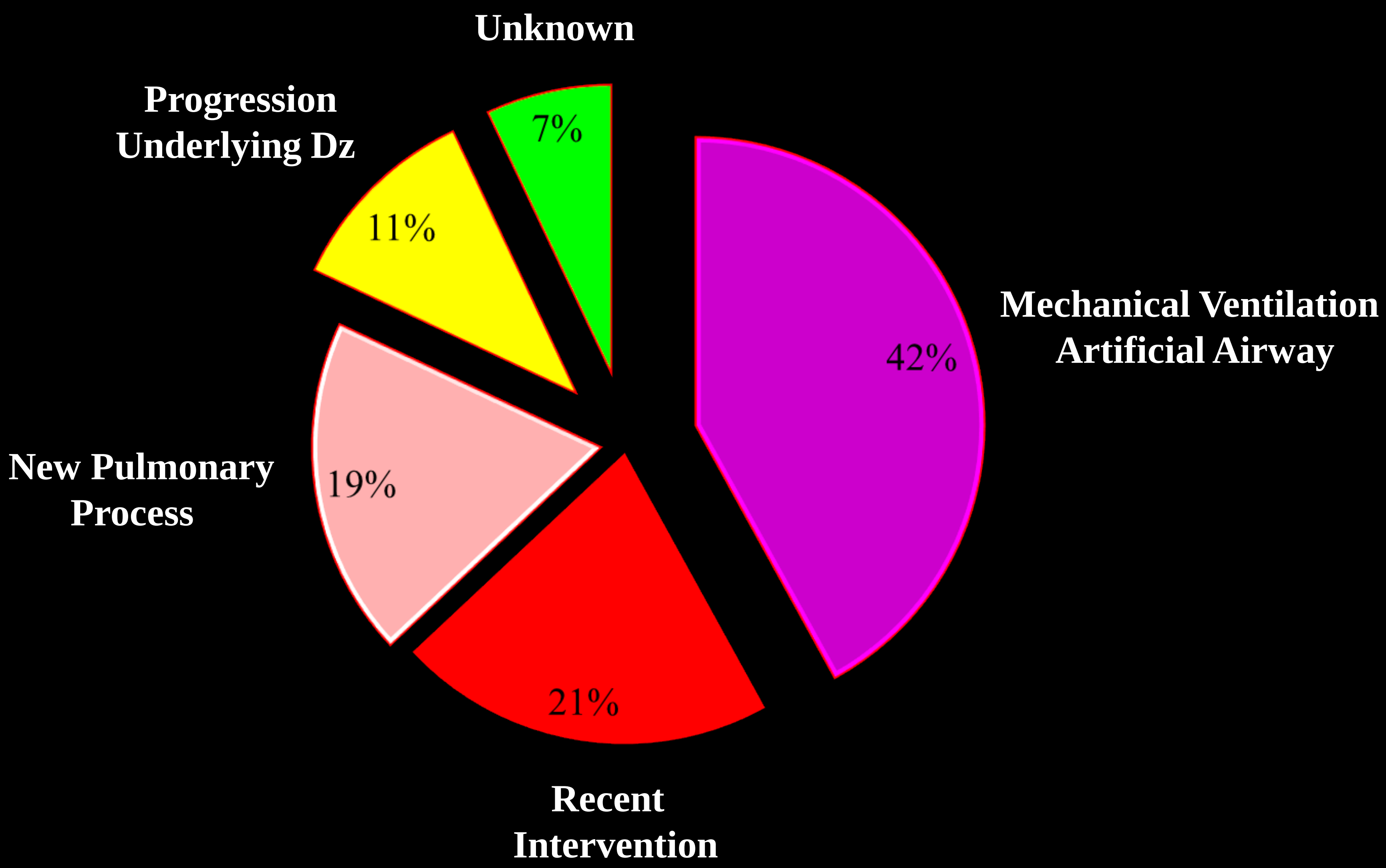
Permissive hypoxemia is a lung-protective strategy that aims to provide a patient with severe acute respiratory distress syndrome (ARDS) a level of oxygen delivery that is adequate to avoid tissue hypoxia while minimizing the detrimental effects of the often toxic ventilatory support required to maintain normal arterial oxygenation. However, in many patients with severe ARDS it can be difficult to achieve a balance between maintaining adequate tissue oxygenation and avoiding ventilator-induced lung injury (VILI). A potential strategy for the management of such patients involves goal-oriented manipulation of cardiac output and, if necessary, hemoglobin concentration, to compensate for hypoxemia and maintain a normal (but not supranormal) value of oxygen delivery. Although it has not yet been studied, this approach is theorized to improve clinical outcomes of critically ill patients with severe ARDS. We stress that the goal of this article is not to convince the reader that this approach is necessarily correct, as data are clearly lacking, but rather to provide a basis for continued thought, discussion, and potential research. *Key words: mechanical ventilation; oxygen delivery; cardiac output; hypoxia; shock; acidosis; critical illness; hypoxemia; acute lung injury; acute respiratory distress syndrome; anemia; physiology; hypercapnia.* [Respir Care [illegible];55(11):1483–1490. © 2010 Daedalus Enterprises]



Hypoxic Events in the Surgical Intensive Care Unit



DHMC Hypoxic Events Surgical Intensive Care Unit



Etiology of 100 Consecutive Hypoxic Events in the Surgical Intensive Care Unit

1. Mechanical ventilator/airway (n = 42)

A. **Primary survey**

1. Supplemental oxygen disruption	9
2. Proximal airway obstruction	6
3. Distal mucous plugging	5
4. Ventilator asynchrony	3
5. Fluctuating FIO_2	3
6. Ventilator disconnect	2
7. Tension pneumothorax	2

B. **Secondary survey**

1. Ventilator adjustments	5
2. Weaning	7

II, **Recent interventions** (n =21)

A. Procedures	7
B. Medications	6
C. Positional changes	5
D. Post-transportation	3

III. New pulmonary process (n=19)

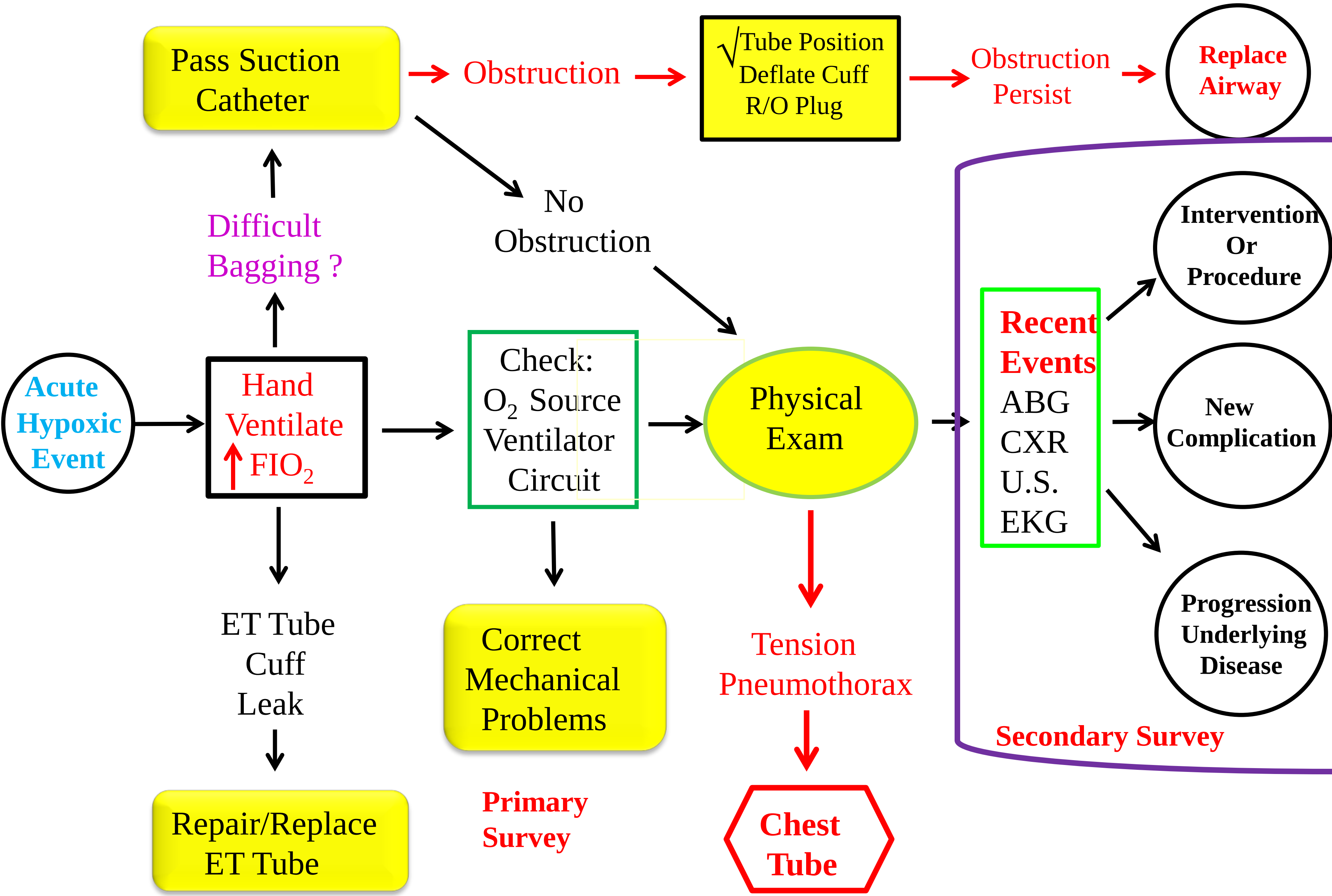
A. Pulmonary edema	6
B. Atelectasis/collapse	5
C. Simple pneumothorax	4
D. Pneumonia	3
E. Aspiration (primary survey)	1

