Inhalational Anesthesia in the Pediatric ICU

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Inhalational Anesthesia

- history
- chemical structure & physical properties
- metabolism & interactions
- end-organ effects
- clinical applications
- delivery in the ICU
Crawford Long

- born in 1815 in Danielsville, Georgia
- MD degree from University of Pennsylvania in 1839
- studied surgery in New York
- practiced medicine in Georgia
- anesthetized patient with an ether soaked towel
  - March 30, 1842
- also used ether in obstetrical cases
William Thomas Green Morton

• originally a dentist
• later went to medical school
  – wife’s parents did not approve of his profession
• September 30, 1846 – ether for tooth extraction
• October 16, 1846 – neck tumor
  – first public display of ether use
History of Inhalational Anesthesia

- nitrous oxide
  - lack of potency
- ether and chloroform
  - flammable + adverse physiologic effects
- 1940’s
  - advances in physical chemistry due to nuclear program
- trichlorethylene
  - hepatotoxicity, neurotoxicity, delayed awakening
Fluorinated Agents

- fluroxene (2,2,2,-trifluoroethyl vinyl ether)
  - first fluorinated hydrocarbon
  - introduced into clinical practice in 1951
  - arrhythmias, nausea/vomiting, hepatotoxicity
- halothane
  - introduced into clinical practice in 1956
History of Inhalation Anesthetics

- Sevoflurane
- Desflurane
- Isoflurane
- Enflurane
- Methoxyflurane
- Halothane
- Ethyl vinyl ether
- Propyl methyl ether
- Isopropenyl vinyl ether
- Trichloroethylene
- Cyclopropane
- Vinethene
- Ethylene
- Ethyl chloride
- Ether
- N₂O
- Chloroform

Year Introduced:
- 1830
- 1850
- 1870
- 1890
- 1910
- 1930
- 1950
- 1970
- 1990

Anesthetics Used in Clinical Practice (Cumulative)
Inhalational Anesthesia

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Inhalational Anesthesia

- alkanes
  - halothane
  - chloroform
- ethers
  - methyl-ethyl ethers
    - isoflurane
    - enflurane
    - desflurane
  - methyl-isopropyl ether
    - sevoflurane
Alkanes: Issues

- cardiovascular depression
- arrhythmias
- hepatotoxicity
Inhalational Anesthetic Agents: Differences

- potency (MAC)
- cardiovascular effects
- metabolism
  - fluoride
  - TFA or HFIP
- solubility
  - gas (blood:gas partition coefficient)
  - fat (blood:oil partition coefficient)
Minimum Alveolar Concentration

- MAC
- used to judge the potency of the agent
- expressed as percentage
- alveolar concentration at which 50% of subjects do not move in response to surgical incision
- lower MAC = higher potency
- modified by several factors
Vapor Pressure

- volatile liquids
  - transform into gas or vapor
- vapor pressure
  - potential to form a gas or vapor
- administered by a vaporizer
  - agent specific
  - variable bypass
  - key index filling system
Inhalational Anesthesia

<table>
<thead>
<tr>
<th>Agent</th>
<th>Vapor pressure (mmHg at 20°C)</th>
<th>Blood:Gas partition coefficient</th>
<th>MAC (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Halothane</td>
<td>243</td>
<td>2.54</td>
<td>0.76</td>
</tr>
<tr>
<td>Enflurane</td>
<td>175</td>
<td>1.91</td>
<td>1.7</td>
</tr>
<tr>
<td>Isoflurane</td>
<td>238</td>
<td>1.46</td>
<td>1.2</td>
</tr>
<tr>
<td>Sevoflurane</td>
<td>160</td>
<td>0.69</td>
<td>2.0-2.3</td>
</tr>
<tr>
<td>Desflurane</td>
<td>664</td>
<td>0.42</td>
<td>6.0</td>
</tr>
</tbody>
</table>
Uptake and Distribution

