LEARNER OUTCOMES

- Discuss the interaction between intracranial pathophysiology, cerebral perfusion and general anesthesia.
- Summarize the fast-track technique for neuroanesthesia.

CEREBRAL ISCHEMIA

- Result of diminished blood and/or oxygen supply to the brain.
- Divided into three categories:
  - Reversible or irreversible
  - Complete or incomplete
  - Global vs. Focal
- Certain areas more susceptible than others to injury.

CEREBRAL PHYSIOLOGY

- CMRO₂ – Cerebral Metabolic Rate of Oxygen
- CBF – Cerebral Blood Flow
- CPP – Cerebral Perfusion Pressure
- ICP – Intracranial Pressure

Cerebral O₂ Consumption (CMRO₂)

- Comprises 20% of total body O₂ consumption (250 ml O₂/min).
- CMRO₂ greatest in grey matter.
- CMRO₂ = 3.0-3.8 ml/100g/min (50 ml/min).
- Physiologic effects:
  - Mentally alert: 3.5 ml/100g/min
  - Mentally confused: 2.8 ml/100g/min
  - Comatose: 2.0 ml/100g/min.
CEREBRAL PHYSIOLOGY

- Cerebral Blood Flow (CBF)
  - Parallels Metabolic Activity
    - \( 1 \text{CMR} = 1 \text{CMRO}_2 = 1 \text{CBF} \)
  - Normal CBF: 50-55 ml/100g of Brain Tissue/Minute
  - 15% of Cardiac Output
  - Regional CBF can vary between 20-80 ml/100g of Brain Tissue/Minute

- Regulation of Cerebral Blood Flow
  - Arterial \( \text{CO}_2 \) Tension (\( \text{PaCO}_2 \))
  - Arterial O2 Tension (\( \text{PaO}_2 \))
  - Mean Arterial Pressure (MAP)
  - Autoregulation
  - Cerebral Perfusion Pressure (CPP)

REGULATION OF CBF

- Arterial \( \text{CO}_2 \) Tension (\( \text{PaCO}_2 \))
  - CBF is directly proportional to \( \text{PaCO}_2 \)
    - Between tensions of 20-80 mmHg
  - Blood flow changes approximate 1-2 ml/100g/min per 1 mmHg change in \( \text{PaCO}_2 \)
  - Hypocapnia results in vasoconstriction and decreased CBF, CBV and ICP
  - Hypercapnia increases CBF by 2 ml/100 g of Brain Tissue for each single Torr increase in \( \text{PaCO}_2 \)

RELATIONSHIP BETWEEN \( \text{PaCO}_2 \) AND CBF

- Arterial O2 Tension
  - Resistant to most changes in \( \text{PaO}_2 \)
  - Hypoxemia leads to a profound increase in CBF
  - Hyperoxia is associated with a less than 10% decrease in CBF

REGULATION OF CBF

- Mean Arterial Pressure
  - Autonomous curve of the cerebral vasculature in the normotensive adult, the hypertensive adult, and the newborn.
REGULATION OF CBF
- Mean Arterial Pressure
  - Severe Hypotension Leads To Cerebral Ischemia
    - 20-25 ml/100g/min - cerebral impairment
    - 15-20 ml/100g/min – produce isoelectric EEG
    - Below 10 ml/100g/min - associated with irreversible brain damage

- Cerebral Perfusion Pressure
  - CPP=MAP-ICP if ICP > CVP
  - CPP=MAP-CVP if CVP > ICP
    - Usually ICP < 10 mmHg, therefore CPP dependent on MAP
  - Normal CPP-80-100 mmHg
    - Decrease in CPP - cerebral vasodilation
    - Increase in CPP - cerebral vasoconstriction
  - Effects of CPP on EEG
    - Lower limit of CPP is 50 mmHg
    - Less than 50 mmHg - slowing EEG
    - Between 25-40 mmHg - flat EEG
    - Less than 25 mmHg - irreversible brain damage

INTRACRANIAL PRESSURE
- Determined By Contents Of Intracranial Compartment
  - Consists of brain and water-80%
  - Blood-12%
  - CSF-8%
- Normal ICP In Supine Position 5-15 mmHg
- Compensatory Mechanisms
  - Displacement of CSF from cranial to spinal compartment
  - Increase in CSF absorption
  - Decrease in CSF production
  - Decreased in CBV

INTRACRANIAL COMPLIANCE
- Measures The Change In ICP In Response To Changes In Intracranial Volume