IV. Progressive underlying disease (n= 11)

A. Sepsis	4
B. CHF	3
C. ARDS	2
D. Pneumonia	2

V. **Unknown causes** 7

Algorithm for Initial Management of Acute Hypoxic Events



Algorithm for Initial Management of Acute Hypoxic Events

→ Obstruction → √ Tube position
Deflate cuff
R/O plug

Difficult
Bagging
↑

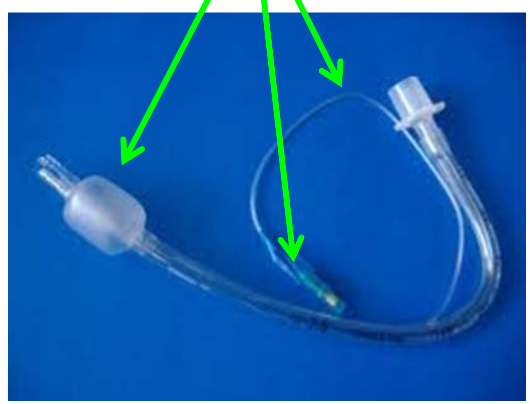
Acute Hypoxic Event → Hand Ventilate
↑FIO_2

Algorithm for Initial Management of Acute Hypoxic Events

Acute Hypoxic Event

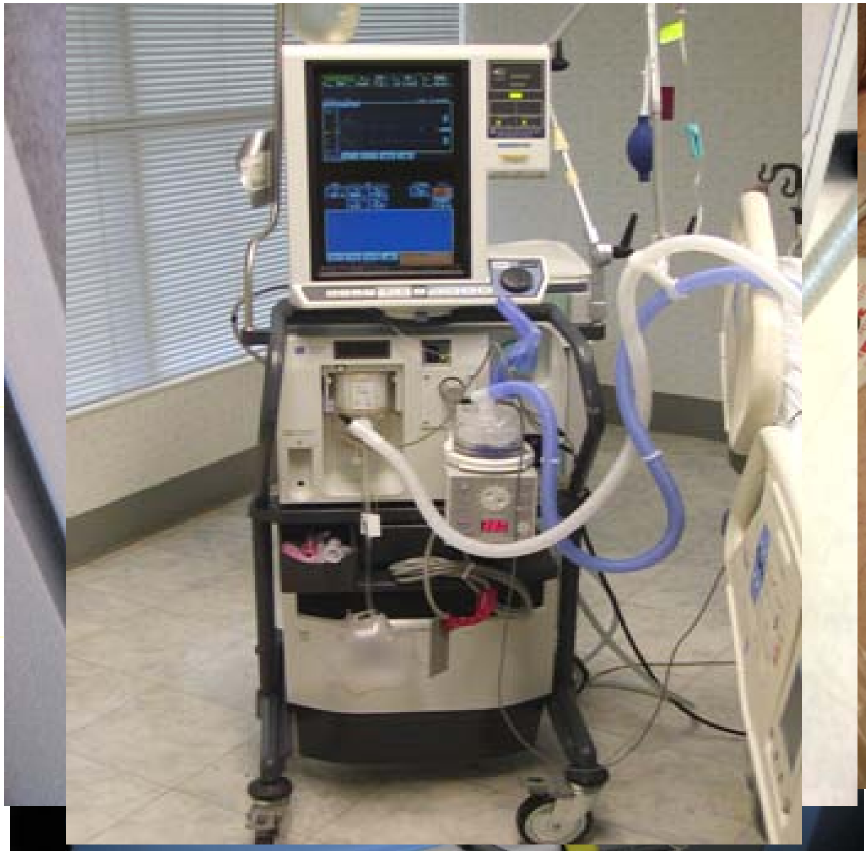
Hand Ventilate
↑ FIO_2

ET Tube Cuff Leak



Algorithm for Initial Management of Acute Hypoxic Events

Acute Hypoxic Event → Hand Ventilate ↑ FIO_2 → Check: O_2 Source, Ventilator Circuit →



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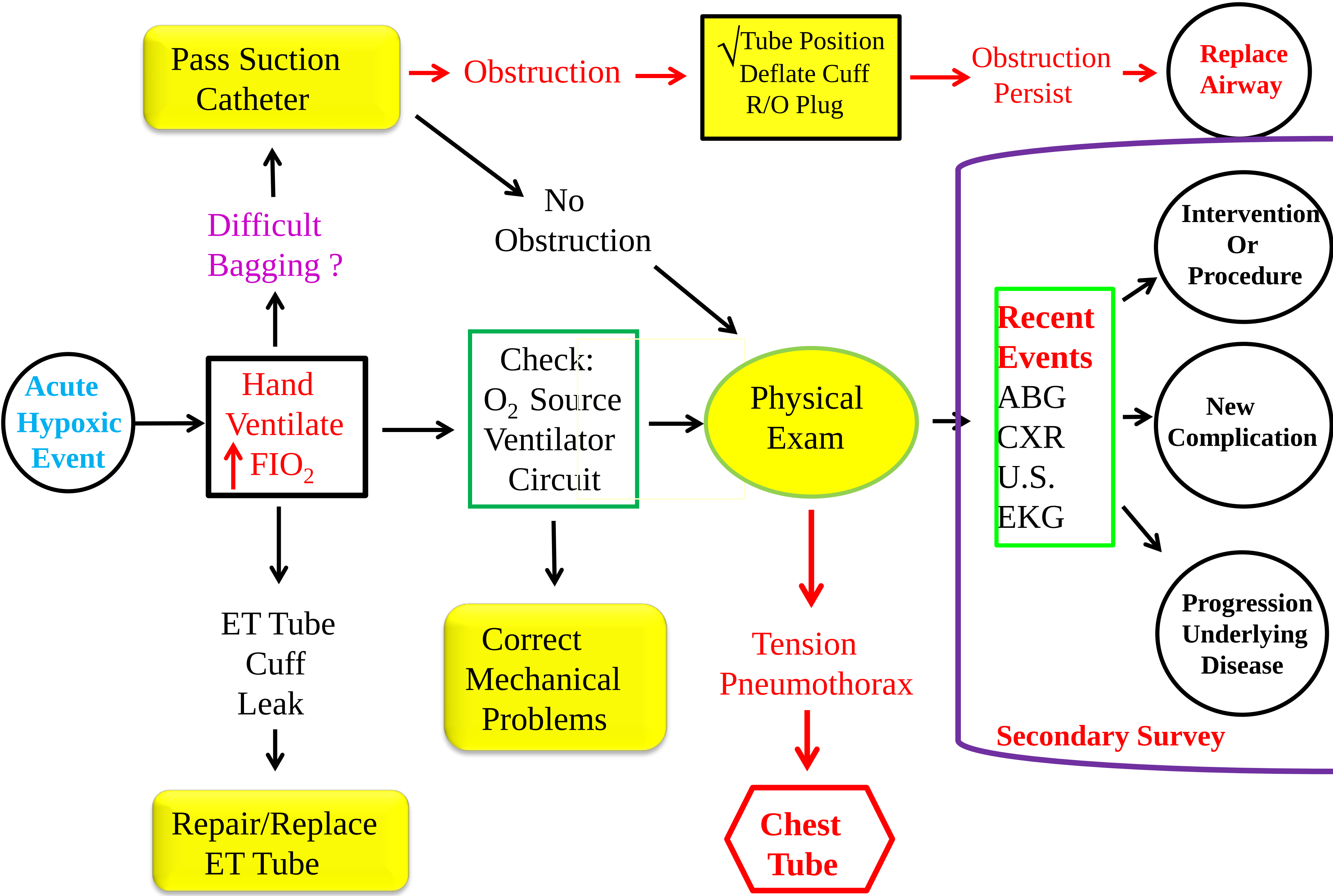
Correct Mechanical Problems