• administered via respiratory route
• onset and offset determined by
  – blood:gas solubility coefficient
• other factors that determine onset
  – minute ventilation
  – inspired concentration
  – cardiac output
• effect of congenital heart disease
  – left-to-right shunt
  – right-to-left shunt
Blood: Gas Partition Coefficients of Anesthetic Agents

<table>
<thead>
<tr>
<th>Anesthetic Agent</th>
<th>Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Desflurane</td>
<td>0.45</td>
</tr>
<tr>
<td>Nitrous Oxide</td>
<td>0.47</td>
</tr>
<tr>
<td>Sevoflurane</td>
<td>0.65</td>
</tr>
<tr>
<td>Isoflurane</td>
<td>1.43</td>
</tr>
<tr>
<td>Enflurane</td>
<td>1.8</td>
</tr>
<tr>
<td>Halothane</td>
<td>2.5</td>
</tr>
<tr>
<td>Anesthetic Agent</td>
<td>Blood:Gas</td>
</tr>
<tr>
<td>------------------------</td>
<td>-----------</td>
</tr>
<tr>
<td>Halothane</td>
<td>2.5</td>
</tr>
<tr>
<td>Enflurane</td>
<td>1.8</td>
</tr>
<tr>
<td>Isoflurane</td>
<td>1.43</td>
</tr>
<tr>
<td>Methoxyflurane</td>
<td>15</td>
</tr>
<tr>
<td>Sevoflurane</td>
<td>0.65</td>
</tr>
<tr>
<td>Desflurane</td>
<td>0.45</td>
</tr>
<tr>
<td>N₂O</td>
<td>0.47</td>
</tr>
</tbody>
</table>
Inhalational Anesthesia

- history
- chemical structure & physical properties
- *metabolism & interactions*
- end-organ effects
- clinical applications
- delivery in the ICU
### Inhalational Anesthetic Agents: Metabolism

<table>
<thead>
<tr>
<th>Anesthetic Agent</th>
<th>Metabolism</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methoxyflurane</td>
<td>50%</td>
</tr>
<tr>
<td>Halothane</td>
<td>20%</td>
</tr>
<tr>
<td>Enflurane</td>
<td>3-4%</td>
</tr>
<tr>
<td>Isoflurane</td>
<td>0.2%</td>
</tr>
<tr>
<td>Sevoflurane</td>
<td>3-5%</td>
</tr>
<tr>
<td>Desflurane</td>
<td>0.02%</td>
</tr>
</tbody>
</table>
Sevoflurane Metabolism

- fluoride
- compound A
  - fluorinated vinyl
- HFIP not TFA
Methoxyflurane Metabolism

- cytochrome $P_{450}$
- present in both liver and kidneys
- local fluoride production in kidneys
  - fluoride concentration in kidney $>$ blood
- nephrotoxicity at 50 µmol/liter in blood
Sevoflurane Metabolism

- cytochrome P$_{450}$ 2E1
- present only in liver
- fluoride concentration in blood $>$ kidney
- no significant risk of toxicity
Formation of Compound A

F₃C → CH–OCH₂F → Carbon Dioxide Absorber

Sevoflurane

F₃C

F₃C

CH–OCH₂F

Sevoflurane

F₂C

F₃C

Compound A

20-30 ppm at ≤ 2 L/min
Compound A Bioactivation Pathway

**Compound A**

- Metabolized via P450
  - No toxicity

- Glutathione S-Conjugate
  - Cysteine S-Conjugate
    - N-acetylation
    - Mercapturic acid (rapid renal elimination)
    - No toxicity

- Returned to plasma
  - N-acetylation
  - Excretion
  - No toxicity

- Hydroxyase (Key bioactivation enzyme)
  - Thioacyl halide
  - Nephrotoxin
Renal β-lyase Activity in Humans Versus Rats for Compound A

