



COMPLICATIONS OF MECHANICAL VENTILATION

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- ▶ “ AN OPENING MUST BE MADE IN THE TRUNK OF THE TRACHEA, INTO WHICH A TUBE OF REED OR CANE MUST BE PUT ; YOU WILL THEN BLOW INTO THIS SO THAT THE LUNG MAY RISE AGAIN.. AND THE HEART BECOMES STRONG..”

ANREAS VESALIUS 1555A.D



TYPES OF COMPLICATIONS

- ▶ EARLY OR LATE
- ▶ COMPLICATIONS DURING AND AFTER INTUBATION
- ▶ COMPLICATIONS OF VENTILATION
- ▶ COMPLICATIONS OF OXYGENATION
- ▶ COMPLICATIONS DUE TO PROLONGED BED REST

TABLE 8-13 Hazards and Complications of Mechanical Ventilation

Condition	Examples
Related to positive pressure ventilation	Barotrauma (pneumothorax, mediastinal air leak, subcutaneous air leak) Hypotension, decrease in cardiac output Arrhythmia Oxygen toxicity Bronchopleural fistula Bronchopulmonary dysplasia (in infants) Upper gastrointestinal hemorrhage
Related to patient condition	Infection (due to reduced immunity) Physical and psychologic trauma Multiple organ failure (may be preexisting)
Related to equipment (ventilator and artificial airway)	Ventilator and alarm malfunction Ventilator circuit disconnection Accidental extubation Main bronchus intubation Postintubation stridor Endotracheal tube blockage Tissue damage Atelectasis (due to inadequate tidal volume)
Related to medical professionals	Nosocomial pneumonia (due to cross-contamination) Inappropriate ventilator settings Misadventures (due to lapses of understanding and communication)

EARLY COMPLICATIONS DURING INTUBATION

▶ **TRAUMA**

1. INFECTION
2. BLEEDING
3. SURGICAL EMPHYSEMA

▶ **ARRHYTHMIAS**

▶ **BRONCHOSPASM**

▶ **ESOPHAGEAL INTUBATION**

▶ **BRONCHIAL INTUBATION**

PREVENTION

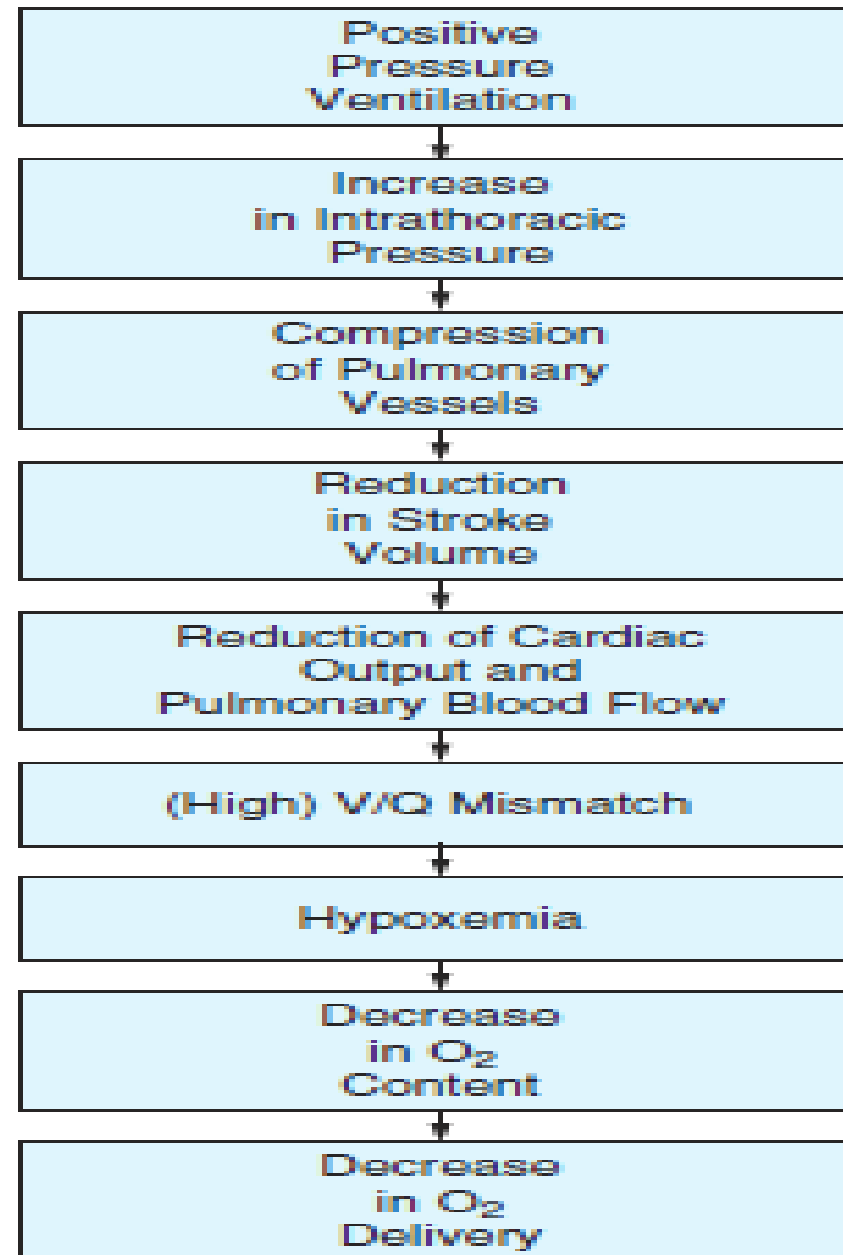
- ▶ CHECK CUFF OF ETT BEFORE ATTEMPTING INTUBATION
- ▶ INTUBATE UNDER VISION
- ▶ RAPID SEQUENCE INTUBATION
- ▶ CHECK TUBE PLACEMENT BY 5 POINT AUSCULTATION
- ▶ CHECK XRAY POST INTUBATION
- ▶ START IV FLUIDS BEFORE INTUBATION TO AVOID SUGGEST POSITIVE PRESSURE INDUCED HYPOTENSION
- ▶ NEBULISE WITH SHORT ACTING B2 AGONISTS/ SHORT ACTING ANTI MUSCURANIC AGENTS
- ▶ ETT SUCTIONING

LATE COMPLICATION OF INTUBATION

- ▶ CORD ULCERATION OR GRANULOMA FORMATION
- ▶ SUPERIOR OR RECURRENT NERVE INJURY
- ▶ TRACHEAL STENOSIS
- ▶ NASAL OR ORAL ULCERATION
- ▶ SINUSITIS

COMPLICATIONS OF VENTILATION-IMMEDIATE

- ▶ POSITIVE PRESSURE VENTILATION-→HIGH INTRATHORACIC PRESSURE-
→COMPRESSION OF PULMONARY VESSELS AND REDUCED VENOUS
OUTPUT-→REDUCED STROKE VOLUME-→ REDUCED CARDIAC
OUTPUT-→HYPOTENSION AND REDUCED O₂ DELIVERY
- ▶ PEEP ALSO INCREASES CVP BUT REDUCES AORTIC PRESSURE AND
CARDIAC OUTPUT
- ▶ DEAD SPACE VENTILATION- ANATOMIC OR PHYSIOLOGICAL



PREVENTION

- ▶ ANTICIPATE HYPOTENSION
- ▶ INTRAVASCULAR VOLUME EXPANDERS (CRYSTALLOIDS AND COLLOIDS) AND VASOPRESSORS TO MANAGE REDUCTION IN CARDIAC OUTPUT DUE TO POSITIVE PRESSURE VENTILATION AND PEEP
- ▶ CUT THE ETT TO REDUCE DEAD SPACE VENTILATION
- ▶ TIDAL VOLUME SET ON VENTILATOR HAS INDIRECT RELATIONSHIP WITH THE DEAD SPACE VENTILATION= REDUCED TIDAL VOLUME INCREASED DEAD SPACE
- ▶ PHYSIOLOGIC DEAD SPACE CAN BE CALCULATED WITH THE HELP OF ABG