Algorithm for Initial Management of Acute Hypoxic Events



Recent Events
ABG
CXR
U.S.
EKG

Intervention Or Procedure

New Complication

1. Repositioning patient
2. Bathing
3. Post-CPT
4. Post-transport
5. Suctioning
6. NG placement
7. Medication: Vasoactive/sedation
8. “They” just got a CXR
9. New central line/procedure
10. Weaning patient

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Selective Intrabronchial Air Insufflation for Acute Lobar Collapse in the Surgical Intensive Care Unit

Max V. Wohlauer, MD, Ernest E. Moore, MD, James B. Haenel, RRT, Clay C. Burlew, MD, and Carlton C. Barnett Jr, MD
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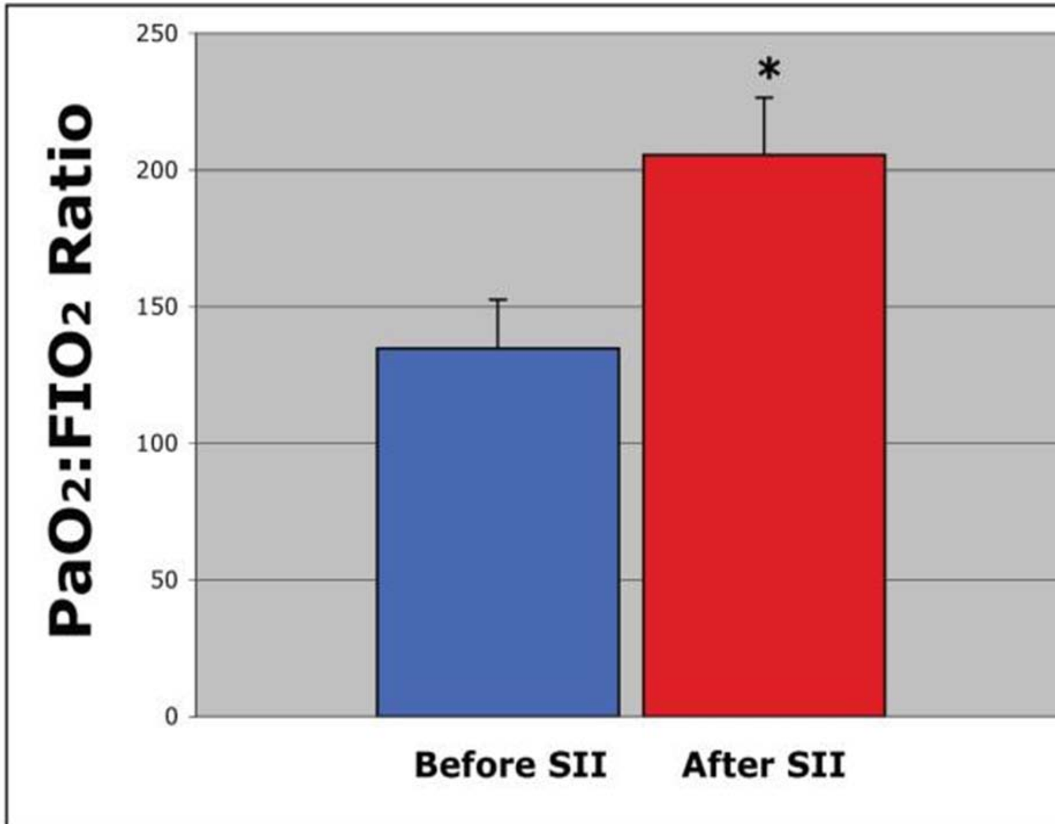
Pt	Indication	Age	$PaO_2:FIO_2$ Before SII	$PaO_2:FIO_2$ After SII
1	Non-compliant	3	225	285
2	Acute hypoxemia	21	87	180
3	Failed Conventional	56	130	130
4	Failed Conventional.	19	340	425
5	Acute hypoxemia	28	90	240
6	Failed Conventional	62	165	180
7	Failed Conventional	26	123	123
8	Failed Conventional	44	192	188
9	Failed Conventional	69	124	130
10	Acute hypoxemia	86	61	188
11	Acute hypoxemia	44	77	97
12	Acute hypoxemia	21	60	338
13	Failed Conventional	12	160	195
14	Acute hypoxemia	18	74	218
15	Failed Conventional	60	146	172
16	Acute hypoxemia	23	100	200
MEAN		39	135	206



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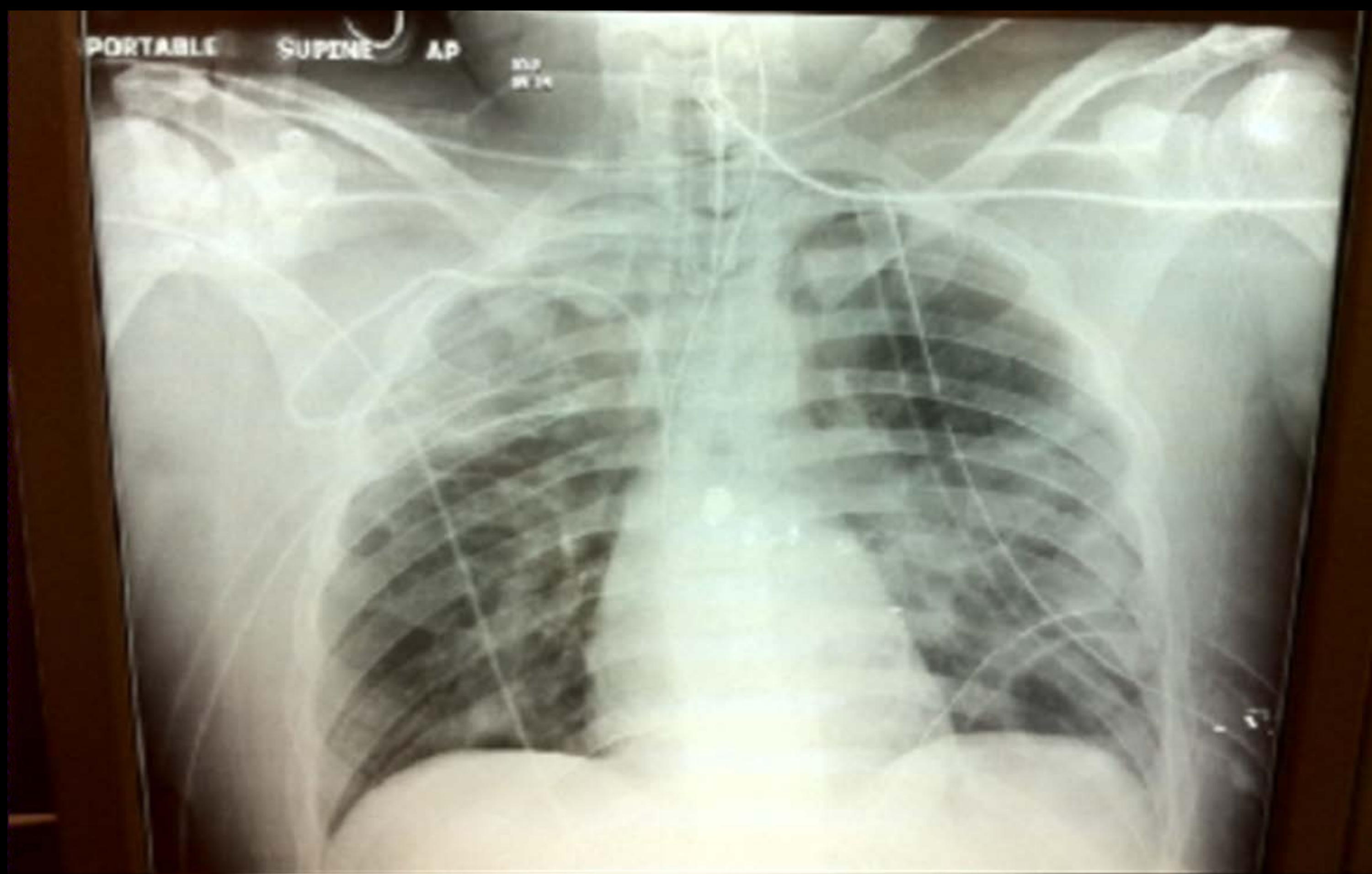