Lash LH et al, Drug Metab Dispos 1990;18:50
Compound A Production

- sevoflurane concentration
- type of CO$_2$ absorbent
- fresh gas flow rate
- temperature (CO$_2$ production)
- time
- water content
Compound A Production

Flow Rate of Anesthetic Gases

Sevoflurane Concentration

Compound A levels at two sevoflurane concentrations (1 and 2%) in a model circuit (laboratory studies) with soda lime as the CO₂ absorbent.
Inhalational Anesthesia

• metabolism ➔
  – HFIP (hexafluoroisopropanol)
  – TFA (trifluoroacetic acid)
• HFIP is glucuronidated and renally eliminated
• HFIP is less reactive than TFA
  – TFA can act as a hapten ➔ hepatotoxicity
• no evidence of hepatotoxicity of HFIP
Hepatotoxicity

Currently Available Anesthetics

- Halothane
- Enflurane
- Isoflurane
- Desflurane

TFA and associated products

New Inhalation Anesthetics

- Sevoflurane
  - HFIP
  - Glucuronide conjugate
  - Excreted
CO₂ Absorber: Agent Degradation

- compound A
  - sevoflurane
- carbon monoxide
  - desflurane
  - isoflurane
  - enflurane
- anesthetic agent destruction
  - increased cost
Desflurane & Carbon Monoxide

- CO₂ absorbent
  - dessicated
  - Baralyme > soda lime
  - flow ≥ 3 liters/minute
- scenario
  - Monday AM case
  - rare reports of toxicity

Carbon Monoxide Production in Dry Soda Lime at 35°C

<table>
<thead>
<tr>
<th>Absorbent</th>
<th>Desflurane</th>
<th>Isoflurane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soda lime, dry</td>
<td>1800</td>
<td>349</td>
</tr>
<tr>
<td>Soda lime, 1.4% water</td>
<td>26</td>
<td>23</td>
</tr>
<tr>
<td>Baralyme, dry</td>
<td>11,600</td>
<td>851</td>
</tr>
<tr>
<td>Baralyme, 1.6% water</td>
<td>5810</td>
<td>725</td>
</tr>
</tbody>
</table>

CO$_2$ Absorber: Agent Degradation

- sodalime - barium hydroxide lime (Baralyme$^\text{R}$)
  - sodium and potassium hydroxides
- abstract labile proton from anesthetic agents
  - more susceptible to degradation
- new carbon dioxide absorbers
  - decreased amounts of strong bases
    - Dragersorb 800 Plus$^\text{R}$, Medisorb$^\text{R}$, Sphasorb$^\text{R}$
      - no potassium hydroxide
      - do contain sodium hydroxide and calcium hydroxide
  - elimination of strong bases
    - Amsorb$^\text{R}$ (calcium hydroxide)
Sevoflurane: Will My Patient Ignite?

ARDS from exothermic Baralyme-sevoflurane reaction.

Fatheree RS, Leighton BL, *Anesthesiology* 2004;101:531

Spontaneous ignition, explosion and fire.

Wu J et al, *Anesthesiology* 2004;101:534

Explosion with Baralyme, sevoflurane, and high gas flows.

Castro BA et al, *Anesthesiology* 2004;101:537
Sevoflurane and Desiccated Absorbent

- *in vitro* experiment
- Baralyme dessicated®
  - 3.5 kg of Baralyme® in a 4 liter flask
  - 10 lpm oxygen flow + flask warmed
  - flow continued until weight of flask no longer changed (2-3 days)
- 1.5 MAC inhalational agent
  - F½O₂ 1.0 at 6 lpm
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Cardiovascular Effects

- dose dependent effects
- modified by
  - co-morbid diseases
  - intravascular volume status
- halothane
  - primary cause of intraoperative cardiac arrest
- varying effects on SVR, HR, and contractility
Cardiovascular Effects

- sevoflurane
  - decreased HR and cardiac output
- isoflurane and desflurane
  - vasodilatation and sympathetic stimulation
    - increased heart rate
    - potential for coronary steal
  - decreased afterload → increased cardiac output
Sevoflurane, Bradycardia & Trisomy 21

