Pediatric Airway Anatomy and Equipment

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Disclosures

• I have none

• Special thanks to Anne Bailey
Large Head

Huekle et al., 1998
Large Occiput

Huekle et al., 1998
Small Jaw

Huekle et al., 1998
Infant vs Adult

- Large Tongue
  - Located entirely in oropharynx
- Larynx more cephalad
  - C-2 (infant)
  - C-3 (2 years old)
  - C-4 (adult)
  - Reduced thyromental distance
Oropharyngeal airway

Correct

Too large: epiglottis down folded

Too small: posterior tongue obstruction

From Cote; A Practice of Anesthesia for Infants and Children, 6th Edition

Intensive Review of Pediatric Anesthesia 2015
Obligate Nose Breathers

- First months of life
- “Interlocked” soft palate and epiglottis
- Separate “aero-digestive tract”
- Simultaneous drinking and breathing
Cervical Spine

NOTE THE POSITION OF THE LARYNX RELATIVE TO THE CERVICAL SPINE AND THE ACUTE ANGLE OF APPROACH IN A CHILD RELATIVE TO THE ADULT.
Shape of Epiglottis

Infant

Adult
• Adult Airway

• Infant Airway

A Practice of Anesthesia for Infants and Children
Infant vs Adult: cricothyroid membrane

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adult</td>
<td>25 X 20 mm</td>
</tr>
<tr>
<td>Infant</td>
<td>3 X 2.5 mm</td>
</tr>
<tr>
<td>Child &lt; 8 yrs</td>
<td>14 X 8 mm</td>
</tr>
</tbody>
</table>


Intensive Review of Pediatric Anesthesia 2015
Infant | Adult
--- | ---

**Traditional vs Contemporary**

- **Overall Shape**
  - Conical vs. **Cylindrical**

- **Narrowest aperture**
  - Cricoid vs **Vocal Cords**

- **Cricoid Ring**
  - Circular vs. **Elliptical**
SOME ANATOMIC CONSIDERATIONS OF THE INFANT LARYNX INFLUENCING ENDOTRACHEAL ANESTHESIA

JAMES E. ECKENHOFF, M.D.
Infant’s larynx

- Narrowest in the subglottic region
- Conical in the coronal projection
- Pyramidal in the lateral projection
“Once considered mandatory for the young pediatric airway, the uncuffed endotracheal tube has now been reduced to a pessimistic meta-induction from the history of anesthesiology”
Cuffed vs. Uncuffed ET tubes

**Uncuffed**
- Larger ID
- Low resistance to air flow
- Prevents inc. WOB
- Allows easy suctioning
- Avoids trauma to subglottic region

**Cuffed**
- Allows use of lower fresh gas flow
- Less use of volatile agents
- Reduced air pollution
- Reduced risk of aspiration
- Avoids multiple intubations
- Improved ventilation and ETCO2 monitoring
- No increased risk for post extubation stridor
- Ability to control cuff pressure

Pediatric cuffed endotracheal tubes, Bhardwaj N, JOACP, 2013;29, 1
### Guide to Internal Diameter of Pediatric Endotracheal Tube; cuffed vs. uncuffed

<table>
<thead>
<tr>
<th>Age (y)</th>
<th>Uncuffed</th>
<th>Khine <em>et al</em></th>
<th>Motoyama <em>et al</em></th>
<th>Salgo <em>et al</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>Birth to &lt; 0.5</td>
<td>3.5</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
</tr>
<tr>
<td>0.5 to &lt; 1</td>
<td>4.0</td>
<td>3.0</td>
<td>3.0</td>
<td>3.5</td>
</tr>
<tr>
<td>1.0 to &lt; 1.5</td>
<td>4.0 - 4.5</td>
<td>3.5</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td>1.5 to &lt; 2.0</td>
<td>4.0 - 4.5</td>
<td>3.5</td>
<td>3.5</td>
<td>4.0</td>
</tr>
<tr>
<td>2.0 to &lt; 3.0</td>
<td>4.5</td>
<td>3.5</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>3.0 to &lt; 4.0</td>
<td>4.5 - 5.0</td>
<td>4.0</td>
<td>4.0</td>
<td>4.5</td>
</tr>
<tr>
<td>4.0 to &lt; 5.0</td>
<td>age (yrs) +4 / 4</td>
<td>4.0</td>
<td>4.5</td>
<td>4.5</td>
</tr>
</tbody>
</table>

