

PICU Handbook

Guidelines for student/resident/fellow coverage in the Pediatric Intensive Care Unit

Purpose of Guideline: To clarify issues relating to patient care coverage and work for the various care providers in the PICU

Caregivers in the PICU and level of responsibility

1. Attending coverage
 - a. Day attending: Primary attending or consulting/co-attending on all pediatric patients and selected adult patients admitted to the PICU
 - b. Backup attending: A backup attending is available during the day and is called at the discretion of the day attending
 - c. Night attending: Night attending for admission, cross coverage, transport calls/consults, code team response.
 - d. Sedation attending: Available some days
2. Resident Coverage
 - a. Pediatric residents: PL2 and PL3. Residents each take patients primarily. PL3 should strive to mentor and guide the PL2 as needed with PICU or hospital procedures.
 - b. Emergency Medicine Intern. The EM intern will take patients primarily. Not all months have an EM intern.
3. Fellow Coverage (varies by month)
 - a. PICU Fellow. The PICU fellow will act in a supervisory capacity, under the direction of the PICU attending, for all patients admitted to the PICU.
 - b. Cardiology Fellow. The cardiology fellow will act in a supervisory capacity, under the direction of the PICU attending, for all cardiology or cardiac surgery patients admitted to the PICU. The cardiology fellow may go to the cath lab or OR for optimal educational experiences.
 - c. Anesthesia Fellow. The anesthesia fellow will take patients primarily along with the Pediatric residents and EM intern.
 - d. Surgical Fellow. The role/responsibilities of the surgical fellow will vary depending on their educational goals.
4. Students
 - a. Subintern (MS4). The subintern will follow patients as the primary caregiver. One of the pediatric residents should be assigned to “back-up” the subintern on each patient.
 - b. Student (MS3). The student will follow patients as the primary caregiver. One of the pediatric residents (generally the PL3) should be assigned to follow the patient along with the student. (see student info page for more specific guidelines re MS3 experience)

Responsibilities of Primary Resident/student

1. Write admission orders and admission note (medical patient) or review admission orders and write admission note (surgical patient)
2. Pre-round on patients and be prepared to present on rounds. (note, residents should not pre-round on subintern patients, and should very briefly pre-round on MS3 patients)
3. Write daily notes. Surgical patients do not need notes on the day of transfer (except cardiac surgical patients, who transfer to the cardiology service on the ward/dncc).
4. When gone from unit (post call, clinic, etc), communicate/sign out with resident/s who remain in the unit. Please also notify the attending that you are leaving and summarize any patient care tasks that still need to be done.
5. Write transfer note for medical patients, communicate patient data to receiving resident.
6. For Shriner’s discharges or home discharges, dictate admission (students should not dictate).

Division of Patients

1. Pediatric PL2, Pediatric PL2, EM PL1, sub-intern, and anesthesia fellow will take patients primarily
2. The above caregivers will distribute patients relatively evenly, within the following guidelines
 - a. The EM intern and pediatric sub-intern should take more straightforward medical and surgical patients until he/she is comfortable with taking more difficult patients. They should follow up to 3-4 patients
 - b. The anesthesia fellows generally do not have substantial pediatric experience, and usually are not familiar with “how to get things done” at OHSU. Because of this, initially they should have fewer patients so that they can familiarize themselves with the various hospital/unit procedures. They should follow up to 3-4 patients.
 - c. The Pediatric PL2 and PL3 should follow up to 5 high-acuity (nursing acuity 6 or 7) or a maximum of 8 patients primarily. Some of these patients will also be followed by a MS3.
 - d. The Sub-intern should follow 1-3 patients (backed-up by one of the pediatric residents)
 - e. The MS3 should follow 1-3 patients (co-followed with Pediatric resident)
3. Patients admitted by the cross cover residents should be divided up the following day, with attention to evening up the distribution of patients according to the above guidelines.

Triage of work when the unit is busy or there are fewer caregivers

1. Round on sicker patients first. If not all patients can be pre-rounded on, surgical patients who are expected to transfer to the floor after a one day stay should be rounded on last. If not all patients are pre-rounded, their data will be reviewed by the entire team at the time of work rounds.
2. The night resident should include an assessment of whether or not the patient might transfer to the floor in sign-out.
3. If urgent transfer to floor orders are needed prior to rounds beginning, the cross cover resident should do them.
4. Daily notes are not needed on surgical patients transferring to the floor.
5. If unable to complete daily notes on all patients, prioritize medical patients over surgical patients.
6. Transfer notes for patients transferring after one day can be very brief.
7. **If unclear about what tasks should take priority, ask the attending.**

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PEDIATRIC INTENSIVE CARE UNIT (PICU) INTRODUCTION

Purposes

1. The provision of specialized care for children with critical illness which may best be provided by concentrating these patients in areas under the supervision of skilled and specially trained team of physicians and nurses.
2. The continuing education of health-care team members.

Administrative Structure

The Medical Directors of the PICU are Dr. Dana Braner and Dr. Laura Ibsen. Attending Pediatrics Intensivists are Dr. Dana Braner, Dr. Laura Ibsen, Dr. Miles Ellenby, Dr. Ken Tegtmeier, Dr. Aileen Kirby, and Dr. Bob Steelman. The Pediatric Intensivists are the primary caretakers (medical patients), or consultants (surgical patients), for each patient admitted to the PICU. There is an intensivist in house 24 hours/day.

The Clinical Manager of the PICU is Christine Pierce. She supervises the nursing and administrative staff of the unit and is responsible for the day-to-day operations of the unit.

Nursing Staff

1. General organization. The PICU nursing staff consists of RNs and appropriate ancillary personnel. Nursing assignments and acuity decisions are made by the nursing staff. If parents make a request to you that relates to nursing staffing, please inform the charge nurse.
2. Continuing education of the nursing staff. An on-going program of education in pediatric intensive care nursing has been the responsibility of the nursing service. In addition, appropriate seminars discussing subjects of pertinence in pediatric intensive care have been and will continue to be organized with physician participation. This will be an effort to maintain and further the critical care skills of nursing personnel in the PICU.

Respiratory Care

The personnel of PICU will work jointly with the Director of Respiratory Therapy so that optimum respiratory care may be provided. The respiratory therapy staff are responsible for setting up and maintaining the ventilators, delivering respiratory treatments, and assisting with patient care that involves respiratory care (i.e., suctioning).

Pediatric Respiratory Therapists rotate through the PICU, DNCC, and the floors.

Physicians and Students

A PL-3 and PL-2 are assigned to the PICU, and they with the Pediatric Critical Care staff and other services will care for all pediatric patients. The Pediatric Intensive Care Unit is available to all pediatric patients regardless of the service primarily responsible for the child.

Other physicians who may rotate through the PICU include PICU fellows, cardiology fellows, pediatric anesthesia fellows, surgical fellows, and emergency medicine interns. Cardiology fellows should supervise the care of cardiac surgery and cardiology patients. PICU fellows will supervise the care of all patients in the PICU. Emergency medicine interns and anesthesia fellows should follow patients as the primary physician. Other visitors (surgical, dental, etc) may tailor their experience to their needs.

Students who may rotate through the PICU include 4th year subinterns and 3rd year students who are in their required Child Health 1 rotation. PICU subinterns will follow their patients as the primary physician, under the supervision of the residents and attending physicians. Subinterns are expected to function as the patients “intern”. Third year students will follow patients under the supervision of one of the pediatric residents, and will have greater supervision than do the subinterns. The 3rd year students are expected to attend all required student lectures for their CH1 rotation.

Admission and Discharge

Any child requiring pediatric intensive care must be admitted to PICU. This is accomplished by calling the PICU attending physician. If a bed is available the patient may be admitted. If the PICU is full, and all beds are occupied, then the physician wishing to admit a patient to the PICU must contact the PICU attending. The critical care attending will then make the disposition regarding discharge of another patient from the PICU after appropriate consultation with the patients primary service and the PICU nursing staff, or other appropriate disposition. There are policies in place regarding triage of surgical and medical patients that are used when beds or nurses are scarce.

These policies are necessary to insure optimum care for all children who require pediatric intensive care.

Type of Patients admitted to the PICU

- Medical patients from the ED. The ED will contact the PICU attending. The intensivist is the attending of record
- Medical patients from the floor. The floor attending or resident will contact the PICU attending who will decide about transfer, then call the PICU charge RN and resident. The intensivist is the attending of record
- Medical patients transported in for outside institutions. The PICU attending will contact the PICU charge RN and resident about the admission. The intensivist is the attending of record
- Cardiac patients may be admitted from the OR, the floor, the ED, or DNCC. If they are immediately post or pre-operative, the primary service is Pediatric Cardiac Surgery, with medical consultation. Functionally, these patients are managed on an hour-to-hour basis by the PICU attendings. Pediatric residents are the primary residents for the pediatric cardiac surgery patients. If they are not pre or post-operative patients (i.e., they are medical cardiac patients), the attending of record is the PICU attending and cardiology is a consulting service.
- Surgical patients from the ED or the floor. The surgical attending or resident must contact the PICU attending to admit a patient to the PICU. The surgical attending is the attending of record. The PICU acts as a consultant for medical issues. Surgical residents write admission

orders. The degree to which the surgical services manage the medical issues of their patients will depend on the service and the patient.

- Surgical patients from the OR. Surgical attending is the attending of record. The PICU acts as a consultant for medical issues. Surgical residents write admission orders. The degree to which the surgical services manage the medical issues of their patients will depend on the service and the patient.
- Orthopedic patients from Shriners are admitted to the service of the Pediatric Intensivist if the orthopedic surgeon does not have privileges. The pediatric residents write admitting orders for most of these patients.
- BBBB/IAC patients. The BBBB service is the primary service and writes all orders on the patients. They should be called for anything that is needed short of immediate resuscitation.

Routine Procedures

There are pre-printed orders for general PICU admits, CV surgery admits (track A and general), and ECMO admits. If you use a pre-printed order and want to write more things, use regular order paper. There are also pre printed orders for sedation drips, muscle relaxant drips, cardiac patient ventilator weaning. Others are being added on an ongoing basis. Admitting orders to the PICU should include the following categories:

- Diagnosis
- Attending physician
- Condition
- Vital sign frequency (routine is q2). If you want things documented more frequently, be specific. (Hourly is reasonable for sick patients)
- Allergies
- Nursing—specific nursing requirements
- Dressing changes
- Chest tube orders
- CVP/A-line orders
- NG
- Foley
- Diet/NPO
- IVF (type/rate)
- Meds
- Drips written in amount/kg/minute (vasoactive) or amount/kg/hour (sedation/narcotic); consult with PICU MD or nursing staff about concentration to order.
- Labs—labs wanted on admission as well as lab schedule if needed.
- Ventilator settings along with weaning parameters (i.e., wean oxygen for O₂ sat>???)
- Call HO orders. It is best to write these and also to speak with the RN caring for the patient about specific issues you are worried about, to ensure accurate communication.
- There are special order sheets for muscle relaxants, sedation, and PCA. If you are unfamiliar with them, ask the intensivist or the nurse to assist in using them.
- Post operative cardiac patients and ECMO patients have pre-printed orders. These will be completed by the intensivist or the pediatric resident with attending supervision.

Verbal Orders

Verbal orders may be taken only when necessary. These must be written and signed as soon as possible after having been executed.

Emergency Procedures

In the absence of a physician, if a child's condition changes while waiting for the physician caring for the child, the nurse may do the following where appropriate:

1. Draw blood gases, electrolytes and hematocrit, and send these to the lab for stat results.
2. Call for chest x-ray or other appropriate x-ray.
3. Administer oxygen.
4. Institute cardio-pulmonary resuscitation with Ambu bag and external cardiac massage.
5. The PICU attending should be called immediately for any sudden, unexplained change in a patient's condition. In the event of a cardio-respiratory or respiratory arrest where the PICU attending is not immediately available, the Pediatric Code 99 team may be called.
6. If an anesthesiologist is needed emergently, the pediatric on call anesthesiology number should be paged. At the present time, the pediatric anesthesiologists are in house 24 hours/day.

Discharge/Transfer Procedures

Decisions regarding transfer of patients from the PICU to the ward will be made in conjunction with the primary service and RN staff. Confirmation of the availability of a ward bed as well as an accepting physician must be made prior to transfer. The PICU attending will contact the receiving attending for medical patients, the residents should contact the receiving resident to give report.

For surgical patients, the surgery service will write transfer orders. For medical patients, the PICU residents write transfer orders. On occasion, the PICU residents can help the flow of patients by writing transfer orders on surgical patients (confirm with surgical service first).

On medical patients, the PICU resident should write a transfer summary prior to transfer to the floor. Any patient discharged from the PICU (including Shriners patients going back to Shriners) need a dictated summary.

The Medical Record

A record of patient admissions, diagnoses, date of discharge, and attending physician will be kept in the PICU.

Visiting Regulations

1. Visitors other than parents may be present with parental permission.
2. Visitors may be limited to two persons at a time at the discretion of the bedside RN.
3. One immediate family member may stay with the patient 24 hours a day.
4. Visitors must check at the desk outside PICU for permission to visit the child.

Pediatric Resuscitation Course

Pediatric resuscitation courses such as Pediatric Advanced Life Support (PALS) will be offered several times per year. All residents are required to complete this course. You will need to recertify for this course at the end of your second year.

Schedule and other rules

- Call is generally q4. We don't make your schedule. Emergency medicine interns are on call with the cross cover 2nd year pediatric resident. Subinterns take call with the PICU senior resident.
- Rounds start at 7:30 M-F. Prerounding, including gathering information about events of the night, vitals with I/Os, labs, and examining the patient must be accomplished prior to rounds. The time needed for this will depend on the acuity of the unit. Residents should not arrive before 6:00 am. If you are unable to pre round on all patients, do so on the most ill or acute patients so that decisions can be made on rounds. It is helpful if the post call person gives accurate, summative sign-out so that pre-rounding is not bogged down by trying to figure out what generally happened over night. The post call person should make a quick go-around the unit prior to the day people coming in so any last minute changes can be relayed. "Discovery Rounds" should be avoided.
- Rounds on the weekend start at 9:00 am. The resident on call the previous night will pre-round on all the patients (subject to change by residents—how you do this is up to you).
- Signout rounds M-F generally start at 4:30. The PICU residents are responsible for signing out to the incoming resident.
- The patient signout sheet is kept up to date by the residents. Help each other, do a good job with it.
- When one of the PICU residents has clinic, he/she should sign out to the other resident. If both residents will be gone for a given time period, please notify the attending on service as soon as possible (i.e., when you figure it out). The attendings have a backup system in place, we need to know when 2 attendings will be needed.
- The residents are responsible for assuring their compliance with work hours regulations, both daily and weekly. We do not keep you schedule. If you are finding it difficult to comply with the regulations, please let us know.
- PICU attending lectures generally occur daily in the conference room, generally at 11:00am. It is assumed you will be present and the attending on service will cover issues during the lecture.
- Procedures: Procedures will generally be done by the resident covering the patient, with supervision by the attending. There will be times when the attending will do the procedures and times when a more senior resident will do the procedure. Our first priority is patient care. As a general rule, lines on infants or hemodynamically unstable patients will be done by the attending. Intubation of patients who are not NPO, who are known to have difficult airways, who are extremely hypoxemic, or patients who are hemodynamically unstable will be done by the attending or an experienced resident.
- Orders: Bedside charts MUST stay at the bedside. Orders should be written on rounds as decisions are made. You MUST tell the nurse if you are writing an order if you would like it to be carried out in a timely fashion.

- You will take an exam at the end of the rotation. It has been developed by a collaboration of Peds intensivists around the country and is used to tailor our educational objectives. It stays with us.
- A PICU reference guide is being developed in collaboration between residents and the attendings. It will exist at some point.

Helpful tips

- PICU nurses are very experienced and invested in the care of these patients. Learn from them. Take their advice and concerns seriously.
- If you disagree with a nurse, please discuss the issue with the attending.
- If a nurse asks you to call the attending, do it.
- If in doubt, call the attending.
- The only stupid question is the one you didn't ask.
- Follow up on anything that was supposed to happen (including labs and x-rays and CT scans. Even if you aren't a neurologist, you will likely notice something really bad that we should know about).
- Keep the surgical residents apprised of any changes in their patients.
- If in doubt about orders on surgical patients, ask the attending the best course of action.

Double Pages and Code 99

A "double page" is a page indicating the emergency need for the house officer named to respond immediately. A "Code 99" page indicates the need for cardiopulmonary resuscitation. One of the PICU residents must carry the code pager at all times. The PICU resident is a member of the code team.

Organ System Issues and Specific Diseases Commonly Encountered in the PICU

A. Endocrine

Diabetic Ketoacidosis

Definition:

1. Metabolic acidosis
2. Ketonuria/ketonemia
3. Hyperglycemia (not mandatory)
4. Dehydration
5. Associated electrolyte disturbances: pseudohyponatremia, hypokalemia, hypophosphatemia

PICU admission criteria: (depends on case/attending)

1. $\text{pH} < 7.25$, $\text{HCO}_3^- < 15$, mental status changes, cardiac arrhythmia
2. Insulin infusion that requires titration

Pathophysiology:

1. Occurs due to an absolute or relative insulin deficiency along with an excess of counter regulatory hormones (e.g. glucagon, catecholamines, cortisol, and growth hormone) as seen with infection or stress results in stimulation of lipolysis and increased levels of circulatory free fatty acids
2. Fatty acids are oxidized in liver resulting in elevated levels of circulating ketone bodies (beta-hydroxybutyrate and acetoacetate)
3. Counter regulatory hormones stimulate hepatic ketogenesis as well as gluconeogenesis and glycogenolysis resulting in excess glucose production and hyperglycemia
4. DKA can occasionally present without hyperglycemia such as during pregnancy, in patients who have been partially treated and those with prolonged vomiting with little to no carbohydrate intake as blood glucose rises, the ability of the proximal tubule to resorb glucose is exceeded and glycosuria occurs resulting in osmotic diuresis and dehydration

Evaluation:

1. Careful history: vomiting, abdominal pain, polyuria, polydipsia, nocturia, weakness, heavy breathing or shortness of breath, symptoms of intercurrent illness, mental status changes, sweet odor to breath, weight loss
2. Physical exam: dehydration (dry mucous membranes, poor skin turgor, poor perfusion), tachycardia, hypotension, Kussmaul respirations, somnolence, hypothermia, impaired consciousness
3. Laboratory studies:
 - venous blood gas
 - metabolic panel/blood glucose
 - urine or serum ketones
 - complete blood count
 - anion gap
 - consider: HgA1C, TSH, freeT4

- other signs of infection i.e. urinalysis/culture

Useful Equations:

1. Correction for pseudo/dilutional hyponatremia: Na^+ (corrected) = Na^+ (measured) + $[(\text{serum glucose} - 100)/100] \times 1.6$
2. Anion gap: $[(\text{Na}^+ + \text{K}^+) - (\text{HCO}_3^- + \text{Cl}^-)]$

Treatment:

1. ABC's → ensure adequate airway, ventilation and circulation
2. Correct fluid deficits
 - calculate fluid deficit (may assume 5-10% dehydration)
 - i.e., total fluid deficit = 10ml/kg for each 1% dehydrated
 - consider administering a 10-20 ml/kg bolus NS over 1 hour
 - replace evenly over 48 hours in addition to maintenance fluids
3. Correct electrolyte deficiencies
 - consider normal saline or 1/2 normal saline
 - potassium shifts extracellularly due to acidosis- therefore despite normal serum potassium levels a total body deficit usually exists
 - if serum K < 5, replace with 40 mEq potassium in fluids initially. You may need to add more.
 - replace hypophosphatemia by using Kphos for 1/2 of potassium replacement
 - example fluids: NS + 20 mEq KCl/L + 20 mEq Kphos/L
4. Correct metabolic acidosis by interrupting ketone production
 - begin with continuous insulin drip 0.05- 0.1 units/kg/hr IV
 - start with lower dose and titrate to achieve glucose drop no more than 50-100 mg/dL/hour
 - monitor blood glucose q1-2 hours → when glucose reaches 250-300 mg/dL add D5 to fluids, change to D10 (try to increase dextrose in IVF's to keep blood sugar 200-300 rather than decreasing rate of insulin drip until acidosis is corrected)
 - monitor venous blood gas and electrolytes q2-4 hours until out of DKA
 - monitor urine for ketones and glucose with each void
 - when acidosis resolved ($\text{HCO}_3^- > 18$), pt tolerating PO and mental status normal consider switching to SQ insulin = 0.5-1.0 unit/kg/day
 2/3 total dose in am (1/3 Regular, 2/3 NPH)
 1/3 total dose in pm (1/2 Regular at dinner, 1/2 NPH at bedtime)
5. Assess for and treat any underlying causes for DKA (e.g. infection)
6. Closely monitor for and treat any complications of DKA

Complications:

1. **Cerebral edema**- the leading cause of mortality; occurs in 1-2% of children with DKA; risk factors include rapid shifts in osmolality, excessive fluid administration, use of hypotonic fluid; symptoms include declining/fluctuating mental status, symptoms of increased intracranial pressure such as dilated or unequal pupils, Cushing's triad.
Treatment: Mannitol, consider intubation, mechanical ventilation
2. Cardiac arrhythmia- due to electrolyte disturbance (hypo/hyperkalemia)

3. Fluid overload
4. Hypoglycemia

Reference: White, Heil. Diabetic Ketoacidosis in Children. *Endocrinology and Metab Clinics* 29(4): December 2000.

Diabetes Insipidus:

Definition:

1. Absence of or inability to respond to arginine vasopressin (AVP)
2. Polydipsia, polyuria with dilute urine, hypernatremia and dehydration
3. Polyuria exceeding 5cc/kg/hr, specific gravity < 1.010
4. Serum sodium > 145mmol/L
5. Central DI → vasopressin deficiency
6. Nephrogenic DI → renal tubular resistance to vasopressin

Pathophysiology:

1. The secretion of antidiuretic hormone, arginine vasopressin, occurs from the posterior pituitary gland in response to changes in serum osmolality and is regulated by the paraventricular & supraoptic nuclei AVP acts at the cortical collecting ducts in the kidney and binds to the vasopressin₂ receptor
2. Binding initiates a G protein/cAMP signaling cascade leading to the insertion of aquaporin protein in the cortical tubular cells allowing water to enter the cell
3. A deficiency of vasopressin is caused by destruction of the posterior pituitary gland by tumors or trauma
4. Nephrogenic diabetes arises from end-organ resistance to vasopressin, either from a receptor defect or medications that interfere with aquaporin transport of water

Epidemiology:

1. Incidence of diabetes insipidus in the general population is 3 in 100,000 slightly higher incidence in males (60%)
2. **Central diabetes insipidus:**
 - approximately 29% cases are idiopathic (isolated or familial) 50% of childhood cases are due to primary brain tumors of the hypophyseal fossa
 - up to 16% of childhood cases result from Histiocytosis X
 - 2% of childhood cases are due to postinfectious complications and another 2% result from head trauma
 - inherited forms of central DI may be autosomal dominant (usu. present >1 year of life) or autosomal recessive (present <1 year)
3. **Nephrogenic DI:**
 - may be x-linked recessive, autosomal dominant or recessive and usually presents <1 week of life
 - acquired forms of nephrogenic DI may be secondary to medications (lithium, amphotericin, cisplatin, lasix, gentamicin, rifampin, vinblastine), electrolyte disorders (hypokalemia, hypercalcemia or hypercalciuria) or due to systemic disorders (Fanconi

Syndrome, diffuse renal injury, obstructive uropathy, RTA, sarcoidosis, Sjogren syndrome, Sickle cell disease and trait)

Evaluation:

1. Clinical history: poor feeding, failure to thrive, irritability, soaking of diapers in infants; polyuria, polydipsia, nocturia, large volume of water; growth retardation, seizures
2. Physical examination: irritability, signs of dehydration (decreased tearing, depressed fontanelle, sunken eyes, mottled or poor skin turgor), signs of shock (hypotension, weak pulses)
3. Laboratory tests:
 - hyponatremia >145 mmol/L, (>180 in nephrogenic DI)
 - hyperchloremia, azotemia, acidosis, high osmolality
 - low urinary sodium and chloride, osmols
 - urine specific gravity < 1.010 (first morning void)
 - 24 hour urine collection- usu. > 5 cc/kg/hour
4. Diagnostic tests:
 - water deprivation test (perform only w/close monitoring and involvement of endocrine team)
 - a rise in plasma osmolality >10 mOsm/kg over baseline with specific gravity remaining <1.0101 establishes diagnosis of DI to differentiate types, administer DDAVP; if urine osmolality rises by more than 450 mOsm/kg, central DI is established; if urine osmols remain <200 mOsm/kg, nephrogenic DI is the likely diagnosis
5. Imaging: consider MRI scan to delineate cause of central diabetes insipidus (suprasellar mass/ pituitary cyst/ hypoplasia/ ectopic gland, etc)

Differential Diagnosis:

1. Diabetes mellitus/DKA
2. Compulsive water ingestion
3. Medications i.e., mannitol
4. Small volume urine loss as in cystitis, urethritis, etc.

Treatment:

1. IV forms (aqueous vasopressin or desmopressin) are used for central DI in acute hypophysectomy or in intensive care settings until able to transition to intranasal forms
2. Monitor urine specific gravity and urine output closely, titrate drip or IV doses appropriately; monitor serum sodium q2-4 hours initially
3. When stable, transition to intranasal DDAVP 5-20 mcg daily (absorption may be poor with rhinitis or sinusitis); oral preparations also available
4. Treat dehydration with oral repletion or if necessary, parental rehydration if severely dehydrated.
5. For nephrogenic DI, a low-osmolar, low-sodium diet should be initiated, and thiazide diuretics administered which increases sodium loss by inhibiting its reabsorption in the cortical tubules

Complications:

1. Mental retardation
2. Seizures
3. Nonobstructive functional hydronephrosis and hydroureters
4. Chronic renal insufficiency
5. Life threatening dehydration and its complications

Reference: Saborio et al. Diabetes Insipidus. *Pediatrics in Review*: 21(4) April 2000.

