DM – SEMINAR

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Filtration & Aerosol Therapy in ICU

Filtration in ICU

Filtration

- In 1942, Langmuir & coworkers
  - Penetration of particles through filter material depends on the size of the particles
  - Highest degree of penetration occurs with particles approximately 0.3 μm in diameter
  - Masks used to prevent inhalation of particles should be tested using this particle size

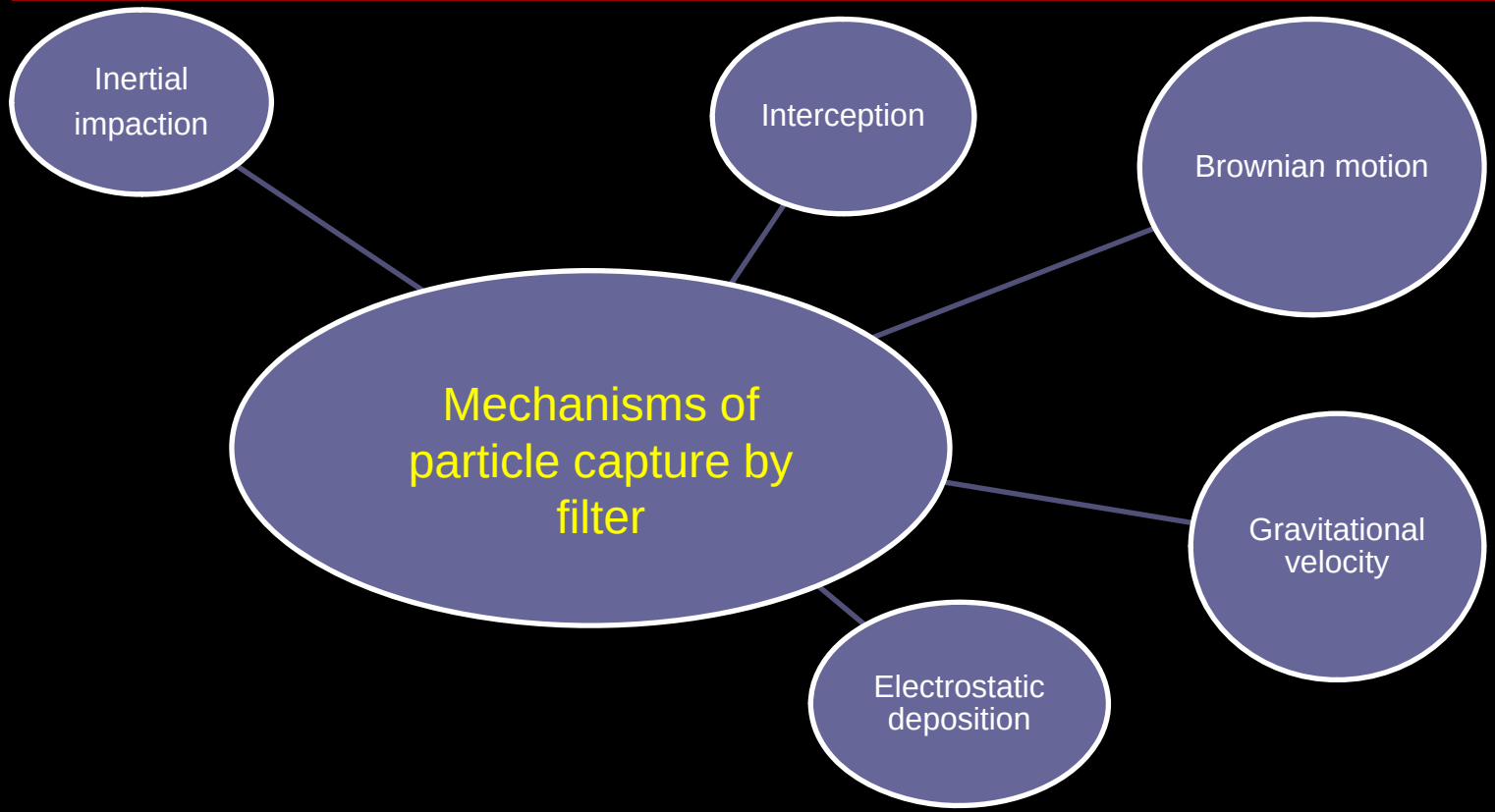
Filtration

- Two types of filters
- Respirator
  - Attaches tightly to the face & covers mouth & nose
  - Categorized as N95, N99, or N100 based on NIOSH rating system
  - Prevent at least 95%, 97% or 99.97% of particles of the most penetrating particle size (MPPS) from passing through

