- ❖ Flow meters show high value due to increased gas density
- ❖ Flow meters calibrated to higher pressure levels
- ❖ Expired gases absorbed and vented outside

Monitors

- ❖ Most instruments left outside chamber
- ❖ View oscillometric measurements through glass port in chamber
  - Blood pressure:
    - Ordinary/fluid filled BP cuffs
    - Finger plethysmography/intra-arterial catheter
    - Aneroid manometer preferred to mercury manometer
  - ECG and EEG:
    - Standard equipment
    - Recording apparatus placed outside
  - Blood gas:
    - Machine placed in adjacent lab
    - Polarographic microelectrodes recommended
  - Respiratory function: With normal instruments

Technique of Anesthesia

- ❖ Regional anesthesia:
  - Safe and effective
  - Avoids need for mechanical ventilation
  - Extreme aseptic precautions as increased bacterial growth in warm and humid chamber
- ❖ General anesthesia: Less preferred

Inhaled Anesthetics

- ❖ Can pollute chamber
- ❖ Effect of volatile agents proportional to partial pressure of anesthetic and not alveolar concentration
- ❖ Effect of 1% halothane at 1 atm equivalent to 0.5% at 2 atm
- ❖ Prefer nonexplosive agents
- ❖ Standardized vaporizers used
- ❖ Recalibrate vaporizers within chamber

Nitrous Oxide

- ❖ May be used as sole anesthetic
- ❖ Induction rapid (<60s)
- ❖ Increased atm pressure allows MAC to be exceeded
- ❖ Induction with nitrous oxide associated with HTN, tachycardia, tachypnea
- ❖ Rapid emergence but severe postoperative nausea and vomiting (PONV)
- ❖ May cause embolism during decompression
- ❖ Dilutional hypoxia possible

Intravenous Anesthetics

- ❖ Behavior unaffected by pressure
- ❖ No pharmacokinetic alteration up to 6 atm pressure

Intravenous Fluids

- ❖ Air volume in drip chamber shrinks during compression and expands during decompression
- ❖ Exclude glass bottles to avoid risk of explosion during decompression
- ❖ Use plastic infusion bottles
- ❖ Infusion pumps to be capable of handling pressure differential

Tubes

- ❖ ETT cuff inflated with water to avoid volume changes during compression/decompression
- ❖ Intragastric tube left open
- ❖ Bladder catheters filled with saline
- ❖ Repressure pressure bags during compression and vent out during decompression
- ❖ PA balloon ports left open to chamber during compression and decompression

Ventilation

- ❖ Pressure controlled/volume controlled used
- ❖ Pressure controlled ventilation needs frequent adjustment of PC level
- ❖ Risk of fire hazard due to O_2 build up in ventilator case
- ❖ ETT cuff inflated in chamber and released before decompression

HIGH ALTITUDE

Introduction

No.	Level	Height
1.	Baseline	3,000 m above sea level
2.	Mild high altitude	3,000–3,600 m
3.	Moderate high altitude	4,200–4,800 m
4.	Extreme high altitude	>4,800 m

Pathophysiological Changes

I. *Central nervous system*

- ❖ Vasodilatation causing:
  - Raised ICP
  - Increased cerebral blood flow
  - Altered behavior
  - Drowsiness, incoordination
  - Lack of judgment
  - Sleep—speech disturbances
  - Unconsciousness, seizures

II. *Cardiovascular:*
- Tachycardia
- Hypertension
- Increased blood volume by 30%
- Increased erythropoiesis
- Hematocrit increases from 40 to 65%
- Local vasodilation due to tissue hypoxia
- Pulmonary HTN due to hypoxic pulmonary vasoconstriction

III. *Hypothermia*:
- Causes:
  - Arrhythmias
  - AV block
  - Hypotension
  - Negative inotropism

IV. *Respiratory system (RS)*:
- Reduced PIO_2
- Reduced ambient pressure
- Reduced gas density
- Increased diffusion capacity (normal 2.1 mL/mm Hg/min)
- Reduced oxygen gradient leading to ventilation perfusion mismatch
- Hypoxia induced hyperapnea: Leftward shift of ODC
- Pulmonary edema due to:
  - Increased hydrostatic pressure
  - Increased pulmonary vascular permeability
  - Coagulation defect
  - Increased oxygen free radicals
  - Increased autonomic activity causing neurogenic pulmonary edema