PHYSIOLOGICAL DEAD SPACE

- ▶ PHYSIOLOGIC DEADSPACE TO TIDAL VOLUME RATIO (V_D/V_T) CAN BE CALCULATED AS FOLLOWS:
- ▶ $V_D/V_T = (P_{ACO_2} - P_{ECO_2}) / P_{ACO_2}$
- ▶ P_{ACO_2} IS ARTERIAL CARBON DIOXIDE TENSION AND P_{ECO_2} IS PCO_2 OF A MIXED EXPIRED GAS SAMPLE. THESE TWO SAMPLES ARE COLLECTED SIMULTANEOUSLY
- ▶ IN PATIENTS ON MECHANICAL VENTILATION, V_D/V_T OF LESS THAN 60% IS CONSIDERED ACCEPTABLE AND THIS VALUE SUGGESTS ADEQUATE VENTILATORY FUNCTION UPON WEANING FROM MECHANICAL VENTILATION

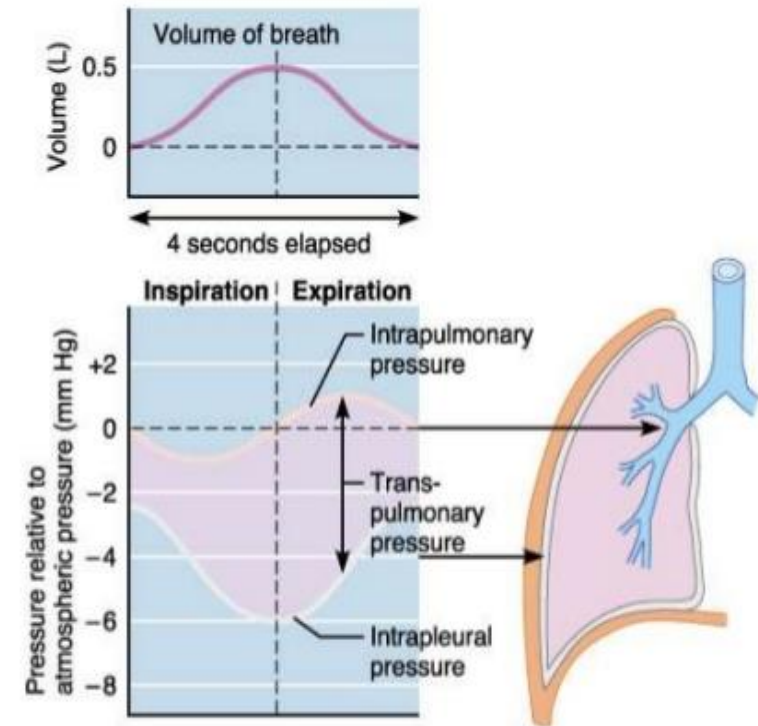
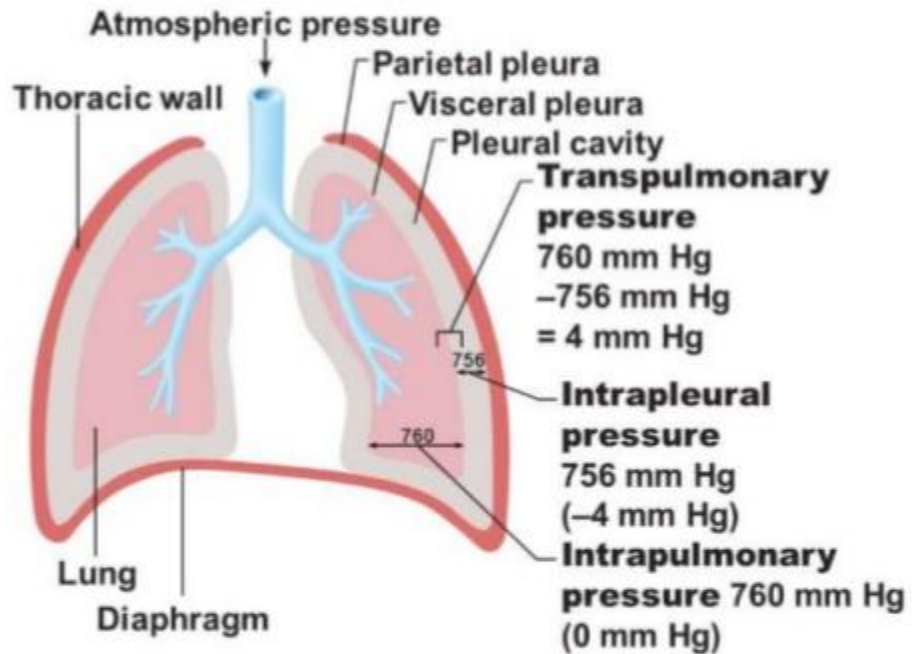
COMPLICATIONS OF VENTILATION

▶ VENTILATOR INDUCED LUNG INJURY - VILI

1. VOLUTRAUMA
2. BAROTRAUMA
3. ATELECTOTRAUMA
4. BIOTRAUMA
5. OXYGEN TOXICITY

▶ VENTILATOR INDUCED PNEUMONIA - VAP

TRANSPULMONARY PRESSURE



VILI

- ▶ LUNG DAMAGE CAUSED BY THE APPLICATION OF POSITIVE OR NEGATIVE PRESSURE TO THE LUNG BY MECHANICAL VENTILATION

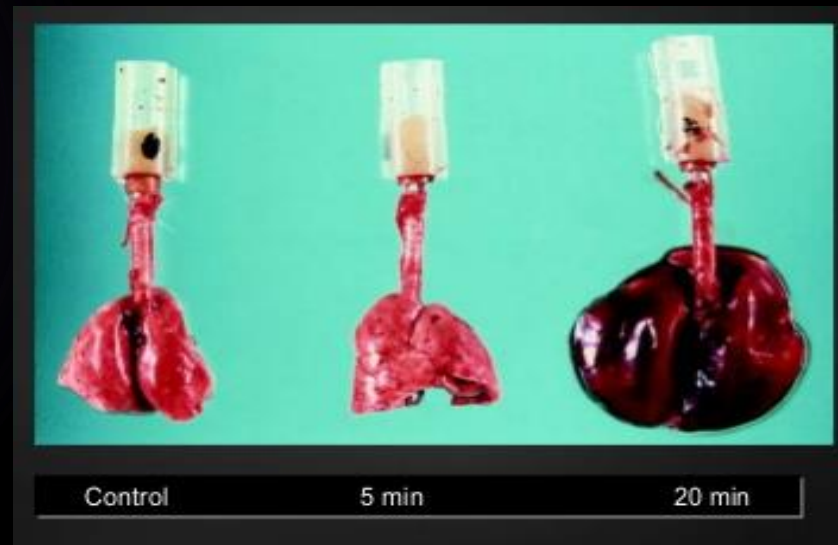
- ▶ THE DAMAGE IS CHARACTERISED BY
 1. INFLAMMATORY CELL INFILTRATES
 2. HYALINE MEMBRANE
 3. INCREASED VASCULAR PERMEABILITY
 4. PULMONARY EDEMA

VOLUTRAUMA

- ▶ OVERDISTENSION OF THE NORMAL ALVEOLAR UNITS TO TRANSPULMONARY PRESSURES ABOVE 30 CMH₂O CAUSES BASEMENT MEMBRANE STRETCH AND STRESS ON INTRACELLULAR JUNCTIONS
- ▶ POSITIVE PRESSURE DURING MECHANICAL VENTILATION FOLLOWS THE PATH OF LEAST RESISTANCE TO RELATIVELY NORMAL ALVEOLI, POTENTIALLY CAUSING ITS OVERDISTENTION
- ▶ THIS OVERDISTENSION LEADS TO AN INFLAMMATORY CASCADE THAT AUGMENTS LUNG INJURY CAUSING ADDITIONAL DAMAGE TO NORMAL LUNG UNITS

BAROTRAUMA

- ▶ LARGE TIDAL VOLUMES AND ELEVATED PEAK PRESSURES LEADING TO RUPTURE OF ALVEOLI WITH SUBSEQUENT AIR LEAK-→ PNEUMOTHORAX AND PNEUMOMEDIASTINUM
- ▶ INCREASED TRANSPULMONARY PRESSURES ABOUT 50 CM H₂O WILL CAUSE BAROTRAUMA