Filtration

- Breathing system filter
  - Stops spread of infectious material at the source so that the environment is not contaminated
  - Applied most commonly for filtration of gases exhaled by patients on anesthesia machines and critical care ventilators

Filtration


Inertial impaction
Interception
Brownian motion
Mechanisms of particle capture by filter
Gravitational velocity
Electrostatic deposition

Filtration

- Inertial impaction
  - Particle cannot follow abrupt change in direction
  - Particle continues in relatively straight path and impacts with the filter fibers
  - Higher face velocities or larger particle mass increases particle capture

Filtration

- Interception
  - Particles with low inertia tends to follow gas streamline
  - Captured due to its diameter that makes contact while passing the filter fiber
  - Variables contributing to interception are
    - Particle diameter
    - Filter fiber diameter
    - Density of the filter fibers

Filtration

- Brownian motion
  - Random chaotic motion of very small particles
  - Causes particle to deviate from carrier gas streamline
  - Increases probability of making contact with a filter fiber
  - Predominant mechanical method of particle capture for small particles (below 0.1 μm)

Filtration

- Gravitational velocity
  - Deviation of particle from its gas streamline due to gravity
  - Little bearing on particle smaller than 5 μm
  - Gravitational settling change - gas flow through the filter medium is vertical or horizontal

Filtration

- Electrostatic deposition
  - Electrostatic attraction causes particle to deviate from gas streamline
  - Most air-borne particulate material carries some electrostatic charge
  - Most NIOSH certified respirators are enhanced with electrostatic properties

AEROSOLS

Definition

‘aero’ air

‘sol’ solution

Particles which are sufficiently small so as to remain airborne for a ‘considerable’ period of time

Suspension of solid or liquid particles in a gas

Definition

Aerosol	Solid or liquid particles suspended in a gas
Atomizer	Device used to form a mist of fine droplets from a liquid.
Nebulizer	An atomizer modified with a baffle or impactor
Fume	Solid-particle aerosol produced by the condensation of vapors or gaseous combustion products
Mist	Liquid-particle aerosol formed by condensation or atomization
Vapor	The gaseous state of substances that are normally in the liquid or solid state
Smoke	Visible aerosol resulting from incomplete combustion; the particles can be solid or liquid
Dust	Solid-particle aerosol formed by mechanical disintegration of a parent material
Powder	A solid substance in the form of tiny, loose particles
Suspension	Mixture in which particles are suspended in a fluid
Solution	Homogeneous mixture of 2 or more substances

Classification

- Aerosols with solid particles
  - Dust
  - Fumes
- Aerosols with liquid particles
  - Fog
  - Mist
  - Spray

Classification

- BLAND:

  Include heated or cooled sterile water/ saline

- MEDICATED:

  Bronchodilators, steroids, mucokinetic agents , anti allergic agents, local anesthesia, antimicrobials, surfactant, insulin , vasopressin

Classification

- Monodisperse
  - Particles that are similar in size
- Polydisperse
  - Large range of particle diameters within aerosol ex. exhaled breath (0.3 μm to > 2000 μm)

Factors affecting Aerosol Delivery

- Polydisperse aerosols
  - Number of particles
    - Count median diameter

      Half of total number of particles is smaller and half is larger
  - Mass, volume
    - Drug dosage, pathogenic substances, or infectious biologic agents
    - Mass median diameter

      Half of total mass is contributed by particle smaller than MMD & half is larger

Factors affecting Aerosol Delivery

- Settling velocity
  - Velocity at which the air resistance is so great that the particle can no longer fall
  - Rate at which the particle will settle out of still air
  - Depends on:
    - Density, diameter & shape of the particle
  - Two of these characteristics must be determined to predict the settling velocity

Factors affecting Aerosol Delivery

- Aerodynamic diameter
  - Not the true diameter of the particle
  - Diameter of a water droplet that would have the same settling velocity as the particle itself
- Mass median aerodynamic diameter
  - One half of the mass is contributed by particle larger than the MMAD, and one half of the mass is contributed by particles smaller than the MMAD