Incidence of Pulmonary Embolism

May 2010 – May 2011: 957 Admits to the SICU

30 Patients (3%) evaluated by CTPE study

# of positive CTPE studies: 3 (total incidence per 957 patients: 0.003)

Percent total positive CTPE studies: 10%

Heparin is one of the most common prescribed drugs in the ICU

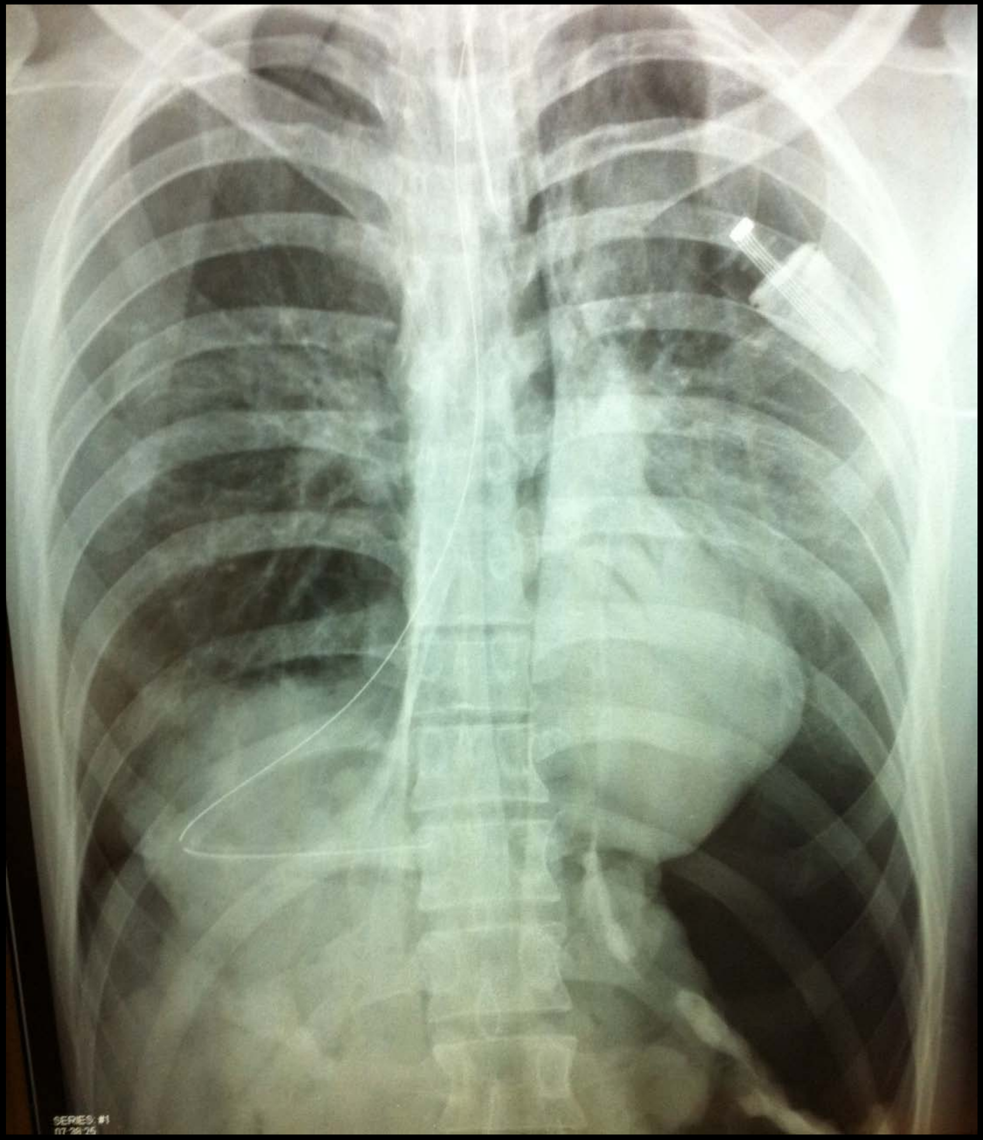
- Prophylaxis
- DVT's
- A Fib
- H.I.T.
- Cavernous sinus venous thrombosis
- Post-op vascular graft
- Carotid/ vertebral vascular injury
- Peri-op MI

In Conclusion

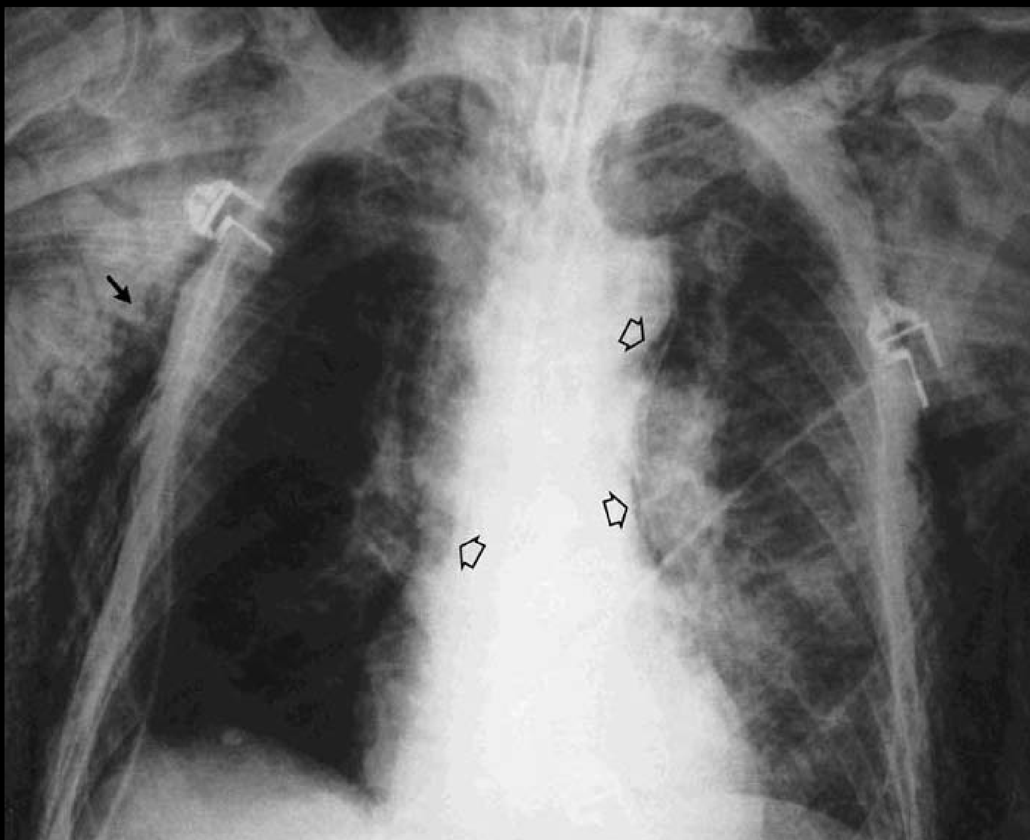
- V/Q mismatch is the most common mechanism for hypoxemia
- Environmental (mechanical) causes of hypoxemia are common
- There is no role for routine ABG's
- Performance of a primary & secondary survey during an acute hypoxic event is 90% successful in identifying the cause of hypoxemia