B. Neurology

Status Epilepticus

Definition:

1. A life-threatening medical emergency defined as frequent or prolonged epileptic seizures
2. Many definitions including a continuous seizure lasting longer than 30 minutes or repeating convulsions lasting 30 minutes or longer without recovery of consciousness between them. Current thinking involves shorter periods of time.
3. Onset may be partial or generalized

Epidemiology:

1. A common neurologic medical emergency, affecting 65,000 to 150,000 persons in the United States yearly
2. Estimated that 1.3-16% of all patients with epilepsy will develop SE at some point in their lives (in some may be the presenting seizure)
3. More common in childhood than in adults, no sexual predominance
4. Mortality rate is as high as 10%, rising to 50% in elderly patients
5. Many possible etiologies as listed below:

Causes of Status Epilepticus
Background of Epilepsy <ul style="list-style-type: none">•Poor compliance with medication•Recent change in treatment•Barbiturate or benzodiazepine withdrawal•Alcohol or drug abuse•Pseudostatus epilepticus•Underlying infection/fever

Presenting de novo

- Recent stroke
- Meningo-encephalitis, meningitis, encephalitis
- Acute head injury
- Cerebral neoplasm
- Demyelinating disorder
- Metabolic disorders (e.g. renal failure, hypoglycemia, hypercalcemia)
- Drug overdose (e.g. TCA's, phenothiazines, theophylline, isoniazid, cocaine)
- Inflammatory states (e.g. systemic lupus erythematosus)
- New onset seizure disorder

Evaluation and Treatment:

1. Evaluate and support ABC's
2. Obtain IV access if possible
 - check glucose
 - if access, draw: lytes including Ca/Mg, Bun/Cr, LFTs
 - consider CBC/blood cx if infection possible
 - draw anticonvulsant levels, tox screen if indicated
3. Administer a rapidly acting benzodiazepine
 - if IV: lorazepam (ativan) 0.5mg-1mg/kg (max 10mg)
 - may repeat ativan
 - administer long acting AED
 - + fosphenytoin 15-20 mg/kg IV or
 - + phenobarbital 15-20 mg/kg IV
4. If seizures persist, consider additional ativan or additional bolus of phenytoin or phenobarb 5mg/kg IV
5. ABC's: continue to eval; may need intubation if not able to manage airway
6. Last resort may need to induce pentobarb or general anesthesia (propofol) coma after airway secured
7. Watch for potential complications including hypothermia, acidosis, hypotension, rhabdomyolysis, renal failure, infection and cerebral edema
8. Continue to search for and treat any underlying cause

Complications:

1. Hypoxia
2. Metabolic and respiratory acidosis
3. Increased or decreased cerebral blood flow
4. Hypo or hyperglycemia
5. Rhabdomyolysis
6. Hyperkalemia
7. Hyperpyrexia
8. Cardiac dysfunction, arrhythmias, hypotension
9. Permanent neurologic sequelae (e.g., motor deficits, MR, epilepsy)
10. Death

Reference: Hanhan, U. et al. Status Epilepticus. *Pediatric Clinics of N. America*: 48(3): June 2001.

Traumatic Brain Injury and Increased Intracranial Pressure

Definition:

1. Increased intracranial pressure results when the volume of one of the cranial contents (brain parenchyma, cerebrospinal fluid, or blood) increases and adaptive measures are unable to compensate
2. Increased ICP is dangerous when it compromises cerebral perfusion, leading to further cell damage, cerebral edema and eventual displacement and herniation of the brain
3. Classification of brain edema:
 - vasogenic**- characterized by increased permeability of brain capillary endothelial cells, as in tumor, abscess, hemorrhage, infarction contusion, lead intoxication, and meningitis; the neurons and glia are relatively normal
 - cytotoxic**- characterized by failure of the normal homeostatic mechanisms that maintain cell size: neurons, glia and endothelial cells swell; prominent in hypoxic-ischemic injury, osmolar injury, some toxins, and secondary injury following head trauma
 - interstitial**- characterized by an increase in the water content of the periventricular white matter due to obstruction of CSF flow

Pathophysiology:

1. The brain is composed of *three components*: brain (cells and intercellular fluid), blood and CSF; increases in the size of any of the three compartments can lead to increased ICP
2. pO₂, pCO₂, pH and blood pressure all effect cerebral blood flow, but may act differently in an injured brain compared to a normal brain
3. Increased pCO₂ will cause an increase in cerebral blood flow, and hence an increase in ICP. Low pO₂ will also cause an increase in cerebral blood flow and ICP
4. Brain injury occurs in 2 phases: (1) the **primary injury** that occurs at the moment of impact and results from a transfer of kinetic energy to the brain and (2) the **secondary injury** that is a biochemical and cellular response to the initial trauma
5. The primary injury causes direct cellular damage; we cannot do anything to reverse the primary injury as neurons do not regenerate
6. The secondary injury is delayed, usu. peaking at 48-72 hours and occurs in response to the hypoxia, hypoperfusion and cell damage that result from the initial trauma; our goal in management is to prevent, as much as possible, secondary injury

Epidemiology:

1. In pediatric trauma patients, head injuries occur in more than 70-80% of those children who require hospitalization and death occurs in 20-40% of those patients
2. Each year, between 29,000 and 50,000 children younger than 19 years suffer permanent disability as a result of TBI
3. The etiology of brain injury and increased ICP is important to understand and is essential in formulating a treatment plan



Causes of Brain Injury and Increased ICP
<u>Generalized Brain Injury</u> <ul style="list-style-type: none"> •Hypoxic-ischemic injury •Diffuse head injury i.e. shaken baby syndrome •Osmolar injury (hypo-osmolality, hyperosmolality, DKA) •Encephalopathies (Reye's syndrome, hepatic encephalopathy) •Infection (meningitis, encephalitis) •Toxins
<u>Focal Intracranial Lesion</u> <ul style="list-style-type: none"> •Vascular: subdural, epidural, intraparenchymal hemorrhage, AVM •Focal traumatic lesion, focal edema w/o bleeding •Tumor •Abscess
<u>CSF Obstruction</u>

Evaluation:

1. Clinical history: -h/o trauma, symptoms including headache, vomiting, depressed level of consciousness i.e. confusion, restlessness, progressive unresponsiveness
2. Physical exam: abnormal posturing, abnormal breathing pattern, abnormal cranial nerve findings, papilledema, hypertension with bradycardia or tachycardia, bulging fontanelle
3. Cushing's triad: increased ICP, hypertension, bradycardia or tachycardia →bradycardia and Cushing's triad is a **late sign of increased ICP**
4. Radiology: CT (non contrast) to evaluate for blood, edema, mass effect

Equations:

Cerebral perfusion pressure (CPP) = MAP-ICP or MAP-CVP

Management:

1. Airway -remember avoid manipulation of neck in trauma; a child w/ a GCS <8 should be intubated as a general rule to protect the airway; use meds during intubation that will reduce the ICP response to intubation.
2. Breathing- ensure adequate oxygenation and avoid hypercapnia (mild hyperventilation is appropriate)
3. Circulation- provision of adequate cardiac output and blood pressure is essential; avoid lowering the osmolality of blood (NO hypotonic fluids, normal saline or LR are good options as is albumin). Initial Neurologic Assessment (GCS, neuro exam, seizures)
4. IV access and Lab evaluation: consider blood gas, electrolytes including Ca/Mg/Phos, Osmolality, blood glucose, LFT's ammonia, CBC/coags, toxicology screen, blood/urine/spinal tap
5. CT scan without contrast- evaluate for signs of trauma, bleed, edema
6. Evaluate and treat possible complications: hyperthermia, glucose abnormalities, seizures
7. Provide analgesia and sedation if indicated
8. Positioning- HOB elevated with head midline to avoid impeding venous return

9. Surgical management if indicated (drainage of blood, removal of tumor, drainage of CSF or shunt revision)
10. Intracranial pressure monitoring (intraventricular drain, intraparenchymal catheter (Camino), subarachnoid bolt). The goal is to maintain cerebral perfusion pressure 50-70 mmHg/ ICP <20, and detect “events”: rebleed, herniation, etc.
11. Mechanical ventilation: sats >95%, avoid hypercapnia, consider short- term hyperventilation
12. Mannitol- decreases blood viscosity by lowering hematocrit, may reduce brain water content in the uninjured portion) → give rapidly, “chronic” dose is 0.25-0.5 mg/kg, in impending herniation give a large 1 gram/kg dose quickly; watch blood pressure and renal function
13. Lasix- synergistic in combo with mannitol for reducing ICP
14. Other: barbiturates-controversial, steroids- will help reduce vasogenic edema (around tumors), no effect on cytotoxic brain edema or in the management of head trauma
15. Fluid Management- avoid hypotension and hypo-osmolality; look for SIADH; reasonable regimens include D51/2 NS or D5NS at slightly less than maintenance (so as to avoid Na overload) follow electrolytes and volume status closely. Do not restrict volume early in resuscitation.

Reference: Enrione, M. Current Concepts in the Acute Management of Severe Pediatric Head Trauma. *Clin. Ped Emergency Medicine*: 2(1): March 2001.

C. Pulmonary

Status Asthmaticus

Definition:

1. The condition of severe, life threatening asthma
2. Unresponsive to the initial doses of bronchodilating agents
3. Progressive respiratory failure

Pathophysiology:

1. Reversible, diffuse lower-airway obstruction caused by airway inflammation and edema, bronchial smooth muscle spasm and mucous plugging
2. Airway obstruction → hyperinflation/VQ mismatch → hypoxemia

Evaluation:

1. Exam: level of consciousness, breath sounds (distant or absent is ominous), central cyanosis, accessory muscle use
2. Chest radiograph- if concerned for foreign body, pneumonia, pneumothorax
3. Arterial blood gas:
 - Early phase → hypoxemia, hypocarbia
 - Impending respiratory failure → hypercobia

Treatment:

1. Beta agonists: intermittent versus continuous inhaled treatments vs. IV terbutaline, re-evaluate frequently

2. Steroids: give early
3. Cardio-respiratory monitoring
4. High flow supplemental oxygen (Non-rebreather if necessary, use blender if possible to avoid 100 % FiO₂)
5. Fluid replacement, avoid vigorous hydration. If severely ill, make sure patient has 2 large bore, well functioning IVs.
6. Antibiotics if clinically indicated
7. Other: anticholinergics, magnesium
8. **Intubation can usually be avoided and requires considerable skill. Mechanical ventilation is also difficult and should be managed by an experienced pediatric intensivist. → aggravates bronchospasm, worsens hyperinflation, risks barotrauma**
If necessary, use low tidal volumes and long expiratory time. Support modes of ventilation (pressure support and volume support) are used frequently.

Asthma Drugs and Doses

Drug	Route	Dose
Albuterol	Nebulized	0.15 mg/kg max 5mg continuous: 0.3mg/kg/hr Typically ordered as 5, 10, 15, or 30 mg/hour.
Prednisone	Oral	2mg/kg/d max 60mg
Methylprednisolone	IV	2mg/kg loading dose max 80 mg, 1mg/kg q 6 hours.
Ipratropium	Nebulized	250-500 micrograms
Terbutaline	IV	Bolus: 10µg/kg max 500µg Drip: 0.4µg/kg/min, titrate up as needed. Usually max 2-4µg/kg/min.
Magnesium Sulfate	IV	25-75 mg/kg/dose max 2g infuse over 20 minutes. Watch for hypotension. If effective, may continue as infusion or bolus q3-4 hours.
Aminophylline	IV	6 mg/kg load followed by infusion 1mg/kg/hr (0.1-0.8 mg/kg/hr for neonates and infants). Uncommonly used.

Complications:

1. Respiratory failure
2. Death
3. Barotrauma with mechanical ventilation

4. Beta agonists- tachycardia, arrhythmia, hypertension or hypotension, agitation/tremulousness, hyperactivity
5. Anticholinergics- anxiety, dizziness, headache, GI upset; aerosol chamber, contraindicated in soy or peanut allergy
6. Magnesium- hypotension, respiratory depression, heart block, flushing, nausea, somnolence
7. Methylxanthines- nausea, vomiting, tachycardia, hypotension, arrhythmia
8. Steroids- hypertension, pseudotumor cerebri, GI bleeding, hyperglycemia

Reference: Werner, H. Status Asthmaticus in Children. *Chest*: 119 (6) June 2001.

Acute Respiratory Distress Syndrome

Definition:

Acute respiratory distress characterized by acute lung injury, noncardiogenic pulmonary edema and severe hypoxia.

“The respiratory distress syndrome in 12 patients was manifested by acute onset of tachypnea, hypoxemia, and loss of compliance after a variety of stimuli, the syndrome did not respond to usual and ordinary methods of respiratory therapy. The clinical and pathological features closely resembled those seen in infants with respiratory distress and to conditions in congestive atelectasis and postperfusion lung.”

Reference: Ashbaugh, *Lancet*, 1967

Diagnostic Criteria: -

1. Identifiable associated condition
2. Acute onset
3. Pulmonary artery wedge pressure \leq 18mm or absence of evidence of left atrial hypertension
4. Bilateral infiltrates on chest radiography
5. Pao₂/Fio₂ ratio \leq 200
 *[Pao₂/Fio₂ ratio \leq 300 is defined as Acute Lung Injury]
 -American-European Consensus Conference Statement, 1994

Risk Factors:

Pulmonary

Bacterial pneumonia
 Viral pneumonia
 Aspiration
 Inhalation injury
 Fat emboli
 Near Drowning

Extra-pulmonary

Sepsis
 Trauma
 Multiple transfusion
 Cardiopulmonary bypass
 Pancreatitis
 Peritonitis
Anything really bad

Pathophysiology:

1. Direct lung injury or systemic insult occurs
2. Release of pro-inflammatory agents i.e. TNF α , interleukins
3. Migration of neutrophils producing oxygen radicals and proteases
4. Endothelial and epithelial cell damage leads to increased permeability and the influx of fluid into the alveolar space. (pulmonary ARDS—epithelial damage, extra-pulmonary ARDS—endothelial damage initially)
5. Surfactant is abnormal
6. Impaired fibrinolysis leads to capillary thrombosis/microinfarction

Pathology of ARDS

Exudative Phase (Day 1-7)	Proliferative Phase (Day 7-21)	Fibrotic Phase (> Day 21)
Interstitial and intra-alveolar edema	Interstitial myofibroblast reaction	Collagenous fibrosis
Hemorrhage	Luminal organizing fibrosis	Microcystic honeycombing
Leukoagglutination	Chronic inflammation	Traction bronchiectasis
Necrosis-Type I Pneumocytes	Parenchymal necrosis	Arterial tortuosity
Hyaline membranes	Type II pneumocyte hyperplasia	Mural fibrosis
Platelet-fibrin thrombi	Obliterative endarteritis	Medial hypertrophy
	Macrothrombi	

Reference: Tomashefski, J. Acute Respiratory Distress Syndrome. *Clinics in Chest Medicine*: 21(3) Sept. 2000.

Evaluation:

1. Physical exam: tachypnea, tachycardia, altered mental status
 2. Blood gas monitoring: initial **respiratory alkalosis** may precede infiltrates, later: alveolar edema → VQ mismatch/shunt → **severe hypoxia**
 3. Imaging: CXR progression from diffuse interstitial infiltrates to diffuse, fluffy alveolar spaces; later reticular pattern suggests interstitial fibrosis. CT demonstrates dependent (posterior if supine) infiltrates and atelectasis, with anterior hyperinflation.
- *Most patients with ARDS develop diffuse alveolar infiltrates and progress to respiratory failure within 48 hours of the onset of symptoms**

Treatment:

1. Treatment of underlying cause or associated condition
2. Ventilatory support- ensures “adequate” oxygenation/ventilation while minimizing ventilator induced lung injury.
 - Appropriate recruitment of alveoli through appropriate levels of PEEP. Avoid under (atelectrauma) or over (volu/barotraumas) inflation.
 - Limit pressures and tidal volumes (<30-35)
 - Tolerate hypercapnia “permissive hypercapnia” well accepted
 - Tolerate hypoxemia? “permissive hypoxemia” ?
 - Consider high-frequency oscillatory ventilator
 - Consider prone position
3. Pharmacologic treatment- no proven role as yet. Drugs sometimes used include steroids (late phase), NitricOxide (no proven survival benefit),
4. Monitor and/or Prophylaxis for complications-
 - GI bleed.
 - Thromboembolism
 - Nosocomial infection
5. Supportive care- nutrition, sedation/pain control
6. ECMO: not proven to improve survival

Ventilator Strategy:

1. Usual mode is PRVC (pressure regulated volume control).
2. Avoid over or under-inflation: Usually this requires PEEP of 6-12, depending on severity. Remember things tend to get worse before they get better-it is not unusual for patients to require increasing PEEP as their disease worsens.
3. Use low tidal volumes, 5-7 cc/kg. Monitor peak pressure (PIP or plateau pressure). It should be less than 30-35.
4. Use longer aspiratory times than usual for age.
5. Tolerate hypercapnia, monitor pH, try to keep >7.2
6. Tolerate hypoxemia if necessary to keep FiO₂ <60%. If on <60%, Sat goal should be ~92, if not able to maintain 92 on <60%, tolerate 85%. Monitor trends closely—absolute numbers are not usually important, trends in numbers are often extremely important.
7. Remember that cardio-pulmonary interactions occur, and ventilator maneuvers may affect hemodynamics.

Complications:

1. Barotrauma- pneumothorax, pneumomediastium, subcutaneous emphysema
2. Cardiac- hypotension
3. GI- stress-related gastrointestinal hemorrhage
4. Death estimated to occur in 20 (low risk)-90% (highest risk, BMT) of cases. Previously well children and those with extrapulmonary ARDS have a better prognosis. The mortality from ARDS has fallen significantly since it was first described in 1967.

Reference: Mortelliti, M. Acute Respiratory Distress Syndrome. *American Family Physician*: 65(9) May, 2002.

D. Infectious Diseases

Meningitis

Definition:

1. Inflammation of the membranes surrounding the brain and spinal cord including the dura, arachnoid and pia mater
2. May present in combination with inflammation of the cerebral cortex, then called meningoencephalitis
3. Associated with evidence of an inflammatory response in the CSF
4. Most commonly caused by viral or bacterial infection, but must consider infection with fungus, mycobacterium and cryptococcus and anaerobes.

Epidemiology:

1. Prognosis depends on age, etiology, time of onset to therapy, and complications
2. Case fatality rate range from 3-5 % for meningococcal meningitis to 10% for pneumococcal meningitis and 15-20% in neonatal cases
3. The common etiologic agents of meningitis can be divided by age group as follows:

<1 Month	1-3 Months	3 Months through School Age	Immunocompromised
Group B Strep	Group B Strep	N. meningitides	Cryptococcus
E. coli	S. pneumoniae	S. pneumoniae	Toxoplasma
Listeria	N. meningitides	H. influenza	Tuberculosis
Enterococcus	H. influenza	Enterovirus	Aspergillus
Enterovirus	Enterococcus	Arbovirus	And all others...
HSV	Enterovirus	HHV6	
CMV	HSV	EBV	
Ureaplasma	HHV6	Mycoplasma	
Candida		Mycobacterium	

Pathophysiology:

1. Inflammation of the meninges is initiated when cell wall and membrane products of an organism disrupt the capillary endothelium of the CNS (e.g. blood brain barrier)
2. The organism/offending agent may enter the CNS by hematogenous spread or by direct invasion
3. Disruption of the endothelium causes transmargination of PMN and subsequent release of cytokines and chemokines

4. Inflammation of the vessels produces capillary leak, leading to edema and potentially to increased ICP
5. Further inflammatory response occurs following antibiotic administration due to rapid bacterial lysis and release of cell wall/fragments

Evaluation:

1. History- fever, headache, neck pain or stiffness, nausea, vomiting, photophobia and irritability; young infants may only exhibit irritability, somnolence and fever; seizures also possible
2. Physical exam- alterations in level of consciousness, stiff neck (Kernig and Brudzinski signs not sensitive in young children), bulging fontanelle, rash, fever, focal neurologic abnormalities in complicated cases, hemodynamic instability
3. Studies- **lumbar puncture**-CSF studies are key to diagnosis. Include cell count, diff, protein, glucose, culture, gram stain, specific stains/cultures as indicated, PCR for enterovirus/HSV, etc.
4. **Lab studies**- CBC w/diff, blood culture, electrolytes (eval for SIADH), consider LFT's- may be elevated with enteroviral infections or disseminated HSV
5. **Imaging** -consider CT scan or MRI if concerned for increased ICP or abscess, or for evaluation in a complicated clinical course (hydrocephalus, subdural effusion, hemorrhage or infarction may be seen). MRI is also helpful in diagnosis and management of herpes meningitis and tuberculosis meningitis
6. **Other** -all patients should have urinalysis, urine culture. When viral meningitis is suspected, swabs of rectum, nasopharynx and eyes indicated in addition to CSF studies

CSF Findings in Infants and Children

<i>Component</i>	Normal Children	Normal Newborn	Bacterial Meningitis	Viral Meningitis	Herpes Meningitis
Leukocytes/mcL	0-6	0-30	>1,000	100-500	10-1,000
Neutrophils (%)	0	2-3	>50	<40	<50
Glucose (mg/dL)	40-80	32-121	<30	>30	>30
Protein (mg/dL)	20-30	19-149	>100	50-100	>75
Erythrocytes/mcL	0-2	0-2	0-10	0-2	10-500

*Adapted from Wubbel, et. Al, Pediatrics in Review. 1998: 19(3) page 80.

*CSF in tuberculous meningitis is notable for low glucose

Treatment:

1. Management of ABCs
2. If bacterial meningitis suspected and if possible after all cultures obtained, begin appropriate empiric antibiotic treatment on basis of age and epidemiologic factors (remember meningitic doses!)
 - in neonates/infants, consider ampicillin and gent or cefotaxime
 - in children consider cefotaxime or ceftriaxone, and addition of vancomycin in cases of possible resistant S. pneumonia
 - if herpes meningitis is suspected, intravenous acyclovir is appropriate
3. In cases of aseptic meningitis, supportive care
4. Evaluation for and treatment of complications i.e. SIADH, seizures
5. Isolation precautions and chemoprophylaxis for exposed individuals if indicated

6. Consider neurosurgical evaluation if indicated (drainage of subdural, placement of ICP monitor)
7. Increased intracranial pressure may rarely occur. In there is clinical evidence of increased ICP, consider ICP monitoring and treatment. The most common cause of death in meningitis is brain death.
8. Supportive care, pain control, GI prophylaxis, nutrition.

Complications:

acute:

- seizures
- increased ICP
- effusion/empyema/abscess/subdural
- SIADH
- herniation
- death

chronic:

- hearing loss
- seizure disorder
- hydrocephalus
- developmental delay

Reference: Wubbel et al. Management of Bacterial Meningitis: 1998. *Pediatrics in Review*. 1998: 19(3), pages 78-84.

Encephalitis

1. Definition:
 - involves inflammation of the cerebral cortex
 - often present with some inflammation of the meninges, i.e., meningoencephalitis
 - an unusual complication of common viral infections, can be subdivided based on etiology and pathogenesis: 1) acute encephalitis, 2) postinfectious encephalomyelitis, 3) slow viral infections of the CNS

2. Pathophysiology:
 - a virus gains access to the CNS by either hematogenous or neuronal routes
 - in anthropoid-borne viral disease there is local replication of the virus at the skin followed by transient viremia which causes seeding of the reticuloendothelial system and later the CNS
 - in contrast, viruses such as HSV and rabies gain access to the nervous system intra-neuronally
 - in acute encephalitis, capillary and endothelial inflammation occurs primarily in the gray matter or gray-white junction; subsequent lymphocytic infiltration results.
 - as the disease progresses astrocytosis and gliosis become evident on histopathology

3. Epidemiology:
 - approximately 20,000 cases of encephalitis occur in the US each year
 - the two endemic causes of encephalitis include rabies and HSV

- HSV accounts for approximately 10% of all US cases of encephalitis
- MMR and polio vaccinations have significantly decreased the incidence of postinfectious encephalitis
- postinfectious encephalomyelitis is still seen with upper respiratory tract, although uncommon, and is most often seen with influenza infection
- arthropod-borne viruses causing encephalitis that are seen in the US include St. Louis encephalitis, Eastern equine encephalitis, Venezuelan equine encephalitis, and La Crosse virus
- other viruses that have the potential to cause encephalitis include enteroviruses, coxsackieviruses, and echoviruses, CMV, EBV, varicella, HHV-6
- rarely bacteria are the cause of diffuse encephalitis and may include listeria and mycoplasma pneumoniae
- Japanese encephalitis is a major cause of encephalitis in China, SE Asia, and India and must be considered in persons who recently traveled or moved from these areas

4. Evaluation:

- clinical history
- fever, headache, disorientation, altered consciousness, behavioral changes; in more severe cases hemiparesis or seizures; photophobia and nausea also seen
- history of travel, season, bite from animal or insect, URI
- in cases of meningoencephalitis, may also see nuchal rigidity
- physical exam- eval for focal neurologic signs, lethargy or somnolence, fever, rash, nuchal rigidity
- HSV infection has predilection for the temporal lobes and thus can lead to findings of aphasia, anosmia, temporal lobe seizure and focal neurologic findings
- studies: labs- CBC, blood and viral cx's including mucous membranes, electrolytes to eval for SIADH CSF evaluation
- may be normal but can see elevated protein levels and mononuclear cell pleocytosis; rarely helpful for isolating the virus
- include viral cultures as well as PCR for HSV, CMV, HHV-6 and enteroviruses if indicated CT
- eval for tumor or abscess that may mimic encephalitis
 - MRI- may see areas of inflammation, edema
 - EEG- to eval for seizure activity

5. Treatment:

- ABCs
- management of increased intracranial pressure
- acyclovir to treat possibility of herpes infection until ruled out
- antibacterial therapy for suspicion of bacterial involvement
- rabies vaccine and immune serum for those potentially exposed to rabies
- supportive care

6. Complications:

- seizures
- neurologic deficits

- death

Reference: Whitley et. al., Viral Encephalitis. *Pediatrics in Review*. June 1999: 20(6).

E. Gastroenterology

Gastrointestinal Bleed

1. Definition:
 - upper GI bleed- originating above the ligament of Treitz
 - usually presents with hematemesis or melena; may present as hematochezia if large amount of blood/rapid transit
 - lower GI bleed- originating below the ligament of Treitz
 - presents as hematochezia
 - must be confirmed by gastrocullt, guaiac, hemocult or hematest for the presence of blood (to rule out food coloring/medications)
2. Risk Factors: liver failure- coagulopathy, esophageal varices
 - surgery/burns/steroids/brain tumors- gastrointestinal ulceration
 - NSAIDs/steroids- ulceration
 - GERD/neuromuscular disease- esophagitis
 - cirrhosis/portal hypertension- gastroesophageal varices
 - constipation- anal fissure/ hemorrhoids
 - family history- inflammatory bowel disease
 - recurrent vomiting- Mallory-Weiss syndrome
3. Diagnosis: -careful history and physical exam, evaluation of vital signs as indicator of volume of blood loss
 - immediately establish IV access (as large an IV as possible x 2)
 - place nasogastric tube to assess extent of active bleeding/confirm presence of fresh blood
 - confirm presence of blood by appropriate testing (i.e. hemocult)
 - baseline blood count; may be misleading in recent bleed, use as comparison
 - other labs: liver function, platelet counts, coagulation times, Apt test
 - imaging: plain films- not very helpful but can see free air/foreign body
 - ultrasonography
 - eval for portal hypertension, vascular anomalies
 - + Endoscopy- **method of choice**; offers both diagnosis and tx (banding, sclerosis- see below)
 - + Meckel's scan- consider in painless, massive bleeding
 - Angiography- when bleeding is massive
 - + MRI/CT- to evaluate mass lesions, vascular malformations
4. Treatment: endoscopic therapy-electrocoagulation, laser tx, sclerosing, elastic band ligation, mechanical clips
 - arteriographic embolization by interventional radiology
 - transjugular intrahepatic portosystemic shunt placement (TIPS)

- surgical repair/excision- Meckel diverticulum, polyp, ulceration
- antibiotics- in few cases of infectious enterocolitis
- H-2 blockers- esophagitis, ulcers, GERD
- Proton pump inhibitors- as above
- Octreotide- a somatostatin analog
- Corticosteroids- for inflammatory bowel disease exacerbations

Causes of GI Bleeding In Children

Infancy	Infant to 6 months	6 months to 5 years	5-18 years
Swallowed maternal blood	Anal fissure	Epistaxis	See 6mos-5years, and:
Hemorrhagic disease- newborn	Esophagitis/gastritis	Esophagitis/gastritis	Mallory-Weiss syndrome
Anal fissure	Infective enterocolitis	Esophageal varices	Gastritis
Infective enterocolitis	Protein-sensitive enterocolitis	Polyps	Peptic ulcer
Protein sensitive enterocolitis	Intussusception	Infective colitis	Chronic ulcerative colitis
Necrotizing enterocolitis	Lymphonodular hyperplasia	Lymphonodular hyperplasia	Crohn's disease
Hirschsprung's	Volvulus	Intussusception	Hemorrhoids
Midgut volvulus	Hirschsprung's	Meckel diverticulum	Coagulopathy
Vascular malformations	Vascular malformations	Vascular malformations	
Gastric ulceration	Duplication cysts	Henoch-Schonlein purpura	
Duplicaton cysts		Hemolytic uremic syndrome	

4. Pearls:

- Currant-jelly stools- indicates mixture of blood, mucous and stool, consider Meckel diverticulum or intussusception massive, painless bleeding
- Meckel's

Reference: Vox, Victor. Gastrointestinal Bleeding in Infancy and Childhood. *Gastroenterology Clinics*: 29(1) March, 2000.