Aerosols & Mechanical Ventilation

- Current devices (MDIs, DPIs & Nebulizers) produce aerosols with MMAD of 1-5 µm
- MDIs & nebulizers can be used with MV
- Nebulizers
  - Pneumatic : small volume, large volume small particle generator
  - Ultrasonic

Aerosols & Mechanical Ventilation

- Nebulizers
  - Jet
  - Ultrasonic
  - Vibrating mesh

Aerosols & Mechanical Ventilation

- Pneumatic/ Jet nebulizers : work on Bernoulli's principle
- Small volume nebulizer (SVN): Hand-hold nebulizers / ventilator circuits
  - Gas flow rates : 6-8 l/m
  - Optimal volume : 4-5 ml
  - Particle size : 1-5 um
  - 10% of aerosol reaches its site of action

Aerosols & Mechanical Ventilation

Pneumatic Jet Nebulizers

Advantages
Patient coordination not required
Effective with tidal breathing
High dose possible
Can be used with supplemental O_2
Can deliver combination therapies

Disadvantages
Lack of portability
Pressurized gas source required
Lengthy treatment time
Doesn’t aerosolize suspension well
Performance variability

Aerosols & Mechanical Ventilation

- Ultrasonic nebulizers
  - Electric charge is applied to a piezo electric crystal (transducer)- ultrasonic vibrations are generated
  - Size of aerosols depend on frequency of transducer while the volume is related to amplitude of sound waves
  - Suitable for long duration aerosol delivery for relief of bronchospasm, upper airway edema & for humidification in tracheostomised patients

Factors affecting Aerosol Delivery

- Devices related factors – MDI vs nebulizers
- Ventilator related factors
- Circuit related factors
- Drug related factors
- Patient related factors

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Aerosol-Generating Devices

- Larger aerosols are trapped in the ventilator circuit & ETT
- MDI with spacer produces aerosols with MMAD of 2µm at the distal end of the ETT
- Nebulizers producing MMAD of < 2µm are more efficient than nebulizers producing larger particles

Aerosol-Generating Devices

- Efficiency of drug delivery with MDIs ranges from 0.3 to 97.5%

Am J Respir Crit Care Med 1996;154:382–387
J Aerosol Med 1992;5:251–259
Chest 1992;102(3):924–930
Respir Care 2002;47(1):31–38.

- Efficiency of drug delivery with nebulizers ranges from 0 to 42%

J Aerosol Med 1992;5:251–259
Am Rev Respir Dis 1992;145(5): 1117–1122
Thorax 1995; 50(1):50–53
Am J Respir Crit Care Med 1995;152:1391–1394.

Configuration of MDIs

- Contains pressurized propellants, surfactants, preservatives, flavoring agents, and active drug
- Designed for use with ambulatory patients
- MV-must be used with different adapters like elbow adapters, inline devices and chamber or reservoir adapters

Configuration of MDIs

- Elbow adapters – ETT
  - Aerosol deposition within the ETT
  - Negligible therapeutic effects
- Inline & chamber adapters – inspiratory limb
  1. Aerosol slows down
  2. Propellant evaporates in expanding fume & decreases the size of the aerosol particles
  - Reduce aerosol drug losses caused by particle-impaction on the walls

Configuration of MDIs

- 4–6-fold greater aerosol drug delivery with chamber than elbow or inline adapters

Chest 1992;102(3):924–930
Chest 1994;105(1):214–218.

- 1.5-2.5 ↑ in aerosol delivery with bidirectional inline adapters than with unidirectional

Respir Care 1998;43(9):705–712

- Comparable efficiency with bidirectional adapters & chambers

Respir Care 1998;43(9):705–712

Configuration of Nebulizers

- Jet & ultrasonic nebulizers
- Connected to either inspiratory limb or Y-piece
- Increased efficiency of jet nebulizers:
  - Placing at a distance from the ETT
  - Adding a reservoir
- Factors influencing nebulizer efficiency are:
  - Diluent volume
  - Operating pressure and flow
  - Duration of treatment

Synchronizing Aerosol Generation

- Actuation of an MDI must be synchronized with the onset of inspiratory airflow
- Actuation 1–1.5 s prior to ventilator breath ↓ efficiency of aerosol delivery by 35%

Am J Respir Crit Care Med 1995;152:1391–1394

- Coordination of MDI actuation i.e. "go with the flow" maximizes MDI drug delivery