INCREASED ICP
- Normal Elastance Of Intracranial Contents
  - Without Intracranial Pathology
- Abnormal Elastance
  - Causes Include
    - Mass Lesions
    - Bleeding
    - CSF Volume
    - Air
    - Foreign Body
INTRACRANIAL PRESSURE

- Increased ICP
  - Normal Elastance Of Intracranial Contents
    - Without Intracranial Pathology
  - Abnormal Elastance
    - Causes Include
      - Mass Lesions
      - Bleeding
      - CSF Volume
      - Air
      - Foreign Body

SYMPTOMS OF ↑ ICP

- Headache
- Nausea
- Vomiting
- Papilledema
- Focal neurologic deficits
- Cushing’s Triad
- Altered consciousness

INTRACRANIAL HYPERTENSION

- Sustained Increase In ICP Above 15 mmHg
- Causes
  - Increase in tissue or fluid mass
  - Interference with normal CSF absorption
  - Excessive cerebral blood flow
  - Increase in brain edema from systemic derangement of blood brain barrier
- ICP > 30 mmHg
  - Decrease in CBF
  - Vicious cycle
    - brain ischemia → brain edema → ↑ ICP → more brain ischemia

ANESTHETIC MANAGEMENT

- Location
  - Supratentorial vs. Intratentorial
    - Tentorium-“tent of the cerebellum”

INTRACRANIAL MASSES

- Methods Of Control
  - Decrease the volume of the brain
    - Diuretics
    - Corticosteroids
  - Decrease the volume of blood
    - Hyperventilation
    - Optimized Hemodynamics (MAP,CVP,PCWP, HR)
    - Positioning
    - Fluid restriction
    - Temperature control (CBF changes 5-7%/C)
  - Decrease the volume of CSF
    - CSF drainage
    - Surgical decompression
INTRACRANIAL MASSES

- Adult Tumors Are Supratentorial
  - Meningiomas
  - Glioblastomas
  - Neuroblastomas
- Childhood Tumors Are Infratentorial
  - Medulloblastomas
  - Cerebellar Astrocytomas
  - Intratentorial Ependymomas
  - Brain Stem Gliomas
- Primary vs. Metastatic

STEREOTACTIC NAVIGATION

- Three Dimensional Imaging
  - Localizes intracranial point in relation to the computed image, using CT, MRI or angiographic studies

STEREOTACTIC NAVIGATION

- Fiducial Markers Indicate Imaging Coordinates
- Coordinates Of Brain Are Automatically Calibrated To Coordinates Of System.

NEUROLOGIC MONITORING

- EEG monitoring
  - Used to monitor balance between oxygen supply and demand in cerebral cortex
  - EEG changes seen when CBF decreases from norm to 20 ml/100g/min
- Burst suppression
  - EEG pattern of periods of electrical silence interspersed with brief periods of activity
- EEG Is Sensitive To All Anesthetics
  - Volatile Agents Have Dose-dependent Suppressive Effect
    - < 0.5 MAC – CMRO₂ decreased
    - 1.0 MAC - ↓ frequency and max. voltage
    - Greater than 1 MAC - burst suppression and isoelectricity
    - 2.0 MAC – electrical silence
  - Opioids Have Minimal Effect On EEG And Evoked Potentials
NEUROLOGIC MONITORING

- Evoked Potentials
  - SSEP - Somatosensory Evoked Potential
    - Most common used nerves
      - Median (wrist)
      - Posterior tibial nerve (ankle)
      - Peroneal nerve (popliteal fossa or below the knee)
  - MEP - Motor Evoked Potential
    - Assesses Descending Motor Pathways

- EP Measurement
  - Latency
  - Amplitude

- Effected By Certain Anesthetics
  - NMR-avoid with use of MEPs
  - Volatile agents decrease amplitude and increase latency
  - N$_2$O-decreases amplitude
  - Changes in anesthetic depth misinterpreted as change attributed to tissue viability

ANESTHETIC MANAGEMENT: CHOOSING THE RIGHT ANESTHETIC

- Awake vs. General
  - Awake Craniotomy
    - Opportunity for brain mapping
    - Reduction in ICU care
    - Shorter hospital stay
  - General Anesthetic
    - Short acting anesthetics provide similar advantages to awake technique
    - Outcome data is not significant

- Barbiturates
  - ↓CBF And CMRO$_2$
  - Maintains Responsiveness To CO$_2$ Changes And Autoregulation
  - Provide Protection During Focal But Not Global Ischemia
  - Anticonvulsant Activity
  - Cause Robin Hood Or Reverse Steal Phenomenon
  - Facilitates CSF Absorption
  - Highly Effective In Lowering ICP