Adapted from: Pediatric cuffed endotracheal tubes, Bhardwaj N, JOACP, 2013;29,
Cuffed vs. Uncuffed ET tubes

Khine formula: \[
\text{Age (yrs)} + 4 \quad \text{uncuffed tubes}
\]
\[
\text{Age (yrs)} + 4
\]

Duracher: \[
\text{Age (yrs)} + 3.5 \quad \text{cuffed tubes}
\]
\[
\text{Age (yrs)} + \frac{3.5}{4}
\]

Microcuff ETT

**Features**

- Ultrathin polyurethane (10 µm) high-volume/low-pressure cuff‡ more distal position along the shaft of ETT‡ sealing at low pressures distal to cricoid, with minimal formation of cuff folds‡ no need to downsize ETT based on ID

- Absence of Murphy eye allows a more distal position of the upper cuff border vs. traditional pediatric cuffed endotracheal tubes (*left*)

- Less risk for intralaryngeal cuff position

**Sizing:**

- 3.0 = >3kg, Term
- 3.5 = 8 mo – 2 yrs
- 4.0 = 2 - 4 yrs

From Smith’s, Anesthesia for Infants and Children 8th ed

Intensive Review of Pediatric Anesthesia 2015
Poiseuille's Law

\[ \text{Flow} = \left( \Delta P \ast \pi \ast r^4 \right) \div \left( 8 \ast \eta \ast l \right) \]

- \( P \) = pressure
- \( \pi \) = pi
- \( r \) = radius
- \( \eta \) = viscosity
- \( l \) = length

<table>
<thead>
<tr>
<th>Normal</th>
<th>Edema 1 mm</th>
<th>Decreased X-sectional area</th>
<th>Resistance Laminar flow</th>
<th>Resistance Turbulent flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infant</td>
<td>~ ↓ 75%</td>
<td>~ ↑ 16x</td>
<td>(R \propto \frac{1}{\text{radius}^4})</td>
<td>~ ↑ 32x</td>
</tr>
<tr>
<td>Adult</td>
<td>~ ↓ 44%</td>
<td>~ ↑ 3x</td>
<td>(R \propto \frac{1}{\text{radius}^5})</td>
<td>~ ↑ 5x</td>
</tr>
</tbody>
</table>

Practice of Anesthesia for Infants and Children
### Laryngoscope Blades Used in Infants and Children

<table>
<thead>
<tr>
<th>Age</th>
<th>Miller</th>
<th>Wis-Hipple</th>
<th>Macintosh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preterm</td>
<td>0, 00</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Neonate</td>
<td>0</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Neonate-2 years</td>
<td>1</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>2-6 years</td>
<td>—</td>
<td>1.5</td>
<td>1 or 2</td>
</tr>
<tr>
<td>6-10 years</td>
<td>2</td>
<td>—</td>
<td>2</td>
</tr>
<tr>
<td>&gt;10 years</td>
<td>2 or 3</td>
<td>—</td>
<td>3</td>
</tr>
</tbody>
</table>

Straight blades are more suitable for use in infants; it better elevates the base of the tongue to expose the glottic opening.