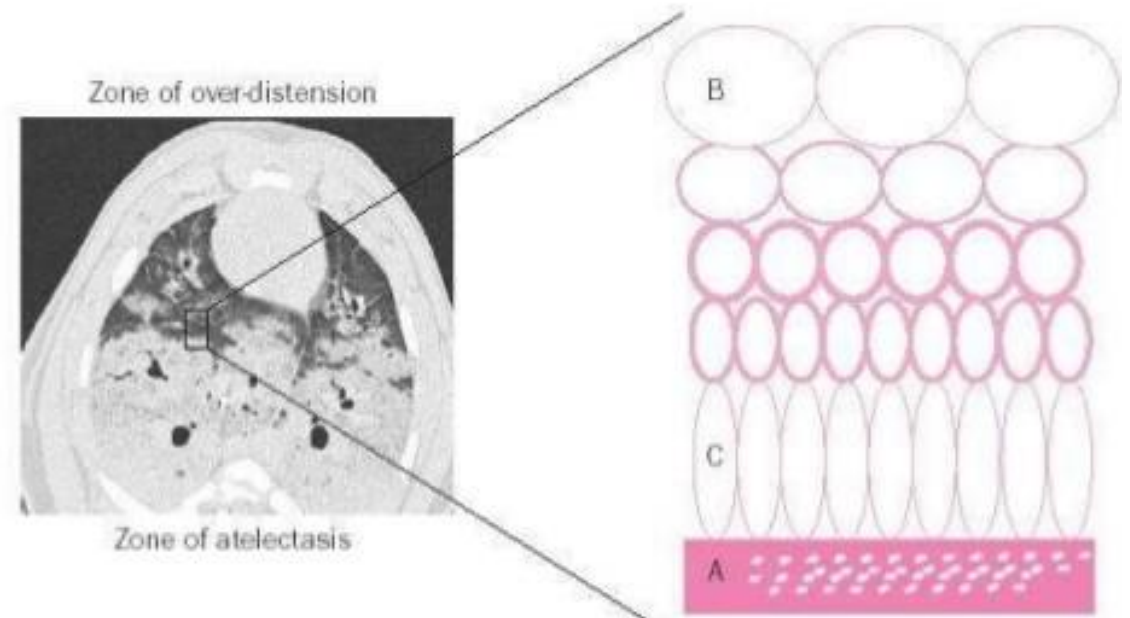


PREVENTION OF VOLUTRAUMA AND BAROTRAUMA

- ▶ PREVENTION IS BY LUNG PROTECTIVE VENTILATION STRATEGIES LIKE LOW TV OF 6 TO 8 ML/KG AND BY ADDING PEEP WHICH PREVENTS ALVEOLAR COLLAPSE DURING END EXPIRATION
- ▶ KEEP PLATEAU PRESSURE (PRESSURE AT THE END OF INSPIRATION) LESS THAN 30 CM H₂O

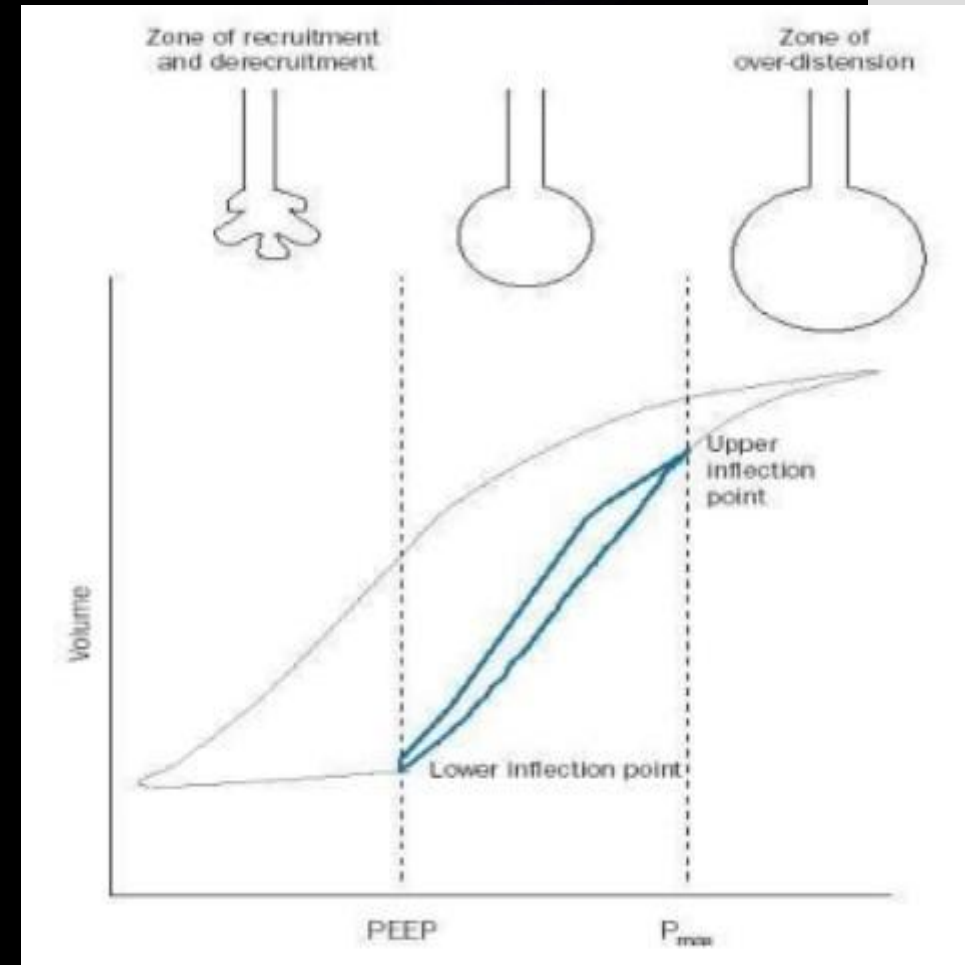
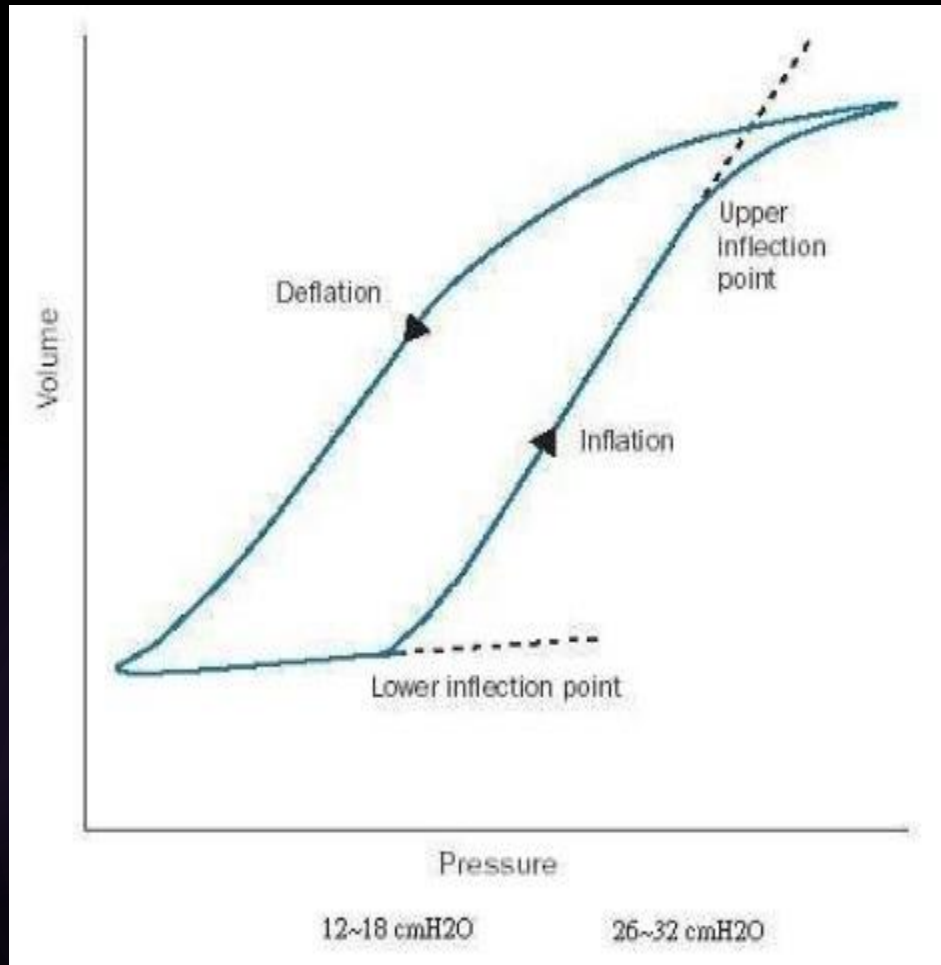
ATELECTOTRAUMA