Intensive Care Med 2003;29(7):1041–1042

Aerosols & Mechanical Ventilation

- Devices related factors – MDI vs nebulizers
- Ventilator related factors
- Circuit related factors
- Drug related factors
- Patient related factors

Ventilator-Related Factors

- Ventilator breath influence aerosol drug delivery
- Tidal volume
  - > 500 ml-dead space is cleared of aerosol-better drug deposition
- Longer inspiratory time
- Slower inspiratory flow
- Longer duty cycle (TI/Ttot)

Aerosols & Mechanical Ventilation

- Devices related factors – MDI vs nebulizers
- Ventilator related factors
- Circuit related factors
- Drug related factors
- Patient related factors

Circuit-Related Factors-Humidity

- Humidification increases loss of aerosol in the ventilator circuit
- Aerosol delivery to LRT ↓ by 40%
- Humidity ↑ size of aerosols from nebulizers
- MDI – humidity interfere with propellant evaporation – keeps particle larger thus reduces particle impaction losses

Circuit Related Factors- Density

- Density of gas influences lung deposition
- High flows – turbulence
- Less dense gas (heliox) makes airflow less turbulent and more laminar
- Drug delivery with MDI - 50% higher with 80/20 heliox than with oxygen

Am Rev Respir Dis 1992;146(2):383–388

Circuit Related Factors- Density

- Nebulizer operation with heliox reduces drug output and respirable mass
- Operate nebulizer with oxygen at a flow rate of 6–8 L/min and to entrain the aerosol into a ventilator circuit containing heliox
- 50% higher aerosol delivery to the lower airways

Am Rev Respir Dis 1992;146(2):383–388

Optimal Aerosol Delivery

Delivering MDI Aerosol with Mechanical Ventilators
Suction endotracheal tube and airway secretions
Shake MDI and warm to hand temperature
Place MDI in spacer chamber adapter in ventilator circuit
Remove HME. Do not disconnect humidifier
Coordinate MDI actuation with beginning of inspiration
Wait at least 15 s between actuations; administer total dose
Monitor for adverse response
Reconnect HME

Optimal Aerosol Delivery

Delivering Jet Nebulizer Aerosol to Mechanical Ventilators
Suction endotracheal tube and airway secretions
Place drug in nebulizer to fill volume of 4–6 mL
Place nebulizer in the inspiratory line 46 cm from the patient Y-piece
Turn off flow-by or continuous flow during nebulizer operation
Remove HME from circuit. Do not disconnect humidifier
Set gas flow to nebulizer at 6–8 L/min
Adjust ventilator volume limit or pressure limit to compensate for flow added by nebulizer
Remove nebulizer from circuit, rinse with sterile water, and run dry; store in safe place

New Frontiers of Aerosol Delivery

- New devices
  - Vibrating plate technology
  - Intratracheal catheter
- New drug formulation
  - Liposomal formulations
  - Surfactant therapy

Vibrating plate technology

Uses a vibrating mesh or plate with multiple apertures to produce a liquid aerosol

Vibrating plate technology

- Efficient
  - Low residual volume
  - No propellants, pressure or heat
- Precise
  - Low velocity aerosol & consistent particle size
    - Targeted for central or deep lung
  - Minimizes deposition in mouth & throat
- Versatile
  - Aerosolizes a broad range of drugs
    - Solutions, suspensions
  - Small and large molecules
    - Proteins

Intratracheal catheter

- Central lumen transmits the liquid to be aerosolized
- Additional lumens surrounds central lumen, through which compressed gas is forced under high pressure (100psi) at a variable flow rate (0.1–3 L/min)

Liposome Formulations

- Liposomal encapsulation provides extended therapeutic response
- Deliver either hydrophilic or lipophilic drugs
- > 80% of an inhaled liposomal formulation was retained in the lung after 8 hours and 52–73% was retained at 24 hours

Traditional vs Newer Devices

Traditional Devices	Newer Technologies
10-20% lung deposition	High lung deposition
Large device waste	Minimal dead volumes
Ambient contamination / waste	Control of ambient loss
Long treatment time (SVN)	Short treatment time
Not very portable	Portable & self contained
CHEAP	EXPENSIVE

Summary

- Two types of filters
- Aerosol delivery to the lungs depends on the particle size
- MV, circuit and patient contribute to the final aerosol delivery to the respiratory tract