From Smith's, Anesthesia for Infants and Children 8th ed
Laryngoscope Blade

Cauldwell, C. Pediatric Anesthesia, 4th
Laryngoscope Blade

Straight Blade = better in younger children with floppy epiglottis
Laryngoscope Blade

Curved Blade = better in older children with stiffer epiglottis
Post-intubation Croup

**Risk factors**

- Use of an ETT with an OD too large for the child's airway (no leak at >25 cm H₂O)
- Changes in position other than supine
- Repeated and or traumatic intubation attempts
- Patient age between 1 and 4 years
- Duration of surgery > 1 hr
- Coughing on the ETT
- Previous history of croup

**Treatment**

- Humidified oxygen
- Nebulized epinephrine
- Dexamethasone
Physiological differences

• BMR twice that of an adult
• FRC near closing volumes
• Atelectasis develops rapidly
• Compliant chest wall
• Uncooperative with preoxygenation
• Unfamiliarity with pediatric airway
• = Rapid desaturations
Supraglottic Airway Device (SAD)

- LMA first developed by Archie Brain, 1982, introduced in US in 1992
- Ideal rescue for FMV
- Conduit for FOI
- More difficult to place the smaller the child
- Does not protect against aspiration
Classification

1\textsuperscript{st} generation devices: standard masks
   1. Laryngeal Mask Airway (LMA) Classic & Unique
   2. Air-Q
   3. Ambu Aura once, Ambu Aura-i

2\textsuperscript{nd} generation devices: gastric access port to drain stomach
   1. LMA ProSeal
   2. LMA Supreme
   3. I-gel
SGA: Mechanism of airway seal

- An adequately placed device forms 2 seals:
  1. A peri-laryngeal seal
  2. A hypopharyngeal seal
     - Better with 2nd generation devices
Limitations of classic SGAs

• Higher complication rates in small infants:
  1. Obstruction (delayed)
  2. Laryngospasm
  3. Axial rotation
  4. Malposition

• Lower airway seal
• No gastric access
Failure of SGA

• 11,910 cases over 4 yrs
• 102 “failures”
  – Leak (25%)
  – Obstruction (48%)
  – Coughing/bucking (11%)
• Predictors
  – ENT procedure
  – Prolonged surgery (>1hr)
  – Congenital airway
  – Inpt status
  – Pt transport
  – ??Age less than 2 yrs

Mathis et al; Anesthesiology Dec 2013
What about intra-cuff pressure?

• With LMAs in children, an intra-cuff pressure of 40 cmH$_2$O (compared with 60, 20) associated with:
  – Better leak pressures
  – Less post-op sore throat than with intra-cuff pressure of 60 cmH$_2$O

• Often air should be removed after insertion to reduce pressure

Paediatr Anaesth 2010 Apr;20(4):313-7
Paediatr Anaesth 2009 Sep;19(9):837-43
Intubating Laryngeal Airway (air-Q)

Advantages:

• Larger cuffed tracheal tubes can be placed
  – Does not require modification to accommodate a cuffed ETT like the standard LMA

• Features to better isolate the epiglottis

• Removable adaptor for wider airway
  – Facilitates removal of the mask after tracheal intubation

• Size 1.5 air-Q ILA
Adequate ventilation does not predict laryngeal alignment

- Anatomic position does not always correspond to functional position
- Patient A and Patient E have the same exact ventilation parameters, but different grade of views on fiberoptic exam

From Jagannathan et al, Anes Analg 2011
Intubation through SGA’s

Fiberoptic bronchoscopy is strongly recommended when intubating through supraglottic devices in children because of the variability of epiglottic down folding.
Videolaryngoscopy

• Advantages
  – Eye and airway don’t need to align
  – Better view with limited neck mobility or mouth opening
  – Share the view

• Disadvantages
  – Variable learning curve, longer to intubate
  – Great view, difficult tube passage
  – Fogging, secretions
  – Loss of depth perception
  – More complicated
  – Expense

The Video Revolution: a New view of Laryngoscopy; Hurford WE, Respiratory Care 8/2010 55:8
Videolaryngoscopy: Evidence base

1. GlideScope
2. Storz VL
3. Airtraq
4. Truview EVO2

• All devices have been used in children with difficult airways† number of case reports
• **ALL STUDIES**: better grades of view; but longer times to intubate vs. direct laryngoscopy (DL), which was not clinically significant
Airway equipment for one lung ventilation (OLV) in children
Selective endobronchial intubation with a traditional ETT