- Propofol
  - Dose-dependent Reduction In CBF
  - 40-60% Reduction In CMRO$_2$
  - Autoregulation And Responsiveness To CO$_2$ Changes Are Maintained
  - Anti-convulsant Effect
  - Reduces Or Has Minimal Effect On ICP
  - More Effective Than Thiopental In Attenuating Rises In MAP, CSF Pressure And CPP During Induction

- Dexmedetomidine
  - Selective Alpha$_2$-adrenoceptor Agonist
  - Slow Onset And Offset
  - Reduces MAC By 50%
  - No Change Or Minimal Decrease In ICP As Long As MAP Is Maintained
  - Does Not Alter Seizure Threshold
**INDUCTION AGENTS**

- **Etomidate**
  - Depresses CMR, CBF, And ICP
  - Decreases CMR In Cortex > Brainstem
  - Decrease CSF Production And Enhances CSF Absorption
  - Epileptogenic Properties
  - Increases EP Amplitude And Latency

- **Ketamine**
  - Dilates Cerebral Vasculature
  - Causes Marked Increases In CBF And CMRO$_2$
  - Impedes CSF Absorption

- **Benzodiazepines**
  - Midazolam
    - Drug Of Choice Due To Short Half-life
  - Lower CBF And CMR
  - Anticonvulsant Properties
  - Significant Decreases In CPP
  - Avoid In Elderly & Unstable Patients
  - Prolong Emergence (Renal Failure)

- **Remifentanil**
  - Acid Methyl Structure Susceptible To Esterase Metabolism In Blood And Tissues
  - Rapid Emergence
    - Increased incidence of hypertension
    - Consider transitional narcotics post-op
    - Permits Immediate Postoperative Neurologic Evaluation
  - No Effect On ICP

**OPIOIDS**

- Minimal Effects On CBF, CMR, And ICP
- Sufentanil Can Increase ICP
- Morphine Not Considered Optimal In Due To Poor Lipid Solubility
- Meperidine Avoided In Renal Failure Patient

**INHALATIONAL ANESTHETICS**

- Produce A Dose-dependent Decrease In Cerebral Metabolic Rate (CMRO$_2$)
  - Iso>>Des=Sevo
- Up To 50% Reduction In CMR With Isoflurane
- Produces EEG Burst Suppression In Higher Doses
INHALATIONAL ANESTHETICS

• Effect On Autoregulation

  - Increase In Cerebral Blood Flow (CBF)
    - Isoflurane > Desflurane > Sevoflurane
    - Minimal or no effect at 0.5 MAC
    - Hyperventilation can blunt the increase in CBF
  - Increased ICP In Presence Of Space Occupying Lesions
  - All Volatile Anesthetics Increase CBV
  - Easy To Monitor End-tidal Concentrations
  - N₂O Increases CBF And Increases CMRO₂

INHALATIONAL ANESTHETICS

• Sevoflurane

  - CBF And CMRO₂ Reduced 50% Below 1 MAC
  - Autoregulation And Responsiveness Of CBF To PaCO₂ Preserved
  - Dose Dependent Increase In ICP
  - Decrease In CVR
  - SSEP And EEG Are Suppressed In A Dose-dependent Fashion

INHALATIONAL ANESTHETICS

• Desflurane

  - Rapid Onset And Emergence
  - Decreases CMRO₂
  - At 0.5 MAC, Does Not Increase CBF Or CBV

EFFECTS OF ANESTHETICS ON MUSCLE RELAXANTS

- Succinylcholine Increases ICP
- Non-depolarizers Have No Clinically Significant Effects On CBF And CMRO₂
- Chronic Anticonvulsant Therapy-shorted Duration Of Action Of NDMR

**Table 23-1.** Comparative effects of anesthetic agents on cerebral physiology.

<table>
<thead>
<tr>
<th>Agent</th>
<th>CBF</th>
<th>CBF</th>
<th>CBF Production</th>
<th>CBF Absorption</th>
<th>CBV</th>
<th>ICP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Halothane</td>
<td>!</td>
<td>!</td>
<td>!</td>
<td>!</td>
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<tr>
<td>Enflurane</td>
<td>!</td>
<td>!</td>
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<tr>
<td>Isoflurane</td>
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<tr>
<td>Nitrous oxide</td>
<td>! !</td>
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<tr>
<td>Benzodiazepines</td>
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</tr>
</tbody>
</table>