F. Renal

Hemolytic Uremic Syndrome

1. Definition:
 - combination of **microangiopathic hemolytic anemia** and variable degrees of **thrombocytopenia** and **renal failure**
 - usually occurs ages 6 months-5 years, previously healthy children
 - most commonly preceded by watery diarrhea that can evolve into hemorrhagic colitis
→ proceeds to hemolysis, thrombocytopenia, then oliguria/anuria several days later
2. Pathogenesis:
 - typically occurs with infection and associated toxin production/release
 - toxin binds and destroys colonic mucosal epithelial cells resulting in blood diarrhea
 - also enters systemic circulation and binds to endothelial cells (especially in the kidneys) causing release of vWF, PAF and plasminogen activator inhibitor resulting in platelet/fibrin thrombi
 - may involve endothelium in the CNS, pancreas, liver, etc.
 - red blood cells become deformed in the occluded vessels and platelets consumed, resulting in hemolytic anemia and thrombocytopenia
3. Etiology/Epidemiology:
 - two types of HUS which differ by presence or an enteritis prodrome
 - the most common type is accompanied by enteritis and is strongly linked to a shiga-like toxin associated with E.coli 0157:H& and others such as enterohemorrhagic E.coli and shigella
 - usually acquired by consumption of raw/undercooked meat, unpasteurized milk and contaminated water/apple juice; person to person spread also possible
 - atypical HUS lacks the preceding diarrheal illness and is less common; has been associated with strep pneumo, drugs and collagen vascular disorders; has been associated with higher complication rates
5. Evaluation:
 - exam: vitals
 - hypertension, tachycardia CNS
 - drowsiness, personality changes, hallucinations, hemiparesis
 - Abdomen- surgical abdomen, tenderness, Hepatosplenomegaly
 - Skin- pallor, petechiae, jaundice, edema
 - Labs:
 - CBC- normochromic, normocytic anemia; thrombocytopenia, ↑WBC
 - Smear- schistocytes
 - Coags- normal
 - Urine- hematuria, proteinuria, anuria, red cell casts
 - CMP- elevated creatinine/BUN, electrolyte disturbances
 - Stool- +E.coli/shigella, +fecal leukocytes

6. Differential Dx: TTP, DIC, IBD
7. Complications: 5-10% mortality rate
 - ESRD 10%
 - CNS involvement 20-30% (seizures most common)
 - Pleural/pericardial effusions
 - Pancreatic insufficiency 4-15% (diabetes most common)
 - Intussusception, gangrenous bowel
 - *poor prognostic factors include: WBC >20,000
 - anuria > 1 week
 - CNS involvement
8. Management: supportive care
 - Blood pressure control (calcium channel blockers, nitroprusside)
 - PRBC infusions
 - Fluid management
 - Correction of electrolyte imbalance
 - Dialysis, indications for: BUN > 100
 - Fluid overload
 - Electrolyte imbalance
 - *avoid platelet transfusions- may contribute to microthrombosis
 - *plasmapheresis may be helpful, more likely in atypical cases

Reference: Corrigan et al. Hemolytic-Uremic Syndrome. *Pediatrics in Review*: 22(11) November 2001.

G. Hematology/Oncology

Tumor Lysis Syndrome

1. Definition:
 - acute tumor lysis syndrome is the consequence of the rapid release of intra-cellular metabolites (potassium, phosphorus and uric acid) in quantities that exceed the excretory capacity of the kidneys
 - potential complications include acute renal failure and hypocalcaemia-onset of tumor lysis is most commonly seen at the onset of therapy for malignancies that are especially sensitive to chemotherapy (i.e., Burkett lymphoma, T cell lymphoma, and other lymphoid malignancies especially with hyperleukocytosis) -usually seen between day 1 and 5 of treatment but may present before onset of therapy secondary to spontaneous tumor degradation
2. Pathophysiology:
 - lymphoblasts contain 4 times the content of phosphate of normal lymphocytes; when the calcium phosphate product exceeds 60, calcium phosphate precipitates in the renal tubules and microvasculature causing renal failure

- hyperkalemia can result from tumor lysis or renal failure
- an elevation in uric acid results from the breakdown of nucleic acids; urates precipitate in the acid environment of the kidney, causing renal failure
- hypocalcaemia occurs secondary to compensatory mechanisms to maintain the calcium phosphate product at 60

3. Evaluation:

- repeated physical examination
- monitor urine output, blood pressure; check weight at least twice daily
- monitor serum creatinine, uric acid, calcium, sodium, phosphate and potassium at least **every 8 hours** until the high risk period is over
- if oliguria occurs, consider imaging with ultrasound or CT scan to look for obstructive uropathy
- EKG with hyperkalemia

4. Prevention:

- **aggressive hydration** to maintain urine output at >5ml/kg/h before chemotherapy and at >3ml/kg/h once chemotherapy begins
- **allopurinol** 300mg/m²/day divided TID- a xanthine oxidase inhibitor, inhibits the breakdown of amino acids into uric acid
- **alkalinization** of the urine pH from >6.5 to <7.5 with NaHCO₃ to increase the solubility of urates and avoid precipitation of crystals in the kidneys
- consider diuresis with lasix or mannitol to achieve desired urine volume
- avoid potassium in fluids

5. Management:

Hyperuricemia

- continue allopurinol/alkalinization

Hyperphosphatemia

- maintain urine output, low-phosphate diet, aluminum hydroxide 150mg/kg/day divided q4-6 hours hyperkalemia
- administer calcium to stabilize cardiac cell membranes sodium bicarbonate at 1-2 mEq/kg IV to drive K into cells
- administer insulin at 0.1U/kg/h simultaneously with glucose (1/2 gram/kg) to move excess potassium into cells, monitor serum glucose carefully sodium polystyrene sulfonate (Kayexalate) to remove K, not useful in emergencies

Hypocalcaemia

- treat with CaCl or Ca gluconate if symptomatic

Dialysis

- indications include: fluid overload with CHF, anuria, electrolyte disturbances intractable to other treatment or with symptoms/EKG findings

Venoocclusive Disease

1. Definition:

- a serious complication of bone marrow transplantation that occurs early in the post-transplant course, with clinical onset usually between day +7 and day +20

- clinical syndrome consisting of sudden weight gain, ascites, and hyperbilirubinemia
2. Pathophysiology:
 - caused by occlusion of the hepatic venules by cellular debris and endothelial swelling related to the toxic effects of the conditioning regimen
 - results in sclerosis of the terminal hepatic veins which leads to increased resistance and the development of portal hypertension
 3. Evaluation:
 - monitor urine output and fluid balance closely
 - twice daily weight measurements
 - blood pressure monitoring
 - daily labs including bilirubin, LFT's
 4. Prevention:
 - aggressive hydration during pre-conditioning phase to preserve filling pressure and prevent further collapse of the hepatic venules
 5. Treatment:
 - aggressive hydration
 - renal dose dopamine 3-5 mcg/kg/min to maintain urine output
 - diuretics i.e., metolazone, furosemide, bumetanide
 - maintain serum albumin >3g/dL to help maintain intravascular volume

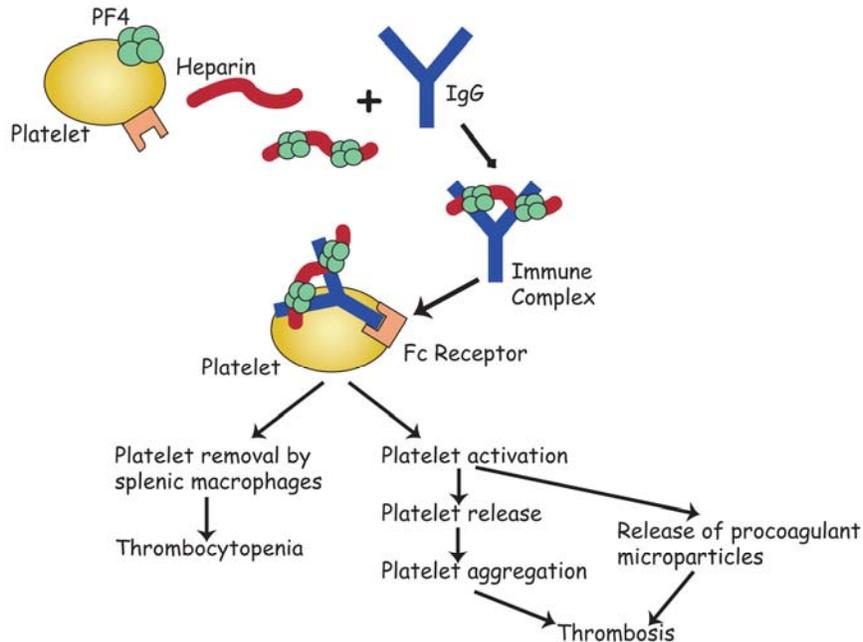
Dilutional coagulopathy (coming)

Disseminated intravascular coagulation (coming)

Heparin Induced Thrombocytopenia

1. Cause and Clinical Significance of Heparin-Induced Thrombocytopenia (HIT):

HIT is the most common drug-induced thrombocytopenia in adults, complicating 1-4% of full-dose exposures to standard heparin. Unlike other thrombocytopenias, HIT carries a high thrombotic morbidity (30-50%) and mortality (10-15%) because it is a syndrome of platelet activation. Heparin forms a complex with platelet factor 4 (PF4) which is released from platelets by platelet activation. Antibody directed against the heparin-PF4 complex binds via its Fab region. The antibody-heparin-PF4 immune complex binds to the Fc receptor on the surface of the platelet leading to activation of the platelet. [Fig. 1]



2. Clinical Characteristics of HIT:

In HIT, the platelet fall is usually 40-50% and the thrombocytopenia is moderate (30-100). The onset is 5-10 days after first exposure to heparin and hours to 2-3 days with re-exposure. In re-operative cardiac surgery in adults either the platelets do not rise post-op, or rise, then fall with no other cause evident. Venous thrombosis (DVT, PE) is more common than arterial (limb ischemia, stroke, MI). Thrombosis may localize to sites of pre-existing pathology (CVLs, shunts, surgical repairs) and be present in unusual locations. Less common presentations include delayed thrombocytopenia (2-3 weeks), heparin-induced skin necrosis (SQ sites), adrenal infarction/hemorrhage, heparin resistance and anaphylactoid reactions

3. Laboratory testing:

Antibody (PF4) ELISAs are sensitive but not specific. More specific for clinical HIT are functional assays based on in vitro heparin-dependent platelet activation (¹⁴C serotonin release, heparin-dependent platelet aggregation, lumi-aggregometry). Unfortunately functional assays are less sensitive and often negative or indeterminate in the first 24-48 hours of HIT. Both assays usually become negative in about 3 weeks, making it difficult to diagnose previous HIT.

4. Treatment:

ALL heparin (lines, flushes, heparin-coated catheters, low molecular weight heparins) must be stopped. Platelet transfusion should be AVOIDED (transfusion may precipitate thrombosis) as should warfarin in the acute phase of HIT (its use may precipitate venous gangrene and thrombosis). Use of alternative anticoagulation is imperative in pre-existing or new thrombosis and should be strongly considered for prophylaxis (up to 50% of asymptomatic patients thrombose). Argatroban, a hepatically excreted, synthetic anti-thrombin with a $t_{1/2}$ of ~ 40-50 minutes, is presently our choice. It is only available IV. Usual dose is 2mg/kg/min by continuous infusion. All patients with HIT should have a hemostasis/thrombosis consult.

I. Shock, SIRS, MOSF

Shock

1. Definition:

- inadequate tissue perfusion to supply oxygen and nutrients to meet the metabolic demands of the body
- three major types include *hypovolemic, distributive and cardiogenic*
- **hypovolemic shock** is the most common form, and is due to an absolute loss of volume from the vasculature (blood loss (hemorrhage), body water loss (dehydration) or loss of plasma)
- **distributive shock** results when total circulating volume has been redistributed and a functional hypovolemic state results (seen in sepsis, Neurogenic shock and anaphylaxis)
- **cardiogenic shock** occurs when the heart is unable to maintain cardiac output (may be intrinsic i.e., heart failure or extrinsic i.e. tamponade)
- **compensated shock** is the state of tissue hypoperfusion in which adaptive physiologic responses are still able to maintain blood pressure
- **decompensated shock** is the state in which the adaptive physiologic responses can no longer compensate and central organ perfusion is no longer maintained as heralded by hypotension

2. Evaluation:

rapid evaluation of airway, breathing and circulation

Clinical history

- underlying disease, recent infection or illness, trauma, surgery, etc.
- physical exam- ABC's first, heart rate, blood pressure, respiratory rate, pulses, skin perfusion, altered mental status, decreased level of consciousness, urine output, other signs of trauma or focus for indication of infection

Studies- labs including CBC, CMP, blood gas, coagulation panel, blood culture; consider amylase in trauma, lactate

- imaging including chest xray, others in trauma (pelvis/abdomen)
- consider CT of head/abdomen if stable
- consider echocardiogram if possibility of cardiogenic shock
- urine and CSF studies in suspected septic shock

3. Treatment:

- establish a patent airway, ensure adequate oxygenation and ventilation (support cervical spine if trauma suspected)
- establish intravascular access
- fluid resuscitation (crystalloids i.e. normal saline/lactated ringer's, colloids i.e., 5% or 25% albumin, or blood products)
- use of inotropes if fluid resuscitation not adequate (dopamine, dobutamine, norepinephrine among others)
- maintain electrolytes
- evaluate for and treat underlying cause

Clinical Signs	Hypovolemic Shock	Distributive Shock	Cardiogenic Shock
Respiratory Rate	↑	↑ or ↑↑	↑↑
Respiratory Effort	Normal	Normal to ↑	↑↑
Heart Rate	↑	↑ to ↑↑	↑↑
Pulse Quality	Thready	Early-bounding Late-thready	Thready
Pulse Pressure	Narrow	Widened	Narrow
Skin Perfusion	Pink, cool distally, nl or prolonged CR	Pink, often warm early, nl to long CR	Mottled gray or blue, cool to cold, prolonged CR
Level of Consciousness	Usually normal unless severe	Lethargic or confused	Lethargic to coma
Urine Output	Decreased	Decreased	Markedly decreased
Stroke Volume	Low	Normal to increased	Markedly decreased
Preload	Low	Low	Often high
Afterload	High	Low	High
Acidosis	Mild to moderate	Mild to marked	Moderate to marked

*Adapted from PALS Provider Manual, AAP, 2002

Intubation

This is a general review of issues relevant to intubation. While the hand skills necessary for performing intubation do take a certain amount of practice, the decision of when to intubate and the choice of technique is of at least equal importance, and is often ignored. While you may not acquire significant “hands on” training in intubating non-neonates during your pediatric residency, you will have the opportunity to learn how to decide when someone should be intubated, as well as the potential complications and problems that may be encountered. THIS KNOWLEDGE MAY BE LIFE-SAVING.

- I. *Indications for intubation--Thinking about the indications will help you decide on a technique.*
 - A. Airway patency
 - B. Requirement for positive pressure ventilation due to pulmonary disease (ie, hypoxia or hypercarbia)
 - C. Significant cardiovascular compromise, shock
 - D. Neurologic-seizures, weakness, head injury

- II. *Techniques*
 - A. Awake, without drugs
 - B. Sedated but not paralyzed
 - C. Anesthetized-+/- rapid sequence induction

- III. *Considerations in determining technique used for intubation*
 - A. Airway anatomy-if primary airway problem, i.e., croup, epiglottitis, foreign body, abnormal anatomy, etc., DO NOT BURN BRIDGES. These patients should not be paralyzed. Paralysis relaxes the pharyngeal muscles, which may obscure landmarks in the difficult airway, and may make bag-mask ventilation difficult. Sedation, along with local anesthetics (i.e., lidocaine spray) may be used to facilitate intubation.
 - B. Cardiovascular stability-hemodynamically unstable patients (i.e., sepsis, toxic shock, certain ingestions) may become even more unstable when sedated, due to loss of sympathetic tone. Any drugs used should be used in smaller doses and titrated to effect. Patients with primary cardiac disease, however, generally do not tolerate unsedated intubations, and carefully titrated anesthesia is warranted.
 - C. Cardiopulmonary arrest-there is no reason to use any pharmacologic intervention. Bag-mask ventilation with cricoid pressure and intubation can generally be accomplished without difficulty.
 - D. “Full stomach”--risk of pulmonary aspiration. These patients should be intubated “awake” to preserve airway protective reflexes, or by *rapid sequence induction* with cricoid pressure.
 1. Recent oral intake
 2. Delayed gastric emptying from ascites, peritonitis, bowel obstruction
 3. Swallowed blood from trauma
 4. Increased intra-abdominal pressure from masses or ascites
 5. Abnormal lower esophageal tone-pregnancy
 6. Gastro-esophageal reflux
 7. Altered level of consciousness

- E. Head injury-laryngoscopy and intubation may lead to increased intracranial pressure in the unanesthetized patient with an evolving head injury. Trauma victims are frequently hypovolemic. Drugs and doses used need to be carefully considered.

IV. *The “awake” intubation*

A. Indications (all relative)

1. Cardiopulmonary arrest
2. Airway anomalies, acute severe upper airway disease
3. Cervical spine injury
4. Facial Trauma
5. Significant hemodynamic instability
6. Any suspicion of difficulty intubating, for any reason.

B. Technique

1. Local anesthetic sprays can be used to topicalize the tongue and pharynx. Nebulized lidocaine (2cc 1% lidocaine in nebulizer) will decrease the laryngospasm and bronchospasm with intubation.
2. Laryngoscopy and intubation should proceed firmly but gently, with attention to the teeth and tongue if the child is struggling

V. *The sedated intubation*

A. Indications

1. Potentially difficult airway
2. Lung disease with moderate to high O₂ requirement (may desaturate during period of apnea necessary for rapid sequence intubation)

B. Technique

1. Carefully titrated drugs, watching for hemodynamic as well as sedative effects. If hemodynamics are stable, more drug can be given if necessary.
 - a. Versed, 0.05-0.1 mg/kg. Use lower doses in the setting of hypovolemia, sepsis, or poor cardiac function.
 - b. Ketamine, 0.5-2.0 mg/kg. Indirect sympathomimetic preserves cardiac output and systemic BP in acutely hypovolemic patients. Direct bronchodilatory properties. Potent sialogogue (premedicate with atropine or glycopyrrolate). Co-administration of a small dose of benzodiazepine will reduce emergence phenomena.
2. Monitor degree of sedation carefully. Watch for signs of impending vomiting or respiratory depression. Gentle ventilatory assistance through cricoid pressure is sometimes necessary in extremely hypoxic or unstable patients.

VI. *The anesthetized intubation--rapid sequence induction*

A. Indications

1. “Full stomach” conditions
2. Head injury
3. Asthma
4. Common theme-Desire to blunt undesirable physiologic response to intubation-hypertension, tachycardia, bronchospasm, increased intracranial pressure.

- B. Contraindication-anticipated difficulty with securing airway, i.e., anatomic abnormality or airway pathology. **NEVER** sacrifice airway safety for the sake of pharmacologic intervention.
- C. Technique-rapid sequence refers to rapid infusion of medications, followed by a brief period where airway protective reflexes are lost, followed by ideal intubating conditions. During the period after medications are given, cricoid pressure is applied and positive pressure ventilation is avoided.
1. Preoxygenate with 100% O₂
 2. NG (if present) to suction. Have suction (LARGE Yankauer) available!!!
 3. Medication sequence--**cricoid pressure** should be applied from the moment drugs are given until the ETT is confirmed to be in the proper position. No positive pressure ventilation.
 - a. Atropine
 - b. Sedation
 - c. Paralysis
 4. When fully relaxed, intubate the trachea, remove the stylet, and attach bag.
 5. If difficulty with intubation arises, or the patient had more lung disease than you anticipated and desaturates significantly without positive pressure ventilation, GENTLY BAG MASK VENTILATE the patient, get the saturations up, and try again.
 6. Confirm ETT placement by breath sounds, mist in tube, ETCO₂ device. Confirm correct placement with CXR.
- D. Drugs to facilitate intubation
1. Atropine 0.02 mg/kg, minimum 0.1 mg
 2. Sedation-Benzodiazepine +/- narcotic, or ketamine, or thiopental.
 - a. Versed 0.05-0.1 mg/kg
 - b. Morphine 0.2 mg/kg or fentanyl 1-2 mcg/kg
 - c. Ketamine 0.5-2 mg/kg
 - d. Thiopental 2-6 mg/kg
 3. Paralysis
 - a. Rocuronium 1.2 mg/kg achieves intubating conditions in 60 seconds. Duration of paralysis 30-60 minutes. Should not be used if there is any anticipated difficulty achieving intubation.
 - b. Succinylcholine 1-2 mg/kg, achieves intubating conditions in 45 seconds. Duration of paralysis 5-8 minutes. This is a long time if you can't get the airway or bag mask ventilate the patient. BE CAREFUL.
- E. Untoward effects of succinylcholine
1. Cardiovascular-succinylcholine stimulates the vagus nerve and sympathetic ganglia leading to bradycardia, hypertension, or hypotension. Atropine prior to administration may prevent bradycardia.
 2. Hyperkalemia-With depolarization there is opening of acetylcholine receptor channels, allowing efflux of potassium from the cell through receptors in the muscle end plate and extra-junctional receptors. In normal patients, there is a rise in serum potassium of 0.5 meq with a dose of succinylcholine. In certain disease processes, there is an upregulation of acetylcholine receptors, and hence, a massive increase in serum potassium with the administration of

succinylcholine. *These include:* burns (3 days to 6 months after injury), spinal cord injury (3 days to 1 year after injury), tetanus, severe intra-abdominal infections, Guillain-Barre syndrome, Duchenne's Muscular Dystrophy, Myotonic Dystrophy, multiple sclerosis, many progressive neuromuscular diseases.

3. Malignant hyperthermia-Succinylcholine is one of the agents that "trigger" MH, a hypermetabolic response to a triggering agent characterized by fever, tachycardia, tachypnea, acidosis, hyperkalemia, ventricular dysrhythmias, and rhabdomyolysis. The mortality is high. Risk factors include positive family history, Duchene's Muscular Dystrophy, and certain myopathies.
4. Increased intraocular pressure
5. Rhabdomyolysis and myoglobinuria
6. Muscle pain-reduced if a defasciculating dose of pancuronium is used
7. Increased intragastric pressure
8. Increased intracranial pressure-blunted by pretreatment with adequate sedation and a defasciculating dose of pancuronium.

Equipment

For any and all intubations, have available:

- **Large suction catheter** "Yankauer" and reliable suction.. 2 suction setups if bleeding. DO NOT use small suction catheters.
- **Bag** and appropriate sized **mask**
- **Oxygen** source
- **Endotracheal tubes**--one up, one down from anticipated size needed
- **Laryngoscopes**-at least 2, preferable 1 straight blade, one curved blade. **CHECK LIGHTS**
- **Stylet**, with lubrication
- **Oropharyngeal** airways
- **Tape**
- **CO2** monitoring device
- **Ventilation** system

Extubation

- Confirm that there is an airleak around the ETT. The airleak should occur at <20cm H2O. If there is no leak, there may be increased risk of stridor and airway obstruction due to tracheal edema. Consider decadron (0.5-1.0 mg/kg/dose, 4 hours before extubation, generally continued for 3-4 doses q6.
- The patient should have been off feeds for 4-6 hours prior to extubation. EVERY EXTUBATION IS A PLANNED RE-INTUBATION.
- Confirm that patient is sufficiently awake and spontaneously breathing, oxygenation is adequate on PEEP <=5, and <=40% O2, and ventilation is adequate.
- Obtain all supplies at bedside for intubation. EVERY EXTUBATION IS A PLANNED RE-INTUBATION. If there is significant concern, have meds drawn up.
- Have epinephrine aerosol available if there is concern that the patient will have stridor
- Suction mouth well, suction trachea via ETT

- Untape ETT and remove
- Observe for ventilation and oxygenation, air movement, stridor or weakness.

Central Line Placement

- A. Indications: Need for central venous pressure monitoring, need for reliable venous access.
- B. Procedure:
 1. Decide on site: subclavian vein, internal jugular vein (contraindicated in patients with increased intracranial pressure), femoral vein (contraindicated in patients with severe abdominal trauma).
 2. Prep and drape area in sterile manner
 3. Approach:
 - a. Internal jugular: place patient in 15-20° angle Trendelenburg position, hyperextend the neck and turn head away from site of line placement, palpate sternal and clavicular heads of the muscle and enter at the apex of the triangle formed, insert needle at 30° angle to skin and aim toward ipsilateral nipple
 - b. Subclavian vein: place patient in Trendelenburg position, hyperextend back with towel roll under thoracic spine, aim needle from distal third of clavicle toward sternal notch
 - c. Femoral vein: flex and abduct hip, locate femoral pulse just distal to inguinal crease, place finger on femoral artery to locate, insert needle at 30° angle to skin medial to pulse which should be 2-3cm distal to inguinal ligament, aim for umbilicus
 4. When blood return occurs, remove syringe and insert guidewire through needle 1/2 to 3/4 the length of the wire. If wire does not thread easily and smoothly, do not force it. Wires are designed to be the appropriate length for the catheter being inserted. If you need an additional wire, it must be at least twice the length of the catheter including the hub.
 5. Remove needle-holding guidewire firmly. NEVER let go of the wire.
 6. Enlarge the entry site with a small dilator. You may need to make a skin nick with blade.
 7. Slip catheter (preflushed with sterile saline) over wire into vein with a twisting motion until hub is at the skin. NEVER let go of the wire.
 8. Remove the guidewire
 9. Secure catheter with sutures
 10. Attach IV tubing
 11. Apply sterile dressing
 12. For IJ or subclavian line, obtain CXR to rule out a pneumothorax. For a femoral vein on the left, obtain abdominal XR to confirm that the line is in the vena cava.