**Roodman S et al, Paediatr Anaesth 2003;13:538**
- case series of 3 patients with trisomy 21
- 2 without CHD, normal echocardiogram and ECG
- one required IV epinephrine

**Wickham Kraemer et al, Anesth Analg 2010;111:1259**
- retrospective review: 208 with trisomy 21 vs. 268 control patients
- higher incidence of bradycardia and hypotension: 57% vs. 12%
- greater use of anicholinergic agents: 24% vs 0%, p<0.001
Desflurane & The Sympathetic NS

- transient response, treatment generally not needed
- does not occur in all patients, less likely in elderly
- opioids or $\alpha_2$-adrenergic agonist control response
- more common with
  - rapid increase in inhaled concentration
  - increase from 1.0 to 1.5 MAC than from 0.5 to 1.0 MAC
- avoid by slow increments in vaporizer setting
  - start at 3-6%
  - start at 6-8% with low flows (0.5-1 liter/minute)
- if treatment necessary
  - short acting $\beta$-adrenergic antagonist
Myocardial Preconditioning

- Langendorff model, laboratory animal (rats)
  - 15 min perfusion, 20 min ischemia, 60 min reperfusion
- four groups
  - control (no pretreatment)
  - isoflurane 1.4%
  - sevoflurane 1.7%
  - two 5-minute ischemic periods separated by 5 min perfusion
- sevoflurane, isoflurane, and ischemic group vs. control
  - recovered left ventricular contractility better
  - less ischemic damage by histological examination
Respiratory Effects

- dose dependent, modified by co-morbid diseases
- decreased alveolar ventilation
  - primarily tidal volume → hypercarbia
- inhibit CNS response to hypoxia + hypercarbia
- inhibit hypoxic pulmonary vasoconstriction
  - worsening oxygenation
- bronchodilatation
  - direct effect on smooth muscle
Sevoflurane & Desflurane: Airway Reactivity
Goff MJ et al, Anesthesiology 2000;93:404

• prospective trial in 50 adults
• thiopental induction, endotracheal intubation
• maintenance anesthesia
  – thiopental infusion (0.25 mg/kg/hr)
  – desflurane 1 MAC
  – sevoflurane 1 MAC
• determination of respiratory resistance
CNS Effects

- sedation, amnesia, general anesthesia
- decreased CMRO$_2$
- slowing of the EEG $\rightarrow$ isoelectric
- occasional CNS stimulation
  - sevoflurane, enflurane
- increased CBF and increased ICP
  - least with isoflurane
  - blunted by hypocarbia
Sevoflurane: CNS Effects

Kaike KK et al, Anesthesiology 1999;91:1952
- case report, 2 adult patients, study on CBF
- paroxysmal EEG potentials during sevoflurane at 4%

Yli-Hankala A et al, Anesthesiology 1999;91:1596
- 30 woman, spontaneous or controlled hyperventilation
- epileptiform EEG activity (spikes or polyspikes)
  • 15/15 with controlled hyperventilation (3 also had clonic movements)
  • 7/15 with spontaneous ventilation
Inhalational Anesthesia

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- end-organ effects
- **clinical applications**
- delivery in the ICU
Clinical Applications

• *procedural sedation*
• ICU sedation during mechanical ventilation
• status asthmaticus
• status epilepticus
Procedural Sedation: Sevoflurane

- prospective, observational case series
- 13 infants, 7 former preterm
  - median post-conceptional age: 46 wks (40-70)
  - median weight: 4.4 kg (3.3-6.5 kg)
- nasal insufflation of sevoflurane
  - nasal cannulae, oxygen flow at 2 liters/minute
  - sevoflurane vaporizer set at 4% (range: 4-8%)
- successful in 12 (6 asleep within 10 minutes)
- rapid recovery
- one episode of desaturation, airway repositioned
Procedural Sedation: Methoxyflurane