* T = Increase, ! = decrease, 0 = little or no change, ? = unknown, CBF = cerebral blood flow, CBV = cerebral blood volume, ICP = intracranial pressure.
THE FAST-TRACK APPROACH TO NEUROANESTHESIA

PRE-OPERATIVE ASSESSMENT
• Neurological Assessment Prior To OR
• Pre-operative Meds
  – Sedatives And Opioids Avoided
  – Steroids
    • Reduce cerebral edema
    • DO NOT improve outcome or lower ICP in face of head injury
    • Complications include hyperglycemia, infection, GI bleeding

PRE-OPERATIVE ASSESSMENT
• Pre-operative Meds
• Anti-epileptic Drugs
  • Dilantin (Phenytoin)
    – Infusion-related adverse reactions due to the sodium hydroxide, propylene glycol and alcohol content of the intravenous formulation
    – Extravasation reported when large doses of undiluted phenytoin are given through a small-bore catheter in a peripheral vein
    – Hypotension and arrhythmias related to rapid administration (> 50 mg/minute) rates
  • Cerebyx (Fosphenytoin)
    – Water-soluble pro-drug of phenytoin that is associated with fewer infusion-related events
  • Keppra (Levetiracetam)
    – Devoid of cardio-toxic effects
    – Acts by binding to synaptic plasma membrane in CNS
    – Inhibits burst firing without effecting normal neuronal excitability
    – Loading dose-1 gm/24 hours

PRE-OPERATIVE ASSESSMENT
• Anti-epileptic Drugs
  • Keppra (Levetiracetam)
    – Devoid of cardio-toxic effects
    – Acts by binding to synaptic plasma membrane in CNS
    – Inhibits burst firing without effecting normal neuronal excitability
    – Loading dose-1 gm/24 hours

MONITORING
• Standard Monitors Plus Arterial Line
  – Permits beat to beat monitoring, extrapolation of data to determine CPP
• Central Venous Line
  – Subclavian approach preferred
  – Indirect correlation of ICP in determination of CPP
  – Central route for vasoactive drugs
**POSITIONING**
- Positioned in head up position, either supine, lateral or prone
- HOB 30 degrees
  - Promotes gravitational drainage of blood and CSF
- Sitting craniotomies avoided unless access is not possible

**IDEAL CHARACTERISTICS OF ANESTHETIC DRUGS**
- Allow rapid onset and rapid emergence
- Maintain hemodynamic stability
- Not increase cerebral blood flow (CBF)
- Decrease cerebral blood volume (CBV)
- Decrease intracranial pressure
- Maintain CO2 reactivity
- Maintain cerebral autoregulation
- Allow for neurophysiologic monitoring of EP and EEG
- Does not increase cerebral metabolic rate (CMR)
- Has anti-convulsant properties
- Decreases cerebral edema
- Protects the brain from ischemia

**INDUCTION**
- Remifentanil-0.25ug/kg
- Propofol 1-2 mg/kg
- Rocuronium 0.6 mg/kg
- Tracheal intubation with reinforced tube

**MAINTENANCE**
- Remifentanil infusion -0.125 ug/kg/min
- Additional boluses as necessary
- Rocuronium infusion – 6-8 ug/kg/min
  - Based on train of four response
  - Not utilized during MEP monitoring
- Desflurane – 0.5 MAC
- If MEP monitoring is used
  - Consider not using volatile agents
  - Propofol infusion 100 ug/kg/min
  - No muscle relaxants after induction dose
- Hyperventilation
  - 25-30 mmHg
  - If ICP is elevated, 20-25 mmHg

**PERIOPERATIVE HYPERTENSION**
- Occurrence
  - Intubation
  - Injection of epinephrine containing solutions
  - Stimulation
    - Pin placement,
    - Incision and opening of the bone and dura
  - Emergence
- Vasoactive modulators
  - Epinephrine, norepinephrine, aldosterone, and cortisol.
  - Elevated in the absence of hypertension

**MANAGEMENT OF PERIOPERATIVE HYPERTENSION**
- Remifentanil 200ug with pin placement
- Hydralazine 10 mg -20 minutes before the end of the procedure
- Supplemented with labetalol 5-10 mg following the discontinuation of remifentanil
EMERGENCE

- Ondansatron-4mg
- Rocuronium Infusion Discontinued Prior To Scalp Closure
- Propofol Infusion Discontinued Following Closure Of Scalp
  - Small Amount Of Accumulation
- Remifentanil And Desflurane (If Utilized) Discontinued Prior To Removal Of Pins
- Transported To CT Scan 20 Minutes After Awakening And Arrival In PACU