Intraosseous needle placement

- A. Indications: Need for emergency venous access, for infusion of fluids or medications.
- B. Procedure
 1. Prep area in sterile manner
 2. If the patient is conscious (i.e., not a code situation) using 1% lidocaine, anesthetize puncture site down to the periosteum
 3. Insert the IO needle perpendicular to skin and down to the periosteum—use a boring motion, a decrease in resistance indicates penetration to marrow and needle should stand firmly without support
 4. Secure needle with dressing and tape. Leave the back of the leg free so you can assess for extravasation
 4. Remove stylet and aspirate marrow (can be sent for glucose, chemistries, type and cross but not CBC)
 5. Infuse 10-20 ml NS and watch for extravasation
 6. Attach standard IV tubing. Any crystalloid, blood product, or drug that can be infused in PIV can be infused in IO with high pressure system. Dress the IO so that it is not dislocated.

Lumbar puncture

- A. Indications: Obtain CSF to evaluate for infection, other disease, evaluate opening pressure.
- B. Procedure:
 1. Apply EMLA to lumbar area, if there is sufficient time (about 20 min prior to LP). Patients who are intubated may be sedated and/or relaxed for the procedure. If they are on a spontaneous mode of ventilation, change to a controlled mode for the procedure and sedation. Consider increasing FiO₂ for the procedure.
 2. Position child in lateral decubitus or sitting with hips, knees and neck flexed.
 3. Locate L3-4 or L4-5 intervertebral space
 4. Prep and drape in sterile manner
 5. Infiltrate skin and interspinous tissue with 1% lidocaine
 6. Use a 20- or 22-gauge spinal needle with stylet and 1.5 inches for infants and small children, 2.5 inches for older slender children, and 3.5 inches for older obese children
 7. Insert the needle at the L3-4 or L4-5 intervertebral space advancing until there is a decrease in resistance or the feeling of a pop as the dura is penetrated
 8. Remove the stylet and check for CSF flow
 9. If measuring opening pressure, attach manometer once CSF is flowing. Read opening pressure when CSF stops flowing up the manometer tubing. There will be some respiratory and/or cardiovascular variation (i.e., “bounce”).
 10. Collect about 1cc per tube and send tubes for 1) culture and gram stain 2) glucose and protein 3) cell count and differential 4) hold. Consider whether or not you want CSF for viral cultures or HSV PCR.

Chest Tube Placement (traditional chest tube):

- A. Indications: Pneumothorax, pleural effusion, emphysema, chylothorax
- B. Procedure:
 1. Consider need for sedation.
 2. Position child supine or with affected side up
 3. Locate the 3rd to 5th intercostals space in the mid to anterior axillary line avoiding breast tissue
 4. Prep and drape in sterile manner
 5. Anesthetize skin, subcutaneous tissue, periosteum of rib, chest-wall muscles and pleura with 1% lidocaine
 6. Make sterile incision one intercostal space below target and bluntly dissect with hemostat until superior portion of rib is reached (Remember nerve-artery-vein run along the inferior side of the rib!)
 7. Push hemostat over tope of rib, through pleura and into pleural space—don't go deeper than 1 cm into pleural space
 8. Spread open hemostat and place chest tube in clamp, then guide to desired distance
 9. Placement: pneumothorax—insert tube anteriorly toward apex, pleural effusion—insert tube inferiorly and posteriorly
 10. Secure tube with purse-string sutures: suture first tied to skin, then wrapped around tube once and tied at the tube
 11. Attach tube to drainage system with -15 to -20 cm H₂O pressure
 12. Apply an occlusive dressing
 13. Obtain CXR to confirm position

Chest Tube Placement (pigtail chest tube):

- A. Indications: Pneumothorax, pleural effusion, chylothorax. These tubes work well for most things except blood and thick empyemas.
- B. Procedure: (basically Seldinger technique)
 1. Consider need for sedation.
 2. Position child supine or with affected side up
 3. Locate the 3rd to 5th intercostals space in the mid to anterior axillary line avoiding breast tissue
 4. Prep and drape in sterile manner
 5. Anesthetize skin, subcutaneous tissue, periosteum of rib, chest-wall muscles and pleura with 1% lidocaine
 6. Insert needle with 10cc syringe attached, aim to midpoint of rib, then “walk” OVER the rib into the pleural space. (Remember nerve-artery-vein run along the inferior side of the rib!)
 7. Withdraw air or fluid to confirm placement
 8. Insert guidewire
 9. Withdraw needle over guidewire. NEVER LET GO OF THE WIRE.
 10. Insert dilator over wire to dilate the tract. Remove dilator

11. Insert pigtail catheter over the wire. Aim up and anteriorly for pneumothorax, down and posteriorly for fluid.
12. Remove wire.
13. Secure tube: suture first tied to skin, then wrapped around tube once and tied at the tube
14. Attach tube to drainage system with -15 to -20 cm H₂O pressure
15. Apply an occlusive dressing
16. Obtain CXR to confirm position
17. Send fluid for studies if needed.

Arterial Line Placement:

- A. Indications: Need for minute to minute blood pressure monitoring, need for arterial blood gas monitoring, need for frequent labs in the absence of a functioning central venous line.
- B. Procedure: (There are multiple techniques for placing an arterial line. This is one method.)
 1. Test with Allen test first: clench hand while simultaneously compressing ulnar and radial arteries, watch for hand to blanch, then release ulnar artery and entire hand flush. If entire hand flushes, procedure is safe to perform.
 2. Locate radial pulse
 3. Secure hand to arm board, leaving fingers exposed
 4. Prep and drape in sterile manner
 5. Infiltrate area of maximal impulse with 1% lidocaine—aspirate first to ensure that you're not in the artery
 6. Use a needle to make a small skin puncture over point of maximal impulse and discard needle
 7. Insert an IV catheter with needle through the puncture site at 30° angle to horizontal
 8. Pass needle and catheter through artery to transfix it and then remove needle
 9. Very slowly withdraw the catheter until free flow of blood is noted
 10. Insert wire. Wire should pass easily
 11. Advance catheter and remove wire. Secure in place with sutures or tape
 12. Apply an antibiotic ointment dressing
 13. Infuse heparinized isotonic fluid (1 unit heparin/ml)
 14. Attach pressure transducer

NOTE: Do not infuse any medication, blood products, or hypotonic or hypertonic solution through an A-line

RADIOLOGY:

CT Head/Body:

Ordering guidelines: always give an indication

Specific considerations: Head--order with contrast to r/o infection or abscess, order with IV and PO contrast when evaluating the abdomen. PO contrast takes time to administer and is not needed to evaluate the liver or spleen. Consider the need for sedation.

MRI head/body:

Ordering guidelines: always give an indication. Consider if you need DWI, FLAIR, etc. If in doubt, ask neuroradiologist or neurologist.

Specific considerations: consider sedation for infants or children. If the patient is intubated, the PICU staff can provide continued sedation. If the patient is not intubated, consider the need for sedation service.

Angio Head/Body:

Ordering guidelines: always give an indication

Specific considerations—you will need to speak with the radiologist to determine the best study and any special considerations. Many of these will need to have sedation or anesthesia.

Vascular lab:

Ordering guidelines: always give an indication. Specify exactly what vessels you want

Specific considerations. If evaluating for SVC syndrome, you need to get an echocardiogram.

Ultrasound:

Ordering guidelines: always give an indication

Specific considerations: call radiology resident if done at night or on weekends

Mechanical Ventilation in the PICU

This fundamental tool in the PICU serves to support the patient in respiratory failure by ensuring adequate ventilation and oxygenation.

Mechanical Ventilation Basics:

Volume Control	Controls	Pressure Control
Rate		Rate
PEEP		PEEP
FiO ₂		FiO ₂
Tidal Volume (TV)		PIP
Inspiratory Time (IT)		IT
Relative Advantages/Disadvantages		
Known TV		No guarantee of TV

Ventilators used in the PICU		
Ventilators	Types of Ventilation	Modes
Servo 300	volume and pressure	PC/VC/SIMV/SIMVcPS/PS, PRVC/VS/CPAP
Infant Star	pressure	SIMV and Assist Control
LP-10	volume and pressure	SIMV and Assist Control
Sensormedics 300 A, B	High frequency	High frequency

Volume Control Ventilation

These ventilators work by delivering whatever pressure is necessary to achieve a set volume. You can set the respiratory rate and the tidal volume (TV). To control the pO₂ you can adjust the FiO₂, the PEEP, and the inspiratory time. PCO₂ is controlled by adjusting the tidal volume and the rate.

Pressure Control Ventilation

In these ventilators, the operator sets the PIP and the machine generates the volume necessary to achieve the set pressure. PCO₂ is controlled by adjusting the respiratory rate and TV. TV is directly proportional to ΔP (PIP-PEEP). As in Volume Control, you can adjust the FiO₂, PEEP, and inspiratory time to affect the pO₂.

Modes of Mechanical Ventilation: Control Modes (Assist Control Modes) vs. Support Modes

Control modes (VC, PC and PRVC) deliver a set breath which is set by the physician. If the patient breathes over the set rate, he or she will receive a fully supported breath, regardless of how much effort is generated. **Support Modes** (VS, PS, CPAP, BiPAP, and SIMV with PS) serve to augment breaths being generated by the patient spontaneously and reliably.

Characteristics of Ventilation Modes

<p>IMV (Intermittent Mandatory Ventilation)</p> <p>Set breath delivered at a fixed interval. No patient interaction, pressure or volume modes.</p> <p>Uses: Commonly for neonates. Contraindications: uncomfortable Advantages: Regular breaths guaranteed. Disadvantages: Patient is not allowed to breathe with the ventilator, i.e. doesn't work with the patient. Ventilator: Sechrist and most others.</p>	<p>SIMV (Synchronous IMV)</p> <p>Set breath delivered within an interval based on the set rate ("master rate"). Ventilator waits for a spontaneous breath by the patient as a trigger to deliver a full breath. If this is not sensed it automatically gives a breath at the end of the interval period. Any other breaths during the cycle are not supplemented</p> <p>Uses: Common in many settings. Can be used as a weaning mode (See SIMV w/ PS). Contraindications: None. Advantages: Works with the patient. Friendlier mode. Disadvantages: Any other breaths during cycle are not supplemented. Ventilators: All but the Sechrist.</p>
<p>PS (Pressure Support)</p> <p>Supports each spontaneous breath with supplemental flow to achieve a preset pressure. Gives a little "push" to get air in.</p> <p>Uses: Helps to overcome airway resistance of the ET tube in the spontaneously breathing patient. Useful as a weaning mode. Contraindications: Patient who is not spontaneously breathing. Advantages: Helps overcome resistance of the ET tube, making spontaneous breathing easier. Disadvantages: Can be uncomfortable for small patients, need to have appropriate sensing. Ventilators: All but the Sechrist.</p>	<p>SIMV w/ PS</p> <p>Combination of SIMV and PS. Extra breaths in the cycle are supplemented with pressure support.</p> <p>Uses: Most circumstances. Weaning mode. Contraindications: None. Advantages: Allows both synchrony with the patient and helps in overcoming the ET tube resistance, allowing easier spontaneous breathing. Disadvantages: Occasional difficulty with the pressure support for some patients. Not useful for the patient who is not spontaneously breathing. Ventilators: All but the Sechrist</p>

<p>AC (Assist Control) or VC (Volume Control)</p> <p>Preset rate and tidal volume (sometimes PIP), either on the patient's initiative or at the set interval a full mechanical breath is delivered.</p> <p>Uses: For patients who have a very weak respiratory effort. Allows synchrony with the patient with maximal support. Patient is on complete mechanical support in this mode.</p> <p>Contraindications: None.</p> <p>Advantages: Provides a great deal of support; fairly comfortable.</p> <p>Disadvantages: Can lead to hyperventilation if not closely monitored. Not a weaning mode.</p> <p>Ventilators: LP-10, Servo 900, Infant Star</p>	<p>PC (Pressure Control)</p> <p>Essentially IMV. Breath is controlled by the Pmax, not the set tidal volume.</p> <p>Uses: In neonates or patients with high airway pressures (ARDS) to avoid barotrauma.</p> <p>Contraindications: Not a friendly mode in the awake patient.</p> <p>Advantages: Pressure limited, decreases barotrauma risk.</p> <p>Disadvantages: No guaranteed TV.</p> <p>Ventilators: All.</p>
<p>PRVC (Pressure Regulated Volume Control)</p> <p>A volume control assist control mode. Adjusts flow rate of the delivered air to achieve set TV at or below the set maximum pressure. Decelerating flow pattern.</p> <p>Uses: All patients. Especially in patients with high airway pressures. Perhaps more friendly to awake patients than SIMV.</p> <p>Contraindications: None.</p> <p>Advantages: Delivers a guaranteed tidal volume while minimizing barotrauma.</p> <p>Disadvantages: None.</p> <p>Ventilators: Only available on the Servo 300.</p>	<p>CPAP (Continuous Positive Airway Pressure)</p> <p>Same as PEEP.</p> <p>Uses: For patients with upper airway soft tissue obstruction or tendency for airway collapse. As a final mode prior to extubation in some patients.</p> <p>Contraindications: Any patient w/o spontaneous respiratory effort. Not a good idea in a patient with obstructive pulmonary disease (asthma, COPD)</p> <p>Advantages: Simple, easy to use.</p> <p>Disadvantages: Provides no supportive ventilation.</p>

Where to Start: Initial Ventilator Settings

Obviously, the individual patient and clinical setting will determine the mechanical ventilation needs, but the following is a good place to start, realizing that the settings will most likely require adjusting to achieve the desired effect.

	Preemie	Infant/Toddler	Child	Adolescent/Adult
Rate	40	30	20	12

Inspiration Time (IT) sec	0.4	0.6	0.7	.9
PIP (P-Peak) cm H ₂ O	16	20	20	20
Tidal Volume (TV) ml/kg	5-10	5-10	5-10	5-10
PEEP	4-5	4-5	4-5	4-5
FiO ₂	1.0 →	Titrate	Down	As Tolerated

Things to Watch Out For:

1. Peak Pressures: Keep below 30-35 to reduce risk of barotrauma.
2. Oxygenation: Want to wean down as quickly as is safe to about 0.6. Inability to wean implies V/Q mismatch. May need to increase PEEP, I-time.
3. Ventilation: Utilize blood gases to guide your ventilation rate. Obtain first gas 15-20 minutes after initially starting ventilation or after major changes. Non-invasive monitoring—ETCO₂ and Oxygen saturation may allow you to do many fewer blood gases.
4. Follow the trend. The trend is your friend, know what it is. The trend is more important than any specific blood gas, oxygen saturation, or chest film.

Resources:

1. Hammer GB, Frankel LR. Mechanical ventilation for pediatric patients. *Int Anesthesiol Clin.* 1997; 35(1): 139-67.
2. Lectures and printed material provided by Ken Tegtmeyer MD (<http://homepage.mac.com/tegtmeyer/residents/vents.html>); Mohan Mysore MD; Mark Wilson MD.

High Frequency Oscillatory Ventilation (HFOV)

Candidates for HFOV:

1. Hyaline Membrane Disease (HMD), aspiration etc. as evidenced by bilateral diffuse, homogenous lung disease on CXR.
2. Patients requiring hyperventilation including ECMO candidates and patients with pulmonary hypertension.
3. Pediatric patients with acute lung injury/ARDS, general guidelines include PEEP >10, FiO₂ >60%.

What to set

1. MAP—Mean airway pressure. Affects degree of recruitment of alveoli and expansion of the lung.

2. Hz—Hertz, cycles per second. Affects ventilation. The LOWER the Hz, the more the piston moves, and the BETTER the ventilation.
3. Power—How MUCH the piston moves, works like “tidal volume”. The amount of gas displaced is less than dead space.

How to start

1. Patient <30K, use 300A, patient >30 kg, use 300B.
2. MAP—4-8 higher than the MAP on conventional ventilation. The worse the complacence, the more the increase will need to be.
3. Hz—smaller patient, higher Hz. Infant-10-14, toddler-6-10, child-5-8, adolescent 4-6.
4. Power—look for CWF (chest wiggle factor). The chest should wiggle, and you should see the wiggle down to the groin.
5. Check x-ray “soon” and repeat in 6-12 hours.
6. Suction as INFREQUENTLY as possible
7. Treat bronchospasm aggressively.

Evaluation and Management of the Post-Surgical Patient in the PICU-An Overview

Why should the Pediatrician know anything about surgery and surgical patients?

There are a number of reasons for our involvement with the surgical patients. Surgical patients are excellent examples of organisms under stress, and a great deal of acute physiology can be learned by caring for them--airway and pulmonary issues, fluid/electrolyte issues, neuroendocrine response to stress, pain and sedation, etc. The patient in ICU must be cared for in a collaborative fashion with the primary surgical service. In general, pediatricians know about infants and children, and "medical" issues, and surgical attendings/residents know about "surgical/technical" issues. If a collaborative relationship is formed, the patients will receive the best of both sets of knowledge. Finally, because of the potential for miscommunication to lead to mis-understandings and problems with care, these patients present excellent opportunities to practice the art of communication and finesse.

Post-operative care must be approached in an organized, timely manner, with attention to the acute nature of the patient's changing physiology. Before the patient arrives, you should familiarize yourself with the patient's past medical/surgical history and the planned surgical procedure. If you don't know what the disease and/or the operation is--ASK or READ! There is usually information available somewhere. Only when you know what they planned to do, and what they did it on, will you be prepared to evaluate your patient when he/she arrives, and anticipate potential problems that you must watch for.

When the patient arrives--the *initial* evaluation

The patient has just undergone general anesthesia, been intubated +/- extubated, and had some fairly invasive procedure performed.

Thus:

ABCs

Look at the breathing pattern

Listen to the chest--breath sounds, stridor?

Listen to the heart--gallop, murmur?

Feel the pulses--strong, weak, thready?

The Anesthetic Record--what it contains, what you need?

The anesthetic record can be viewed as the "history of present illness" for the surgical patients--it contains information related to maintaining physiologic stability during the course of the operation. You will need to learn to read it and interpret the information it contains. Each hospital's record is somewhat different, but all will contain the following information:

1. Induction of anesthesia--IV or mask, smooth or difficult?
2. Intubation--rapid sequence?, blade and tube size used, number of attempts, any notations about anatomy?

3. Maintenance of anesthesia--potent inhalational agents (halothane/isoflurane/sevoflurane), nitrous oxide, narcotics, propofol. Regional techniques--epidural, caudal, local infiltration or Nerve block.
4. Ventilator parameters--rate, tidal volume, FiO₂
5. Vital signs--BP, HR, SaO₂, temp
6. Fluids--ins and outs--type or fluid, crystalloid/colloid/blood
7. Blood loss
8. Any “events” should be recorded
9. Extubation--problems, especially bronchospasm or stridor
10. ANY drugs given (including antibiotics)
11. Lines and tubes

Fluids in the Operative and Post-operative patient

Pediatrician: “Why do they always get so much fluid?”

Anesthesiologist: “Because they need it”

The anesthesiologist must provide maintenance (=preoperative hydration status+length of NPO+normal 4,2,1 maintenance needs) + replacement of “third space” losses (open belly, hot lights, extensive dissection of tissues) + replacement of blood loss (see later discussion). Major abdominal procedures can lead to losses of 15 cc/kg/hr in “third space” losses which must be replaced.

Effect of Anesthesia on Fluid Balance:

General anesthesia produces vasodilatation and some degree of myocardial contractility (usually overcome by sympathetic drive induced by the surgical stimulus), and thus a volume bolus may be needed. Mechanical ventilation can increase evaporative loss if gases are not adequately humidified, which is often the case during long OR procedures. These factors will increase the need for volume/fluid. Other factors, including increased intrathoracic pressure brought about by mechanical ventilation, a stress response to surgical stimulus, or the prone position, may lead to increased ADH production and decreased urine output. Hence, usual fluids are isosmotic (L. or NS, with or without Dextrose), and urine output may not reflect intravascular volume status.

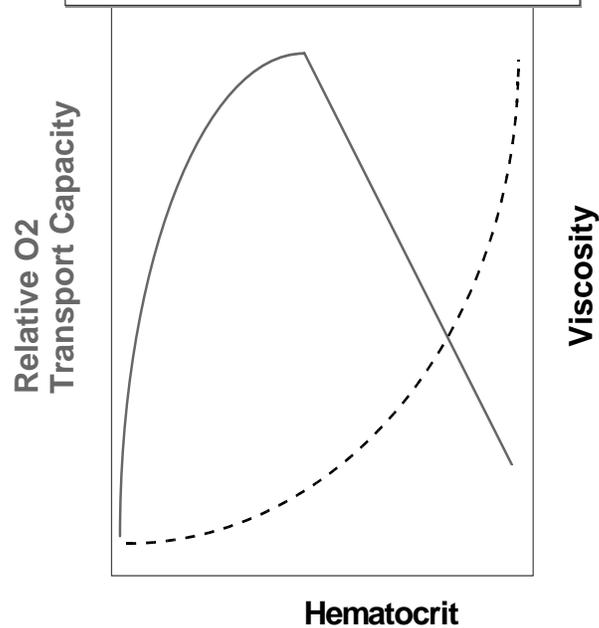
Assessment of Fluid Balance:

Vital signs (HR/BP) combined with a knowledge of the *amount* of anesthesia being delivered, urine output (with above caveat in mind), acid-base status, and occasional invasive monitoring (CVP, PA catheter) are used to estimate how balance the patients fluid/volume status is. As you might imagine, this can sometimes be difficult.

Types of Fluids

For resuscitation purposes (including the OR), fluids are categorized as crystalloid (salt solutions) or colloids. There is much discussion about which is better, what the cost/benefit ratio is, etc. You should at least be aware of which is which, and of the implications of choosing one over the other.

Is There an Optimal Hematocrit?



Sodium will leave the vascular space and go into the interstitial space, but be excluded from the intracellular space by the Na-K exchanger. Albumin is retained more in vascular space, if the capillaries are intact. Water flows along its concentration gradient, hence, water will leave the vascular space with the sodium, and less so with albumin. Thus, after about an hour for fluid shifts, 1 liter gets you about 200ccs of intravascular space if NS, about 500cc if albumin.

Others:

L.--125cc

NS--180cc

5% albumin--490cc

Hetastarch--710cc

Whole blood--900cc

7.5%

BLOOD loss and replacement

Blood loss in the operating room is *estimated*, but this may be inaccurate, especially during long cases. One needs to consider replacing volume, cells, and coagulation factors. Coagulation factors will only become a clinically relevant issues with massive transfusion or DIC. There is controversy (in the literature and with respect to individual patients) regarding when one needs to transfuse the patient. Remember that the function of red cells is to carry hemoglobin, carried by cardiac output. O₂ transport capacity will thus be a factor of Hg level and the ability of the Hg to get to cells--which will be adversely affected by hyper viscosity. Thus the “optimal” hematocrit is probably somewhere around 30-35. This does not, however address the issue of “tolerable” hematocrit--healthy patients will tolerate much lower hematocrits, and there is a risk involved in any transfusion. Hence, debate.

When to transfuse?

$MABL = (EBV \times (\text{patient hct} - \text{minimum tolerated hct})) / \text{Patient's pre-op hct}$

MABL--maximum allowable blood loss, EBV--estimated blood volume

Example--10 kg healthy child, without significant lung disease

$MABL = 70\text{cc/kg} \times 10\text{ kg} \times (42-25)/42 = 285\text{cc}$

Thus, up to 285cc, blood loss can be replaced with crystalloid (at a ratio of 4:1), and any further blood loss should be replaced with packed cells.

Component Therapy

During a massive transfusion, coagulation factors and platelets will be reduced due to dilution, as they are not present in packed cells. What constitutes a “massive” transfusion varies, but 0.75-3.0 blood volumes is a reasonable range. If not replaced, bleeding will be greater, necessitating greater packed cell transfusion, etc. Whole blood does contain coagulation factors, but is very rarely available. One must remember, however, that those injuries which necessitate massive transfusion (IE, large blood loss with resultant acidosis and shock, severe trauma, sepsis) may also lead to DIC (disseminated intravascular coagulation), in which factors/platelets are consumed as well as diluted.

Large Volume Transfusion--other Complications

Hyperkalemia (increased K⁺ in supernatant of packed cells)

Hypocalcaemia (citrate binding of Ca⁺⁺)

Hypothermia is blood warmer inadequate or not used

Altered Oxygen-Hg dissociation curve--shift to left with most blood products (decreased 2,3 DPG), thus, Hg “holds onto” O₂.

Extubation

Criteria for extubation in the operating room are the same as those elsewhere--the patient must have an adequate airway, maintain oxygenation and ventilation (adequate strength as well as lung function), and have a neurologic status able to protect the airway and maintain adequate drive. Patients can be extubated “awake” or “deep” (i.e., asthmatics), but one should avoid extubation in a light plane of anesthesia, which can lead to laryngospasm.

Airway--Is there a tube leak? Is the pre-existing airway pathology that might now be worse? Did the operation affect the airway (trachea, cords, pharynx)

Breathing--Are the lungs normal or abnormal. Has there been enough fluid administered that there is concern about pulmonary edema? Did the operation involve the chest or abdomen in a way that will adversely affect the patient’s ability to breathe deeply?

Neuro--Has anesthesia worn off to a degree that the patient can protect his airway and have adequate drive. (Awake, following commands, spontaneous eye opening, protective airway reflexes) How much/what type of narcotic has been used? Has paralysis worn off/been reversed? (typically, paralytics will be reversed with glycopyrrolate/neostigmine at the end of a case). Small/young infants are at increased risk of apnea following general anesthesia.

Any problems related to extubation should be noted on the anesthesia record, and communicated in report form the OR or PACU.

Post-Operative Issues and Problems

Respiratory

Airway--check ETT size and position if patient returns intubated (CXR) .

Stridor--causes include trauma to trachea or cords, laryngeal edema, recurrent nerve damage, arytenoid dislocation. Treatment is as for viral croup--racemic epi, decadron, and re-intubation if necessary.

If patient’s airway is compromised due to decreased mental status, a jaw thrust and nasal airway may temporize the problem.

Pulmonary--Assess quality of breath sounds, respiratory drive. Check CXR if intubated. Generally patients will require some oxygen due to atelectasis, narcotics, and splinting.

Cardiovascular

Most pediatric patients will not have invasive monitoring in place (IE, CVP, PA line). Some will have arterial catheters. CV status must be assessed clinically, therefore, in the majority of patients. Remember that the In/Outs will not necessarily reflect the patient’s intravascular volume status (due to blood loss replacement, third space losses, evaporative losses). Of note, hypercarbia will lead to sympathetic nervous system activation, with impressive hypertension and tachycardia.

Pain

Most post-operative patients will have pain, which must be addressed in some fashion. Pain relief is best managed presumptively (i.e., don't wait till the patient is in tremendous pain before treating it, and drugs must be TITRATED to effect. Modalities include narcotics (scheduled, prn, PCA), non-steroidals (ketorolac, ibuprofen), Tylenol, and regional techniques (epidural, caudal catheters, nerve blocks). Titration of drugs in the infant or ventilated/sedated/paralyzed patient requires assessment of vital signs.