Anesthetic Considerations

- Remote site:
  - Suboptimal equipment
  - Increased risk of infection and pollution—lack of properly built OT
  - Risk of fire hazard and explosion
- Risk of perioperative hypoxia—supplemental oxygen therapy very important
- Hypothermia common—maintain OT temperature between 21 and 24°C
- Warm intravenous fluids essential
- Judicious fluid doses to avoid pulmonary edema
- Increased bleeding tendency due to:
  - Raised venous pressure
  - Venodilation
  - Coagulopathies
  - Increased capillary density
  - Raised blood volume
- Increased risk of aspiration

Preoperative Preparation

- NPO 6 hours
- Informed consent
- Opioid/benzodiazepine premedication
- Antisialogogues—glycopyrrolate/atropine
- Antibiotic prophylaxis
- Antiaspiration prophylaxis
- DVT prophylaxis

Machine

- Boyles type F with Goldman vaporizer for halothane
- Spirometers used to calibrate flowmeters
- Flowmeters show low reading at high flows due to low gas density
- Hazardous if low flow anesthesia used with high nitrous oxide concentration
- Oxygen analyzers show false low reading unless calibrated
- Oxygen analyzer essential if low flow used
- Venturi devices deliver higher O_2 than at sea level
- Venturi mask delivering 35% at sea level delivers 41% at 10,000 feet
- Reduce fire hazard by:
  - Avoiding ether
  - Use battery operated lights in OT
  - Reduced overall fire risk as PIO_2 is low

Regional Anesthesia

- Increased incidence of bowel and bladder distension after subacromial bursal block (SAB)
- Increased incidence of postdural puncture headache due to:
  - Chronically increased CSF pressure
  - Dehydration
- Duration of action of local anesthetics shortened
- Prevent Phrenic N palsy during:
  - Interscalene block
  - Supraclavicular block
  - Stellate ganglion block

Induction

- All patients at risk of aspiration due to delayed gastric emptying
- Rapid sequence induction (RSI) preferred
- Thiopentone has slower onset due to prolonged brain arm circulation time at high altitude
- Propofol, etomidate, benzodiazepines safe

- Larger amounts of propofol required
- Ether induction slow and requires high concentration
- Gas volume in ETT cuff and PAC balloon expands
- Periodic checking of blood glucose levels as high altitude increases glucose consumption

Inhalational Agents

- Potency proportional to partial pressure and not percentage in mixture of O_2
- Nitrous oxide potency reduced as barometric pressure reduces
- Nitrous oxide to be given at 50% to be effective
- Fixed concentration of volatile anesthetics have reduced potency
- Halothane can be used:
  - Ideal for rapid induction and recovery
  - High potency
  - Non inflammable
  - Reduced incidence of laryngospasm
- Delivery of halothane increased at high altitude though partial pressure remains constant
- Isoflurane also suitable

Neuromuscular Blockade

- Succinylcholine safe for short duration surgery
- NDMR action prolonged in hypothermic patients
- Continue assisted ventilation till patient regains complete consciousness
- Complete reversal mandatory as patients are dependent on hyperventilation for oxygenation
- Maintain PaO_2 and $PaCO_2$ at baseline levels rather than normal values

Ventilation

- High oxygen concentration to be given due to:
  - Anesthetic deprived compensatory mechanisms
  - Reduced PIO_2 and PAO_2 at high altitude
  - Hypoxic brain damage at lower PaO_2
  - Reduced compensation for acidosis at high altitude
- Ventilation at high altitude dependant on hypoxic drive
- Administration of narcotics blunts hypoxic drive and precipitates hypoxia

Temperature

- Warm OT and warm IV fluids mandatory
- Warming blankets
- Humidified inspired gases
- Heated peritoneal/bladder/colonic lavage

Fluid Balance

- Challenging due to preexisting hypovolemia and hypoosmolarity
- Fluid bolus prior to induction in hypovolemic patients
- Avoid aggressive fluid challenges in patients at high risk ***for High Altitude Pulmonary Edema***
- Titrate to maintain renal perfusion
- Clear IV lines of air bubbles as development of R to L shunts through ***Patent Foramen Ovale*** common in high altitude