- ▶ LUNG INJURY ASSOCIATED WITH REPEATED RECRUITMENT (OPENING UP OF COLLAPSED ALVEOLI) AND DECRUITMENT
- ▶ LOW END INSPIRATORY VOLUME INJURY



VENTILATION STRATEGIES TO MINIMISE ATELECTOTRAUMA AND SHEARING STRESS

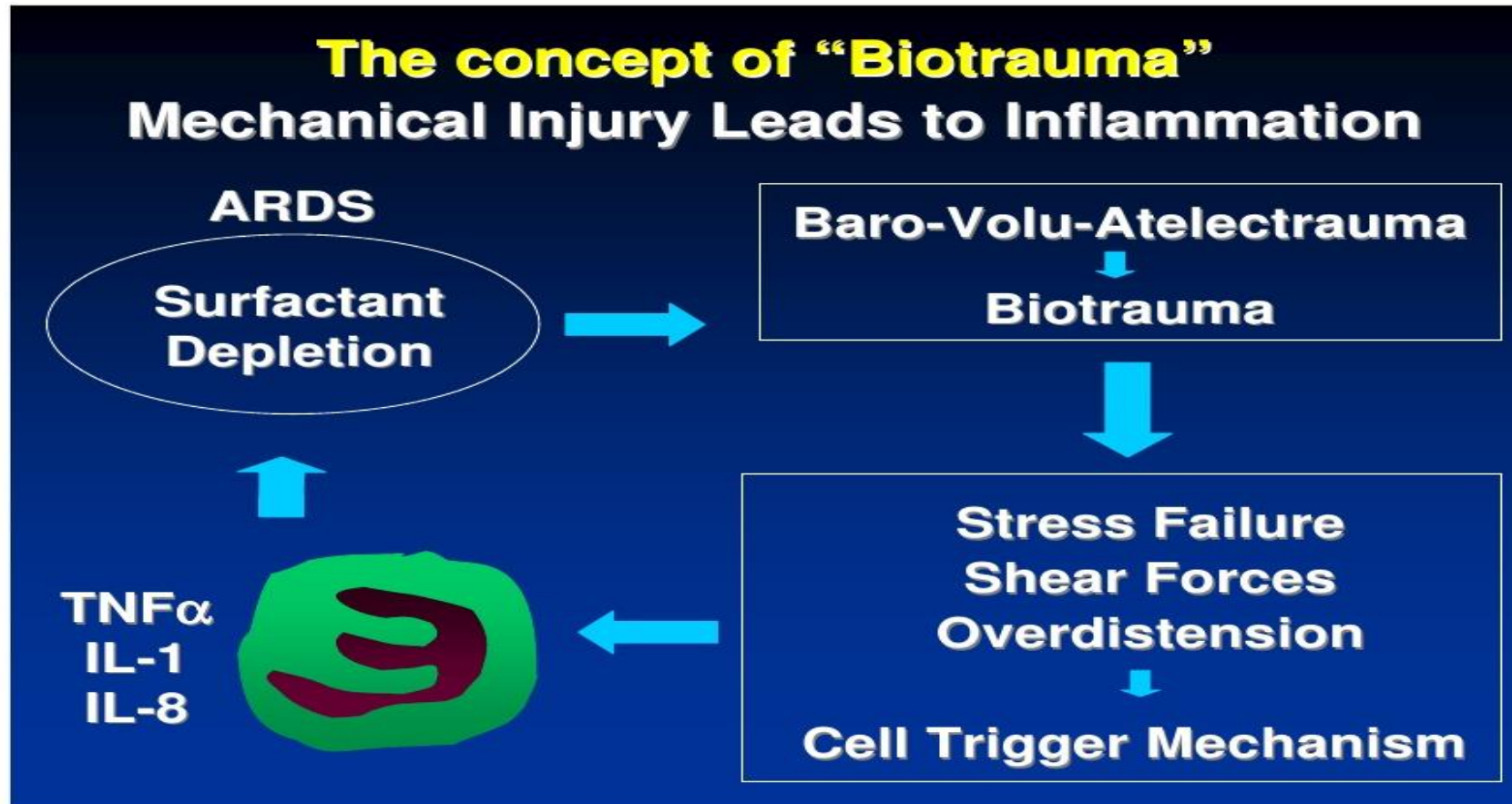
- ▶ HIGHER PEEP- PEEP TO BE SET 2 CM H₂O MORE THAN THE LOWER INFLECTION POINT OF THE PRESSURE VOLUME CURVE
- ▶ KEEP PEAK PRESSURES LESS THAN 40 CM H₂O
- ▶ RESPIRATORY RATE LESS THAN 30 CM H₂O
- ▶ RECRUITMENT MANOEUVRES
- ▶ PRONE POSITIONING- GRAVITATIONAL RECRUITMENT MANOEUVRES



BIOTRAUMA

- ▶ MECHANOTRANSDUCTION- PHYSICAL FORCES DETECTED BY THE CELLS AND CONVERTED INTO BIOCHEMICAL SIGNALS
- ▶ MECHANOTRANSDUCTION AND TISSUE DISRUPTION LEADS TO UPREGULATION AND RELEASE OF CYTOKINES AND CHEMOKINES WITH SUBSEQUENT CHEMOATTRACTION AND ACTIVATION RESULTING IN PULMONARY AND SYSTEMIC INFLAMMATORY RESPONSE AND MULTIORGAN DYSFUNCTION
- ▶ STRATEGIES TO AMELIORATE IT INCLUDE PROTECTIVE LUNG VENTILATION STRATEGIES AND USE OF NEUROMUSCULAR AGENTS

BIOTRAUMA



Biologic alterations

Increased concentrations of:

- Hydroxyproline
- Transforming growth factor- β
- Interleukin-8

Release of mediators:

- Tumor necrosis factor α (TNF- α)
- β -catenin
- Interleukin-6 (IL-6)
- Interleukin-1 β (IL-1 β)

Recruitment of:

- Pulmonary alveolar macrophages (PAMs)
- Neutrophils

Activation of epithelium and endothelium

Physiological abnormalities

Increased physiological dead space

Decreased compliance

Decreased P_{aO_2}
Increased P_{aCO_2}

Systemic effects

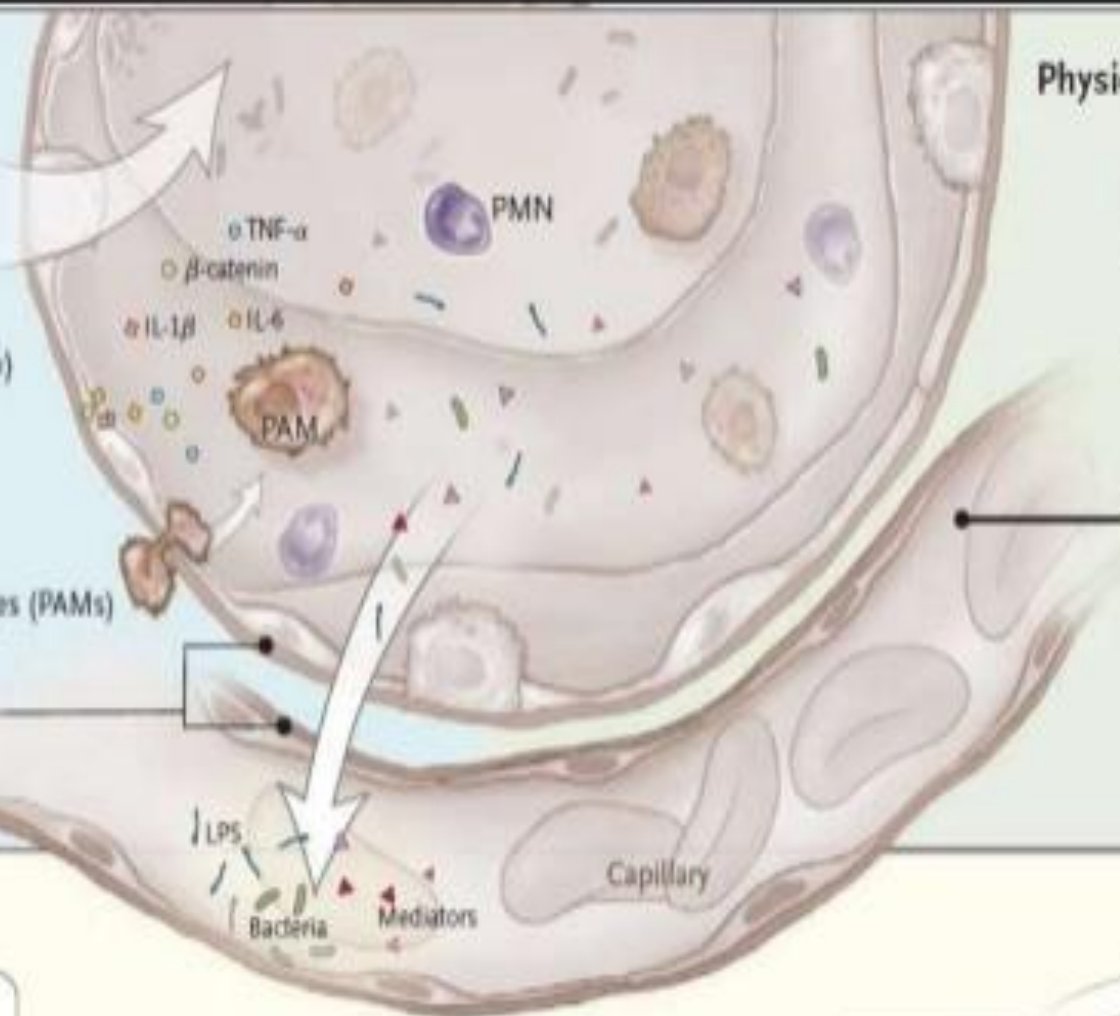
Translocation of:

- Lipopolysaccharides (LPS)
- Bacteria
- Various mediators

Multiple mechanisms
(e.g., increased apoptosis)

Multiorgan
dysfunction

Death



OXYGEN TOXICITY DURING MECHANICAL VENTILATION

- ▶ $\text{FiO}_2 > 60\%$ IN 72 HOURS CAUSES OXYGEN TOXICITY → LEADING TO FREE RADICAL INJURY AND DIFFUSE ALVEOLAR DAMAGE AKIN TO ARDS
- ▶ OXYGEN SHOULD BE USED JUDICIOUSLY AND WITHIN 24 HOURS THE FiO_2 MUST BE BROUGHT TO LESS THAN 60%

Sequence of Pulmonary Changes during Hyperoxic Exposure in Humans

O_2 at 1 atm	Exposure Duration	Manifestions
100%	>12 h	Decreased tracheobronchial clearance; decreased forced vital capacity; cough; chest pain
	>24 h	Altered endothelial function
	>36 h	Increased alveolar-arterial oxygen gradient; decreased carbon monoxide diffusing capacity
	>48 h	Increasing alveolar permeability; pulmonary edema; surfactant inactivation
	>60 h	Acute respiratory distress syndrome
60%	7 days	Mild chest discomfort without changes in lung mechanics; possible changes in morphometry
24–28%	Months	Subclinical pathological changes; no clinical toxicity documented

VENTILATOR ASSOCIATED PNEUMONIA (VAP)

- ▶ A SUBSET OF HOSPITAL ACQUIRED PNEUMONIA THAT OCCURS AFTER 48 TO 72 HOURS OF ENDOTRACHEAL INTUBATION
- ▶ EARLY ONSET- LESS THAN 4 DAYS
- ▶ LATE ONSET- MORE THAN 4 DAYS
- ▶ OCCURS IN 10 TO 65% VENTILATED PATIENTS
- ▶ LONGER THE DURATION OF MV HIGHER THE CHANCES OF DEVELOPING VAP
- ▶ MORTALITY DUE TO VAP CAN GO UPTO 76% IN PATIENTS WITH PSEUDOMONAS OR ACINETOBACTER PNEUMONIA