Common Procedures and Common Problems

Spinal Fusion--Respiratory, Pain, Fluid Balance

The post-operative course will be affected by the patient's general medical history, degree of curvature, extent of the repair, and intraoperative course (fluid balance, blood loss, narcotics given). The most dreaded complication is paralysis, and patients who are cognitively able to follow commands will be submitted to a "wake-up test" intra-operatively, before closure of the wound. Potential post op problems include respiratory depression (excess analgesia), respiratory difficulty due to splinting (inadequate analgesia), pain control (difficult), and fluid balance. Spinal fusion patients can develop SIADH with some frequency, likely due to manipulation of the spine and spinal cord. They also might not urinate due to inadequate volume restoration. Thus, if a post-op fusion does not have adequate urine output, you must decide if he is dry or developing SIADH. This can be difficult to assess on purely clinical grounds, as the overall fluid balance is always quite positive, and the HR may be high due to pain. Look at the anesthesia record for clues as to volume status (IE, is fluid replacement adequate given blood loss and duration of the case). Check a serum sodium--if high, the problem is likely inadequate volume, if low, the problem is likely SIADH. If it's still not clear, you can check a urine sodium--it should be high (>40) if the patient is volume replete (SIADH), low if volume depleted. Treat accordingly.

LeFort Osteotomy--AIRWAY, AIRWAY, AIRWAY

Various bones of the face are broken and the face re-aligned in this operation. There is typically a fair bit of blood loss and there can be significant swelling of the involved tissues. The most important things to monitor are the status of the airway and continued bleeding. If the jaws are wired shut, there should be wire-cutters at the bedside. Pain and nausea must be treated as well.

Tracheostomy--Airway, sedation, ventilation

The most critical issues for the fresh trach is not losing it. Until the tract heals, the swelling can make replacing the trach tube difficult. Hence, patients who are "wild" should be adequately sedated, especially if they were trached because they were impossible to intubate. In other situations, remember that an ETT is still an option if the tube comes out and can't be replaced (but try to avoid that situation!!!). Mechanical ventilation will depend on the underlying lung status--typically the patients return from the OR on a ventilator, and are weaned according to

their pulmonary status. There are “stay sutures” which are at the base of the incision and can be held up to help provide a “tract” should the trach tube come out.

Craniosynostosis--Blood Loss

During craniectomy for craniosynostosis one or more of the sutures of the cranium are cut. As one might expect, there is typically a large blood loss. You should be aware of whether the patient is syndromic or not (those with a “syndrome” typically have more sutures in need of repair, and might well have other problems), and the extent of the repair. Because of the large blood loss, they typically receive quite a bit of fluid intra-operatively as well as post-operatively. Monitor fluid balance, respiratory status, and blood loss (dressing).

Perioperative Management Of Patients With Congenital Heart Disease: A Multidisciplinary Approach

Basic Principles

The perioperative care of the infant, child, and adult with congenital heart disease requires a coordinated, multidisciplinary approach to patient care that emphasizes teamwork and the unique contributions of all those involved in the continuum of patient care—pediatric cardiologist, pediatric cardiac surgeon, pediatric cardiovascular anesthesiologist, perfusionist, pediatric intensivist, nurses, advanced practice nurses, physicians assistants, respiratory therapists, child life therapists, and family members. Each member of the team brings unique knowledge and perspective to the care of the patient and recognizing and integrating all members of the team in the ongoing care of the patient is essential in providing optimal care for these patients. The presence of trainees from medicine, nursing, respiratory therapy, or other disciplines adds to the size and complexity of the team caring for the patient, and the roles and responsibilities of these individuals must be explicitly acknowledged.

Perioperative care encompasses both pre and post operative care of the patient with congenital heart disease. Although many infants and children with congenital heart defects are managed as outpatients until their repairs, some infants or older children with severely abnormal physiology require stabilization and critical care prior to surgery. Many of the basic principles of cardiac intensive care apply to both pre and post operative care and will be considered in this chapter. In addition to supportive care and stabilization, pre operative management includes thorough evaluation of the anatomy and physiology of the heart and the physiologic status of the patient as a whole so that appropriately planned and timed surgery can take place.

Basic principles of pediatric critical medical and nursing care remain relevant in the pediatric congenital cardiac patient. Pediatric cardiac patients are cared for in specialized cardiac intensive care units and in multidisciplinary intensive care units. There is some data that institutions that perform more surgeries have improved outcomes (info here—based on surgeon, unit, hospital?? Is it surgeon numbers that really matter?). Regardless of the focus of the unit, a commitment to ongoing education and training, as well as a collaborative and supportive environment is essential. We feel strongly that a unit dedicated to the care of infants and children is best able to care for these patients (down on the adult units caring for kids).

General Principles of Oxygen Delivery and Utilization

Oxygen delivery (DO_2) is described by the following equation: $DO_2 = Q_s (CaO_2)$, where Q_s is the systemic cardiac output and CaO_2 is arterial O_2 content. In turn, CaO_2 (ml/dl) = Hgb (g/dl) * SaO_2 * 1.34 (ml/g) + PaO_2 (mmHg) * 0.003 (ml/dl/mmHg) where, Hgb is the hemoglobin concentration, SaO_2 is the arterial O_2 saturation, and PaO_2 is the arterial O_2 tension. Oxygen utilization (VO_2) is $Q_s (CaO_2 - CvO_2)$, where CvO_2 is the mixed venous oxygen content. Oxygen delivery is therefore primarily dependent on systemic cardiac output,

hemoglobin concentration, and oxygen saturation. Dissolved oxygen (PaO₂) makes a small contribution to oxygen delivery.

Ventricular output (Q) is directly related to heart rate and stroke volume. Stroke volume is in turn dependent on preload, afterload, and myocardial contractility. Both pulmonary blood flow (Q_p) and systemic blood flow (Q_s) are determined by these fundamental forces. In the patient with two ventricles, ventricular interdependence, or the affect of one ventricle on the other, may play a role in pulmonary or systemic blood flow. In some situations, including the post operative state, the pericardium and restriction due to the pericardial space may also play a role in ventricular output.

When evaluating the loading conditions of the heart and myocardial contractility, it is important to consider the two ventricles independently as well as their affect on one another. In previously healthy pediatric patients without heart disease, right atrial filling pressures are commonly assumed to reflect the loading conditions of the left as well as the right ventricle. In the patient with congenital heart disease, this is frequently not true. Pre-existing lesions and the affects of surgery may affect the two ventricles differently. For example, the presence of a right ventricular outflow tract obstruction will lead to hypertrophy of the right ventricle. That right ventricle will be non-compliant, and the right atrial pressure may therefore not accurately reflect the adequacy of left ventricular filling.

Oxygen content (CaO₂) is primarily a function of hemoglobin concentration and arterial oxygen saturation. Thus, patients who are cyanotic can achieve adequate oxygen delivery by maintaining a high hemoglobin concentration. Arterial oxygen saturation is commonly affected by inspired oxygen content, by mixed venous oxygen content of blood, by pulmonary abnormalities, and by the presence of a R to L intracardiac shunt. Arterial oxygen content in the patient with a single ventricle and parallel pulmonary and systemic circulations will depend on the relative balance between the circulations as well. In the patient with intracardiac shunt or the single ventricle patient, arterial oxygen content is also affected by the relative resistances of the pulmonary and systemic circuits, as this determines how much blood flows through the lungs relative to the systemic output. Low mixed venous oxygen content contributes to desaturation and suggests increased oxygen extraction due to inadequate oxygen delivery, which in turn is either due to inadequate systemic cardiac output or inadequate hemoglobin concentration.

A thorough understanding of these fundamental principles of cardiac output and oxygen delivery is essential for the perioperative care of the patient with congenital heart disease.

General Principles of Anatomy and Pathophysiology Affecting Pre-operative and Post-operative Management

An understanding of the anatomy and pathophysiology of the congenital cardiac lesion under consideration allows one to determine the pre-operative care or resuscitation needed and to predict the expected post-operative recovery.

Acyanotic Heart Disease

Children with acyanotic heart disease may have one (or more) of three basic defects: 1) left-to-right shunts (e.g., atrial septal defect, ventricular septal defect); 2) ventricular inflow/outflow obstructions (e.g., aortic stenosis, coarctation of the aorta); and 3) primary

myocardial dysfunction (e.g., cardiomyopathy) (Table 22-1). These lesions may lead to decreased systemic oxygen delivery by causing maldistribution of flow with excessive pulmonary blood flow (Q_p) and diminished systemic blood flow (Q_s) ($Q_p/Q_s > 1$), by impairing oxygenation of blood in the lungs caused by increased intra and extravascular lung water, and decreasing ejection of blood from the systemic ventricle.

Maldistribution of Flow: $Q_p/Q_s > 1$

In infants with left-to-right shunts, pulmonary blood flow (Q_p) increases as pulmonary vascular resistance (R_p) decreases from the high levels present perinatally. (37,132) If Q_p is sufficiently increased, pulmonary artery pressure may also increase, particularly with left to right shunts distal to the tricuspid valve, such as large VSD or truncus arteriosus. As pulmonary flow increases, left ventricular volume overload may occur with cardiac failure, decreased systemic output, pulmonary congestion and edema. Over time, increased Q_p leads to a series of pulmonary microvascular changes which first produce reversible pulmonary vasoconstriction and later fixed pulmonary vascular disease (see Chapter 4 on 'Regulation of Pulmonary Vascular Tone'). As R_p increases over time, Q_p decreases (Table 22-3). The primary determinant of pulmonary blood flow is pulmonary vascular resistance. In patients with increased and reactive R_p , LV function may be normal but oxygen delivery may be limited by decreased RV output or by the development of intracardiac right-to-left shunting. If pulmonary pressures exceed systemic pressures, right to left shunting predominates and the patient becomes cyanotic. Depending on the type and size of the lesion, pulmonary over circulation that remains uncorrected may lead to pulmonary vascular obstructive disease as early as 6 months of age.

Pulmonary over circulation can lead to congestive heart failure through several mechanisms. Increased Q_p leads to left (systemic) ventricular volume overload and raises left ventricular end diastolic, left atrial, and pulmonary venous pressures. The increases in pulmonary artery and pulmonary venous pressures raise the pulmonary hydrostatic pressure gradient and these promote transudation of fluid into the interstitial space and ultimately lead to alveolar edema. Right ventricular end diastolic pressure, and hence, right atrial and systemic venous pressures, are also elevated. Venous return may be decreased. High systemic venous pressure contributes to interstitial edema and may lead to decreased organ perfusion. The maldistribution of flow with reduced Q_s is accompanied by a reduction in renal blood flow and resultant stimulation of the renin-angiotensin system (see Chapter 5 on Renal Function in Heart Disease). Fluid accumulation is aggravated by sodium and water retention by the kidney.

Pulmonary edema reduces CaO_2 through increased intrapulmonary shunting in the lungs. In addition to pulmonary over circulation, other causes of pulmonary edema in patients with acyanotic heart disease include left ventricular inflow- or outflow obstruction and diastolic dysfunction of the left ventricle. These children demonstrate an increased respiratory rate, diffuse rales and increased work of breathing. The chest x-ray demonstrates diffuse interstitial and alveolar infiltrates.

Myocardial Dysfunction

Diastolic and to a lesser extent systolic dysfunction decrease oxygen delivery in patients with cardiomyopathy.^{50, 77} Diastolic dysfunction raises LVEDP and pulmonary venous pressures ultimately leading to pulmonary edema. Systolic dysfunction decreases ejection fraction and systemic output. Cardiomyopathy represents the primary defect in a variety of heritable and inflammatory heart diseases (See Chapter 47 on Heritable Heart Disease and 44 on

Inflammatory Heart Disease). Patients with structural congenital heart defects may also develop myopathic changes in the heart. Graham et al. (32,51,58,73) have shown that cardiomyopathy may be produced by volume or pressure overload depending on the type of defect (Table 22-4). The myopathic changes will be important both pre and post-operatively.

Cyanotic Heart Disease

Children with cyanotic heart disease have a right-to-left shunt and therefore always demonstrate systemic arterial desaturation. 95 As with acyanotic heart disease, there may be some combination of shunt, obstruction, and myopathic changes, all of which must be considered. Infants with cyanotic heart disease may be divided into two physiologically distinct groups, those with decreased pulmonary blood flow and those with increased pulmonary blood flow.

Ductal Dependent Pulmonary Blood Flow (Decreased Pulmonary Blood Flow)

These patients have decreased systemic venous blood entering the pulmonary circulation. Patients in this group may have obstruction to flow from the pulmonary ventricle either at the outlet (e.g., Tetralogy of Fallot, Pulmonary Atresia) or inlet (e.g., Tricuspid Atresia). Patients whose pulmonary blood flow is dependent on a patent ductus arteriosus may present with severe hypoxemia and acidosis as the ductus closes. With decreased Q_p and the obligatory presence of an atrial or ventricular septal defect, the blood in the systemic ventricle consists of desaturated systemic venous blood (via the septal defect) and a smaller volume of saturated pulmonary blood (Q_p/Q_s < 1). The decreased Q_p results in decreased oxygen uptake from the lungs, and thus decreased systemic oxygen delivery. In the initial stages, Q_s may be normal. If systemic oxygen delivery remains inadequate, anaerobic metabolism and myocardial dysfunction develop, resulting in a further reduction in oxygen delivery. The end result can be severe hypoxemia and acidosis. Patients with decreased Q_p require a stable conduit for pulmonary blood flow and a high hemoglobin concentration (> 14 mg/dl) to maximize oxygen content CaO₂) and oxygen delivery (D02).

Ductal Dependent Systemic Blood Flow (Increased Pulmonary Blood Flow)

Patients with ductal dependent systemic blood flow have increased pulmonary blood flow but decreased systemic blood flow due to obstruction of systemic output which can occur at a variety of locations. (61,114,116) These infants may have acceptable arterial saturation but develop decreased oxygen delivery as a result of decreased systemic output (i.e., hypoplastic left heart syndrome, interrupted aortic arch, co-arcuation.) Patients may present with profound shock due to dramatic reduction in systemic perfusion and oxygen delivery if the ductal flow is inadequate. Systemic blood flow in patients with severe left ventricular outflow obstruction is dependent on flow through a patent ductus arteriosus into the aorta distal to the obstruction.

Pre-op Stabilization, Surgical Planning

The degree to which infants and children will require pre-operative stabilization will depend on the nature and severity of the lesion, the degree to which the lesion has affected the myocardial function, and the presence of other organ system involvement. Many of the concepts involved in pre-operative stabilization will be applicable to post operative care.

Preoperative stabilization of the ill infant or child focuses on establishing adequate oxygen delivery through manipulation of total cardiac output, Q_p , Q_s , hemoglobin concentration, and oxygen saturation. Additionally, any abnormalities of other organ systems, such as pneumonia, renal insufficiency, or seizures, must be evaluated and corrected if possible.

Manipulation of Q_p and Q_s and the balance between the pulmonary and systemic circulations is achieved by manipulation of the preload, afterload, and inotropic state of the right and left ventricle. Pulmonary vascular resistance is affected by pH, alveolar pO_2 , lung volume (atelectasis or overdistension), noxious stimuli, hematocrit, and many medications. The patient with excessive pulmonary blood flow and consequent low systemic oxygen delivery can be managed with maneuvers to increase pulmonary vascular resistance (R_p), which will lead to decreased Q_p and increased Q_s . In the patient with ductal dependent pulmonary or systemic blood flow, the balance of pulmonary and systemic flow can be manipulated by manipulation of pulmonary vascular resistance or the systemic vascular resistance if needed.

Afterload reduction may improve myocardial function by decreasing ventricular wall tension, thus improving stroke volume and decreasing myocardial oxygen consumption. . Systemic vascular resistance can be lowered by agents that vasodilate (milrinone, dobutamine) and by avoiding agents that raise SVR (high dose dopamine, epinephrine, norepinephrine) or situations that raise SVR (pain, agitation). Patients with left to right shunts and LV volume overload show improved LV function after cautious reduction of elevated systemic afterload. 11 CHF in infants with VSD is associated with stimulation of the renin-angiotensin system. Angiotensin converting enzyme inhibition with captopril and enalapril reduces systemic vascular resistance (R_s), decreases Q_p/Q_s and increases LV output in a dose dependent manner.¹⁹ Potent intravenous vasodilators such as nitroprusside have unpredictable effects on R_p/R_s and therefore on Q_p/Q_s , and should be avoided in infants with left-to-right shunts and volume overload.¹⁰

Children with LV outflow obstruction and pressure overload such as severe aortic stenosis may have massively increased, fixed afterload. Vasodilator administration will not increase Q_s , but rather may cause shock, myocardial ischemia, or life threatening arrhythmias. In this situation afterload reduction is accomplished by relief of the fixed obstruction by surgical or catheterization techniques.

The myopathic ventricle requires a greater than normal preload to maintain output. If the infant presents with CHF, pulmonary edema, and a stable systemic blood pressure, diuretics may be useful to reduce LVEDP and relieve pulmonary edema without compromising ventricular output. On the other hand if the infant with a myopathic ventricle presents with hypoperfusion, hypotension and acidosis, carefully titrated fluid administration may be necessary to optimize preload and increase cardiac output.

Inotropic drugs increase contractility at least in the short term. Unfortunately, inotropic drugs which increase cytosolic Ca^{++} concentration may also impair relaxation of the heart and decrease ventricular compliance (see Chapter 2 on Normal and Abnormal Myocardial Contraction) and limit preload.⁷⁸ In addition, increased inotropy is associated with increased myocardial energy requirements. . Therefore, in patients with a pressure overloaded ventricle and risk of myocardial ischemia, inotropic agents with minimal chronotropic activity should be selected. Finally, CHF may be associated with desensitization of beta-adrenergic receptors and a blunted response to beta adrenergic agonists.²¹ There is an important role for use of inotropes which do not rely on beta adrenergic stimulation such as milrinone, a phosphodiesterase inhibitor.^{4,5,28}

Treatment of pulmonary edema without pulmonary overcirculation are directed at increasing both oxygen content and delivery. These children will benefit from oxygen administration to treat the hypoxia and diuretic therapy to reduce the intravascular volume and left atrial pressure. Positive pressure ventilation with positive end expiratory pressures (PEEP) can improve end expiratory lung volume, decrease intrapulmonary shunting by opening collapsed alveoli, improve compliance, increase tidal volume and decrease the work of breathing. (59) In addition, increased intrathoracic pressure with positive pressure ventilation and PEEP reduces LV afterload, thus improving systemic ventricular function and lowering end diastolic pressure (LVEDP). Because positive pressure ventilation will affect systemic venous return, LV afterload, and pulmonary vascular resistance, the net effect on oxygen delivery will depend on intravascular volume status, myocardial function, and lung mechanics. Assisted mechanical ventilation of the child with pulmonary edema may directly increase both CaO₂ and systemic output.

Post Operative Care

Postoperative care requires a thorough understanding of the anatomic defect, the pathophysiology of the pre-operative heart as well as any other organ system involvement, the anesthetic regimen used, cardiopulmonary bypass issues, and the details of the operative procedure. Invasive and non-invasive monitoring and laboratory or radiographic monitoring is tailored to the needs of the individual patient and will depend on the lesion, the repair, and expected post-operative issues.

Mechanical Ventilation and Pulmonary Support

Patients who require mechanical ventilation post-operatively do so for a variety of reasons: airway control, abnormal lung function, reduction of oxygen delivery needs, assurance of stability during the immediate post operative period, because of the affect of positive pressure ventilation on cardiac loading conditions, or due to neurologic concerns or residual anesthesia. Mechanical ventilation, either in the operating room or the intensive care unit, is continued until there is adequate hemostasis, the heart rate and rhythm are stable and close to normal for age, cardiac output is adequate with minimal inotropic support, oxygen saturation is adequate and lung function is close to normal, and the patient is awake enough to have adequate respiratory drive and airway protective reflexes. Depending on a number of factors, these conditions may be met in the operating room or the intensive care unit much later in the post-operative course.

Cardiopulmonary interactions can exert important influences on the hemodynamics of the postoperative patient but must be evaluated critically and optimized for the specific patient situation. For example, while early extubation and spontaneous ventilation after Fontan operation is often thought to improve hemodynamics, if atelectasis or hypoventilation occurs, pulmonary vascular resistance will increase, and hemodynamics will be adversely affected.

Monitoring of mechanical ventilation and pulmonary adequacy is accomplished via physical examination, non-invasive monitoring of oxygen saturation and end tidal carbon dioxide, attention to lung mechanics, blood gases, and chest radiographs. The need for tracheal suctioning and the quality and quantity of secretions should be followed as well.

Once patients are weaned from mechanical ventilation, care must be taken to avoid atelectasis. Infants and young children typically will move and cry spontaneously, but older children and adolescents frequently will need assistance with sitting and standing, and will need

encouragement to deep breathe and move. Incentive spirometry and a guided program of progressive ambulation is essential and should be initiated as soon as physiologically safe.

Cardiac Evaluation and Support

The routine evaluation of the cardiovascular system after surgery depends on a combination of physical exam, non-invasive monitoring, and invasive monitoring.

Repeated physical examination is an essential part of the evaluation following cardiac surgery. Although a vital part of patient assessment, physical examination remains the least quantifiable and most subjective. Distal extremity temperature, capillary refill and peripheral pulses suggest the adequacy of tissue perfusion. A prolongation of capillary refill greater than 3 - 4 seconds indicates poor systemic perfusion. Changes in the character of murmur or attenuation of a shunt murmur may reflect significant changes in the child's condition. The child should (frequently) be examined for changes in cardio respiratory status.

Noninvasive monitoring includes examination, pulse oximetry, central and peripheral temperatures, and surface ECG monitoring. The surface ECG provides information on heart rate and rhythm. Cool extremities with normal or rising rectal temperature suggests decreasing and inadequate systemic cardiac output.

Before invasive monitoring is planned, the risk-benefit ratio of catheter placement should be considered. Vascular catheters are commonly placed in the operating room, and include central venous catheters, right atrial catheters, left atrial catheters, pulmonary artery catheters, and arterial catheters. Central venous or right atrial catheters provide right-sided filling pressures, as well as information about tricuspid valve function. They enable indirect assessment of cardiac output by providing systemic venous oxygen saturation¹⁹, and they provide a site for infusion of pharmacologic agents. Because of their relative safety and extraordinary utility, most cardiac surgery patients will have a central venous/right atrial line. Central venous catheterization can be obtained by percutaneous cannulation of the internal jugular vein or by placing the catheter directly into the right atrial appendage at the time of surgery.

Left atrial catheterization provides measurement of pressures in the left side of the heart, information about mitral valve function, and measurement of left atrial desaturation due to right-to-left shunting in the lung. The indications for left atrial catheter placement are abnormal mitral valve function, abnormalities of left ventricular diastolic and/or systolic function, and abnormal lung parenchyma. Left atrial catheter placement carries the serious risk of introduction of air into the systemic arterial circulation. This can be kept to a minimum by careful management of these lines, the use of air filters, and appropriate education of the care team. The recent introduction of intraoperative echocardiography has resulted in a more selective use of left atrial lines.¹⁴⁵

Pulmonary artery catheters provide access for measurement of pulmonary pressures, pulmonary arterial saturation, and cardiac output.^{46,71} Indications include the risk of pulmonary hypertension, residual left-to-right shunts, and decreased cardiac output. Pulmonary artery catheters should be used in children whose postoperative pulmonary artery pressure is greater than 1/2 systemic arterial pressure and in children who are at a high risk for pulmonary artery hypertension (Table 22-6). Pulmonary artery catheters are placed during surgery through the right ventricular outflow tract and advanced into the main pulmonary artery. Contraindications for pulmonary artery catheter placement are a large right ventricular outflow tract patch or any anatomic condition which will not allow placement of the catheter through a muscle bundle.

Arterial catheterization is required in all children who undergo surgery for congenital heart disease and allows for continuous blood pressure monitoring as well as repeated measurements of a variety of laboratory studies,

Support of the cardiovascular system is directed at optimizing cardiac output and oxygen delivery. This is accomplished by optimization of heart rate, preload, afterload, and entropy, and is guided by invasive, non-invasive, and laboratory monitoring. When cardiac output measurement is not available, mixed venous oxygen saturation trends can provide information regarding the adequacy of oxygen delivery. Studies have demonstrated that mixed venous saturations are a reliable and early indicator of cardiovascular dysfunction and failure to measure this may worsen outcomes in some situations.⁸ A decreasing mixed venous oxygen saturation, despite escalating support, indicates abnormal convalescence and the need for aggressive intervention. Another indicator of failing oxygen delivery is the development of lactic acidosis... The sequential evaluation of serum lactate levels provides important assessment of the adequacy of oxygen delivery. Lactate levels are usually high immediately after surgery but should decrease to < 2.0 mmol/L if oxygen delivery is adequate.³⁰ Persistent elevation of lactate requires evaluation. Metabolic acidosis that is not accompanied by elevated lactate is usually a hyperchloremic metabolic acidosis (non anion gap metabolic acidosis) and generally resolves without treatment.

Hematology, thrombosis and hemostasis

Postoperative bleeding is the result of inadequate surgical hemostasis or of coagulopathy, either due to residual heparin, to dilutional effects, or to disseminated intravascular coagulation. If bleeding is not corrected after correction of coagulopathy or if the blood loss is greater than 10 cc/kg/hour, surgical bleeding should be considered and exploration strongly considered. Chest tubes and mediastinal drainage tubes must be kept clear and patent if there is ongoing bleeding in order to prevent the occurrence of cardiac tamponade.

Heparin induced thrombocytopenia (HIT) is increasingly recognized in the pediatric population. HIT is the most common drug-induced thrombocytopenia in adults, complicating 1-4% of full-dose exposures to standard heparin. We have reported a similar rate of occurrence of HIT in a pediatric cardiac surgical population. In HIT, the platelet fall is usually 40-50% and the thrombocytopenia is moderate (30-100). The onset is 5-10 days after first exposure to heparin and hours to 2-3 days with re-exposure. Thrombosis may localize to sites of pre-existing pathology (CVLs, shunts, surgical repairs) and be present in unusual locations. Less common presentations include delayed thrombocytopenia (2-3 weeks), heparin-induced skin necrosis (SQ sites), adrenal infarction/hemorrhage, heparin resistance and anaphylactoid reactions.

Antibody (PF4) ELISAs are sensitive but not specific. Positive ELISAs are found in 40-60% of asymptomatic adult re-operative cardiac surgery patients. A recent abstract found them in 31/64 children (median age 29 months) undergoing re-operative cardiac surgery, only 1 of whom had clinical HIT. Unfortunately a negative ELISA does not exclude HIT. More specific for clinical HIT are functional assays based on in vitro heparin-dependent platelet activation (¹⁴C serotonin release, heparin-dependent platelet aggregation, lumi-aggregometry). Unfortunately functional assays are less sensitive and often negative or indeterminate in the first 24-48 hours of HIT. Both assays usually become negative in about 3 weeks, making it difficult to diagnose previous HIT.

If HIT is diagnosed, all heparin (lines, flushes, heparin-coated catheters, low molecular weight heparins) must be stopped. Platelet transfusion should be AVOIDED (transfusion may

precipitate thrombosis) as should warfarin in the acute phase of HIT. Use of alternative anticoagulation is imperative in pre-existing or new thrombosis and should be strongly considered for prophylaxis. Argatroban, a hepatically excreted, synthetic anti-thrombin with a $t_{1/2}$ of ~ 40-50 minutes, is presently our choice. Usual dose is 2mg/kg/min by continuous infusion. Anticoagulation is monitored by either PTT (target 1.5 – 3.0 x normal) or by ACT (target on ECMO 180-200).

