Are Children Just Little Adults?

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Anatomy and development: spinal cord and epidural space largest source of variation; spinal cord ends at L2 level until age 1 yr; relatively increased cerebrospinal fluid (CSF) volume per kilogram necessitates use of higher doses of local anesthetic for subarachnoid blocks ([SAB]; occasionally used during repair of inguinal hernias in children with history of premature birth); epidural fat loosely packed until 5yr of age (allows caudal catheters to thread easily); intercrystal line (landmark for epidural placement) lower in small children and moves higher with age (related to incomplete ossification of bone)

Protein synthesis in infants: hepatic synthesis low until age 1 yr; serum α-1-acid glycoprotein (AAG) increases with surgery for 72 hr but still decreased overall; decreased plasma cholinesterase levels do not clinically affect metabolism of ester local anesthetics (eg, chloroprocaine)

Cardiovascular stability: hypotension with regional anesthesia (RA) rare <8 yr of age; postulated mechanisms — less resting vagal tone allows heart rate to compensate; less venous pooling in lower extremities; allows delivery of higher concentrations of local anesthetic

Dosing of local anesthetics in children: dose per kilogram guidelines apply and vary based on location of injection (eg, intercostal, epidural, peripheral); general rule for bupivacaine or ropivacaine 0.5 mL/kg for 0.5% and 1 mL/kg for 0.25%; lidocaine less potent (slightly lower volumes allowable)

Epidural infusions: ropivacaine (less potent and less cardiotoxic) or bupivacaine 0.4 to 0.5 mg/kg per hour (usually 0.1% concentration); chloroprocaine has been tested in babies at ≤30 mg/kg per hour (has short half-life in plasma [minutes]; anesthetic of choice for children <6 mo of age; motor block greater in older children); bupivacaine and ropivacaine in children <6 mo of age — 0.2 mg/kg per hour; concern over increased plasma levels of bupivacaine shifted focus to ropivacaine (infusion rates of 0.4 mg/kg per hour well below toxic levels); however, studies show doses of bupivacaine could increase by factor of 6 (in children) or 2 to 5 (in neonates) for single-dose blocks and remain below toxic levels (not recommended, but does give option for higher doses when necessary); bupivacaine useful in small children when motor blockade less concerning (also more cost effective); ropivacaine safer option for epidurals requiring higher concentration and volume (for, eg, scoliosis surgery)

Safety of general anesthesia (GA): assess risk-benefit ratio and likelihood of patient cooperation with procedure done under sedation; most younger children require GA for block placement; although American Society of Regional Anesthesia and Pain Management (ASRA) recommends interscalene blocks not be placed under GA, interscalene and brachial plexus blocks routinely performed under GA on children at speaker’s institution; spinal cord injuries far less likely using trans-scalene approach; sedation reduces sensitivity to local anesthetic toxicity to 60% in adults (not tested for paresis)

Studies: United Kingdom (2007) — among 10,000 epidurals, with all but one performed under GA, 6 nerve injuries reported (all resolved in <1 yr); Pediatric Regional Anesthesia Network (PRAN) — documented 15,000 blocks (95% under GA), with transient neurologic deficit reported after =1 in 1000 epidural catheters placement and after 1 peripheral nerve catheter placement (all resolved in <3 mo); potential association with residual neuromuscular blockade still under investigation; limitations of data include difficulty assessing pre- or nonverbal children (even verbal children unable to describe paresthesia), and reliance on self-reporting

Test dose of epinephrine: use 0.5 µg/kg (for children ≥30 kg, use standard adult dose of 3 mL 1:200,000 solution; equivalent to 0.1 mL/kg 1:200,000 epinephrine); positive test dose shows ≥25% increase in T-wave amplitude (most sensitive); systolic blood pressure and heart rate less sensitive due to effects of GA; when present, increased blood pressure or heart rate has high positive predictive value

Peripheral blocks: usual dose 0.2 to 0.3 mL/kg; lower doses (eg, 0.1 mL/kg) sacrifice duration; 20 to 30 mL maximum dose, with higher doses used for lumbar plexus or proximal sciatric blocks; peripheral nerve catheters — 0.1% to 0.2% ropivacaine at 0.1 mL/kg per hour; with careful patient selection and counseling of parents, children as young as 5 yr of age can be discharged home with catheters and allowed to control administration of bolus dose (requires direct line of communication between patient and provider); femoral nerve blocks — rare in infants and small children; upper extremity blocks — used for orthopedic surgery and tendon transfer for children with cerebral palsy