- **Advantages**
  - Relatively straightforward
  - Can be placed by either bronchoscopic or fluoroscopic guidance

- **Limitations**
  - Difficult to change from one-lung ventilation to two-lung ventilation
  - Bronchial extubation‡
    - Unintentional movement of the tracheal tube causing cephalad displacement and loss of lung isolation
  - Poor seal if an uncuffed ETT used
Double lumen tubes

• Advantages
  • Rapid and easy separation of the lungs
  • Ability to suction both lungs
  • Ability to switch to two-lung ventilation
  • The ability to administer CPAP to the operative lung

• Limitations
  • Smallest commercially available size is 26F cannot be used in children weighing less than 30 to 35 kg or younger than 8 to 10 years old
Univent tube

**Features**

- The bronchial blocker is incorporated within the tracheal tube & can be advanced to block the operative lung
- Blocker can be withdrawn to ventilate both lungs
- The OD is larger than that of a conventional ETT of the same ID
- Smallest size 3.5 mm ID (OD 8.0 mm)

From Smith’s, Anesthesia for Infants and Children 8th ed

Intensive Review of Pediatric Anesthesia 2015
Bronchial Blocker

• A bronchial-blocker device consists of a small balloon that is purposefully inflated within the proximal portion of the main bronchus to isolate one of the lungs under bronchoscopic guidance

OPTIONS:
1. Arndt endobronchial blocker
2. Fogarty embolectomy catheter
Arndt endobronchial blocker

Features:
• Consists of an endobronchial blocker catheter, the Multiport Airway Adapter and a CPAP adapter
• The blocker is placed through a conventional endotracheal tube using a pediatric bronchoscope.

Advantages:
• Contains a central channel:
  – Allows suctioning (for lung deflation)
  – Delivery of oxygen and CPAP.

Limitations:
• Too large for use in neonates and infants: 5F is smallest available size (5F for tracheal tubes of 4.5 to 5.5 mm ID)
Arndt bronchial blockade

Smith’s, Anesthesia for Infants and Children

Intensive Review of Pediatric Anesthesia
2015
Fogarty catheter

**Advantages:**
Has a balloon at its distal end that can be placed within the proximal main bronchus to isolate the lung either with bronchoscopic or fluoroscopic guidance.

**Disadvantages:**
- The catheter is usually placed outside of the tracheal tube in small infants.
  - Distal tip can be displaced proximally if the patient's position changes.
  - Total airway obstruction can result if the inflated balloon slips back into the trachea.
- Suctioning or application of CPAP is not possible because of the lack of an inner channel.
Effects of Positioning on V/Q in Children vs. Adults

Adult:
ventilation preferentially distributed to DEPENDENT lung

Infant:
ventilation is greatest in NON DEPENDENT lung

Hammer,G; SPA 2012
Other Anesthesia Monitors and Equipment
The Mapleson Circuits

- Advantages: light weight, easily adjust peak inflation pressure, provide positive end expiratory pressure, and the have the ability to use relatively low O\textsubscript{2} flows.
- The most commonly used circuit for infants and intrahospital transport is the Mapleson D configuration for versatility with both controlled and spontaneous ventilation.

From Cote; A Practice of Anesthesia for Infants and Children, 6th Edition

Intensive Review of Pediatric Anesthesia 2015
Bain Circuit=Mapleson D
Heat and Moisture Exchanger (HME)

• Provides **80% humidity** given **80 minutes** to saturate
• Dead space (3, 8 ml)
• Increased work of breathing
• Benefits:
  – Prevention of hypothermia (resp: 10% total heat loss)
  – Decreased atelectasis
  – Improved mucociliary clearance
Pulse Oximetry

- Pulse oximeters: 2 absorption spectra for oxygenated and deoxygenated Hb
- MetHb: >10% causes SpO2~85%
- Sickle Cell: slight overestimate of oxyhemoglobin (~3%)
- Fetal Hb: no change
- Initial studies: black, green, blue nailpolish; more recent did not find
Effect of methemoglobin on measured oxygen saturation by pulse oximetry

Nellcor SpO2 reading (blue circles) and true SaO2 (red squares) versus MetHb percent at FiO$_1$ = 1.0.