Normal versus Abnormal Convalescence

Convalescence after cardiac surgery may be characterized as normal or abnormal. Normal convalescence is recovery that is expected given the pre-operative state of the patient, the procedure performed, and the expected effects of cardiopulmonary bypass or other interventions. Abnormal convalescence is recovery that is prolonged or unexpected given what is known about the patient and the interventions that have been performed. It may be due to unknown or under appreciated abnormal pre-operative anatomy or physiology, to unexpected complications of bypass, to residual anatomic defects, or to abnormalities in other organ systems such as pneumonia or sepsis. It is crucial to identify abnormal convalescence and to characterize it thoroughly so that appropriate intervention can take place in a timely fashion.

The effects of cardiopulmonary bypass (CPB) have been described as a "whole body inflammatory response" because of the generalized activation of complement, neutrophils, cytokines, and other mediators.²⁵ These effects of cardiopulmonary bypass (CPB) and related techniques are discussed in detail in Chapter 21. It is important to appreciate those effects which are anticipated sequelae of CPB and those that suggest abnormal convalescence.

Most congenital heart defects are repaired on cardiopulmonary bypass and require a period of time during which the circulation to the heart is interrupted by aortic cross clamping and infusion of cardioplegia. This provides the surgeon with a still, flaccid heart on which to operate, however, the heart may be "ischemic" during this time. Ischemic injury to myocardium, produced (or unable to be prevented) by the protection used for operative repair, can present serious problems in the postoperative period. Depressed ventricular function in the immediate period following CPB, or inability to wean a patient from CPB, may be due to ischemic injury.^{150,27} This condition can usually be treated with inotropic support, recognizing that inotropic support following CPB further increases myocardial oxygen demand. For patients with severe ventricular dysfunction, consideration of ventricular extracorporeal support with ECMO (patients less than 5 kg), or with RVAD or LVAD (for selected patients over 5 kg) is reasonable if it is felt that the ventricular dysfunction may be reversible. For the intensive care physician, knowledge of the aortic cross clamp time (ischemic time) and the period of total circulatory arrest is important. These times can be predictive of the degree of postoperative ventricular dysfunction and the amount of support that can be predicted. ?? numbers here??

Patients who require extracardiac repair only and patients with simple shunting lesions who require closure (patch or ligature) without valvar involvement should require minimal inotropic support. When performed in the neonatal period, these children may require inotropic support with a single agent. Requirement of multiple agents and increasing inotropic requirements indicate abnormal convalescence. Patients with more complicated perioperative pathophysiology and those who require circulatory arrest will require more intensive myocardial and respiratory support. In the first 24 - 48 hours inotropic support may be generous and escalation of inotropic support should be anticipated in the first 24 hours due to myocardial edema/injury. Failure to respond to moderate increases in inotropic therapy and the need for high levels of inotropic therapy (Dopamine/Dobutamine > 15 μ g/kg/min, Milrinone > 1.0

$\mu\text{g}/\text{kg}/\text{min}$, Epinephrine $> 0.1 \mu\text{g}/\text{kg}/\text{min}$) indicate abnormal convalescence and the need for a thorough investigation.

Pulmonary dysfunction is a common occurrence after cardiopulmonary bypass.^{35,150} Lung injury is mediated by a variety of mechanisms including an inflammatory response initiated by activation of complement which occurs during cardiopulmonary bypass.⁶⁹ This also occurs after hypothermic cardiopulmonary bypass which causes complement activation, leukocyte degranulation, an increase in capillary permeability, and widespread endothelial injury (See Chapter 21 on Cardiopulmonary Bypass).²³ Microvascular dysfunction with platelet aggregation and mediator release increases pulmonary vascular resistance, extravascular lung water, and airway resistance and decreased lung compliance. All of these increase intrapulmonary fluid and can decrease oxygen delivery.

Management of pulmonary insufficiency in the postoperative period requires an understanding of the physiologic consequences of cardiopulmonary bypass. Pulmonary function tests after cardiopulmonary bypass demonstrate reduced static and dynamic compliance, end expiratory lung volumes less than physiologic FRC, an increase in alveolar-arterial oxygen gradient, and atelectasis.^{75,156} These abnormalities are related to endothelial injury and interstitial edema and result in alveolar collapse and microatelectasis. Therapy for children with pulmonary insufficiency is directed at reducing atelectasis and improving the ventilation/perfusion mismatch with positive end-expiratory pressure (PEEP) and an inspiratory time adequate to aerate all lung units. Very low PEEP (<4) and very short inspiratory times do not provide adequate lung expansion or aeration of all lung units. Diuresis consistent with the hemodynamic status of the child may encourage the resolution of pulmonary edema and atelectasis.

The effects of cardiopulmonary bypass on renal function are not completely understood. Cardiopulmonary bypass with hypothermia, non-pulsatile perfusion, and reduced mean arterial pressure causes the release of angiotensin, renin, catecholamines and antidiuretic hormones.^{44,48,49,66,67,82} These circulating hormones result in reduced renal blood flow. There are no confirmatory studies linking low-flow, low pressure, and non-pulsatile perfusion during CPB with postoperative renal dysfunction,^{49,67} but reduction in cardiac output in the postoperative period is associated with the development of renal dysfunction. After total circulatory arrest, it is common to observe a period of oliguria or anuria which usually resolves after 24 hours.^{44,49} This oliguria is seen less frequently in infants whose CPB perfusion flow rates are maintained at 150-200 cc/kg/min during the recovery following circulatory arrest.

Treatment of renal dysfunction in the postoperative period includes increasing renal perfusion pressure using inotropic agents. Diuretics are the primary agents for promoting urinary output after cardiopulmonary bypass. Furosemide (1-2 mg/kg) every 6-8 hours induces a vigorous diuresis and reduces renal cortical ischemia associated with cardiopulmonary bypass.⁶⁶ Continuous infusion of diuretics is useful in patients sensitive to fluid shifts. During the immediate postoperative period diuretics should be used cautiously because of the ongoing capillary leak that is the result of CPB. After resolution of the capillary injury, usually 24-48 hours postoperatively, a vigorous diuresis can be initiated.

Nutrition is an essential component in the care of the postoperative patients. Early aggressive feeding is now advocated for the majority of patients. Early feeding reduces gut translocation of bacteria and decreases the need for total parenteral nutrition and its attendant risks. Feedings are usually begun when bowel sounds are present.. Feedings are withheld in high-risk patients, such as those with severe pre-operative acidosis or those with marginal post-

operative hemodynamics.¹⁰⁴ In those children, a delay in feeding is usually indicated until the patient has demonstrated resolution of acidosis and organ dysfunction. Necrotizing enterocolitis in the post-operative period can lead to significant morbidity and mortality.^{81,104} The diagnosis of necrotizing enterocolitis should be considered in any infant with abdominal distention, bloody stools, and pneumatosis intestinalis. Children who cannot tolerate enteral feeds require parenteral nutrition to support caloric needs (see Chapter 17 on Nutrition and Metabolism).

Cardiac surgical patients are frequently hyperglycemic in the initial postoperative period. Many infants have received steroids pre and intraoperatively, and all patients have undergone a physiologically stressful event. There is evidence in the adult literature that control of hyperglycemia significantly improves outcome in patients in the intensive care unit (NEJM article). At the present time, there is no data on any beneficial or detrimental effect of control of hyperglycemia in critically ill pediatric patients. If blood glucose is controlled with insulin, care must be taken to avoid hypoglycemia.

Terminology and Definitions

Atriotomy - an incision into the wall of the atrium. Allows visualization of the interior of the atrium, the AV valve, and allows access to the ventricle through the AV valve. Puts the patient at some risk for dysrhythmias because it can alter electrical conduction in the atrium. Used commonly in many procedures.

Complete Repair - is a repair in which post-operatively the patient has separation of pulmonary and systemic blood flow and an otherwise functionally normal heart, if not anatomically normal.

Conduit - an artificial pathway forming a track for blood to follow. Can be from a ventricle to the aorta or pulmonary artery, can be across a stretch of a blood vessel or between vessels. Commonly made of Gore-Tex, but can be cadaveric or porcine in origin, can also be valved or unvalved.

Cross Clamp - consists of placing a clamp across the entire diameter of the vessel described (usually refers to the aorta). Cross clamping the aorta interrupts blood flow beyond the point of the clamp. This prevents blood flow from entering the surgical field in an area of the aorta being manipulated and can also be used to prevent air embolization during surgery on the left side of the heart. The risks involved with cross clamping involve interruption of blood flow to the spinal arteries with some risk of paralysis. Also requires retrograde perfusion of the coronary arteries to allow oxygen supply to the myocardium.

CVP - central venous pressure. This is the pressure usually measured in the right atrium through a central venous catheter. This reflects the filling pressure of the right side of the heart.

Cyanosis - literally means blueness. To appear cyanotic a patient must have 4-5 gms of deoxygenated hemoglobin floating in bloodstream. Can be difficult to detect in severely anemic patient. Generally, anyone who has oxygen saturations less than 85% on room air, in the absence of pulmonary disease should be suspected of having cyanotic heart disease. A patient without a right to left shunt should be expected to show a significant rise in pO₂ on an ABG after 30 minutes on 100% FiO₂.

Filling Pressure - this refers to the pressure required by each side of the heart to generate optimum force of contraction. We can speak of right or left sided filling pressures. Filling pressure is measured by right atrial, left atrial, or "CVP" lines.

Palliative repair - usually a palliative procedure is one which overcomes a lethal problem in a defect without totally correcting it. Post-operatively these patients are usually still cyanotic, with mixing lesions, still functionally and anatomically abnormal hearts

Pulmonary Hypertension - as the name implies increased vascular resistance to blood flow in the pulmonary vascular bed. This is the normal state in the fetus where systemic vascular resistance (SVR) is lower than PVR. It can be seen as part of the disease entity of Persistent Pulmonary Hypertension of the Newborn (PPHN). It can also be reactive to prolonged increased

pulmonary blood flow related to a left to right shunt, or to any number of obstructive lesions distal to the pulmonary outflow tract.

Pump Run - when a patient is placed on cardiopulmonary bypass. This is done in any patient with an open-heart procedure to allow emptying the heart of blood to ease visualization of the abnormalities which the surgeon is trying to repair. During the pump run the coronary arteries must receive perfusion, and the heart must be kept cold to decrease its metabolic demand. This is done by inserting a canula into the coronary sinus and infusing a fibrillation solution with highly oxygenated blood and high potassium. Clotting factors and platelets can get consumed and/or activated while on the pump, so the longer the pump run the more like coagulopathy will be present.

Side Biting Clamp - a clamp used to allow manipulation of a large vessel without necessarily stopping the flow through the vessel (i.e. the aorta). Clamps onto the side of the vessel giving substrate to operate on while diminishing the risk of bleeding. Used often in shunt placement, sometimes in coarctation repair.

Total Circulatory Arrest - stoppage of all blood flow, including the pump. Can be done for brief periods in infants kept at low temperatures (~15-20C). Allows a clear operating field, free of blood return.

Ventriculotomy - an incision into the ventricular wall during surgery exposing the interior of the ventricle. Can be done when the atrial approach does not adequately expose VSD's or when the surgical repair otherwise mandates it. Puts patient at risk for right bundle branch block from interrupting the conduction system. Also leads to more myocardial insult and thus a somewhat stiffer ventricle. Can be difficult in the face of aberrant coronary arteries.

Pacing

Temporary

Atrial and ventricular wires are commonly placed in the epicardium at the time of surgery to allow for potential treatment if dysrhythmias develop post-operatively, particularly heart block. These are intended to be temporary and can be removed without difficulty after the patient recovers by gentle tension.

Atrial pacing

For a patient with pure sinus node dysfunction and intact conduction through the AV node. This mode is used if a higher heart rate is desired

Ventricular pacing

Usually only done as a short-term treatment in patients who only have ventricular wires in place.

AV sequential pacing

Commonly done in post-operative patients requiring pacemaker support due to faulty or delayed conduction, generates both atrial contraction and ventricular contraction allowing for some AV pause

Threshold: the setting at which there is “capture” of the atrium or ventricle (i.e., pacing works to create a conducted beat). The pacemaker should be set at twice the threshold. There is an atrial setting and a ventricular setting. Thresholds should be checked every 12 hours (by RN or attending) in patient who is pacemaker dependent.

Sensitivity: The setting at which the pacemaker “senses” an intrinsic beat. If it is too sensitive, it picks up “noise” and thinks there is a beat, and inhibits the paced beat. If it is not sensitive enough, it will not sense an intrinsic beat and will produce a paced beat regardless of what the heart is doing.

Permanent Pacemakers

Internationally Standardized Nomenclature

1	2	3	4
Chamber sensed	Chamber paced	Mode of Response	Rate Modulation
V	V	Triggered	Programmable
A	A	Inhibited	Multiprogrammable
D	D	Dual	Communicating
	O	None	Rate modulation None

Extracorporeal Membrane Oxygenation/Ventricular Assist Device ECMO/VAD

Note: There are pre-printed orders for ECMO patients. Please use the appropriate pre-printed orders.

What is it?

ECMO - Basically, prolonged cardiopulmonary bypass outside of the OR.

VAD – Mechanical assist of cardiac output outside of the OR

What is the difference between ECMO and VAD?

Essentially they are mechanically the same except the VAD does not have a membrane oxygenator in the circuit, hence oxygenation and ventilation in the VAD patient are entirely dependent on the patient's own lung function and mechanical ventilation

Indications:

ECMO: Reserved for patients who would otherwise not survive because of either severe pulmonary disease making conventional or high frequency ventilation not practical, or reversible myocardial depression that prevents adequate cardiac output to be compatible with life.

VAD: used as a device for ventricular rest following major cardiac surgery, particularly those procedures that lead to a single ventricle supporting output to both the pulmonary and systemic circulations. At OHSU, all patients undergoing Stage I repair of HLHS and some other single ventricle repairs are supported with VAD immediately after surgery.

Contraindications:

<35 weeks gestational age (risk of IVH bleeds too high)

<2000g (limited by size of canulas and effectiveness of pump)

Intracranial hemorrhage prior to going on ECMO (>Grade I IVH).

Uncontrollable bleeding at any site

Irreversible condition

Mechanics: for VenoArterial ECMO/VAD

Patient=>Venous Canula=>Pump=>Membrane Oxygenator=>Heat Exchanger=>

Arterial Canula=>Patient

Venous Canula: usually placed in the right atrium, if placed intra-operatively the canula usually directly enters the right atrium, if post (or non)-operatively placed access is achieved through the right IJ.

Pump: Roller pump.

Membrane Oxygenator: both oxygenates and removes carbon dioxide, manipulated by sweep gas composition.

Heat exchanger: rewarms the blood before return to the body

Arterial canula: tip usually placed at the arch of the aorta. If placed non-operatively access is achieved through the right common carotid.

Anticoagulation:

Conventional Circuit: advantage is that the circuit lasts longer than the bonded circuit. The disadvantage is that risk of bleeding is higher. *Significant consideration must be made before any invasive procedure (chest tube, line placement, etc.) is performed on a patient on ECMO with systemic anticoagulation as the bleeding risk is high.*

Monitor anticoagulation with ACT (activated clotting time).

Monitoring

In addition to coagulation there are three main labs that are watched

Pre-lung Blood Gas

This represents the patient's mixed venous saturation.

Post-Lung Blood Gas

This measures the function of the membrane itself. PO₂'s should be very high in a well functioning membrane.

Arterial Blood gas

This is measured from a peripheral (or umbilical) artery. It gives you an idea of how much blood flow is going through the patient's lungs and how well they are functioning. A higher PO₂ most likely correlates with minimal blood flow through the lungs

Medications

GENERAL ORDERING INFORMATION:

mg/kg dosing: Doernbecher has instituted a policy regarding ordering medications to reduce errors. The policy states:

Medication orders written in the Pediatric Intensive Care Unit (PICU) will comply with all existing PICU / OHSU / Doernbecher policies with the following additions:

All medication orders must be written in dose per kilogram of body weight (e.g. mg / kg / per day or per dose, mcg / kg / per day or per dose) until the adult dosage is reached.

Medications that are traditionally written on a per m² basis may continue to be written in this fashion (i.e., chemotherapy).

The RN signing off the order is responsible for validating calculation accuracy.

Orders will not be faxed to pharmacy without the dosage / kilogram information.

Pharmacists will not accept orders that are not written utilizing the dosage / kilogram method.

This policy applies mainly for patients weighing less than 50 kg, but it is a good habit to get into for all patients, regardless of weight. The following components are required for all medication orders:

Date and time of order

Drug name

Dose **and** dose per kg of body weight **or** mg/m² calculation

mg/kg/day or mg/kg/dose

mcg/kg/day or mcg/kg/dose

units/kg/day or units/kg/dose

Route of administration

Dosing interval

Patient weight on order sheet containing medications, usually at top right hand corner

Legible signature and legible pager number

For example, a 10 kg patient needing vancomycin would be written:

Joe Patient

10 kg

7/1/03 1400 Vancomycin 100 mg IV q6h (10 mg/kg/dose)

Signed: Sally Resident, 14793

OTHER MISCELLANEOUS MEDICATION HELPFUL HINTS:

GI Prophylaxis: Most all PICU patients are made NPO, and are placed on “GI prophylaxis” meaning an acid blocker to prevent stress gastritis. Ranitidine is commonly used, doses include:

2-4 mg/kg/**day** IV divided q6-8 hours or

2-10 mg/kg/**dose** PO/NG/NJ q6-8 hours.

Once the patient is eating (or getting feeds via NG or NJ) and is transferred to the ward, the ranitidine can often be discontinued.

Therapeutic Levels:

When ordering medications for a patient, make sure you know which ones need therapeutic levels monitored. You can order the level at the time of initial drug ordering. Most medications are at steady state within 3 doses. In most instances, in patients with normal renal and hepatic function, obtaining only a trough prior to giving the 3rd dose will allow you to adjust the dosing frequency up or down to get a therapeutic level. In patients with hepatic or renal insufficiency or failure, ordering both a peak and trough around the 3rd dose will allow you to adjust the frequency (if the trough is high or low) and/or the dose (if the peak is high or low).

Common medications requiring therapeutic level monitoring:

Antibiotics:

Aminoglycosides – Gentamicin, Tobramycin, Amikacin,
Vancomycin

Cardiac:

Digoxin
Procainamide

Anti-epileptic:

Carbamazepine (Tegretol), Phenytoin (Dilantin), Phenobarbitol, Valproic Acid

Asthma:

Theophylline

DRIPS:

In the PICU, drips are often used for their vasoactive properties (post-operative heart patients or patients in shock) or sedative/anxiolytic or pain-reducing properties. Some helpful general information about drips and how to calculate them follows.

1. All medications must be ordered as “mg” or “mcg” mixed in some solution, i.e., NS or D5W. This gives the concentration of the medication (mg/ml or mcg/ml.)
2. The orders for drips must include the drip dose (“mcg/kg/hr” or “mg/kg/min”) AND the drip rate (“ml/hr”). TRA means “to run at.”
3. Some medications are ordered as *milligrams* in some volume of fluid and then run at “mcg/kg/min” so you must make sure that the units have been properly converted.
4. The drips are run through an infusion pump and have a minimum rate of 0.2 ml/hr.
5. Many medications that are infused as drips come in standard concentrations and are written on pre-printed order sheets. Sedative/narcotic/paralytic drips have their own order sheet. Vasoactive medication drips are listed on the cardiac admission order sheets. If you don’t know the appropriate standard drip concentration, ask the attending or RN.

Example:

3 kg post-operative heart baby, returning to the PICU on ECMO needs a dopamine drip written. (Post-CPB Order Sheet has a section for IV fluids and medications with dopamine for <10 kg as an option.) You decide the dose will be 10 mcg/kg/min. For 3 kg patient, the dose calculation is therefore (3 kg) (10 mcg/kg/min) = 30 mcg/min.

On the order form the concentration is written for you, 80 mg in 50 ml D5W.

Then rearrange the fractions to have the units cancel to end up with ml/hr.

$$\frac{(50 \text{ ml}) (\underline{1 \text{ mg}}) (30 \text{ mcg}) (60 \text{ min})}{(80 \text{ mg}) (1000 \text{ mcg}) (\text{ min}) (1 \text{ hr})} = 1.125 \text{ ml/hr}$$

Your final order will look like this:

“Please mix 80 mg of dopamine in 50 ml D5W TRA 1.1 ml/hr = 10 mcg/kg/min.”

This order:

Tells the pharmacist how much medication to put in the bag of IV solution.

Tells the RN how fast to run the drip on the infusion pump.

Tells you and everyone else what the dose is (10 mcg/kg/min) because *this* is what you adjust based on the patient’s clinical picture. Once the drip is made up and brought to the bedside, subsequent orders can be written simply as, “increase dopamine gtt to 15 mcg/kg/min” and the RN will calculate what infusion rate is needed for that dose.

Analgesics

Morphine sulfate (MSO4) (0.05 - 0.2 mg/kg initial dose)

- *Class:* Opiate Analgesic
- *Half-life:* 2-4 hours (4.5-13.3 hours in neonates)
- *Duration of action:* 3-4 hours
- *Metabolism:* by liver, excreted in urine and bile
- *Dosing Frequency:* Q1-4 hours or as a continuous drip
- *Precautions:* respiratory suppression with increasing doses, histamine release, has caused seizures in neonates
- *Uses:* post-operative pain control, sedation, tet spells, can also increase cardiac output

Fentanyl (1-2mcg/kg per dose initially)

- *Class:* opioid analgesic
- *Half-life:* 2-4 hours
- *Duration of action:* 1-2 hours
- *Metabolism:* by liver, excreted by kidney (<10%)
- *Dosing Frequency:* Q30min-1hour, continuous drip
- *Precautions:* may cause chest wall rigidity in neonates at high doses.
- *Uses:* Post-operative pain management, rapid tolerance develops, may need to increase drip rate daily to maintain equianalgesic dose.

Nalbuphine (Nubain) (0.05-0.1mg/kg initial dose)

- *Class:* Partial opioid agonist (mixed agonist/antagonist)
- *Half-life:* 5 hours
- *Duration of action:* 3-6 hours
- *Metabolism:* by liver, excreted in urine
- *Dosing Frequency:* Q1-4 hours (as with MSO4) can be in drip
- *Precautions:* equal respiratory depression in standard doses as MSO4, at higher doses the effect plateaus.
- *Uses:* in post-operative pain management or to relieve itching related to narcotics. Frequently used with epidural opioids

Sedatives

Midazolam (Versed) (0.05-0.1mg/kg initial dose)

- *Class:* benzodiazepine
- *Half-life:* 1-4 hours
- *Metabolism:* extensively by liver (microsomally), excreted in urine, some in feces
- *Dosing Frequency:* Q1-2 hours, to continuous drip
- *Precautions:* respiratory depression, when used alone in some patients can produce paradoxical effect. Cimetidine can prolong half life when used concomitantly
- *Uses:* as anxiolytic/sedative in association with analgesic agents for patients with severe pain, or in whom sedation is desired for various reasons.

Lorazepam (Ativan) (0.03-0.09mg/kg/dose)

- *Class:* benzodiazepine
- *Half-life:* 10-12 hours (40 hours in neonates)
- *Metabolism:* liver, excreted in urine
- *Dosing Frequency:* Q4-8 hours
- *Precautions:* as with Versed, longer acting so prolonged effect of respiratory suppression
- *Uses:* Sedative for patients who will need prolonged sedation. Can also be used to help wean patients from Versed drips

Chloral Hydrate (25-75mg/kg max dose 2gm/day)

- *Class:* sedative hypnotic
- *Half-life:* around 8 hours
- *Metabolism:* by liver to trichloroethanol (active metabolite) then excreted in urine
- *Dosing Frequency:* Q6hours to Qday
- *Precautions:* Trichloroethanol is carcinogenic in mice, prolonged usage may put patient at risk. Arrhythmias with high levels, withdrawal similar to EtOH withdrawal after prolonged, regular usage.
- *Uses:* additional sedation of a different class, sedation for procedure

Propofol (Diprivan) (25-50 mcg/kg/min drip, 0.5-1mg/kg bolus)

- *Class:* sedative hypnotic
- *Half-life:* minutes, increases with increasing duration of therapy

- *Metabolism:* by liver excreted in urine
- *Dosing Frequency:* Only used as continuous drip or short acting bolus
- *Precautions:* severe myocardial depressant proportionate to dose. No preservatives in solution so at high risk for infection unless aseptic technique is adhered to, particularly for prolonged drips.
- *Uses:* Insoluble in water so supplied in solution of 10% Intralipid. Used for short term sedation when extra sedation is needed. Also used overnight prior to extubation on patients who have had prolonged sedation to allow decreasing other sedatives, rapid wean prior to extubation. FDA does not approve use in pediatric patients for sedation in the PICU

Paralytic Agents

Vecuronium (Norcuron) (0.1mg/kg, 0.2mg/kg for rapid sequence intubation)

- *Class:* non-depolarizing neuromuscular blocker
- *Duration of action:* 30-40 minutes
- *Metabolism:* excreted primarily in bile, partially in urine
- *Dosing Frequency:* Q1-2 hours prn to continuous drip
- *Precautions:* must be prepared to manage airway or intubated prior to use. Do not use without adequate sedation/pain control. Prolonged administration can produce prolonged muscle weakness after stoppage
- *Uses:* as a paralytic in patients who need prolonged mechanical ventilation with significant lung disease, those with significant pulmonary hypertension,

Pancuronium (Pavulon) (0.04-0.1mg/kg initially then 0.01mg/kg per dose as needed)

- *Class:* non-depolarizing neuromuscular blocker
- *Duration of action:* 35-45 minutes
- *Metabolism:* excreted mostly unchanged in urine, some metabolism by liver and elimination in bile
- *Dosing Frequency:* Q25-60minutes
- *Precautions:* must be prepared to manage airway or intubated prior to use. Do not use without adequate sedation/pain control.
- *Uses:* as a paralytic in patients

Cisatracurium (Nimbex) (0.1mg/kg)

- *Class:* non-depolarizing neuromuscular blocker
- *Duration of Action:* 20-35 minutes, up to 45 minutes
- *Metabolism:* rapid non-enzymatic degradation (Hofman elimination) in bloodstream
- *Dosing Frequency:* usually a continuous drip or prn
- *Precautions:* Cis form minimizes Histamine release caused by Atracurium
- *Uses:* ideal as neuromuscular blocker in patient with compromised renal and/or hepatic function

Diuretics

Furosemide (Lasix) (0.5-1mg/kg, Max Dose 10mg/kg/day)

- *Class:* loop diuretic
- *Half-life:* 30min-2 hours, duration of action 2 hours
- *Metabolism:* minimally by liver, 50-80% excreted in urine
- *Dosing Frequency:* Q2 hours to Qday
- *Precautions:* Ototoxicity, hypokalemia, hypocalcemia
- *Uses:* diuresis, treatment of hyperkalemia

Bumetadine (Bumex) (0.02-0.1mg/kg, Max Dose 0.35mg/kg/d)

- *Class:* loop diuretic
- *Half-life:* 1-1.5 hours duration of effect 2-4 hours
- *Metabolism:* by liver, excreted in urine (80%) and feces (10-20%)
- *Dosing Frequency:* can be continuous drip to prn
- *Precautions:* same as for Furosemide
- *Uses:* Diuresis when not responding to Furosemide; has less ototoxicity at equi-therapeutic doses, should change usage when Furosemide dose gets high

Metolazone (Zaroxilyn) (0.2-0.4mg/kg/day)

- *Class:* Thiazide-like diuretic
- *Half-life:* approximately 14 hours, slowly absorbed from GI tract
- *Metabolism:* 70-95% excreted unchanged in urine, also in bile, may undergo
 - enterohepatic recycling
- *Dosing:* oral/enteral only
- *Precautions:* dumps both Na and K, can cause bone marrow suppression
- *Uses:* compliments activity of loop diuretics by functioning with a different mechanism. Has been shown to improve urine output even with very low GFR not found in other thiazides. Can improve urine output in patients whose renal function is not responding to high dose loop diuretics. Does not decrease GFR as other thiazides can.