Caudal blocks: standard dose 1 mL/kg 0.25% bupivacaine with 1:200,000 epinephrine; achieves high lumbar to low thoracic level (≈T10); duration (time to first request for analgesia) 3 to 6 hr; duration doubles with addition of 1 mg/kg clonidine, but...
associated with increased postoperative sedation; complication rate for single-injection caudal extremely low; use caution with bone contact (due to incomplete ossification); risk for infection higher with catheters in situ >48 hr (decreased with tunneled catheters); technique — several available; speaker places fingers on posterior superior iliac spines and palpates sacral hiatus in midline; errors — entry into transverse foramina; injection into medullary bone; subcutaneous placement (produces skin wheal and blanching); needle — speaker recommends 22-g angiocatheter (18-g if threading catheter); sharper needle risks increased bleeding, but allows catheter placement to preserve access to caudal space

Epidural: recent practice supports direct puncture at level of surgery; depth estimate of 1 mm/kg probably underestimate; depth to epidural space approaches adult values in children >30 kg; ultrasonography helpful for identifying epidural space and tracking catheter advancement in infants, but of limited benefit in older children; if unfamiliar with pediatric epidural placement, begin with school-age children (have strong ligaments and lack osteophytes); young children have less angulation of spinous processes of thoracic spine, which facilitates midline access

Measuring Hemoglobin with Pulse Oximetry

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Spectrophotometry: measurement of absorption of monochromatic light when passed through known substance; gold standard for measurement of hemoglobin; Lambert-Beer law — when monochromatic light passes through any substance, intensity of the beam is reduced due to absorption; quantification of absorption allows calculation of concentration of substance; although highly accurate in laboratory, requires modification for in vivo application

Pulse oximetry: measures variable absorption of 2 wavelengths of light by oxyhemoglobin and deoxyhemoglobin, and compares pulse peaks and troughs to ascertain percentage of O2 saturation

Measurement of hemoglobin concentration with pulse oximetry: assumes O2 saturation of 100% (ie, uses arterial pulse); absorption measured at multiple wavelengths; multiple calculations performed using approximate optical path length; assumptions and artifacts — patient must weigh >4 kg; presence of osteoporosis or low calcium affects absorption; low perfusion pressure and motion can produce artifacts; cyanosis or hyperoxia may affect accuracy; however, precision documented in presence of hemoglobinopathy (eg, sickle cell anemia)

Equipment: NBM 200MP — uses occlusion release technology; cannot be used in children; Rainbow SET — only device currently available for use in children; pediatric study withdrawn while probe in redevelopment

Bland-Altman analysis: used to assess agreement between 2 methods of measurement; requires defining clinically acceptable limits of agreement; for measurement of hemoglobin based on pulse oximetry, values should remain within 1 to 2 g/dL of laboratory values

Clinical data: no peer-reviewed evidence currently available in children, but abstracts show good bias and precision; adult studies show wide variability and contradictory results; study of patients in cardiac critical care unit found patient-based bias (ie, hemoglobin variations in individual patients over course of hospital treatment), and concluded method unsuitable; devices that fail do not provide readings (thereby limiting acquisition of faulty data)

Benefits: reduced frequency of venipuncture (improves comfort of pediatric patients and reduces iatrogenic anemia); possible reduction in transfusion rates; potential for real-time detection of occult blood loss during surgery

Indications for use: currently, best used for data acquisition to allow refinement of software and improvement of technology; after these goals successfully achieved, evidence of advantages and improved outcomes must be demonstrated (no proven outcome benefit currently in literature for either pulse oximetry or pulmonary artery catheters); randomized trials not necessarily required to establish benefit

Continuous Cardiac Output Monitoring

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Measurement of cardiac output (CO): most practitioners use composite of blood pressure, heart rate, and pulse oximetry data to evaluate cardiovascular status, while CO desired parameter; multiple methods of CO measurement available; definitive reference point for monitors established in animal models using flow probes around aorta and pulmonary artery; clinical reference point in humans achieved with direct Fick and transpulmonary thermodilution methods (use of pulmonary artery catheters difficult in pediatrics); validation of products — studies of variable design; no standard process available in pediatrics

Maintenance of delivery of O2 (DO2) to tissue: primary goal of anesthesiologists; determined by content of O2 in blood (CaO2) and speed of blood delivery (CO); standard monitors not always adequate for assessment of tissue perfusion