- licensed for use in
  - Australia, New Zealand, Middle East
- issues with renal toxicity (flouride)
- Pentrox Inhaler™
  - Medical Developments International (Victoria, Australia)
  - tubular hand held device, 22 mm mouthpiece
    - can also use standard anesthesia mask
    - oxygen inlet to administer supplemental oxygen
  - primed with liquid methoxyflurane
  - one-way valve, exhalation through separate chamber
    - charcoal
  - dilutor hole (can vary concentration from 0.1-0.4%)
  - used on US reality TV show Survivor
Procedural Sedation: Methoxyflurane


- prospective, observational case series
- 14 children, 6-13 years of age, extremity injuries
- used both for analgesia and procedural sedation
  - 4 to 25 minutes
  - intermittently (7) and continuously (7)
- no adverse effects
- efficacy
  - 4 with fractures and high pain scores: satisfactory analgesia
  - 4 with fractures and low pain scores: minimal effect
  - 6 for procedural sedation: effective
  - 13 of 14 would chose methoxyflurane again
Clinical Applications

- procedural sedation
- *ICU sedation during mechanical ventilation*
- status asthmaticus
- status epilepticus
Inhalational Anesthetic Agents: Advantages

- large clinical experience in Europe
- easy to titrate
- inhalational administration
- rapid onset and offset
- amnesia, sedation, and analgesia
- limited development of tolerance
- beneficial physiologic effects
  - anti-convulsant
  - bronchodilator
  - cerebral protection
  - myocardial preconditioning
Inhalational Anesthesia: PICU Sedation

- prospective study, isoflurane in 10 pediatric patients
  - 3 weeks to 10 years of age
  - inspired concentration adjusted by ICU physician
  - opioids and benzodiazepines tapered

- duration of sedation
  - 29 to 769 hours (mean: 245 hrs)
  - 13 to 497 MAC-hours (mean: 131)

- findings
  - highest fluoride concentration: 26.1 μmol/L
  - decreased creatinine clearance: 1 of 5
  - increased LFT’s: 3 of 10
  - abstinence syndrome: 5/10 (all received ≥ 70 MAC-hours)
**AnaConDa™ vs. Midazolam**

- prospective trial, 40 adult ps, mechanical ventilation
- isoflurane (AnaConda™) versus midazolam

<table>
<thead>
<tr>
<th>Medication</th>
<th>Isoflurane</th>
<th>Midazolam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time within desired range of sedation</td>
<td>59%</td>
<td>54%</td>
</tr>
<tr>
<td>Time to extubation (minutes)</td>
<td>10 ± 8</td>
<td>252 ± 271</td>
</tr>
<tr>
<td>Time to follow commands (minutes)</td>
<td>10 ± 8</td>
<td>110 ± 132</td>
</tr>
</tbody>
</table>
Inhalational Anesthesia in the PICU

- retrospective evaluation of sedation - 29 pediatric patients
  - upper airway issues: croup or epiglottis
  - 12 of 29 received isoflurane (inspired concentration of 0.25-1.5%)
- withdrawal phenomena
  - ataxia, agitation, hallucinations and confusion
  - not if administered for ≤ 15 hours

  *Kelsall AWR et al, Crit Care Med 1999;22:1032*

- CDH repair while on ECMO in 13 neonates
- fentanyl 22 µg/kg/hr + bolses (n=7) vs. isoflurane (n=6)
- fentanyl patients
  - higher MAP and HR during procedure
  - 7/7 received SNP vs. 1/6 with isoflurane

  *Atkinson JD et al, ASAIO 1994;40:986*
Inhalational Anesthesia Withdrawal

- 4-year-old, 19 days of isoflurane (ET = 0.8-1.2%)
  - follows commands
  - MAC-awake = 0.3-0.4 MAC (isoflurane = 0.4-0.5%)
- 32 days of administration, agent stopped
  - agitation, diaphoresis, tachycardia, hypertension, diarrhea
    *Arnold JH et al, Anesthesiology 1993;78:985*