Deep Vein Thrombosis

- Common due to:
  - Hypercoagulability
  - Polycythemia
- Increased risk of postoperative stroke/TIA/DVT

Dissociative Anesthesia

- Advantageous as:
  - Minimally suppresses ventilation
  - Reduces dose of opioids
- Ketamine 1–6 mg/kg total dose + atropine 20 µ/kg + midazolam 0.05 mg/kg for TIVA useful
- Useful if supplemental O_2 not available for use

ANESTHESIA IN SPACE

Physiological Changes in Space

- Cardiovascular changes:
  - Increase in LV end diastolic volume
  - Paradoxical reduction in CVP due to microgravity
  - Reduced LV mass due to cardiac atrophy/injury
  - Central redistribution of blood
  - Facial edema
  - Diuresis with plasma volume depletion (≥20%)
- Autonomic dysfunction:
  - Especially on return to earth
  - Occurs due to:
    - Cardiovascular deconditioning
    - Reduced intravascular volume
    - Increased NO expression
    - Downregulation of α-adrenergic receptors
    - Ventricular atrophy
    - Changes in arterial stiffness
- G forces:
  - Increase in gravitational forces during launch as space craft accelerates to orbital speed
  - Absence of gravitational stress (microgravity) during the period in space
- Neuromuscular changes: Skeletal muscle atrophy even after short missions

Technical Challenges

Airway

- Difficult intubation due to facial edema
- Both intubator and patient to be secured
- Intubator to stabilize head of patient by holding it between knees
- Use smaller size ETT if vocal cord edema is present
- LMA, intubating LMA, cuffed oropharyngeal airway used alternatively

Fluid Therapy

- Hypovolemia may not be adequately treatable due to reduced quantity of supplies
- Air fluid interface in IV fluids generate bubbles as fluids and gases do not separate on basis of differing densities due to lack of gravity
- Air bubbles do not rise up but remain mixed in solution
- IV bag to be degassed before flight/removed by in-line filteration as IV fluid bags contain fluids akin to foam

Neuromuscular Blockade

- Succinylcholine to be avoided as it may cause cardiovascular collapse
- Disuse and skeletal muscle atrophy due to immobilization causes proliferation of extra-junctional receptors causing hyperstimulation and cardiac arrest on SCH use
- Resistance to NDMR may occur

Subarachnoid block: Increased risk of cardiovascular collapse due to autonomic dysfunction

Vaporizers

- Devices which depend on gravity induced separation of fluids and gases malfunction
- This is because vaporizers require gravity to confine liquids to bottom of reservoir

Closed Environment

- Safe use of anesthetic gases difficult in space craft
- Drugs used in flight should not be capable of reaching crew through the closed cabinet atmosphere
- Dumping of exhaust O_2 into cabin atmosphere avoided to prevent fire hazard
- Minimum flow system for xenon may be useful

Complications

Nephrolithiasis and Osteoporosis

- Due to gravitational unloading
- This causes loss of calcium from bones along with hypercalciuria

Space Motion Sickness

- GERD may occur during flight and after landing
- Dizziness, drowsiness, nausea, and vomiting
- Increased risk of aspiration

Hemorrhage and Hypovolemia

- Reduced chances of bleeding
- This is because due to high surface tension of blood, it will remain on surface of wound
- Chances of arterial bleeds spilling out still remains
- Hypotension may be increased by preexisting volume loss and increased G forces during reentry

Ebullism

- Cabin pressure in space craft is 760 mm Hg
- That of extra-vehicular activity (EVA) space suits is 222 mm Hg
- This reduced pressure in EVA suit increases risk of decompression sickness
- If the suit is disrupted during EVA, astronauts ambient pressure quickly drops to zero
- This causes generalized bubble formation called ebullism
- Body fluid boils due to ambient pressure being lower than saturated water vapor pressure

Hypoxia

- Astronauts breathe 100% oxygen in EVA suits
- Disruption of the suit causes hypoxia

Electrolyte disturbances: Hypokalemia and hypomagnesemia common due to reduced dietary intake

Other Advantages

- On board diagnostic tools like remotely guided USG examination
- Remote robotic surgery substituted for on-board surgeon

INTRAOPERATIVE ANAPHYLAXIS

Introduction

Rapid systemic reaction, with potentially life threatening consequences, to a substance to which the individual is already sensitized.