Antiarrhythmic Agents

Adenosine (Adenocard) (50mcg/kg initial dose, then increase by 50 for each subsequent dose)

- *Class:* endogenous nucleoside
- *Half-Life:* <10 seconds
- *Metabolism:* rapidly taken up by erythrocytes and vascular endothelial cells, becomes part of body pool of nucleosides
- *Dosing Frequency:* repeat doses can be given as early as 2 minutes after initial dose
- *Administration:* should be given in most central venous access site as rapidly as possible. Central venous access is preferred but not essential
- *Precautions:* may produce a short-lasting first, second or third degree av block.
- *Use:* Adenosine works by decreasing conduction through the av node. It is used exclusively in supraventricular tachycardia to convert to sinus rhythm. If unsuccessful after 3 doses, or patient becomes unstable, synchronized cardioversion should be performed (This would include fresh post-op heart patients as they may not be able to withstand the significant transient decrease in BP that can occur with this agent).

Lidocaine (1mg.kg iv slowly, 20-50mcg/kg/min as a drip)

- *Class:* a Class 1b anti-arrhythmic agent (membrane stabilizing), also an amide local anesthetic
- *Half-Life:* Initial 7-30minutes, terminal 1.5-2 hours
- *Metabolism:* by liver to active metabolites GX and MEGX, which are later metabolized by the liver
- *Dosing Frequency:* doses can be given Q3-5 minutes, otherwise can be used as a drip
- *Precautions:* CNS depressant, may cause seizures at high doses (although does have anti-convulsant properties), can cause respiratory arrest. Also suppresses cough and gag reflexes.
- *Uses:* treatment of choice for premature ventricular contractions, used for ventricular dysrhythmias

Procainamide (15mg/kg over 15 minutes, 20-80mcg/kg/min as continuous drip)

- *Class:* a Class 1a anti-arrhythmic agent
- *Half-life:* 3-4 hours
- *Metabolism:* acetylated to active form N-acetyl procainamide (NAPA), actively secreted in urine as well as filtered. All forms are excreted in urine.
- *Dosing Frequency:* may be administered as frequently as Q5 minutes or as continuous infusion.
- *Precautions:* contraindicated in complete heart block, Lupus, and Torsades des Pointes. Can cause transient hypotension
- *Uses:* for lidocaine resistant ventricular tachycardia, reentrant tachycardias, atrial fibrillation and flutter associated with WPW

Amiodarone (5mg/kg IV over 30 minutes)

Antihypertensives

Nifedipine

- *Class:* Calcium Channel blocker, (a dihydropyridine)
- *Half-life:* 2-5 hours
- *Metabolism:* primarily hepatic
- *Dosing:* must be drawn from capsule with TB syringe then dose is calculated from total extracted.
- *Precautions:*
- *Uses:* in patients who can take oral, or sublingual meds, can be used for acute hypertensive episodes

Labetolol

Class: blocker

Half-life:

Metabolism:

Dosing:

Precautions:

Uses:

Esmolol (as a drip 25-250mcg/kg/min)

- *Class:* blocker
- *Half-life:*
- *Metabolism:*
- *Dosing:*
- *Precautions:*
- *Uses:* Hypertension, frequently after coarctation repair

Nitroprusside (as a drip, usual range 0.1-10 mcg/kg/min)

- *Class:* arteriolar vasodilator, NO donor
- *Half-life:*
- *Metabolism:*
- *Dosing:*
- *Precautions:* Monitor cyanide levels, especially in the setting of renal failure
- *Uses:* Hypertension, afterload reduction

Hydralazine

- *Half-life:* about 4 hours, although serum levels don't correlate well with activity
- *Metabolism:* extensively by the liver
- *Dosing:*
- *Precautions:* can cause a Lupus like syndrome in as many as 10-20% of patients who receive a prolonged course.
- *Uses:* can be used for acute hypertensive episodes, but it is not the drug of choice

Cardioactive Drips

Adrenergic Receptors

Alpha - peripheral vasculature

stimulation causes vasoconstriction

Beta - (remember 1 heart, two lungs)

Receptor stimulation acts through adenylate cyclase forming cAMP

Beta 1 - cardiac receptors

stimulation increases contractile strength

and increases heart rate

Beta 2 - pulmonary receptors, and peripheral vasculature

stimulation causes smooth muscle relaxation of bronchial walls

smooth muscle relaxation in peripheral vasculature

Drugs to Improve Cardiac output

Dobutamine (3-20mcg/kg/min)

- *MOA:* almost exclusively a Beta-1 agonist with no alpha effect, and minimal beta-2 effect

- *Effect:* inotropic and chronotropic effects on the heart, some decrease in peripheral vascular resistance and some improvement of AV node conduction
- *Use:* to improve cardiac output and blood pressure, can be administered peripherally
- *Risk:* increases myocardial oxygen demand, may increase heart rate excessively

Dopamine (2-20mcg/kg/min)

- *MOA:* precursor of norepinephrine, stimulates dopaminergic, *alpha* and *beta* adrenergic receptors (little or no beta-2 effect)
- *Effect:* at low doses (2-5mcg/kg/min) minimal alpha effects, causes more splanchnic dilatation, improving renal blood flow (a dopaminergic response). At medium doses (5-10mcg/kg/min) beta effects start to predominate. At high doses (10-20mcg/kg/min) alpha effects more prevalent
- *Use:* good first line to improve cardiac output when used in mid-range
- *Risk:* high doses may cause vasoconstriction. Adverse effects on immune function.

Epinephrine (0.01 to 1 mcg/kg/min, or higher in very critical situations, usual dose range in cardiac patients is 0.03-0.3, in septic patients doses may be higher)

- *MOA:* potent non-selective beta agonist also an alpha agonist (Beta>alpha)
- *Effect:* increases inotropic and chronotropic cardiac activity also causes peripheral vasoconstriction, decreasing peripheral perfusion
- *Use:* to increase cardiac output and blood pressure, at lowest doses (<0.1mcg/kg/min has primarily beta-1 effects)
- *Risk:* can cause profound peripheral vasoconstriction, compromising tissue perfusion. Long term use downregulates catecholamine receptors, decreasing effect, also increases myocardial oxygen demand

Drugs to Improve Cardiac Output and cause Vasodilation

Milrinone (0.30-1.0mcg/kg/min)

- *MOA:* phosphodiesterase inhibitor, prolonging the effect of cAMP, allowing increasing ionized calcium entry into cardiac cells, increasing myocardial contractility, and cAMP dependent vascular relaxation
- *Effect:* peripheral vasodilator and positive inotropic effect on heart, improved diastolic relaxation. May cause reflex tachycardia due to vasodilation
- *Use:* afterload reduction, additional inotropic support when catecholamines already in use.
- *Risk:* as with other inotropes, can also potentially cause too much vasodilation leading to hypotension, use caution in severely hypovolemic patients

Drugs to cause vasodilation

Nitroprusside (Nipride) (0.5-10mcg/kg/min)

- *MOA:* it has direct activity on vascular smooth muscle (donates an NO group to be specific)
- *Effect:* peripheral vasodilator by relaxation of smooth muscles in vessels
- *Use:* used as an afterload reducer, primarily an arteriolar vasodilator, can increase tissue perfusion in patients receiving vasoconstrictors, can be given peripherally.

- *Risk:* Cyanide and Thiocyanate toxicity from prolonged usage of high doses (using Na thiosulfate decreases risk 10mg/mg nitroprusside). Risk of severe hypotension in patient who is intravascularly dry. Overcomes hypoxic vasoconstriction in the lungs, so initiation can cause increased VQ mismatch and therefore more difficulty in oxygenation.

Nitroglycerin (0.5-5mcg/kg/min)

- *MOA:* relaxes peripheral vascular smooth muscle by donating an NO group
- *Effect:* causes peripheral vasodilatation, decreasing pre-load and decreasing blood pressure, helps prevent vasospasm
- *Use:* most commonly used in post-operative arterial switches to help prevent coronary vasospasm, sometime used as a preload reducer, can be given peripherally.
- *Risk:* can cause severe hypotension in patient who is intravascularly dry, risk of methemoglobinemia, otherwise similar to nitroprusside.

Drugs to cause pulmonary vasodilation

Nitric Oxide (0-80ppm inhalation)

- *MOA:* Activates cGMP pathway causing direct smooth muscle relaxation in local vascular bed
- *Effect:* since given as inhalational agent, causes relaxation of pulmonary vascular bed only, with no systemic effect
- *Use:* used to decrease pulmonary vascular resistance in patients in whom pulmonary hypertension is a problem, either from a cardiac output standpoint or from a oxygenation standpoint
- *Risk:* can combine with Hgb to form methemoglobin, needs closed ventilatory circuit and constant monitoring. *NO is now FDA approved for PPHN, but the cost is \$3000/day for up to 4 days.*

Drugs to increase systemic vascular resistance (increase afterload)

Norepinephrine (Levophed) (initial dose 0.05-0.1mcg/kg/min, titrate to effect)

- *MOA:* Potent alpha adrenergic agonist and beta agonist (alpha>beta)
- *Effect:* vasoconstriction and inotropic and chronotropic effects, increasing blood pressure, both by increasing SVR and by increasing CO
- *Use:* in patients already on vasopressors requiring more support to maintain blood pressures
- *Risk:* decreases blood flow to all organs and tissues, can cause worsening metabolic acidosis due to ischemia

Phenylephrine (Neo-Synephrine) (0.1-0.5mcg/kg/min as drip, 5-20mcg/kg as bolus)

- *MOA:* alpha adrenergic agonist
- *Effect:* constricts both arterial and venous blood vessels, increasing systemic vascular resistance without changing cardiac dynamics
- *Use:* In patients who need blood pressure support, where muscular outflow obstruction may be worsened by the use of Beta agonists, such as unrepaired TOF or hypertrophic cardiomyopathy.

- *Risk:* decreases flow of blood to all organs, reducing oxygen supply and potentiating ischemia at very high doses can have some beta effect.

Also Epinephrine and Dopamine to some extent

Adjunct:

Steroids - can upregulate catecholamine receptors, improving function and decreasing dose requirements of vasopressors

Cardio Pulmonary Equations

Pulmonary to Systemic Blood Flow Ratio (Qp:Qs Equation):

$$Qp:Qs = \frac{\text{Sat (aorta)} - \text{Sat(SVC)}}{\text{Sat (pulm venous)} - \text{Sat (PA)}}$$

This equation can be used to determine the relative blood flow between the body and the lungs. The goal in any patient is for this ratio to approach 1, so there is equal blood flow to the lungs and body. In patients who have all of their pulmonary blood flow supplied by a shunt from the aorta (i.e., Norwood after stage 1 repair), you can use this equation to help determine the ideal oxygen saturation for a patient. For these patients:

Sat (aorta) = arterial oxygen saturation (as measured from ABG)

Sat (SVC) = mixed venous sat, which in this case should be measured before the right atrium as mixing occurs from pulmonary venous return, artificially elevating the MVS.

Sat (pulm venous) = as we usually cannot measure this we assume that, with healthy lungs the blood will be fully oxygenated, i.e. =100%

Sat (PA) = pulmonary artery saturation, which in a patient whose entire pulmonary blood flow comes from a shunt from the aorta, should equal the Sat (aorta).

Example:

A patient POD#3 s/p Norwood, relatively stable has oxygen saturations around 80% (by pulse ox, correlating with gases). MVS from a jugular line is 60%. What is this patient's Qp:Qs?

$$\frac{Qp}{Qs} = \frac{80\% - 60\%}{100\% - 80\%} = \frac{20}{20} = 1$$

Oxygen Content (CxO₂) (for any sample of blood)

$$CxO_2 = 1.34x [\text{Hgb}] x (\text{O}_2 \text{ Sat}) + 0.003P_xO_2$$

Where:

[Hgb] is the concentration of hemoglobin in gm/dl

O₂Sat is the oxygen saturation of the specimen of blood

P_xO₂ is the partial pressure of oxygen (in mmHg) of the sample of blood

Fick Principle

$$VO_2 = (\text{CaO}_2 - \text{CvO}_2) * Q$$

Where:

VO₂ is the oxygen consumption

CaO₂ is arterial oxygen content

CvO₂ is venous oxygen content

Q is cardiac output

The following equations can be used in solving the Fick Principle, but give you values based on patients body size

Oxygen availability (DO_2) (620+/-50 ml/min/m²)

$$DO_2 = CaO_2 * CI * 10$$

CI = cardiac index = CO/Body surface area

Oxygen Consumption (VO_2) (120-200ml/min/m²)

$$VO_2 = CI * avDO_2 * 10$$

avDO₂ = DO₂ (arterial blood) - DO₂ (venous blood)

Oxygen Extraction (26 +/- 2 %)

$$O_2 \text{ ext} = (avDO_2 / CaO_2) * 100$$

Oxygenation Index

$$OI = MAP_x (FiO_2 * 100) / PaO_2$$

Where:

MAP is the mean airway pressure

FiO₂ is the set fraction of inspired oxygen the patient is receiving

PaO₂ is the partial pressure of oxygen (in mmHg) from an arterial blood gas

Sedation, Analgesia, Paralysis

making life in the PICU safer, more comfortable, and easier for all.

Laura Ibsen, M.D.

Goals of ICU Sedation

Analgesia for painful diseases and procedures

Compliance with controlled ventilation and routine intensive care

Amnesia for the periods of sedation

Reduce the physiologic responses to stress

Avoid complications

How???

Know what you are trying to do

Know your drugs

Know your patient

If you don't know the indications and contraindications to the drug you are considering, and if you are not prepared to deal with complications, *DONT DO IT.*

It is essential to get comfortable with the idea of titrating drugs to effect--there is no "dose". There are guidelines, but each situation, and each patient will be different. A dose of morphine that wouldn't touch a narcotic-tolerant oncology patient could cause life-threatening respiratory depression in an adolescent with a broken arm. Watch the nurses give the drugs, and watch their effect. Keep in mind what the "target" response is. It is the **ONLY** way you will ever be competent to provide adequate analgesia and sedation. **WATCH**, and **PAY ATTENTION**. You will learn something and you will be able to provide better care.

Classes of drugs commonly used in the PICU

Narcotics

Benzodiazepines

Non-steroidal anti-inflammatory agents (Ketorolac)

Ketamine

Propofol

Neuroleptics

Barbiturates

Paralytics-depolarizing and non-depolarizing

Situations in which some combination of the above drugs are commonly needed

Mechanical ventilation, post-operative

Mechanical ventilation, ARDS

Mechanical ventilation, Asthma

Mechanical ventilation, Epiglottitis or croup

Head injury

Post-operative

Chest syndrome

Intubation--various scenarios

Painful procedures--chest tubes, lumbar puncture, bone marrow aspirate, dressing changes, endotracheal tube suctioning

As you think about the drugs you would choose for each situation, think **concretely** about what you are trying to achieve--NO movement whatsoever in the patient with a tenuous airway, analgesia while attempting to allow “wake-up” for extubation post-operatively, etc. Different drugs do different things--often you should use a “balanced” approach.

Basic (very basic) pharmacologic principles

1. Onset of action-- $t_{1/2\alpha}$ reflects initial distribution from blood to highly perfused tissues. Clinical onset of action is the time necessary to see effect of the drug.
2. Half life--the time it takes for the concentration of drug to decrease by 1/2. Elimination constant, $K_{el}=0.693 \times T_{1/2}$. ($T_{1/2\alpha}$ =redistribution and metabolic clearance)
3. Volume of distribution--relates the amount of drug in the body to the concentration of drug in the blood or plasma--the fluid volume that would be needed to account for all the drug in the body. Small V_d implies that the drug is retained within the vascular compartment, large V_d implies distribution through the body of sequestration in certain tissues. V_d (ml/kg)=Dose (mg/kg) /concentration at time 0 (mg/ml).
4. Clearance--The ability of the body to eliminate a drug, expressed as a volume of blood cleared of drug per unit time. $Cl=V_d \times K_{el}$
4. Metabolism--mostly renal and/or hepatic for most drugs.
5. Bioavailability--the percent of the dose reaching the systemic circulation as unchanged drug following administration by any route.

Opioids (a.k.a. narcotics)

Opioids provide both pain relief and sedation. They are the most commonly used class of drugs for analgesia in the PICU. In addition to their analgesic properties, narcotics decrease responsiveness to external stimulation and reduce the level of consciousness. Nevertheless, the sedative properties of narcotics are inferior to those of the benzodiazepines, and amnesia following narcotic administration is incomplete.

	Relative Dose	Elimination $t_{1/2}$	Clearance (ml/kg/min)
<i>morphine</i>	0.1 mg	114 min	14.7
<i>meperidine</i>	1.0 mg	222 min	15.1
<i>fentanyl</i>	1-5 mcg	202 min	11.6
<i>methadone</i>	0.1 mg	15 hours	

Morphine

Minimal direct effect on myocardial performance

Histamine release--may induce hypotension if large doses are given rapidly

Dose related analgesia, sedation, euphoria
Dose related respiratory depression

Meperidine

Respiratory depression similar to other opioids
Normeperidine (metabolite) is epileptogenic
Mild vagolytic
Histamine release and myocardial depression in high doses
Less biliary tract spasm

Fentanyl

Synthetic opioids, highly lipid soluble, short distribution T1/2 but long elimination T1/2
Metabolized almost exclusively in the liver, thus may accumulate with altered hepatic blood flow
Provides hemodynamic stability, even in very high doses, and blunts pulmonary vascular responses.
May produce Muscle rigidity (“hest wall rigidity”) if given as large fast bolus
Commonly causes lowering of HR (unrelated to pain relief or sedation)

Methadone

Potent analgesic effects, minimal hemodynamic effects
Long half-life
Absorption after oral administration reliably 50-70% that of IV
Sedative and euphoric properties may be less pronounced than those of morphine
Useful for pain control as well as for treating abstinence phenomena.

Untoward Effects of Opioids (a.k.a. side effects)

Respiratory depression--All opioids cause dose related respiratory depression by shifting the CO₂ response curve to the right, and abolishing the ventilatory response to hypoxemia. Depending on the drug you can see decreased ventilatory rate or tidal volume (thus, the *rate* may be ok, but the *tidal volume* may be inadequate). Respiratory depression may occur at any age.

Reversal--Naloxone (narcan)

Full reversal--0.1 mg/kg; >20 kg, 2.0 mg.

“Partial” reversal--titrate to effect--start with 2-10 mcg/kg. The easiest way to do this is to take 0.4 mg (i.e., 1 cc of 0.4mg/cc vial) and dilute in 10 cc NS=40mcg/cc. Thus, 1cc per 4 kg body weight equals 10 mcg/kg. Most useful for patients who are expected to have significant residual pain (i.e., surgical, chest syndrome, Sickle Cell pain crisis, oncology)

The half-life of naloxone is significantly shorter than morphine, demerol, or fentanyl. If there has been a significant overdose, more than one dose will be necessary. A continuous infusion may be needed.

Pruritis--Several of the opioids cause itching, and there is significant inter-patient variability in susceptibility. It may be alleviated by beardy.

Tolerance and Dependence--Tolerance generally develops after 2-3 days of frequent or continuous usage. Dependence (i.e., the potential for withdrawal symptoms) generally develops after 5-7 days of frequent or continuous use. Tolerance is treated by increasing the dose as needed for pain relief. Dependence is treated with gradual withdrawal of the drug, either using the initial drug, or converting to methadone for convenient dosing. Treatment of withdrawal can be difficult if the patient has been receiving narcotics for prolonged periods. In general, the longer the period of treatment, the longer the period of withdrawal needed. Alternatively, one can treat symptoms with alternative drugs (a method usually reserved for those who have a psychological as well as physical dependence on the drug).

Benzodiazepines

Benzodiazepines provide hypnosis, anxiolysis, anterograde amnesia, and anticonvulsant activity. They **DO NOT** provide analgesia. Once more, they *DO NOT* provide analgesia. They are useful for providing sedation and treating seizures, but one must remember to treat pain with an analgesic

Midazolam has a short onset of action, short duration of action, and relatively short elimination

	Relative Dose	t1/2 (redistribution) (min)	t1/2 (elimination) (hours)	Vd (Liter/kg)	Clearance (ml/kg/min)
Diazepam	0.3-0.5	30-60	21-37	1.0-1.5	0.2-0.5
Lorazepam	0.05		10-20	0.8-1.3	0.7-1.0
Midazolam	0.15-0.30	6-15	1-4	1.0-1.5	6-8

half-life. For these reasons, it is useful for short procedures, but inconvenient for prolonged sedation. It may be used as a constant infusion. Continuous administration may result in prolonged sedation even after the infusion is discontinued if the rate of administration is too high. There have also been reports of dystonia and choreoathetosis after midazolam infusion and may represent benzodiazepine withdrawal, persistent effects of the drug, or the combined effect of multiple drugs.

Diazepam has a short onset of action, like midazolam, and slightly longer duration of action, but a long elimination half-life. Thus, with repeated doses, it may accumulate.

Lorazepam is less lipid-soluble, and has a longer duration of action with a shorter elimination half-life, thus is more appropriate than diazepam for prolonged sedation. (Longer duration of action but less risk of accumulation with repeated dosing.)

Untoward Effects of Benzodiazepines

Tolerance--As with the narcotics, dose may need to be increased after 2-3 days

Dependence--Dependence and withdrawal phenomena can be severe. Withdrawal needs to be done carefully, looking for signs of withdrawal (tremor, high HR, BP). Too rapid withdrawal in severely dependent patient can cause seizures.

Choreoathetoid movement disorder--Usually improves with time

Personality changes--Usually improves with time, though after long term, high dose use, personality changes may remain apparent to family members for weeks-months.

Respiratory depression--Dose related.

Reversal--Flumazenil--Benzodiazepine receptor antagonist

0.2 mg over 30 sec. may increase dose up to 0.5 mg/minutes. Up to 5 mg total.

Contraindicated--where benzodiazepines have been used to treat seizures, chronic benzodiazepine use, TCA's present, mixed drug overdose.

Ketamine

Ketamine is chemically related to phencyclidine and cyclohexamine. Ketamine hydrochloride is water soluble at commercial concentrations, but is quite lipid soluble as well and quickly crosses the blood-brain barrier.

Pharmacokinetics are very similar in children and adults. With intravenous administration, the distribution half-life is less than 30 seconds, the redistribution half-life 4.7 minutes, and the elimination half life 2.2 hours. Clinically, one sees peak concentrations within one minute of IV administration, with rapid absorption by the brain and early immediate induction of clinical effects. With redistribution to peripheral tissues, the decrease in CNS levels correlates with resolution of the clinical effect, generally within 15-20 minutes.

The anesthetic state produced by ketamine has been classically described as a functional and electrophysiological dissociation between the thalamoneocortical and limbic systems. Ketamine is a potent analgesic at sub-anesthetic concentrations, and the effects may be mediated by different mechanisms. Ketamine blocks NMDA receptors, and there is some data that it interacts with opiate receptors as well as CNS muscarinic receptors.

Clinical Effects of Ketamine

CNS

Ketamine produces a dissociative state. Its effect on intracranial pressure remains controversial in practice, but controlled studies in which ventilation was controlled showed no effect on intracranial pressure. It probably does, however, increase CMRO₂, and hence, use in patients with intracranial injury should probably be avoided if possible.

“Emergence” phenomena are frequently reported after the use of ketamine in older adolescents. Concordant treatment with a benzodiazepine has been shown to prevent the development of unpleasant emergence phenomena.

Cardiovascular System

Ketamine inhibits reuptake of catecholamines in both the peripheral circulation and the CNS in a dose-dependent fashion. It has a direct negative inotropic effect on the myocardium, and a direct vasodilatory action on vascular smooth muscle. This is generally overwhelmed by central sympathetic stimulation that occurs, however, leading to increases in heart rate, systemic arterial pressure, and possibly systemic vascular resistance. The cardiovascular effects of ketamine are attenuated by alpha and beta blocking agents, verapamil, benzodiazepines, and high epidural blockade.

Respiratory effects

Ketamine is a mild respiratory depressant, and there is a dose related increase in respiratory depression with incremental doses of ketamine. In children, respiratory rate, tidal volume, and minute ventilation are unaffected, but the CO₂ response curve is shifted to the right. Ketamine generally preserves airway patency, and protective airway reflexes are not repressed. Transient stridor or laryngospasm are rarely reported, and are associated with coincident respiratory infection. Ketamine increases oral secretions, and this may be more clinically important in those children with upper respiratory infections. Laryngospasm and the potential for emesis/aspiration are more pronounced in infants and patients with a full stomach, hence these patients should be considered at risk for airway compromise.

Ketamine is a potent bronchodilator. The mechanisms of this response is considered to be a combination of drug induced increase in circulating catecholamine, direct smooth muscle dilatation, and inhibition of vagal tone.

Neuromuscular Effects

Ketamine increases skeletal muscle tone, and there are frequently random movements of the head or extremities. Ketamine also appears to potentiate the effects of neuromuscular blocking agents, both depolarizing and non-depolarizing.

Intraocular Pressure

The effects of ketamine on IOP are controversial, and the literature contains various contradictory reports regarding the potential for increased IOP during ketamine anesthesia.

Dosage Recommendations

In the intensive care unit all anesthetic/analgesic/sedative agents should be titrated to effect, with the unique physiology of each patient kept in mind. This makes dosage recommendations difficult. These children may be compromised from a pulmonary, hemodynamic, or neurologic perspective, and judicious use of any agent is warranted. Ketamine, for example, while supporting hemodynamics in the majority of patients, can cause hypotension if the patient's myocardial reserve is limited. Thus, these recommendations are NOT to be interpreted as policy, but as simple guidelines.

Analgesia-.25-.75 mg/kg IV: Dissociation/anesthesia-1.0-2.0 mg/kg IV in a well-hydrated patient with good hemodynamics, 0.25-1.0 mg/kg in a severely dehydrated patient of a patient with compromised myocardial function.

Continuous infusion-1 mg/kg IV followed by 0.5-1.0 mg/kg/hour
Tolerance develops with repeated doses, and the optimal dose will need to be increased.
Co-administration of benzodiazepines reduces the incidence of emergence phenomena in older children, but will prolong the duration of sedation. This is not generally problematic in the intensive care setting, but should be considered.

Propofol

Propofol (2,6 diisopropyl phenol, “Diprivan”) has low aqueous solubility, and the commercial preparation is a 1% (i.e., 10 mg/ml) solution in “intralipid” (i.e., 1.2% egg phosphatide, 2.25% glycerol.). It has a rapid onset and short duration of action, and produces respiratory and cardiac depression that is dose related. It is most useful for short procedures or “short” continuous infusions (see below).