Effect of carboxyhemoglobin on measured oxygen saturation by pulse oximetry

SpO$_2$ and cooximetry versus carboxyhemoglobin (COHb) at FiO$_2$ = 1.0. SpO$_2$ consistently overestimates O$_2$ saturation in the presence of COHb. At COHb = 70 percent, SpO$_2$ is still roughly 90 percent, while oxyhemoglobin has fallen to 30 percent.
FiO$_2$: fraction of inspired oxygen; O$_2$: oxygen; SpO$_2$: standard pulse oximetry.
Multiple wavelength pulse oximetry

- Uses at least 7 wavelengths of light
- Can measure Hb, COHb, MetHb

From Masimo
Capnography

- Sidestream: Larger A-a CO\(_2\) gradients in small children; needs to be as close to pt as possible
  - Fast sampling rate improves accuracy

- Mainstream devices are now available with dead space <1ml

- Low ETCO\(_2\): deadspace, poor perfusion, shunt, ETT leak

- High ETCO\(_2\): hypoventilation, production (MH, fever)
Near Infrared Spectroscopy

- Light in near infrared range (700-1000 nm) can pass thru skin, bones, tissues
- Estimates cerebral oxygenation (balance of supply and demand)
- Assumes 85% of cerebral blood volume in light path is venous; 15% arterial; unaffected by poor perfusion
- Also used on kidney, mesentery for regional perfusion
Processed EEG:
BIS (Bispectral Index)

• Uses Fourier transformation and EEG to calculate number from 0-100 to estimate depth of anesthesia
• Unreliable in children under 2 yrs
• BIS higher in toddlers than older children for comparable depth of anesthesia
• Nitrous, ketamine tend to increase BIS
SSEP               MEP

Response (cortical SSEP)
- Somatosensory Cortex
- Dorsal Column
- Dorsal Column Ganglia

• Stimulus: Post Tibial N

• Stimulus (transcranial)
- Motor cortex
- Corticospinal Tract
- α motor neuron

Response
- Peripheral Nerve (neurogenic motor EP)
- Peripheral Muscle (myogenic motor EP)
SSEP

- Any procedure that involves central sensory pathways
- Dose dependent increased latency, decreased amplitude by volatile agents
- Nitrous oxide: Decreased amplitude; no change in latency
- Hypothermia: Decreased amplitude; Increased latency
- Hypotension: Decreased amplitude
MEP

• Measures descending pathways
• Very sensitive to volatiles/nitrous
• Technique usually TIVA, no relaxant
Temperature Monitoring

- Skin: poor representation of core
- TM: need a good seal for probe to reach steady state; perforation?
- NP: must be close to soft palate without ETT leak; nose bleeds
- Oral: inaccurate
- Esophageal: must be in distal 2/3
- Axillary: must be over ax artery with arm adducted and no cold IV fluids going into arm
- Rectal: core, but feces, cold venous blood from legs
- Bladder: highly accurate
Temperature

• Redistribution hypothermia: initial drop in first hour due to vasodilation
• Prevention is key; rewarming is difficult
• Warming IV fluids ineffective to Rx hypothermia w/o rapid blood loss or CPB
• Cold IV fluids will cool: usually 15°C below core temp; larger gradient
Temperature

- Radiation and convection: 85% heat loss--Room temp of 22 degrees: 70% heat loss due to radiation
- Radiant warmers
- Heat lamps
  - Pt uncovered
  - Prep and drape
- Warm air blankets: active heating with convection
- Warm room and cover patient
Primary References

• Smith’s Anesthesia for Infants and Children. Davis et al
• A Practice of Anesthesia for Infants and Children. Cote et al
• A Practical Approach to Pediatric Anesthesia. Holzman et al.