Types

- Allergic anaphylaxis:
  - Type I IgE mediated release of inflammatory mediators
  - Involves mast cells and basophils

- Anaphylactoid reaction:
  - Direct non-immune mediated release of inflammatory mediators
  - Direct complement activation contributory

Risk Factors

- Female gender
- Old age
- History of pulmonary/cardiovascular disease
- History of atopy
- Food allergy
- Latex allergy
- Intravenous drug administration

Etiology

- Muscle relaxants: *Most common*
  - Succinylcholine
  - Rocuronium
  - Atracurium
- Natural rubber:
  - Latex gloves
  - Tourniquets
  - Foleys catheter
- Antibiotics:
  - Penicillins
  - Betalactams
  - Bacitracin
  - Vancomycin
  - Polymyxins
  - Amphotericin
- Hypnotics:
  - Thiopentone
  - Propofol
- Opioids:
  - Morphine
  - Meperidine
- Colloids:
  - Dextran
  - Gelatin
  - Mannitol
- Drugs affecting coagulation:
  - Aprotinin
  - Heparin
  - Protamine
- Others:
  - Bupivacaine
  - Ester local anesthetics
  - β-blockers
  - Radiocontrast allergy
  - Povidone iodine

Mechanism

- Initial exposure to antigens causes IgE release
- IgE binds to mast cells and basophils
- Reexposure to multimeric antigen causes cross linking of IgE receptors
- Degranulation of mast cells and basophils
- Release of inflammatory mediators:
  - Histamine
  - Prostaglandins
  - Serotonin
  - Tryptase
  - Kinins
  - Leukotrienes

Symptoms

- Flushing
- Urticaria
- Dyspnea
- Periorbital/perioral edema
- Wheezing
- Generalized rashes
- Localized edema

Signs

- Hypotension
- Bronchospasm
- Cardiovascular collapse
- Arrhythmias
- Laryngeal edema
- Tachycardia
- Angioedema
- Pulmonary HTN
- Acute tubular necrosis
- Pulmonary edema

Signs Under Anesthesia

- Increased peak inspiratory pressure
- Increased end tidal carbon dioxide
- Decreased oxygen saturation
- Decreased urine output
- Disseminated intravascular coagulation

Severity: Ring and Meissner scale

No.	Severity	Description
1.	Grade I	Erythema, pruritis
		Angioedema, urticaria
2.	Grade II	Urticaria, erythema
		Hypotension, tachycardia, presyncope
		Dyspnea, wheezing, bronchospasm
		Nausea, vomiting, diarrhea
3.	Grade III	Profound hypotension, arrhythmias
		Bradycardia, cardiovascular collapse
		Laryngeal edema, bronchospasm, hypoxia
		Confusion, unconsciousness
4.	Grade IV	Pulseless electrical activity
		Cardiac arrest

Investigations

I. *General*:

- Carboxypeptidase levels
- Complement C3 and C4 levels elevated at 30 minutes, 1 and 4 hours post episode
- Tryptase estimation:
  - Blood sample taken 30 minutes after onset of reaction
  - Values > 20 ng/mL suggestive of anaphylaxis
  - Half life of tryptase 2 hours
  - Serum levels decrease over time
  - Repeat sample at 6 and 24 hours after reaction for tryptase levels
  - Does not differentiate anaphylaxis and anaphylactoid reaction
  - May be absent in the presence of anaphylaxis