RISK FACTORS FOR VAP

Ventilator-associated pneumonia

Independent risk factors

Age >60 years

COPD/PEEP/pulmonary disease

Coma/impaired consciousness

Therapeutic interventions

Intracranial pressure monitoring

Organ failure

Large volume gastric aspiration

Prior antibiotics

H₂ blocker +/- antacids

Gastric colonization and pH

Season: fall, winter

Ventilator circuit changes 24 vs. 48 h

Reintubation

Mechanical ventilation ≥ 2 days

Tracheostomy

Supine head position

VAP

VAP Types

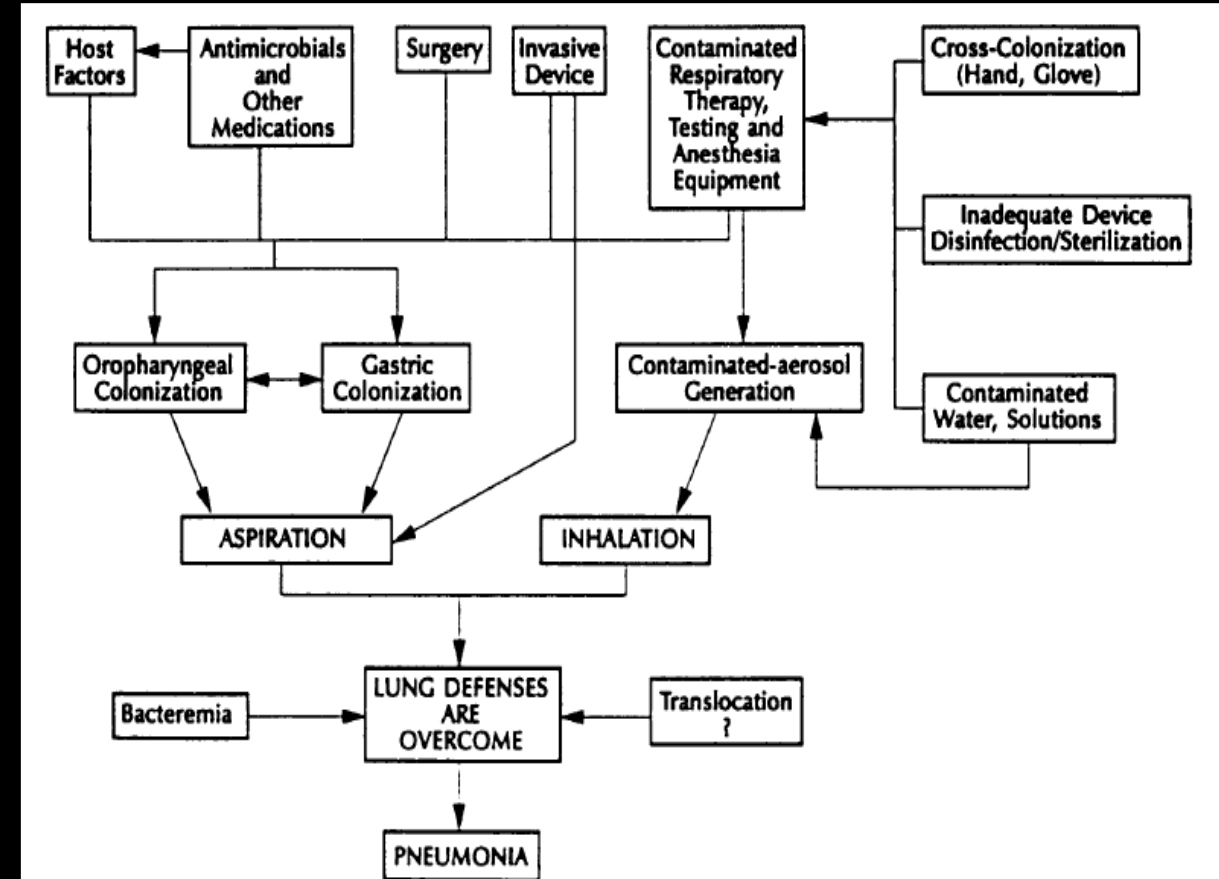
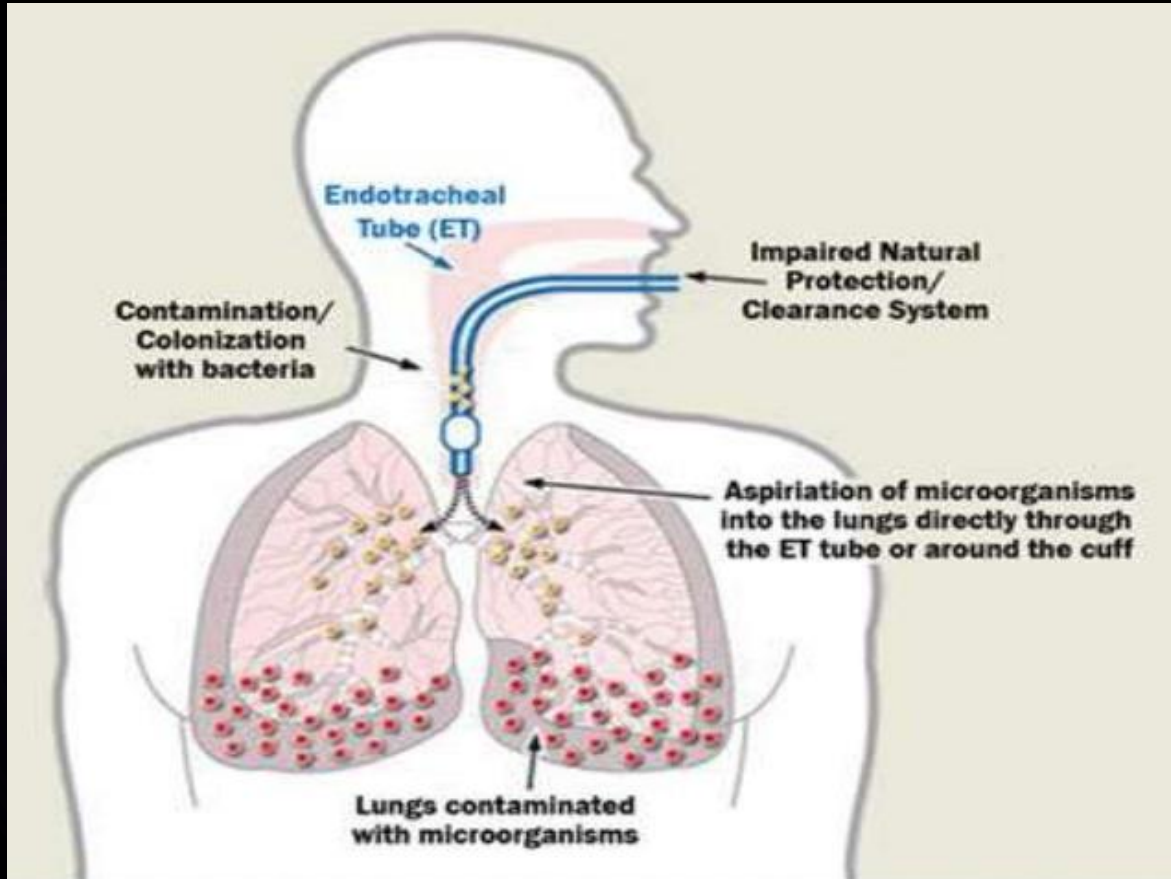
Early Onset VAP

- Occurs in the period of **2-5 days** post intubation
- Pathogens responsible are **susceptible** to antibiotic therapy
 - *Staphylococcus Aureus* (Meth sensitive)
 - *Streptococcus pneumoniae*
 - *Hemophilus influenzae*
 - *Proteus species*
 - *Serratia species*
 - *Klebsiella pneumoniae*
 - *Escherichia coli*

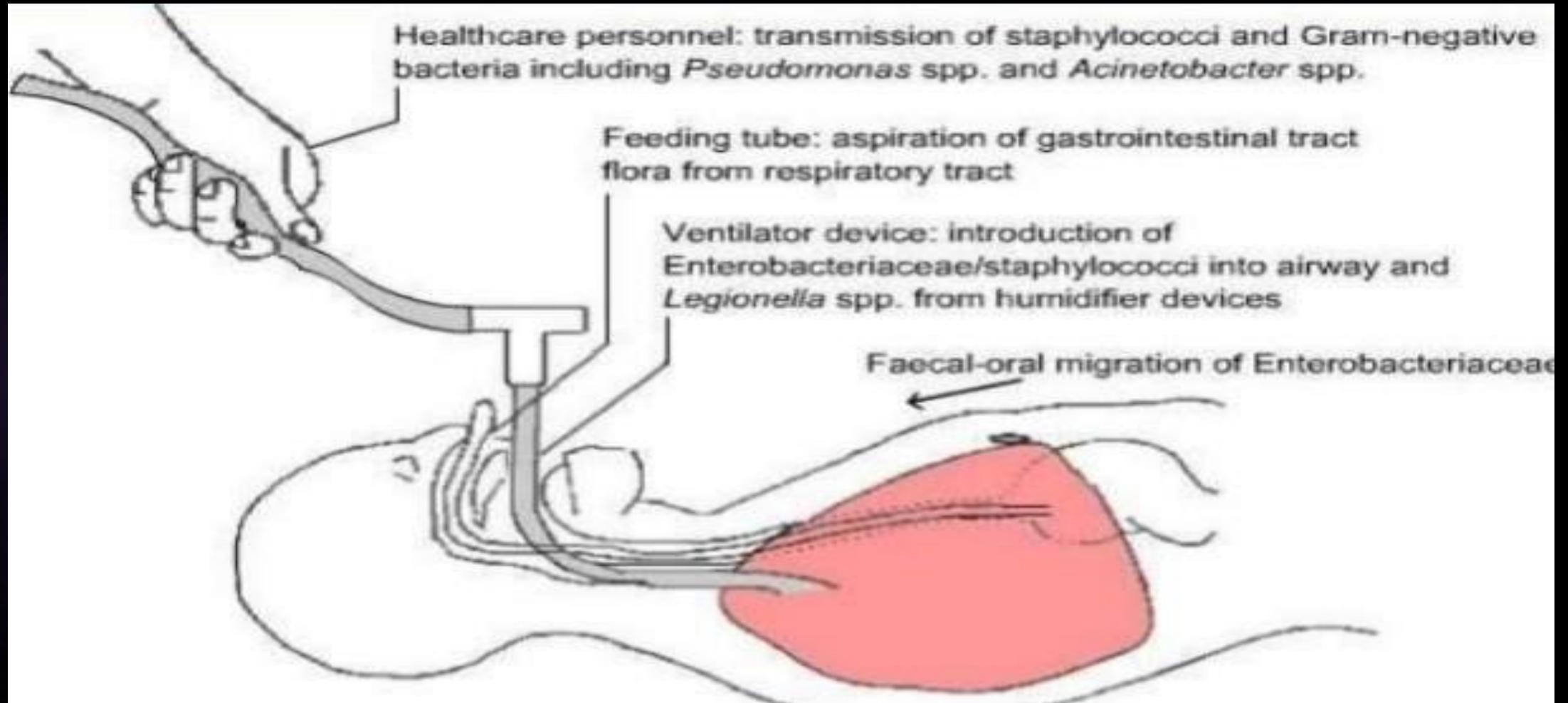
Late Onset VAP

- **>5 days** post intubation
- Usually caused by antibiotic-**resistant** organisms
 - *Pseudomonas aeruginosa*,
 - Methicillin-resistant *Staphylococcus aureus* (MRSA),
 - *Acinetobacter* species
 - *Enterobacter* species
 - Vancomycin-resistant *enterococcus* (VRE)

PATHOGENESIS OF VAP



PATHOGENESIS OF VAP



CLINICAL DIAGNOSIS OF VAP

▶ CLINICAL PULMONARY INFECTION SCORE (CPIS)