Continuous CO monitors: electrical methods — developed by National Aeronautics and Space Administration; utilizes beat-to-beat variability in thoracic electrical properties to calculate CO; current technologies measure bioimpedance (inaccurate), electrical velocimetry (comparable to esophageal echocardiography), or bioreactance (used increasingly in adults, but evidence in pediatrics scarce); esophageal ultrasonography — measures velocity time interval of blood flowing in descending aorta, and calculates cross-sectional area of aorta to derive stroke volume; easily performed, but surgical techniques may interfere; important to measure flow in central aorta; measurements may be affected by phase errors in blood flow

Measurements of arterial pressure waveforms: convert pressure-time curve to volume-time curve, which requires assumptions of aortic compliance, capacitance, and systemic vascular resistance; pulse contour monitors — heavily marketed for adults; become progressively more inaccurate as values approach extremely high or low CO (when correct information most critical); wide range of cardiovascular function and arterial pulse contours limit application in pediatric environment

Adequacy of CO: desired information adequacy of total CO, rather than actual numeric value of CO; venous oximetry — measured by oximetry probe (available in pediatric sizes) placed on central venous catheter; accuracy declines in extremes of range, but valuable as early warning tool in pediatric intensive care unit; near infrared spectroscopy — transcutaneous measurement of hemoglobin saturation of all blood (not just pulsatile component) in tissue; venous blood provides information about adequacy of perfusion; detects perfusion deficits due to hemorrhage, sepsis, and low CO states; interpretation of numbers complex and needs further development

Potential errors: problems exist with all technologies mentioned; important to limit number of steps in linkage between measured value and desired measurement (CO); linearity — potential sources of error increase as linearity declines; calibration

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range — all devices calibrated under normal physiologic conditions; premarket tests under extremes of physiology would make device more clinically usable; market-driven adoption — evidence base virtually nonexistent; pediatric outcome studies difficult to obtain; market drives adoption of techniques before evidence established; physician knowledge — physician misinterpretation of data large source of error; physicians must understand technology to properly utilize data

Possibilities: development of accurate continuous CO monitors will improve understanding of physiology from measurement (rather than from assumption); accuracy may improve through linking of different modalities; computer-based decision making may aid information-dense environment of anesthesia

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PEDIATRIC PERPLEXITIES

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1. In children <1 yr of age, the spinal cord ends at:
   (A) T12  (B) L1  (C) L2  (D) L3

2. Which of the following statements about chloroprocaine is correct?
   (A) Has been tested in babies at doses of ≤30 mg/kg per hour
   (B) Should be avoided in children because of decreased plasma cholinesterase levels
   (C) Has decreased motor block effects in older children
   (D) Has a prolonged plasma half-life in children <6 yr of age

3. Choose the true statement about general anesthesia (GA) and block placement.
   (A) According to the American Society of Regional Anesthesia and Pain Management (ASRA), blocks should never be placed under GA
   (B) Interscalene blocks are routinely placed under GA using the trans-scalene approach
   (C) Sedation is safer than GA in pediatric patients
   (D) Epidurals placed under GA result in a high incidence of nerve injury

4. Which of the following is the most common response to a positive test dose?
   (A) Elevated heart rate  (C) Increased respiratory rate
   (B) Elevated systolic blood pressure  (D) T-wave amplitude increase of >25%

5. The Lambert-Beer law states:
   (A) Any given wavelength of light is amplified when passed through a prism
   (B) When monochromatic light passes through any substance, the intensity of the beam is reduced by absorption
   (C) Absorption of monochromatic light is inversely proportional to optical path length
   (D) The variable absorption of 2 distinct wavelengths of light passing through a substance allows calculation of the substance density

6. Measurement of hemoglobin concentration with pulse oximetry assumes:
   (A) pH is >7.35  (C) Partial pressure of carbon dioxide is ≤40 mm Hg
   (B) The patient is euvolemic  (D) Oxygen saturation of 100%

7. Factors that may affect accuracy of hemoglobin monitoring with pulse oximetry include all the following, except:
   (A) Cyanosis  (C) Low perfusion pressure
   (B) Increased bone density  (D) Hyperoxia

8. Pulse contour monitors become _______ accurate at extremes of cardiac output; they have limited application in _______.
   (A) More; children  (C) Less; children
   (B) More; adults  (D) Less; adults

9. Which of the following techniques is useful as an early warning sign in the pediatric intensive care unit?
   (A) Venous oximetry  (C) Pulse contour monitoring
   (B) Near-infrared spectroscopy  (D) Electrical velocimetry

10. Continuous cardiac output monitoring devices are calibrated under a wide range of physiologic conditions.
    (A) True  (B) False

Answers to Audio-Digest Anesthesiology Volume 55, Issue 13: 1-D, 2-C, 3-C, 4-B, 5-D, 6-A, 7-C, 8-B, 9-A, 10-A