II. *Invivo tests*:

- Skin prick testing:
  - Done 4–6 weeks after anaphylactic episode due to mast cell depletion
  - Test with suspected agents and positive and negative controls
  - Freshly prepared diluted drugs used
  - Skin pricked with needle containing small quantity of allergen
  - On front of forearm/back of trunk
- Intradermal skin testing:
  - Done 4–6 weeks after anaphylactic episode due to mast cell depletion
  - Done only if skin prick test is negative
  - Drug concentration of prick test diluted by 1:10
  - 0.2–0.3 mL introduced intradermally with hypodermic needle
  - Slightly greater risk of systemic reaction
- Scratch test: Deep dermal scratch done with blunt bottom of lancet
- Patch test: Patch containing allergen applied to skin
- Bronchial challenge test:
  - In cases of strong suspicion
  - Patient inhales nebulized histamine or methacholine
  - Degree of airway obstruction measured with spirometry
  - Patients with airway hyperreactivity respond to lower dose of drug
  - Post bronchodilator may be used to differentiate asthma from COPD
  - Done only with availability of full resuscitation facilities

III. *Invitro tests*:

- Radioallergosorbent test (RAST):
  - Measures presence of specific IgE antibodies in serum
  - Insoluble disk coupled with specific drug added to patients serum
  - Radiolabeled anti-human antibody added to mixture
  - Radiolabeled anti-human antibody binds to IgE antibodies already bound to antigen
  - Unbound IgE antibodies washed away
  - Amount of radioactivity proportional to serum IgE for allergen

Management

General

- Stop administration of offending drug
- Terminate or rapidly complete surgery
- IV fluids:
  - Loss of 40–50% IV volume
  - Rapid administration to compensate for peripheral vasodilatation
  - 1–2 liters boluses of balanced salt solution
  - Titrate to maintain SBP > 90 mm Hg

Airway

- Administer 100% oxygen
- Endotracheal intubation:
  - Secure airway early
  - Those with apnea, coma, increasing hypercapnea, exhaustion
  - *Rapid sequence intubation*
  - Largest sized ETT used if no airway edema to minimize resistance
  - Ventilatory strategy:
    - Small tidal volume (6–8 mL/kg)
    - Slower respiratory rate
    - Shorter inspiratory time
    - Longer expiratory time (I:E = 1:4 or 1:5)
    - Permissive hypercapnea
  - Delay extubation as airway edema may continue for 24 hours

Bronchodilators

- Ipratropium bromide 0.03%—500 µg in 2.5 mL NS nebulization
- Albuterol 0.3% 2.5–5 mg in 3 mL NS nebulization
- Albuterol 100–200 µg IV bolus
- Terbutaline 250–500 µg subcutaneously repeated every 20 minutes for 3 doses
- Aminophylline 5 mg/kg IV over 20–30 minutes

Epinephrine

- *Drug of choice* as α_1 supports blood pressure while β_2 supports bronchodilation
- Highest peak blood levels with intramuscular administration in anterolateral thigh
- Subcutaneous injection provides uncertain and delayed absorption
- 0.2–0.5 mg IM (1:1,000) repeat every 5–15 minutes if no improvement (*Class I, LOE C*)
- 50–100 µg IV boluses if anaphylactic shock (*Class I, LOE B*)
- 5–15 µg/min infusion to maintain blood pressure in shock (*Class IIa, LOE C*)
- 2–2.5 mg in 10 mL instilled endotracheally

Antihistaminics

- Diphenhydramine (H_1 blocker)—0.5–1 mg/kg IV
- Ranitidine (H_2 blocker)—1 mg/kg IV

Corticosteroids

- Methylprednisolone 0.5–1 mg/kg bolus followed by 0.8 mg/kg Q4–6H
- Hydrocortisone 1–5 mg/kg IV bolus followed by 2.5 mg/kg Q4–6H
- Decrease airway edema and reduce recurrence
- Hydrocortisone preferred due to fast onset

Vasopressors

- Other vasopressors useful in those cases unresponsive to epinephrine (*Class IIb, LOE C*)
- Dopamine 2–20 µg/kg/min infusion
- Norepinephrine 0.05 µg/kg/min infusion
- Vasopressin:
  - 1–2 IU IV for hypotension
  - 40 IU IV for cardiac arrest
- Methoxamine and metaraminol other alternatives