SCORE > 6 → VAP

▶ 2-1-2 RULE

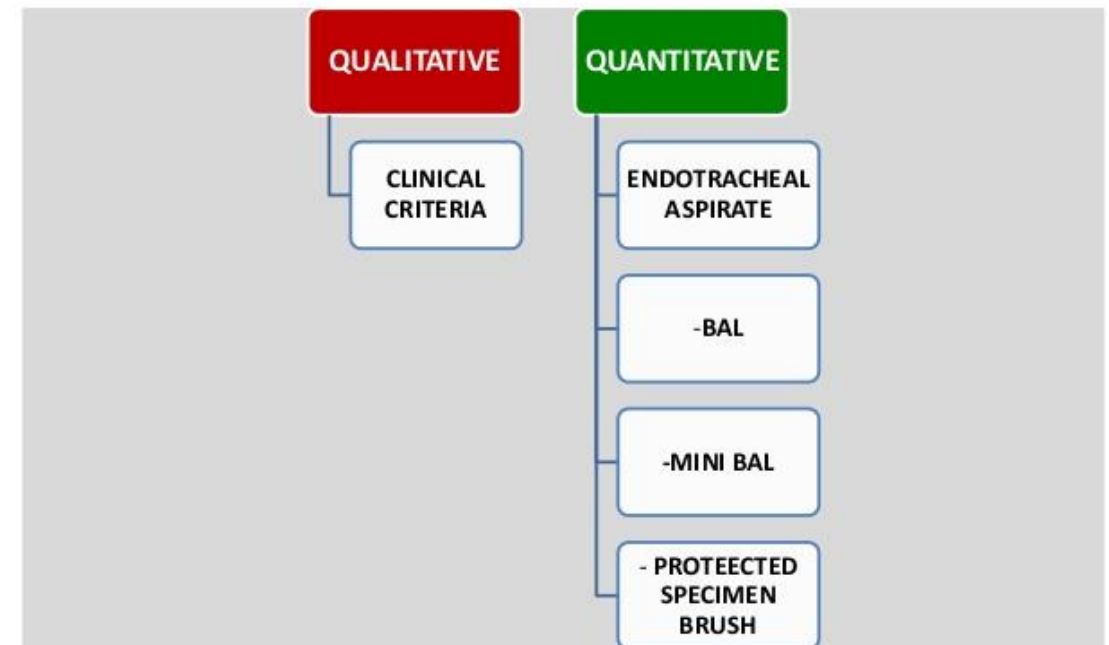
1. NEW ONSET OPACITIES ON CXR X 2 DAYS
2. EITHER (1) FEVER OR LEUKOPENIA OR LEUKOCYTOSIS
3. 2 OF THE FOLLOWING-
 - ▶ CHANGE IN ET SECRETIONS
 - ▶ NEW ONSET DYSPNEA/TACHYPNEA
 - ▶ BRONCHIAL BREATH SOUNDS OR RALES
 - ▶ WORSENING GAS EXCHANGE

CPIS		
Assessed parameter	Results	score
Temperature	36.5–38.4 °C	0
	38.5–38.9 °C	1
	≤ 36 or ≥ 39 °C	2
Leukocyte count	4,000–11,000/mm ³	0
	< 4,000 or > 11,000/mm ³	1
	≥ 500 Band cells	2
Tracheal secretions	None	0
	Mild/non-purulent	1
	Purulent	2
Radiographic findings (on chest radiography, excluding CHF and ARDS)	No infiltrate	0
	Diffuse/patchy infiltrate	1
	Localized infiltrate	2
Culture results (endotracheal aspirate)	No or mild growth	0
	Moderate or florid growth	1
	Moderate or florid growth AND pathogen consistent with Gram stain	2
Oxygenation status (defined by PaO ₂ :FiO ₂)	> 240 or ARDS	0
	≤ 240 and absence of ARDS	1