SCLEROSOL

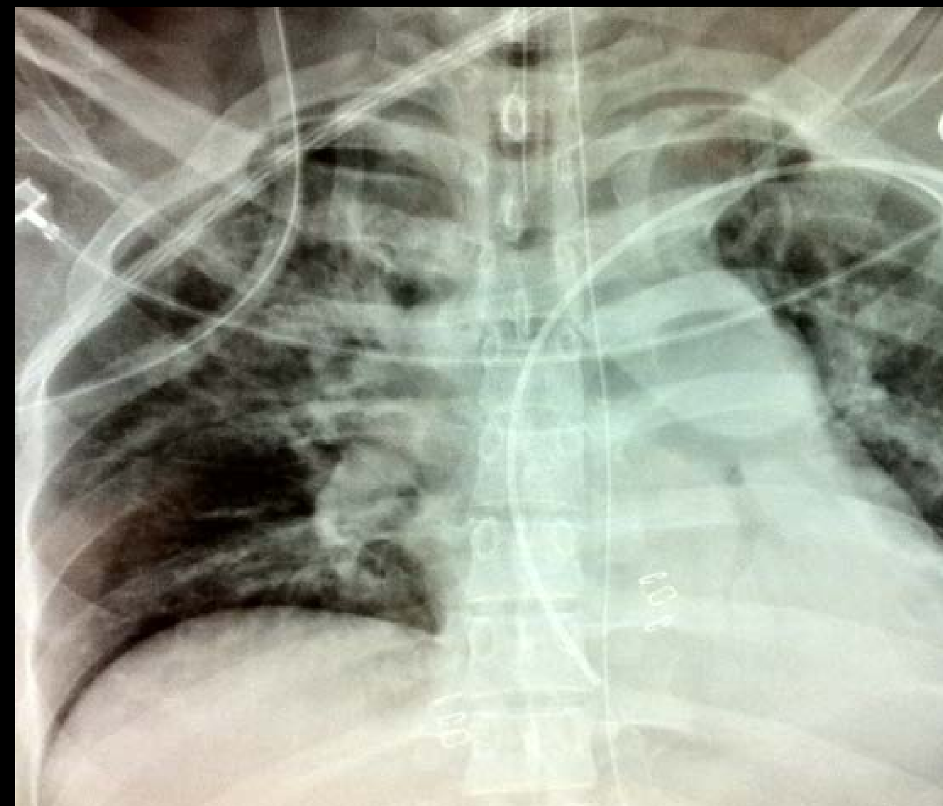

PORTABLE
SUPINE
AP


SERIES: #1

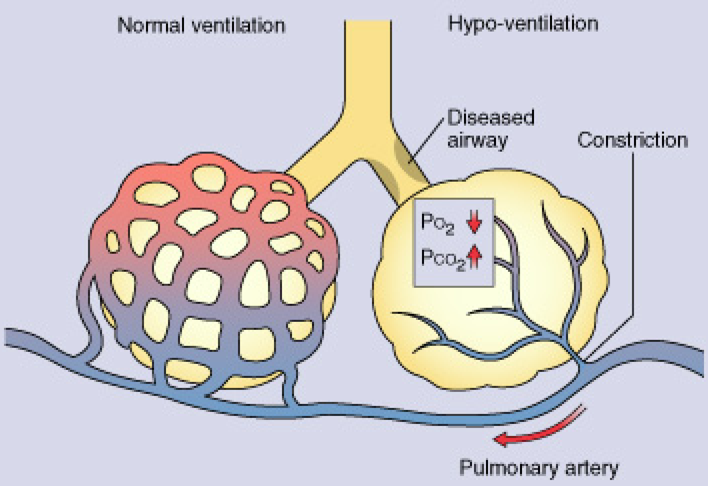
Algorithm for Initial Management of Acute Hypoxic Events




30 cm



Hypoxic vasoconstriction serves to reduce blood flow to poorly ventilated areas



Physiologic mechanisms of hypoxemia

Decreased alveolar partial pressure of oxygen (P_{AO_2}); normal alveolar minus arterial difference ($P_{AO_2} - Pa_{O_2}$)

Decreased P_{IO_2}:

Lower atmospheric pressure (P_{ATM}) with normal fraction of inspired oxygen (F_{IO_2})(e.g., high altitude)

Lower F_{IO_2} with normal P_{ATM} (e.g., iatrogenic)

Alveolar hypoventilation:

$P_{AO_2} = P_{IO_2} - Pa_{CO_2}/R$ (e.g., depressed respiratory drive)

Increased $P_{AO_2} - Pa_{O_2}$

Diffusion limitation — blood leaving an alveolus fails to reach equilibration with alveolar gas; rarely significant as a cause of clinical hypoxemia

Ventilation-perfusion ($\dot{V}/\dot{Q}$) mismatching — specifically, the low $\dot{V}_A/\dot{Q}$ areas cause hypoxemia by contributing blood with reduced content to the arterial mixture

Shunt — the extreme of low $\dot{V}/\dot{Q}$; shunt flow of deoxygenated blood has no contact with alveolar gas

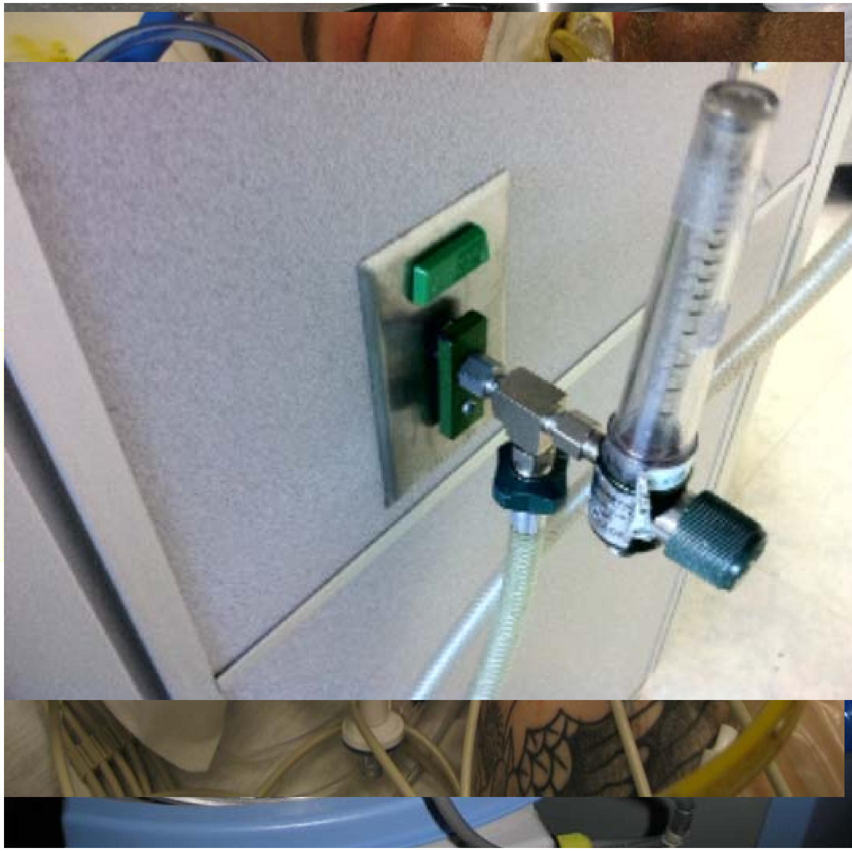
On 100% oxygen ($F_{IO_2} = 1.0$) only the shunt mechanism contributes to the $P_{AO_2} - Pa_{O_2}$ difference. Breathing air or on any $F_{IO_2} < 1.0$, both shunt and low $\dot{V}/\dot{Q}$ areas (plus any diffusion limitation) contribute to the $P_{AO_2} - Pa_{O_2}$ difference. This combined effect is termed *venous admixture* and has also

Algorithm for Initial Management of Acute Hypoxic Events

Acute Hypoxic Event → Hand Ventilate ↑ FIO_2 → Check: O_2 Source Ventilator Circuit →

↓

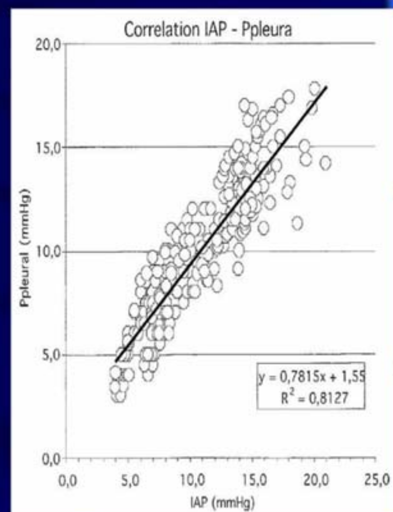
Correct Mechanical Problems



IAH and the lung

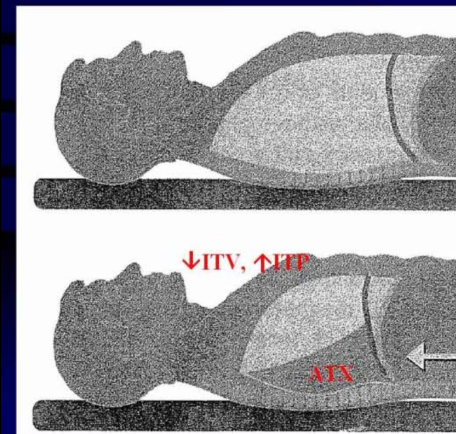
High IAP :

- Diaphragm elevation
- ↑ ITP, ↑ Pleural Press
- ↓ FRC
- ↑ PIP (on volume control MV)
- ↑ Atelectasis
- ↓ Compliance
- ↓ PaO2:FiO2 ratios
- ↑ Inflammatory response



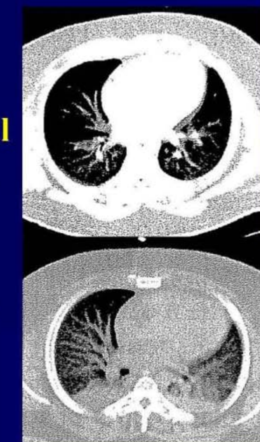
Cheatham and Malbrain, Acta Clin Belg 2007