Others

- Ketamine: May be useful if intubation planned
- Heliox:
  - Mixture of 70% helium and 30% oxygen
  - Reduces turbulence in airflow
  - Not useful if >30% oxygen required
- Volatile anesthetics:
  - Isoflurane/sevoflurane in refractory bronchospasm
  - Increases ease of mechanical ventilation
- Glucagon:
  - 20–30 µg/kg or 1–5 mg bolus followed by 5–15 µg/min infusion
- Magnesium sulfate:
  - 40–60 mg/kg or 2 g IV bolus
  - Used for refractory bronchospasm

Extracorporeal Life Support

- Cardiopulmonary bypass for anaphylaxis followed by cardiac arrest (*Class IIb, LOE C*)
- Requires equipment and expertise

Differential Diagnosis

- Pulmonary embolism
- Acute myocardial infarction
- Aspiration
- Vasovagal reaction

ELECTRICAL SAFETY IN OPERATING ROOM

Introduction

- Operating theater is at a high risk for fire hazards as:
  - Variety of electrical equipment are close to each other
  - Unconscious patient who cannot protect himself

Predisposing Factors

- Confined space
- Electrical items
- Electrically sensitive persons:
  - Patient with breaks in skin—abrasions
  - Wet dressings
  - Implanted pacemakers
  - Monitoring lines connected to transducer
- Inflammable materials:
  - Oxygen
  - Ether
  - Bowel gas

Risk Factors

I. *Circumstantial*:
   - Non uniformity of electrical fixtures
   - Poorly designed electrical distribution system
   - Poor maintenance

II. *Human*:
   - Unskilled electrician
   - Non adherence to regulations
   - Overloaded cables
   - Excessive fuse sizes
   - Inadequate earthing

III. *Environmental*:
   - Heat
   - Humidity
   - Animals: Rats and rodents

Types of Electrical Hazard

- Shock—when person becomes final component that closes electrical circuit
- Electrocution—when amount or path of flow of current through person becomes lethal
- Burns
- Fires
- Explosions
- Failure of equipment

Classes of Electrical Equipment

Describes method of electrical protection.

Class I

- Any conducting part of equipment is earthed
- Fuses present at wall socket, live and neutral sides of equipment
- Any electrical leakage channeled to earth and breaks circuit

Class II

- Accessible conducting parts have doubly reinforced insulation
- This prevents possibility of accessible part becoming live
- Earthing wire not required

Class III

- Uses voltages not higher than Safety Extra Low Voltage (SELV)
- Usually less than 25 V for AC and 60 V for DC
- Unlikely for electrocution at such low voltages
- Equipment which uses either batteries or SELV transformers
- Can cause microshock
- Does not meet current standards as limitation of voltage alone not sufficient to ensure patient safety

Electrocution

Mechanisms

I. *Resistive coupling*:
   - Person touches faulty wire or equipment while in contact with earth
   - Body becomes part of an electrical circuit
   - Leakage current passes through the body to the earth

II. *Capacitative coupling*:
   - Occurs in presence of high frequency current
   - Equipment attached behaves like one of the plates of the capacitor
- Body becomes part of an electrical circuit
- Current passes through the body

Factors Affecting Severity

- Type of current—AC current more dangerous
- Size of current—50–60 Hz frequency most dangerous
- Electrical path (especially current density through the heart)
- Duration of current flow
- Timing in relation to ECG

No.	Strength of current	Injury
1.	<1 mA	Nil
2.	1 mA	Tingling
3.	5 mA	Pain
4.	15 mA	Muscular tetany, pain, asphyxia
5.	50 mA	Expiratory respiratory arrest
6.	75 mA	Arrhythmias
7.	100 mA	Ventricular fibrillation
		Cardiac arrest
8.	>5 Amp	Sustained asystole
		Contact burns

Injuries Caused

- Functional disruption of tissues
- Burns
- Respiratory failure
- Ventricular fibrillation
- Blunt trauma

Types of Shocks

Macroshock

- *Most common*
- 100–300 mA current, as low as 50 mA
- Electrical charge occurs through intact skin
- Travels to heart and out again
- Current distributed somewhat evenly through body parts
- Examples:
  - Contact with faulty class I equipment
  - Defibrillator use

Microshock

- Very low level shocks which go undetected
- Usually <1 mA current
- Charge directly delivered to heart muscle
- Examples:
  - Shock delivered via central line/pacemaker wire