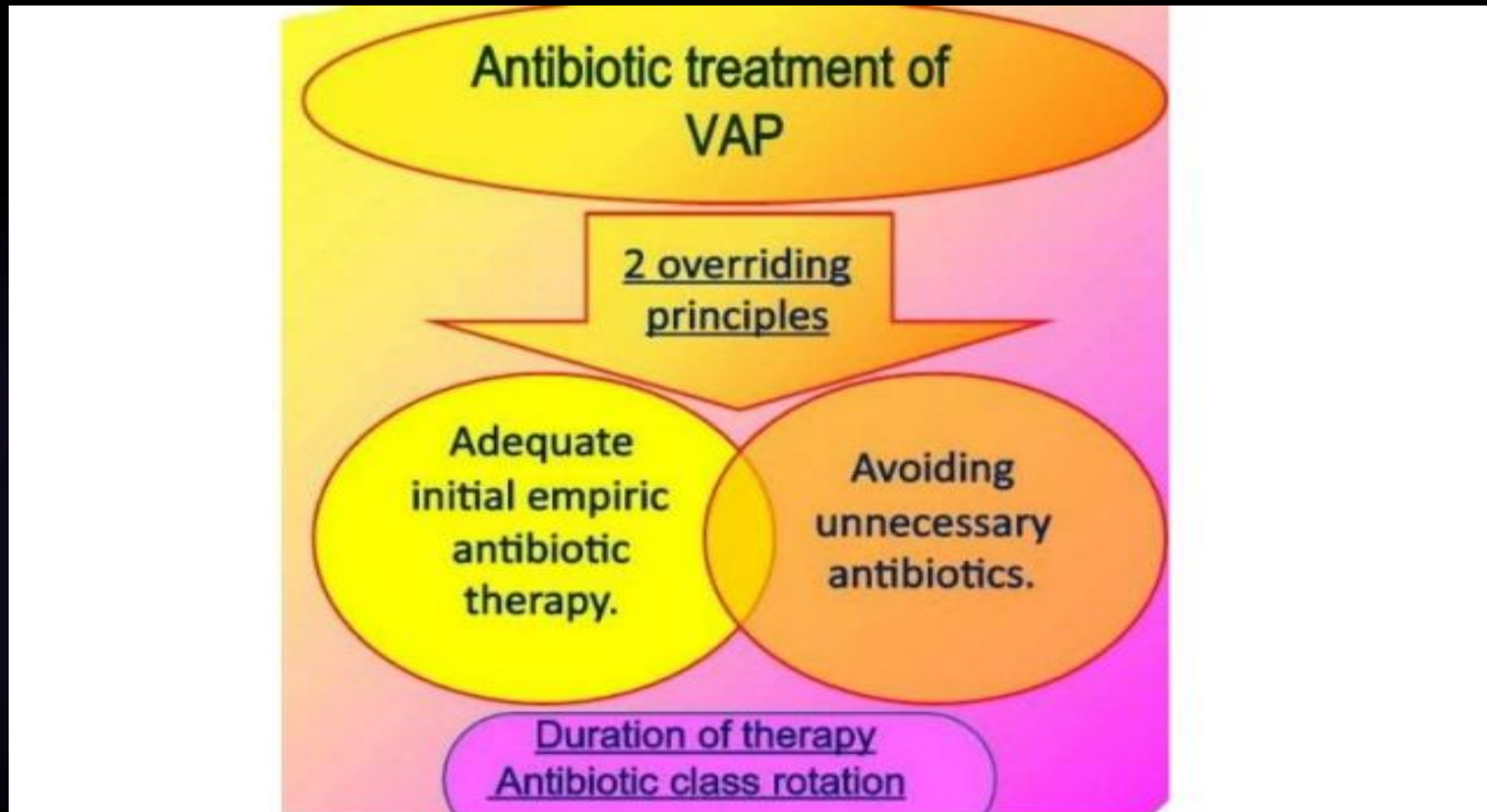
MICROBIOLOGICAL DIAGNOSIS OF VAP

- ▶ 10^4 CFU/ML- BAL
- ▶ 10^3 CFU/ML- PSB
- ▶ 10^5 CFU/ML- ET ASPIRATE

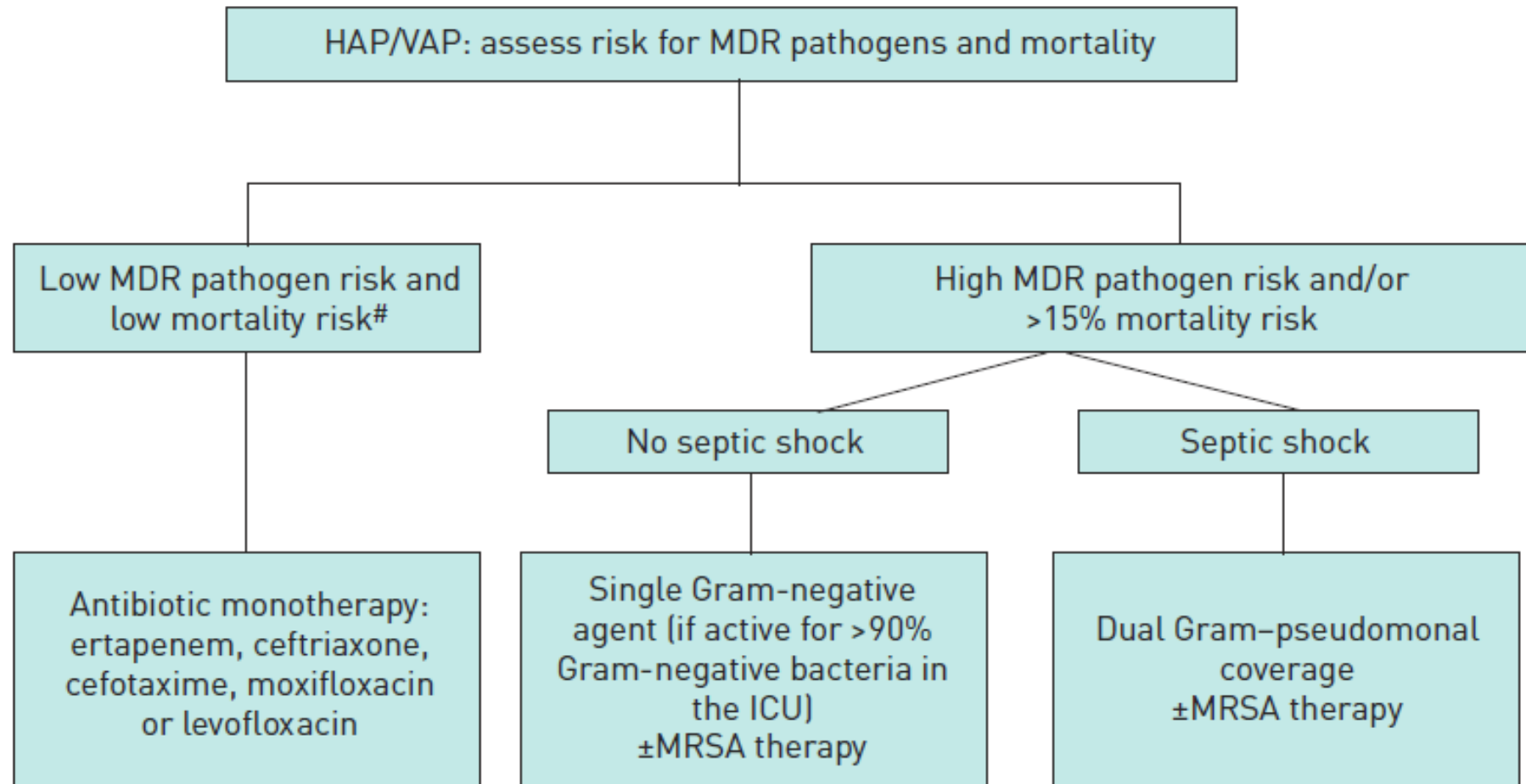
Microbiological diagnosis ATS/IDSA



TREATMENT OF VAP



ANTIBIOTIC PROTOCOL FOR VAP



ANTIBIOTIC PROTOCOL FOR VAP

Patients with Mild to Moderate Nosocomial Pneumonia, No Unusual Risk Factors, Onset Anytime, or Patients with Severe Nosocomial Pneumonia with Early Onset*†

Core Organisms	Core Antibiotics
Enteric gram-negative bacilli	Piperacillin-tazobactam 3.375 g IV q 4 h
	or
(non- <i>Pseudomonas</i>)	Piperacillin-tazobactam [‡] 4.5 g IV q 6 h
	or
<i>Enterobacter</i> spp.	Cefotaxime 1–2 gm IV q 8 h
	or
<i>Escherichia coli</i>	Ceftriaxone 1 g IV q 12 h
	or
<i>Klebsiella</i> spp.	if allergic to penicillins/cephalosporins
<i>Proteus</i> spp.	Clindamycin
	or
<i>Serratia marcescens</i>	vancomycin plus Ciprofloxacin IV
	or
	aztreonam
<i>Hemophilus influenzae</i>	
Methicillin-sensitive <i>S. aureus</i>	
<i>Streptococcus pneumoniae</i>	

Patients with Mild to Moderate Nosocomial Pneumonia with Risk Factor, Onset Anytime*

Core Organisms Plus	Core Antibiotics Plus
Anaerobes	Clindamycin 600 mg IV Q 8 h
	or
(recent abdominal surgery, witnessed aspiration)	Piperacillin-tazobactam 3.375 g IV q 6 h (alone)
<i>Staphylococcus aureus</i>	+/- Vancomycin (until methicillin-resistant <i>S. aureus</i> is excluded)
	or
(coma, head trauma, diabetes mellitus, renal failure)	Linezolid
<i>Legionella</i> spp.	Fluoroquinolone
	or
	Macrolide
<i>P. aeruginosa</i> (prolonged ICU stay, steroids, antibiotics, structural lung disease)	Treat as severe nosocomial pneumonia (Table 130-6)

Patients with Severe Nosocomial Pneumonia with Risk Factors, Onset, or Patients with Severe Nosocomial Pneumonia, Late Onset*†

Core Organisms Plus:	Therapy
<i>P. aeruginosa</i>	Aminoglycoside (gentamicin, tobramycin, amikacin) [‡]
	or
<i>Acinetobacter</i> spp.	Fluoroquinolone <i>plus</i> one of the following:
Consider methicillin-resistant <i>S. aureus</i>	Piperacillin-tazobactam 3.375 g IV q 4 h
	or
	Piperacillin-tazobactam [§] 4.5 g IV q 6 h
	or
	Imipenem 500 mg IV q 6 h
	or
	Meropenem [§] 1.0 g IV q 8 h
	or
	Ceftazidime 2.0 g IV q 8 h
	or
	Cefepime 1–2 g IV q 8 h
	or
	+/- Vancomycin 1 g IV q 12 h
	or
	Linezolid 600 mg IV/PO q 12 h

PREVENTION OF VAP

- ▶ 7 VAP BUNDLES
- ▶ HEAD ELEVATION 30 TO 45 DEGREES
- ▶ DAILY SEDATION HOLIDAY
- ▶ STRESS ULCER PROPHYLAXIS
- ▶ DVT PROPHYLAXIS
- ▶ DAILY ORAL CARE WITH CHLORHEXIDINE AND SUBGLOTTIC SUCTIONING
- ▶ PRACTICE HAND HYGIENE BY HEALTH CARE PERSONNEL
- ▶ REPLACE NGT WITH OROGASTRIC TUBE

COMPLICATIONS DUE TO PROLONGED VENTILATION

- ▶ INFECTIONS AND SEPSIS
- ▶ BED SORES
- ▶ NEUROMUSCULAR WEAKNESS

REFERENCES

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- ▶ 'Summary of the international clinical guidelines for the management of hospital-acquired and ventilator-acquired pneumonia'. *Torres et al. ERJ Open Res* 2018; 4: 00028-2018

THANK YOU!



Approximate Fraction of Inspired Oxygen with Low- and High-Flow Oxygen Devices

100% O ₂ Flow Rate (L/min)	F _{IO₂} (%)
Low-Flow Systems	
Nasal cannula	
1	24
2	28
3	32
4	36
5	40
6	44
Transtracheal catheter	
0.5–4	24–40
Oxygen mask	
5–6	40
6–7	50
7–8	60
Mask with reservoir bag	
6	60
7	70
8	80
9	90
10	>99
Non-rebreathing	
4–10	0.60–1.00
High-Flow System	
Venturi mask*	
3 (80)	0.24
6 (68)	0.28
9 (50)	0.35
12 (50)	0.40
15 (41)	0.50