IAH and the lung



Normal

IAH

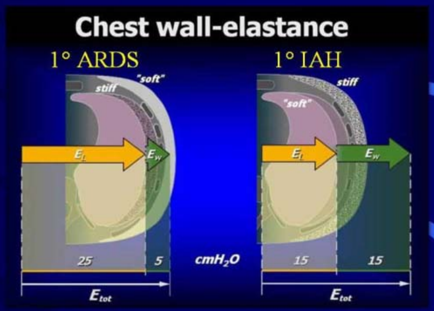


Pelosi, Acta Clin Belg 2007

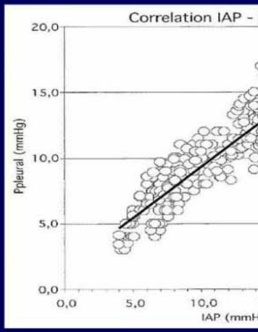
IAH and the lung

Elevated IAP effect on lung

- Marked reduction in chest wall compliance
- Increased atelectasis / reduced recruitment



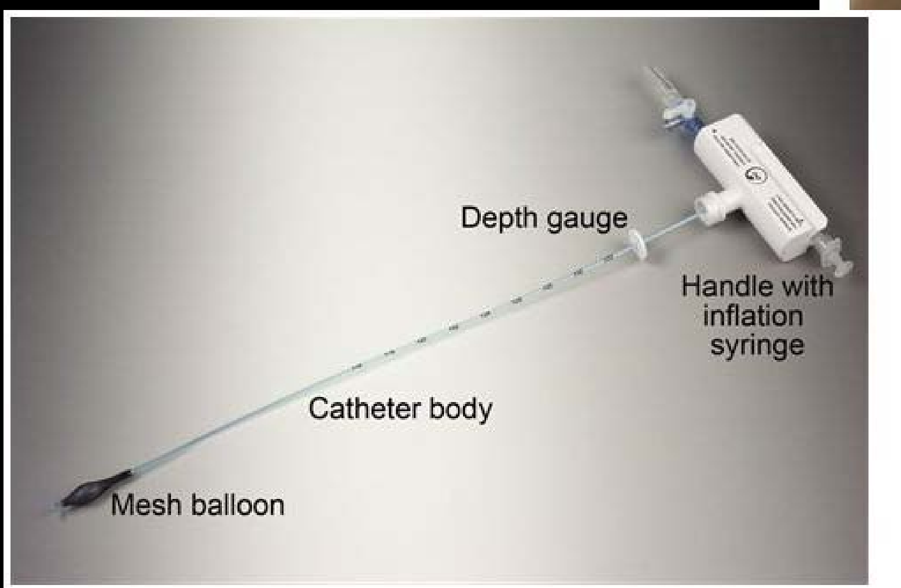
Ventilation optimization and IAH

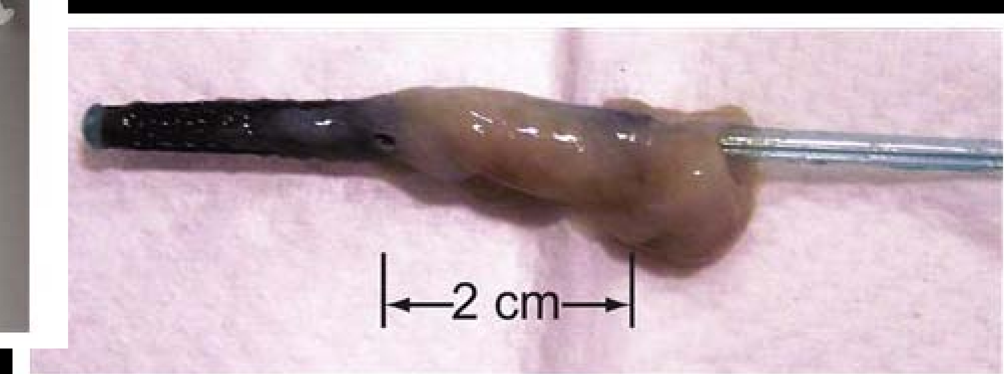


Ppleural ≈ Peso ≈ IAP

Useful for establishing PEEP settings to enhance alveolar recruitment.

- Pelosi suggests setting PEEP = IAP
- Quintel suggests incremental ↑PEEP, observe PaCO effect, repeat
- Talmor suggests setting PEEP = TPP of 0-10 (TPP=Pplat-Ppleural where Ppleural ≈ Peso or ≈ IAP


Depth gauge
Handle with inflation syringe
Catheter body
Mesh balloon


2 cm

AT&T 3G 10:10 PM 60%

Hypoxic events in the surgical intensive care unit. [Am J Surg. 1990] -...

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Hypoxic events in the surgical intensive care unit.

Moore FA, Haenel JB, Moore EE, Abernathy CM.

Am J Surg. 1990 Dec;160(6):647-51.

PMID: 2252129 [PubMed - indexed for MEDLINE]

Related citations

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Microstream capnography improves patient monitoring during moderate sec [Pediatrics. 2006]

Accuracy of pulse oximetry in the intensive care unit. [Intensive Care Med. 2001]

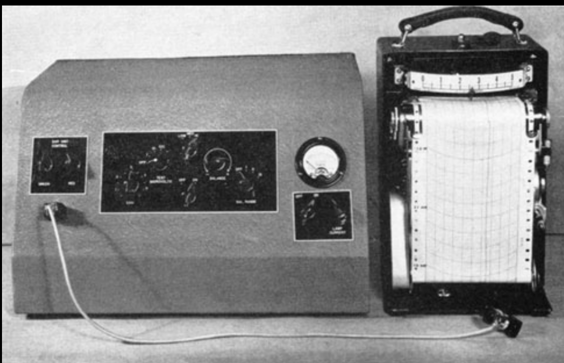
Monitoring of extubated patients: are routine arterial blood gas [Anaesth Intensive Care. 2010]

Review Respiratory monitoring in the intensive care unit. [Am Rev Respir Dis. 1988]

Review [Non-invasive method of arterial oxygen saturation monit [Tijdschr Kindergeneeskd. 1988]

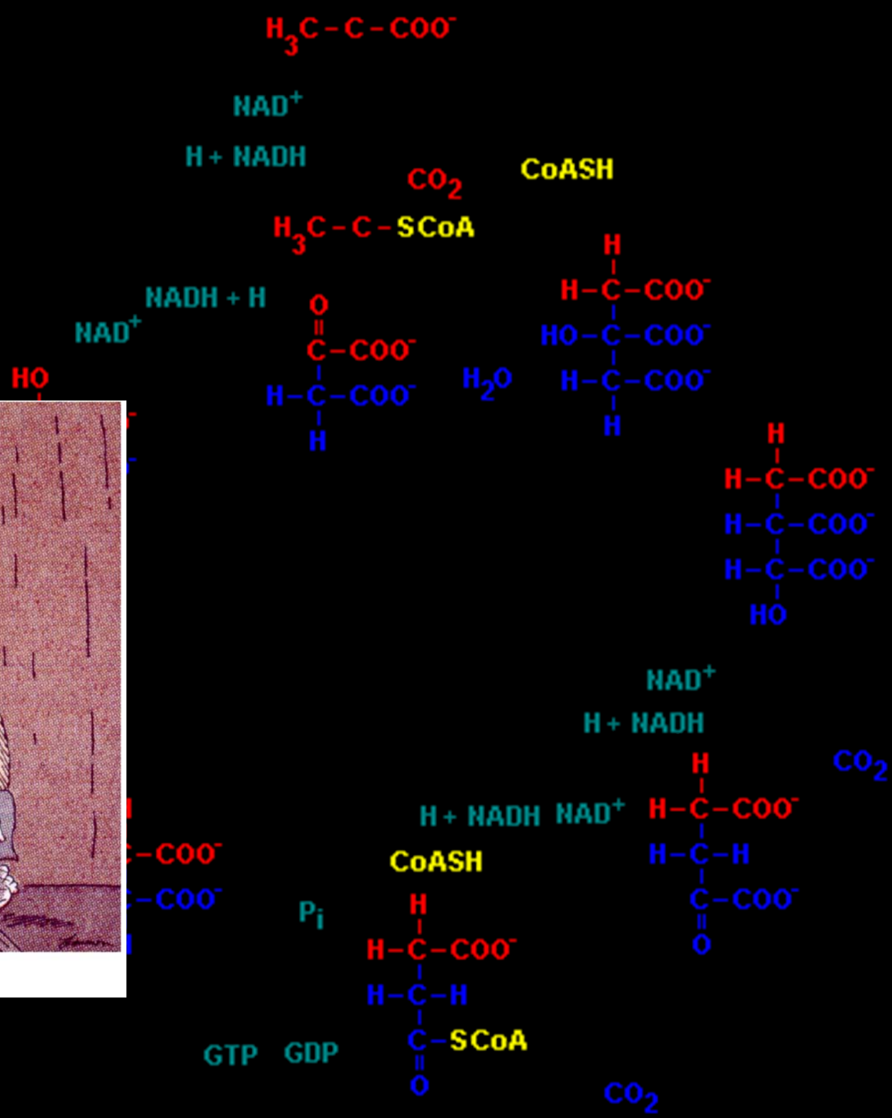
See reviews...