- 7-year-old boy
- isoflurane, unspecified concentration for 4 days
- agitation, visual and auditory hallucinations, seizure
  *Hughes et al, Acta Paediatr 1993;82:885*
Clinical Applications

- procedural sedation
- ICU sedation during mechanical ventilation
- *status asthmaticus*
- status epilepticus
Inhalational Anesthesia: Asthma

- first reports appeared in 1930’s
  - ether, cyclopropane
- modern day anesthetics (halothane) in 1970’s
- remains primarily anecdotal
- airway effects of inhalational anesthetic agents
  - blunts reflex bronchoconstriction
  - direct effect on intracellular calcium
    - smooth muscle relaxation
Inhalational Anesthesia: Asthma

- case series of 6 pediatric patients
- appendix outlining their protocol

### Table 1. Summary of isoflurane experience with six pediatric patients

<table>
<thead>
<tr>
<th>Preisoflurane</th>
<th>Patient</th>
<th>Age/Sex</th>
<th>pH</th>
<th>Paco₂ (torr)</th>
<th>PIP (cm H₂O)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>13 yrsF</td>
<td>7.27</td>
<td>77</td>
<td>62</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>14 yrsM</td>
<td>6.96</td>
<td>96</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>10 yrsM</td>
<td>6.99</td>
<td>110</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>15 yrsM</td>
<td>7.05</td>
<td>85</td>
<td>64</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>15 monthsF</td>
<td>7.07</td>
<td>72</td>
<td>&gt;30 (anesthesia bag)</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>14 monthsF</td>
<td>Unavailable</td>
<td>&gt;60*</td>
<td>64-65</td>
<td></td>
</tr>
</tbody>
</table>

### Postisoflurane

<table>
<thead>
<tr>
<th>Patient</th>
<th>Elapsed Time</th>
<th>pH</th>
<th>Paco₂ (torr)</th>
<th>PIP (cm H₂O)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10 mins</td>
<td>7.45</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td>2</td>
<td>30 mins</td>
<td>7.30</td>
<td>44</td>
<td>45</td>
</tr>
<tr>
<td>3</td>
<td>30 mins</td>
<td>7.30</td>
<td>50</td>
<td>35</td>
</tr>
<tr>
<td>4</td>
<td>40 mins</td>
<td>7.08</td>
<td>65</td>
<td>45</td>
</tr>
<tr>
<td>5</td>
<td>75 mins</td>
<td>7.18</td>
<td>59</td>
<td>22</td>
</tr>
<tr>
<td>6</td>
<td>12 mins</td>
<td>7.28</td>
<td>48</td>
<td>35</td>
</tr>
</tbody>
</table>

*PIP: peak inspiratory pressure. To convert torr to kPa, multiply value by 0.133.
*End-tidal CO₂ monitoring.
Isoflurane & Asthma: Entry Criteria

- intubated patient with status asthmaticus
- peak inspiratory pressures of $\geq 40$ cmH$_2$O
- maximal medical therapy
  - intravenous corticosteroids
  - magnesium
  - anticholinergic therapy
  - terbutaline $\geq 5.0$ µg/kg/min
Isoflurane & Asthma: Protocol

- **isoflurane**
  - start therapy at 1-2%, adjust by 0.1% every 5–10 minutes
  - goal: PIP ≤ 35 cm H₂O
  - maintain for 2–4 hours before weaning the medication
- **discontinue sedation and neuromuscular blocking agents**
  - isoflurane ≥ 1%
- **continue intravenous β-adrenergic agonists**
  - unless the patient develops ventricular arrhythmias
  - differing mechanisms of action
- **continue inhaled anticholinergic agents and β-adrenergic agonists**
- **maintain serum magnesium levels of 3.0–4.0 mg/dL**
- **continue intravenous corticosteroid therapy**
Isoflurane & Asthma: Complications

- hypotension
  - volume replacement with crystalloid up to 40-60 mL/kg
  - vasopressor therapy
    - epinephrine at 0.05 μg/kg/min or dopamine at 5 μg/kg/min
- arrhythmias
  - maintain normal potassium, magnesium, and calcium
  - discontinue β-adrenergic therapy
  - discontinue isoflurane
- nephrotoxicity or hepatotoxicity
  - follow serum electrolytes, BUN, creatinine, hepatic enzymes
  - urine output
  - serum fluoride
    - decrease or discontinue isoflurane if $\geq 30 \, \mu M$. 
Isoflurane & Asthma: Weaning

- PIP ≤ cm H$_2$O with tidal volumes ≥ 8 mL/kg
  - PaCO$_2$ <60 mmHg and pH ≥ 7.2
  - decrease isoflurane by 0.1% every 20–30 minutes
- isoflurane ≤ 1%
  - reinstitute sedation and analgesia as needed
  - reinstitute β-adrenergic agonist therapy
Clinical Applications

- procedural sedation
- ICU sedation during mechanical ventilation
- status asthmaticus
- *status epilepticus*
Inhalational Anesthesia: Status Epilepticus

- dose-dependent effects
  - slowing and decreased amplitude of EEG signals
  - burst suppression – isoelectric EEG
- reports are anecdotal
  - first pediatric case reported in 1985
- recent concern regarding potential neurotocity
- use included in published SE protocols
Isoflurane & Status Epilepticus

- largest case series of pediatric patients
  - 11 applications in 9 patients, 6 were 2-13 years of age
- failure of conventional therapy
  - phenobarbital, benzodiazepines, phenytoin
- isoflurane effective
  - seizures recurred in 8 of 11 when isoflurane decreased
  - 6 of 9 patients died, cognitive deficits in remaining 3
- adverse effects
  - hypotension, n=1
  - elevated serum fluoride concentration, n=1
Inhalational Anesthesia

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- clinical applications
- delivery in the ICU
Inhalational Agents: Disadvantages

- equipment
  - delivery, monitoring, scavenging
- cost of agent and equipment
- who adjusts concentration
- physiologic effects
  - hepatitis
  - cardiovascular depression
  - cerebral vasodilatation
  - fluoride release (renal effects)
  - MH triggering agent
- altered metabolism of other drugs
Isoflurane in the PICU: Monitoring & Equipment

- machine for delivery
- anesthesia gas scavenging system
- end-tidal CO₂
- cardiorespiratory support with pulse oximetry
- arterial access for BP and ABG monitoring
- central venous access
- in-line volatile gas analyzer for anesthetic agent
- closed system for suctioning
OHSA requirements
Suctioning issues – patient disconnects
Inhalational Agents: PICU Delivery

- move patient to operating room
- use anesthesia machine in Pediatric ICU
  - quick and easy, limited preparation time
  - ICU ventilators are not meant for sick patients
    - limited modes of ventilation, PEEP, PIP
- middle ground
  - Serve 900D anesthesia machine
- modify ICU ventilator
- administer it using ICU ventilator
  - vaporizer in-line of inspiratory limb
  - into inspiratory limb
  - Servo 900 C
Isoflurane through the Servo 900C

Diagram:
- O2 flowmeter
- Isoflurane vaporizer
- High pressure oxygen source
- Inspiratory line
- Expiratory line
- Endotracheal Tube
- Patient
- Gas analyzer
- Servo 900C
- Low pressure inlet
AnaConDa™ = Anesthesia Conserving Device,
Hudson RCI, Uplands Vasby, Sweden
Inhalational Anesthesia

- history
- chemical structure & physical properties
- metabolism & interactions
- end-organ effects
- clinical applications
- delivery in the ICU
Therapeutic applications and uses of inhalational anesthesia in the pediatric intensive care unit.

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