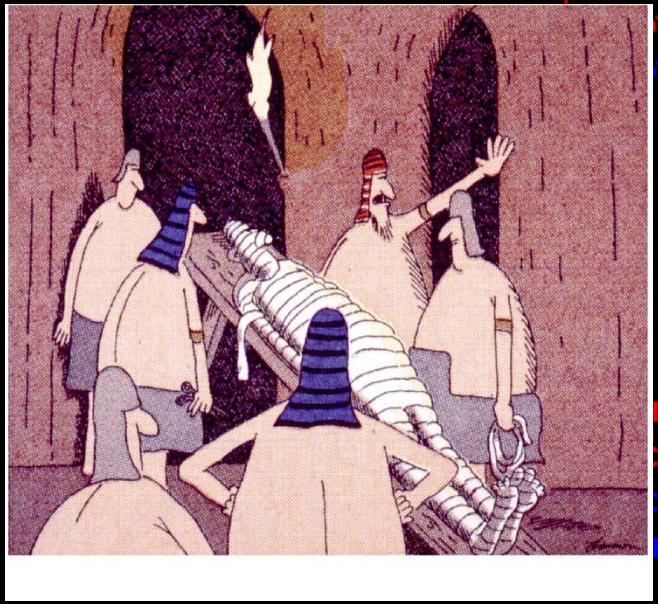
See all...



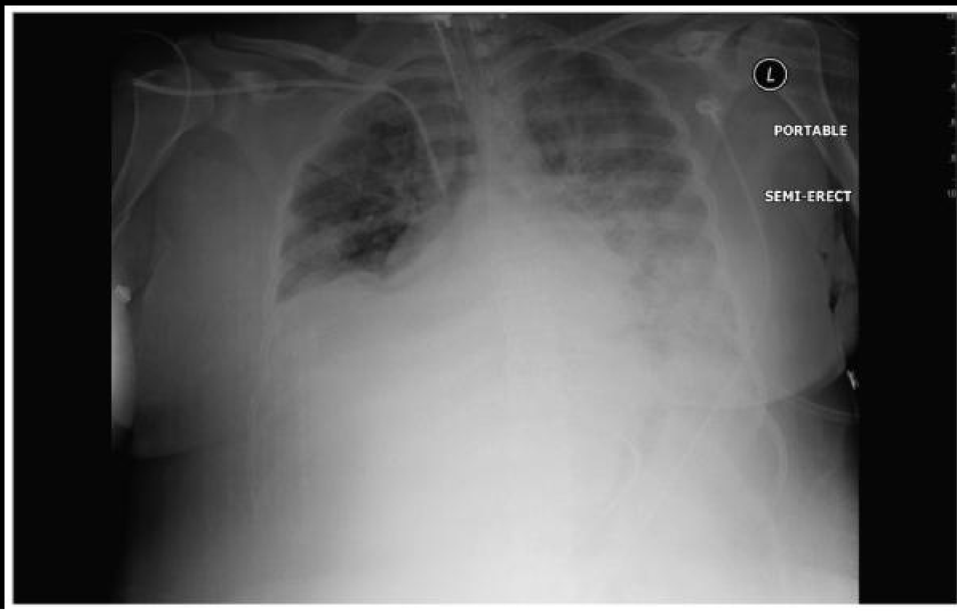
A mural of William Green Morton performing surgery on a patient anesthetized with ether in the Ether Dome at Massachusetts General Hospital on Oct. 16, 1846.

Photo of mural taken by Adam Lenhardt at the Ether Dome at Massachusetts General Hospital, Boston.


NAD+
H + NADH
CO2
CoASH
SCoA
NADH + H
NAD+
H2O
NAD+
H + NADH
CO2
H + NADH
NAD+
CoASH
Pi
GTP
GDP
CO2



Getting Back to the Basics!

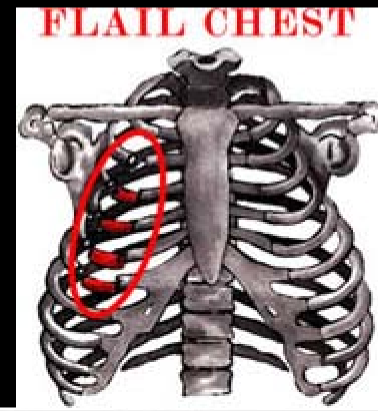
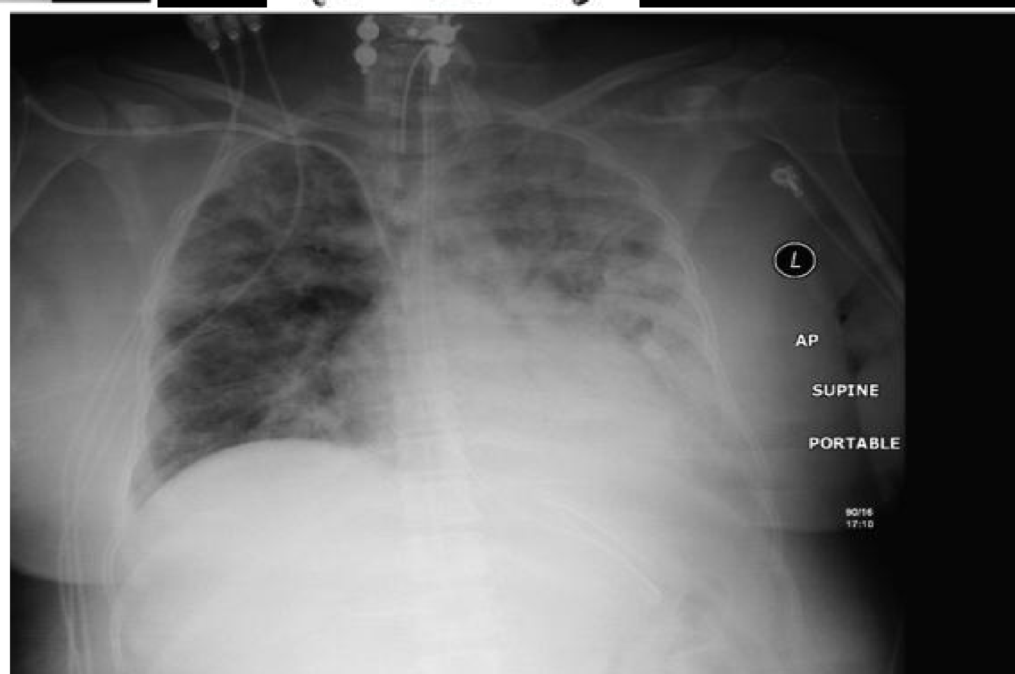
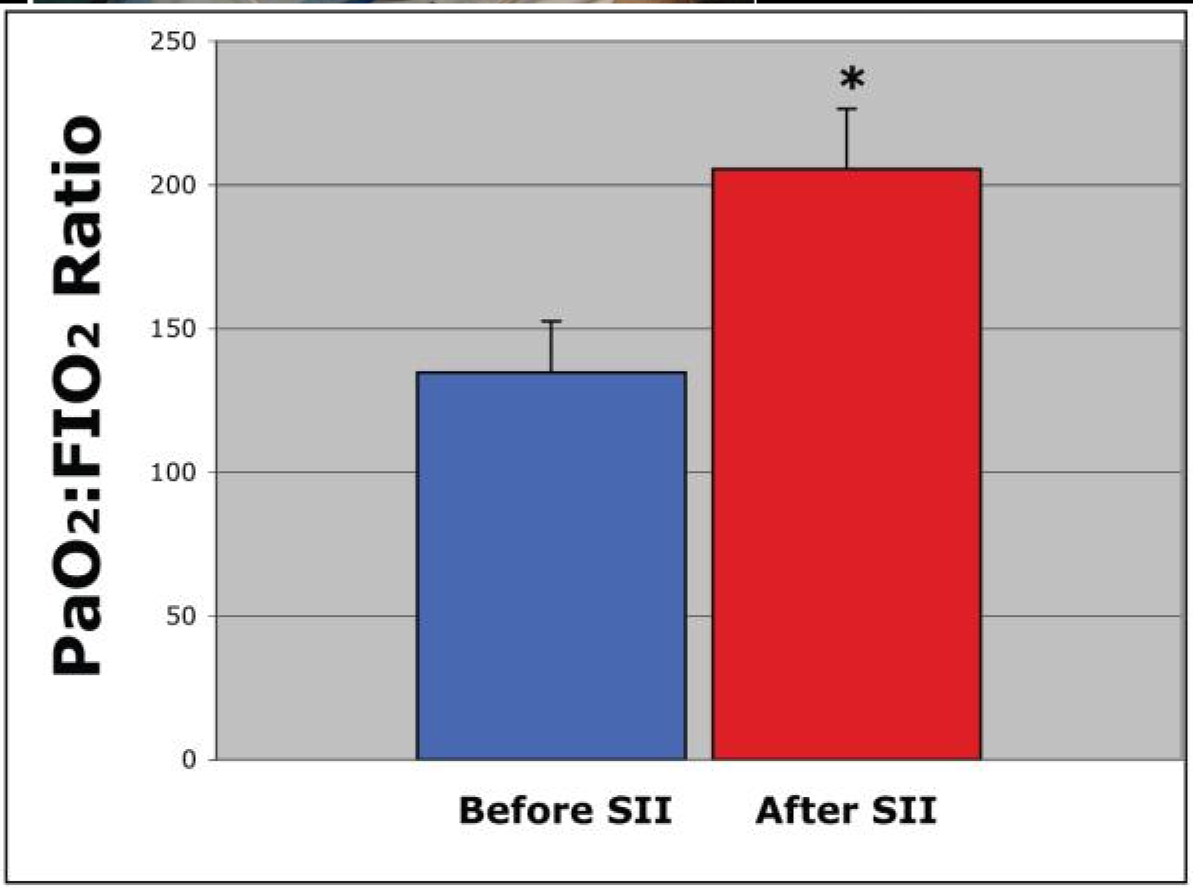


Table 2

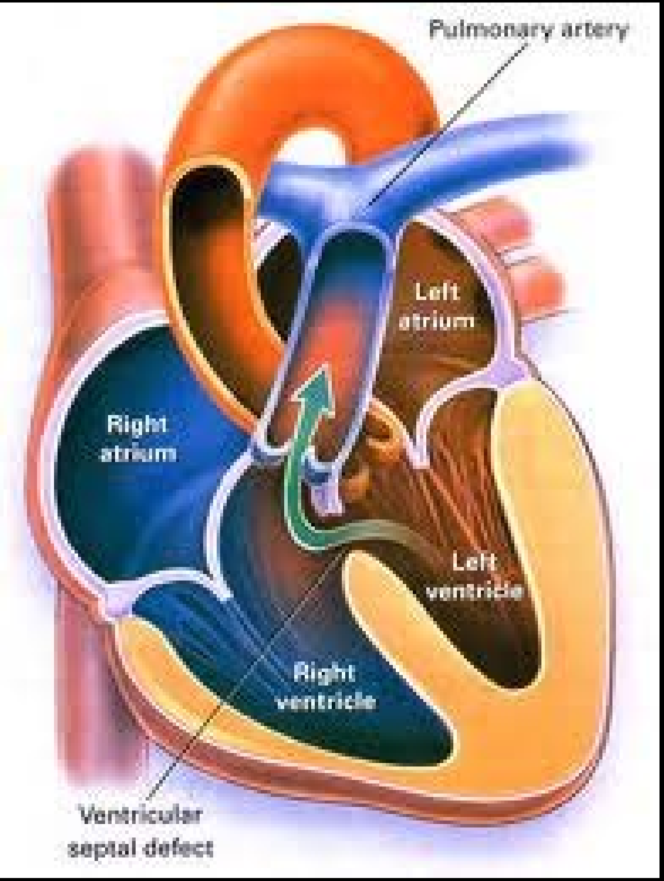
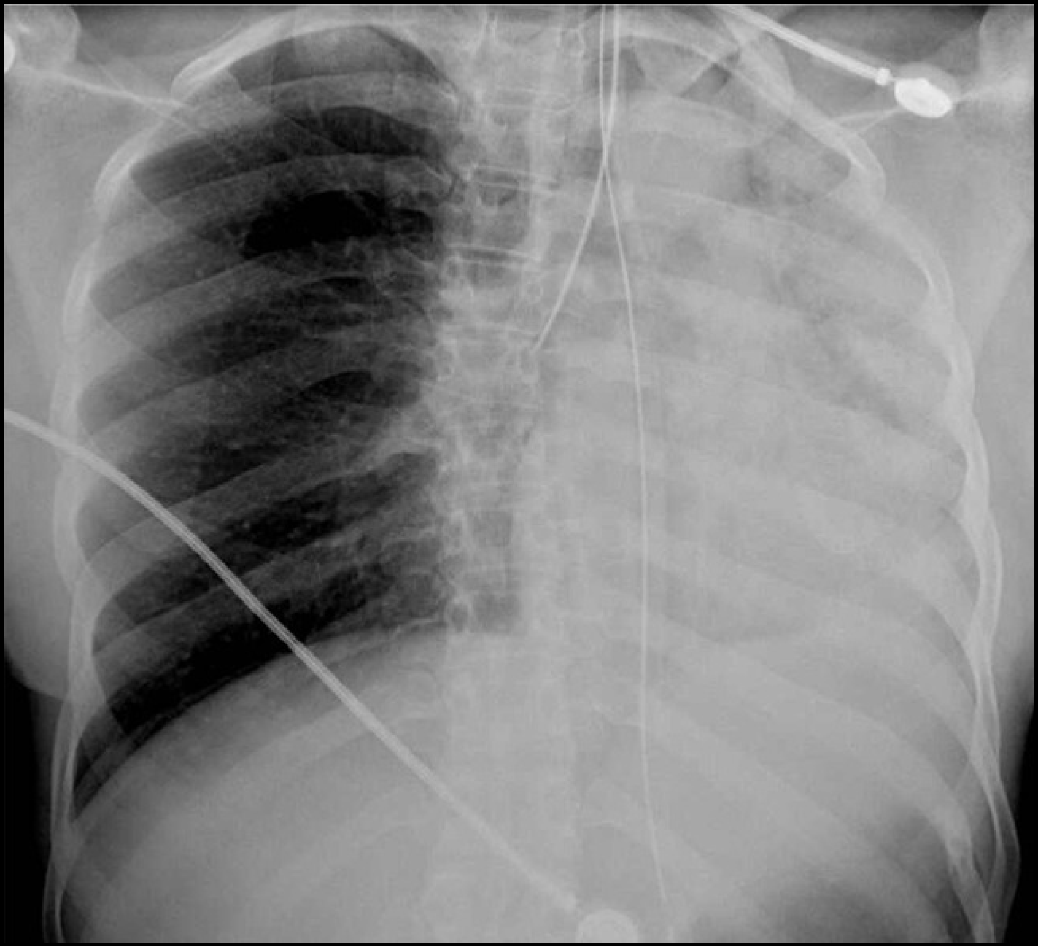
Patients, indications for therapy, their age, and average PaO_2 to FiO_2 ratios before and after selective intrabronchial air insufflation.

Pt	Indication	Age	PaO_2:FIO_2 Before SII	PaO_2:FIO_2 After SII
1	Non-compliant	3	225	285
2	Acute hypoxemia	21	87	180
3	Failed Conventional	56	130	130
4	Failed Conventional.	19	340	425
5	Acute hypoxemia	28	90	240
6	Failed Conventional	62	165	180
7	Failed Conventional	26	123	123
8	Failed Conventional	44	192	188
9	Failed Conventional	69	124	130
10	Acute hypoxemia	86	61	188
11	Acute hypoxemia	44	77	97
12	Acute hypoxemia	21	60	338
13	Failed Conventional	12	160	195
14	Acute hypoxemia	18	74	218
15	Failed Conventional	60	146	172
16	Acute hypoxemia	23	100	200
MEAN		39	135	206



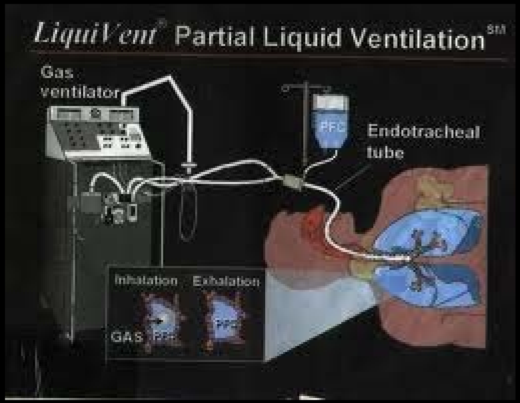


PaO2:FIO2 Ratio
250
200
150
100
50
0
*
Before SII
After SII


Pulmonary artery
Left atrium
Right atrium
Left ventricle
Right ventricle
Ventricular septal defect



ACETYLCYSTEINE
SOLUTION, USP
20% (200 mg/mL)
NOT FOR INJECTION
30 mL VIAL
PRESERVATIVE FREE
Rx Only


SURVANTA


LiquiVent® Partial Liquid Ventilation℠
Gas ventilator
PFC
Endotracheal tube
Inhalation
Exhalation
GAS


TOBI
Tobramycin Solution for Inhalation

ACUTE HYPOXIC EVENTS DURING MECHANICAL VENTILATION