Propofol’s unique pharmacokinetics are its most attractive feature-rapid onset of hypnosis and rapid resolution of effects after discontinuation of the drug. The distribution of propofol is describes by an open three-compartment model: rapid initial distribution from blood to highly perfused tissues (brain, heart, lung, liver)- $t_{1/2} \square 1.8-4.1$ min, redistribution and metabolic clearance- $t_{1/2} \square 21$ to 69 min, and slow return from poorly perfused tissues to blood- $t_{1/2} \square 184-834$ min. Propofol has a large central volume of distribution, is highly protein bound, and has an apparent high volume of distribution at equilibrium.

Propofol is extensively metabolized in the liver and possibly other sites to inactive glucuronide and sulfate conjugates which are excreted in the urine. In adults with renal or hepatic disease, propofol pharmacokinetic parameters are not significantly altered.

Clinical effects are realized within 40 seconds of administration, and emergence occurs within 10 to 30 minutes, depending partially on the length of administration.

Clinical Effects of Propofol

CNS

IV administration of propofol produces hypnosis with minimal excitation, usually within 40 seconds. Propofol is not an analgesic. It appears to decrease ICP, presumably by reducing CBF and increasing cerebrovascular resistance, and also decreases CMRO₂. CPP may be reduced to unacceptable levels. Propofol may be an effective anti-convulsant for status epilepticus unresponsive to other drugs.

Cardiovascular

Propofol may produce hypotension by a direct vasodilatory effect on both arterial and venous beds and by reducing sympathetic tone. High concentrations of propofol have a direct negative inotropic effect. Propofol is thus more likely to induce hypotension in patients with hypovolemia, compromised myocardial function, or vasomotor instability.

Respiratory

Propofol acts as a moderate respiratory depressant, and blunts both hypoxic and hypercapnic ventilatory drive. Minute ventilation, tidal volume, and FRC are all decreased during its use. As well, as high levels, airway protective reflexes are blunted.

Propofol is a mild bronchodilator and pulmonary dilator, but does not affect hypoxic vasoconstriction.

Metabolic

Propofol significantly decreased V_{O_2} and V_{CO_2} in excess of its sedative effects, possibly due to a decrease in cellular metabolism. Serum and urine cortisol levels are decreased, but the adrenal response to ACTH is preserved. Hypothalamic function, thyroid function, or glucose metabolism have not been shown to be affected.

There have been a number of reports of profound metabolic acidosis in children who have received propofol for long-term (>24 hours) sedation. The etiology of the metabolic acidosis remains unclear, but probably precludes routine use of propofol for long-term sedation in the PICU.

Immunologic

Anaphylaxis has been reported with propofol use. Because of its carrier, it is contraindicated in patients with known hypersensitivity to egg.

Untoward Effects

Pain on injection is relatively common, and can be ameliorated by concomitant injection of 1% lidocaine, generally in a ratio of 1cc lidocaine to 10-20cc propofol.

Hyperlipidemia may occur with long-term use.

Green urine (no clinical significance)

Ability to support bacterial growth due to carrier media (thus, should be treated as a sterile injection).

In vitro evidence of inhibition of neutrophil chemotaxis.

Excitatory phenomena when there are low serum levels of drug.

Dosage Recommendations

As with all anesthetics, keep hydration status, vascular tone, and inotropic state in mind. If patient is not intubated, have available equipment to secure an airway.

Induction (i.e., intubation): 0.5-1.0 mg/kg (i.e., 0.5-1.0cc/10 kg)

Bolus method for short procedures: 0.1-0.5 mg/kg/bolus, every 3-10 minutes.

Maintenance (sedation-OR): 15-100 mcg/kg/min, (i.e., 0.075ml/kg/hour to 0.6 ml/kg/hour) start low, increase as necessary. Occasionally need to use up to 300 mcg/kg/min.

ICU sedation: initial 5-10 mcg/kg/min, increase as necessary in 10 mcg /kg/min increments, up to 100 mcg/kg/min.

Muscle Relaxants

Muscle relaxants are used when you need to have the patient NOT MOVE, and to have NO MUSCLE ACTIVITY. They provide ZERO sedation or analgesia. Once more, **ZERO** sedation or analgesia. **DO NOT FORGET.**

Indications for Muscle Relaxants (always relative)

Intubation

Mechanical ventilation where risk of extubation is great, or risk of barotrauma/volutrauma is high

Procedures such as central line placement of biopsy in the intubated patient

Intractable intracranial hypertension (IF ICP being monitored)

Reduction of CO₂ production/O₂ consumption (??not clear if this is true)

Depolarizing Neuromuscular Blocker--Succinylcholine

Non-depolarizing neuromuscular blockers

Pancuronium, vecuronium

Atracurium, cis-atracurium

Doxacurium

Rocuronium

Succinylcholine

“Sux” is loved and hated both. You must understand why before you use it safely. It is a “depolarizing” neuromuscular blocker--it depolarizes the neuromuscular junction by binding the Ach receptor and further transmission of nerve impulses cannot be propagated. It has a **rapid onset of action**--average 45 seconds to achieve intubating conditions, and **short duration of action**--generally 5-8 minutes. It is **vagotonic** and bradycardia is common and may be hemodynamically significant, necessitating premedication with atropine in most cases.

Fasciculations occur in children and adults, are rare in infants. There is a rise in serum K⁺ of 0.5 meq in “normal” patients (those w/o muscle disease), and hence is to be avoided in states of hyperkalemia. The rise in serum K is *massive* in certain pathologic states--burn injury, crush injury, spinal cord injury, certain neuromuscular disease. It is also a triggering agent for malignant hyperthermia (which may be fatal), and patients who are known to have MH, who have a family history of MH, or who have a condition that puts them at risk for MH should **NEVER** receive sux.

Risk of Hyperkalemia--burn injury, tetanus, spinal cord injury, encephalitis, crush injuries, certain neuromuscular diseases, intra-abdominal sepsis.

Risk of Malignant Hyperthermia--Positive family history, Muscular dystrophies (esp. Duchenne), central core myopathy, remember to include “unknown” myopathies.

Other Untoward Effects of Sux:

Jaw stiffness, usually masseter muscle spasm. There is controversy about the relationship of MMM to Malignant hyperthermia.

Arrhythmias--usually vagal in origin. Premedicate with atropine.

Myoglobinemia--Relatively frequent (40 % if given Sux and halothane), occasionally significant enough to produce myoglobinuria.

Increased Intraocular pressure--avoid in the presence of eye injury.

Inability to intubate--even 5 minutes can be a LONG TIME. Short duration of action is not a license to use sux in a situation when the patient should not be paralyzed.

Non-depolarizing Neuromuscular Blockers

These drugs have a longer onset of action and longer duration of action than succinylcholine. They act as competitive antagonists of Ach at the neuromuscular junction. They do not affect potassium and are not MH triggering agents. They differ in their chemical structure, route of metabolism and elimination, onset and duration of action.

	Dose (mg/kg)	onset	Duration	Side Effects	Metabolism
Pancuronium	0.1	2 min	4-6 min	tachycardia with bolus use	Renal (60-80%) and biliary excretion
Vecuronium	0.1-0.3	1.5-2 min	20-30 (children) 60-80 (infants)		hepatic metabolism, biliary (80%) and renal (20%) excretion
Atracurium	0.3-0.6	2-3 min	15 min	histamine release (mild)	Hoffman degradation
Rocuronium	0.6-1.2	60sec	60 min		

Problems Associated with Neuromuscular Blocker Use

Loss of a valuable patient monitor--without muscle activity you must depend on vital sign changes to assess pain and anxiety, as well as abdominal assessment.

Fluid retention without muscle activity to stimulate venous and lymphatic drainage.

Long-term weakness has been associated with continuous infusions of neuromuscular blocking agents, most commonly the steroid based NMBs (vecuronium) used in conjunction with steroids. There are now reports of significant myopathy associated with Atracurium, however, so the implication of the steroid base as etiologic may not be valid. Excessive blockade should be avoided. This may be accomplished by Train of Four testing, giving drugs as intermittent boluses, or by stopping paralysis on a regular basis and observing the time needed for return of function.

Many antibiotics, especially the aminoglycosides, have neuromuscular blocking properties (complex and varied mechanisms). Aminoglycosides should be avoided if possible if continuous infusions of NMBs are used. If not avoidable, depth of paralysis should be monitored.

Blood Products in the PICU

CONSENT:

Before giving any patient a blood product at OHSU, the parent should be given a copy of the handout “What You Should Know About Blood Transfusion” to read. This sheet describes the benefits and potential risks of transfusions, as well as describing blood safety measures, alternatives to Red Cross donor blood and describes the “Bloodless Medicine and Surgery” program at OSHU.

A “Transfusion Blood Consent” form should be signed before ordering blood products for a patient for the *first transfusion* of that hospitalization. If the patient needs more blood products after the first transfusion, a new consent form does not need to be signed each time during the same hospitalization. However, if a patient receives a transfusion during one hospitalization, is discharged, and then is readmitted, a new consent form needs to be signed.

There is also a “Transfusion Blood Refusal” form for any patient (or parent) who does not want blood products given.

There is a blood product-ordering sheet that should be used to order all blood products.

DONOR SCREENING/BLOOD PROCESSING:

All blood that is given to patients at OHSU comes from the Red Cross. The blood that is donated for transfusion is screened for antibodies including hepatitis B, hepatitis C, HIV-1, HIV-2, human T-cell lymphotropic virus (HTLV) I and HTLV II. Additionally, a RPR/VDRL test for syphilis, hepatitis B surface antigen and HIV p24 antigen are also done. If any donor unit is positive for these tests, the test is repeated and if confirmed, the unit is destroyed. Because most of the screening tests look for antibodies within the donor’s serum, it is possible for a donor to have been infected with an agent but not produced antibody before donating blood. Therefore, with these screening and confirmatory tests, the risk of infection from a unit of blood is small, but not zero. The following is a list of approximate risk of transfusion, and may help you discuss this issue in an educated manner with a concerned parent.

Syphilis	<1:100,000
Hepatitis A	1:1,000,000
Hepatitis B	1:250,000 – 1:30,000
Hepatitis C	1:100,000
HIV-1 &-2	1:2,000,000 – 1:500,000
HTLV I & II	1:600,000

Both donor blood and the recipient blood are also tested for type (ABO) and Rh status (positive or negative), which reflects the D antigen on the red cells. In addition, an “antibody screen” is done which detects autoantibodies or alloantibodies. Direct Coombs testing will detect IgG or complement on the surface of the red cells. Indirect Coombs testing will detect the presence of free-floating antibodies that will coat or activate complement on the surfaces of normal red cells.

If you need to transfuse any blood product, first you must order a “type and screen” for that patient. The patient’s blood will be drawn and sent to the laboratory where ABO and Rh type

will be done, as well as the antibody screen. If you then order a blood product for the patient, a “cross-match” will be performed so that washed donor red cells are incubated with the patient’s serum. Agglutination is detected and graded. Direct Coombs testing is then done. If both the antibody screen and the Direct Coombs test are negative, and the cross-match does not produce a reaction, then the blood is compatible and can be given to the patient. If the antibody screen or cross-match is positive, then an Indirect Coombs test is done to evaluate compatibility for the patient.

CHOICE OF BLOOD PRODUCT AND AMOUNT TO GIVE:

PRODUCT	<i>COMPOSITION</i>	<i>INDICATIONS</i>	<i>ADMINISTRATION</i>	<i>COMMENTS</i>
Whole Blood	RBCs, leukocytes and platelets as well as clotting factors, especially Factors VIII and V.	Oxygen carrying capacity or volume replacement for severe blood loss (>20%).	10 ml/kg over 2-4 hours. This amount will raise Hct by 5%.	Not used commonly since it contains leukocytes and has higher risk of transfusion reactions. Very difficult to obtain.
<i>PRBC</i>	RBCs, no plasma.	Oxygen carrying capacity, trauma, bleeding, chronic anemia.	10 ml/kg over 1-2 hours in patient's with nl cardiac function. Slower if CHF, faster if bleeding. Discuss with attending the amount to give for cardiac patients. This will raise Hct by ~5%.	One unit = 250-350 ml. Order in increments of "1/2 unit" or "__ units" or may give 60 ml or less to neonate.
<i>FFP</i>	Procoagulant and anticoagulant plasma proteins.	Replacement of plasma procoagulant and anticoagulant plasma proteins.	10-15 ml/kg as rapidly as tolerated (15-30 minutes). This will increase level of all factors by 10-20%.	Give for prolonged INR, aPTT
<i>Cryoppt</i>	Factors VIII, XIII, fibrinogen and fibronectin.	Deficiencies of VIII, vWF or fibrinogen.	One "button" of cryo = 7 ml = 1 unit. 1 unit per 5 kg will raise fibrinogen ~50	May give with FFP or alone. Specify in FFP or saline
<i>Apheresis Platelets</i>	Platelets from single donors.	Thrombocytopenia or platelet function defects.	10 ml/kg as rapidly as tolerated (usually 30-60 minutes). This will increase platelet count by 50,000.	No cross-match needed, but are ABO type-specific. One unit = 200-250 ml.

OTHER INFORMATION ON HOW TO ORDER BLOOD PRODUCTS:

Leukoreduced - Now, *all* blood products at OHSU are leukoreduced at the red cross, and therefore considered “CMV-safe.” You do not need to write this in the order. This may change in the future, so stay informed.

Irradiation - Order irradiated PRBC or platelets for patients who are immunosuppressed and who may be at risk for transfusion associated graft-versus-host disease. In our PICU, this is mostly for the Hematology/Oncology patients, infants <1 who had heart surgery. It takes only five minutes for the blood bank to do this. It is not necessary to irradiate FFP or cryoprecipitate.

Sickle-cell free – Order this type of red cell for all post-operative cardiac patients.

Neonatal – Order this type of PRBC for all patients under one month of age. Repeated transfusions will be taken from the same unit.

RCL- Red cell leukoreduced. This is the basic type of blood.

RC5—Red cells that are less than or equal to 5 days old. Potassium levels are low. Only indicated for massive transfusion and hyperkalemia. Limited quantity.

Washed cells—indicated for massive transfusion and hyperkalemia, and certain antibody problems. Usually necessitates discussion with transfusion medicine.

Calcium

Blood products contain citrate, which binds ionized calcium. Albumin binds ionized calcium. Ionized calcium is active (NOT total calcium). The usual dose of Calcium chloride is 10 mg/kg for $Ca^{2+} < 1.2$. If large quantities of blood products or albumin are given (and sometimes small amounts), the ionized calcium may fall.

Guidelines of the Task Force for the Determination of Brain Death in Children

Brain death is defined as the irreversible loss of function of the brain, including the brainstem. OHSU policy: <http://ozone.ohsu.edu/HealthSystems/medstaff/x-e.htm>

History Determination of cause of death is necessary to ensure the absence of treatable or reversible conditions (i.e., toxic or metabolic disorders, hypothermia, hypotension, or surgically remediable conditions).

Physical examination (documented by 2 examiners)

1. Coma or unresponsiveness, no motor response to pain.
2. Loss of consciousness and volitional activity
3. Absent brainstem function
 1. Fixed and dilated or midposition pupils
 2. Absent spontaneous and oculocaloric/oculovestibular eye movements
 3. Absent movement of facial and oropharyngeal muscles
 4. Absent corneal, gag, cough, sucking, and rooting reflexes
4. Apnea—no respiratory effort with pCO₂ up to 60 or rise of 20 mmHg. Must document pre and post test blood gas as well as lack of respiratory effort during period of exam.

Spinal cord reflex withdrawal not included

Consistent examination throughout the observation period

Table 1. Age-Dependent Observation Period

Age	Hours Between 2 Examinations	Recommended Number of EEGs
7 d-2 mo	48	2
2 mo-1yr	24	2 (not needed if angiography or flow study negative)
>1 year	12	Not needed

If hypoxic encephalopathy present, observation for 24 hours is recommended. This may be reduced if an EEG shows ECS or a radionuclide study is negative for CBF. One report suggests that a second EEG is not necessary at all; however, the number of patients in this study, aged 2 months to 1 year, was small.

Table 1 Initial requirements for clinical determination of brain death^{12,23}

Clinical or neuroimaging evidence of an acute catastrophic cerebral event consistent with the clinical diagnosis of brain death

Exclusion of conditions that may confound clinical assessment of brain death (ie, acute metabolic or endocrine derangements)

Confirmation of the absence of drug intoxication or poisoning

Core body temperature $\geq 32^{\circ}\text{C}$ (90°F)

Table 2 Apnea testing

1. Disconnect the ventilator.
2. Deliver 100% oxygen at a rate of 6 L/min. The oxygen cannula can be placed at the level of the carina.
3. Observe the patient closely for respiratory movements (ie, abdominal or chest excursions that produce adequate tidal volumes).
4. Measure PaO_2 , PaCO_2 , and pH after approximately 8 minutes and reconnect the ventilator.

Table 5 Confirmatory tests of brain death

Test	Results
Cerebral angiography	No intracerebral filling at level of carotid bifurcation or circle of Willis Patent external carotid circulation
Electroencephalography	No electrical activity during a period of at least 30 minutes of recording
Transcranial Doppler sonography	No diastolic or reverberating flow Systole-only or retrograde diastolic flow Small systolic peaks in early systole
Somatosensory and brain stem auditory evoked potentials testing	No responses
Technetium Tc 99m brain scan (cerebral blood flow scan)	No uptake of radioisotope in brain parenchyma ("hollow skull phenomenon")
Magnetic resonance imaging	Not yet determined

Table 4 Apnea test results

Result	Findings
Positive	Respiratory movements are absent. Posttest arterial P_{aCO_2} is ≥ 60 mm Hg. Result supports clinical determination of brain death.
Negative	Respiratory movements occur regardless of arterial P_{aCO_2} level. Result does not support clinical determination of brain death. Apnea test can be repeated.
Occurrence of cardiovascular or pulmonary instability	Systolic blood pressure decreases to < 90 mm Hg. Arterial oxygen desaturation occurs. Cardiac dysrhythmia occurs. The nurse should immediately obtain a blood sample for arterial blood gas analysis and reconnect the ventilator. Confirmatory test to finalize clinical determination of brain death may be performed at discretion of physician.
Inconclusive	No respiratory movements are observed. Posttest arterial P_{aCO_2} is < 60 mm Hg without marked cardiovascular instability. Apnea test can be repeated with 10 minutes of apnea.

When a child may die

Talk with the family!! Understand their values and fears. Tell them as soon as the team knows the child is going to die.

Determine the best place for the child to die (PICU, ward, Heme Onc, home, hospice facility)

Make sure the child is comfortable. Remember non-pain discomforts: nausea, constipation, depression

Consider involving child life, pain team, ethics, PCP, chaplains as appropriate.

** We need to discuss how much palliative care info we want here- just resources? What would be helpful? —Resources and how to get them.

When a child is dying: Dying, withdrawal, DNR, etc—probably need an explanation of how people die and how different modes are treated differently?

1. Offer a chaplain to the family (available 24 hrs), or offer to contact their spiritual supports. This offer is one many families, regardless of their personal beliefs, will take advantage of.
2. Contact child life if they have been helpful to the family, or if there are siblings involved.
3. Discontinue labs and any meds not needed to maintain patient comfort.
4. Adjust the monitor (nurse will likely do). All the alarms need to be turned off. The contrast on the monitor needs to be turned completely down (so the family can't see the decreasing heartbeat). Some families really want the monitors left on. I try to ask them, or at least tell them what I'm doing. Sometimes we leave them on and look at the central monitor, sometimes we take everything off. I tend to leave on so I can anticipate what's happening.
5. Help get things cleaned up. Nurses and families will appreciate your involvement.
6. Give the family the opportunity to hold their child BEFORE we turn the vent off, extubate, turn the inotropes off, etc. This way the family can hold their child before death. Not all families want to hold their child, and depending on the mechanism of injury and age of the child, may not be appropriate. They should always be given the opportunity to participate as much as they want.
7. Continue pain management until the child is dead (this is either by bolusing by hand or keeping the drip going; dose may be increased).

After a child dies:

- Call the director of shift operations (4-8105), who will:
 - Provide the death certificate (to be signed by resident OR attending)
 - Discuss organ donation and autopsy with the family
 - Help the family start planning funeral/cremation
 - Provide a list of support groups
- Remove machines, etc. from the room so the family can have time alone with their child in as “de-medicalized” room as possible. The family is given all the time they need. Be around to answer questions that the nurses can't answer. Even after the child dies, some family members need reassurance that they did the right thing by taking their child off the meds and vent, and some want the DOCTOR'S reassurance.
- The nurses will give the family all the time they need, helping the family to bathe their child, hold their child, do hand and foot prints, and hair clips. You may participate in any and all of these activities

- Sign the death certificate if the attending is not available, and give to the director of shift operations.
- Special Situations:
 - B. Suspected NAT - the family cannot be left alone with the child after death. In some cases, a total body bone scan will need to be done after the child dies and the child can never be left alone.
 - C. Medical examiner cases - usually we take all tubes out of the child so the family can hold them, but in these cases, we must leave all tubes in place.

How people die

- i. Cardiovascular death
 - 1. Failed resuscitation
 - 2. Resuscitation not attempted (DNR)
 - 3. Support withdrawn (inotropes, ventilator, etc)
- ii. Brain death
 - 1. Declared brain dead. In this case, support is not withdrawn, machines are removed.

OHSU SUGGESTED GUIDELINES FOR NUTRITION CARE
PEDIATRIC NUTRITIONAL SUPPORT

I. Preliminary Factors:

- A. Nutritional assessment:
 1. Goals for calories, protein, fluid, fat, non-protein calorie to nitrogen ratio
 2. Plot growth history on NCHS growth curve.

- B. Identification of primary objective for parenteral nutrition:
 1. Supplemental.
 2. Maintenance of present body stores.
 3. Repletion of a mal-nourished patient.
 4. Promotion of "catch up growth."

- C. Estimation of duration of parenteral alimentation.
 1. Peripheral access for short-term use.
 2. Central access for long-term use.
 - ≤ 6 weeks - PICC line
 - > 6 weeks - Hickman, Bronac

II. CALORIES

- A. Primary Objective: Normal or Catch up growth/anabolism.

Central line is usually indicated.

Daily Energy Requirements (Non-protein kcal/kg) (13)

<u>Age</u>	<u>Non-protein kcal/kg/day</u>
Preterm	120-140
< 6 months	90-120
6-12 months	80-100
1-7 yr	75-90
7-12	60-75
>12-18	30-60

Circumstances that increase caloric requirements:

Fever	12% for each degree above 37°C
Cardiac Failure	5-25%
Major Surgery	20-30%
Burns	up to 100%
Long term growth failure	50-100%
Protein calorie malnutrition	50-100%

III. FLUIDS

- A. Calculate daily fluid allowance based on maintenance requirements. If additional losses need to be replaced, use non-TPN fluid and Y into the line.

Maintenance requirements for fluid based on weight

<u>Body weight</u>	<u>Fluid requirements per day</u>
1-10 kg.	100ml/kg
11-20 kg.	1000 mls plus 50 ml/kg for each kg > 10 kg.
> 20 kg.	1500 mls plus 20 ml/kg for each kg > 20 kg.

- D. **Note that maintenance water requirements normally average 100ml/100 cal/day (1ml/1cal used).** Hence any physiological process that increases the caloric requirements of a child will increase the fluid requirements as well.
- E. Start with 100-120% of maintenance fluid for central TPN and 120-150 % maintenance fluid for peripheral TPN.

IV. CARBOHYDRATE

- A. Carbohydrate is required as a principal calorie source and should provide 50-60% total non-protein calories.
- B. Hydrated glucose (dextrose) provides 3.4 cal/gm.
- C. Carbohydrates are initiated in a slow stepwise fashion to allow an appropriate response to endogenous insulin and thus prevent glucosuria and subsequent osmotic diuresis.

Glucose in excess of 16 mg/kg/min or 24 g/kg/day should be evaluated.

General Guidelines:

Maximum dextrose concentration (final concentration).

Peripheral: 10%-13%
>13% IV associated with an increased incidence of phlebitis.

Central: **30%** dextrose

2. **Central TPN**

- A. **Usually begin with 15%** dextrose concentration, unless patient is at risk for refeeding syndrome.

- B. Monitor daily for tolerance particularly while advancing. Check glucose after 1 hour on new solution.
- C. **Increase dextrose concentration by 2-5 gm/100ml per day as tolerated** until goals are met. Increase slowly if at risk for refeeding syndrome.

Glucose intolerance is unusual in children with gradually advanced glucose concentrations. Insulin is rarely necessary.

- 4. Any infant or child who suddenly demonstrates glucosuria at a concentration of dextrose that had previously been tolerated is suspect for sepsis.

V. PROTEIN

A. Daily protein requirements (g/kg)

Neonates		2.5-3 gm/kg
Infants	2.0-2.5 gm/kg	
Children	1.5-2.0 gm/kg	
Adolescents	.8-2.0 gm/kg	
Critically Ill	1.5-2.0 gm/kg	

B. General guidelines:

- 1. Begin with 2g/dl amino acids, except for patients with renal insufficiency.
- 2. In general the amino acid concentration in peripheral veins should not exceed 2% (because of increased osmolality). Amino acid solutions through central line usually need not exceed 3% but may go up to 5% to meet protein goals.

C. The non-protein: nitrogen ratio.

The desired ration of 150-100:1 is generally recommended.

D. Complications of Excess Protein Administration

Short Term Complications

Azotemia
Hyperammonemia

Long Term Complications

Abnormal Plasma Aminograms
Cholestatic Jaundice

VI. INTRAVENOUS FAT

- A. A concentrated source of calories, particularly beneficial during periods of fluid restriction.
- B. The low osmolality and high caloric density of lipid emulsions makes them useful for peripheral parenteral alimentation.

- C. Administration prevents occurrence of fatty acid deficiency. Prevention of E.F.A.D. can be accomplished with 2-3% of total calories as essential fatty acids or linoleic acid per day, or 0.5 gm IL/kg body weight.
- D. 20% Intra-lipid provides 2 Cal/ml.
- E. 20-30 % of total calories (not to exceed 50%) as fat are recommended for normal caloric balances.

General guidelines

1. Start infusing fat emulsion over 20-24 hours to improve clearance; may gradually taper time to 10-12 hours.
2. Monitor tolerance closely. Draw triglyceride level initially and after each dose increase.
If TG level is elevated to > 400 IL must be adjusted.

GUIDELINES FOR ADMINISTERING 20% LIPID EMULSION (2)(6)

	<u>Premature SGA Infants</u>	<u>Full-Term AGA Infants</u>	<u>Older Children</u>	
Initial Dose		0.5 gm/kg/day	1gm/kg/day	1gm/kg/day (2.5ml/kg/day) (5ml/kg/day) (5ml/kg/day)
Increase Daily Dose by	0.25 gm/kg/day (1.25ml/kg/day)	0.5 gm/kg/day (2.5ml/kg/day)	1 gm/kg/day (5ml/kg/day)	
Maximum Dose	3 gm/kg/day	4 gm/kg/day	2 gm/kg/day	(15 ml/kg/day) (20 ml/kg/day) (10 ml/kg/day)

VII. Recommended Maintenance Daily intake of Electrolytes and Minerals for Pediatric Parenteral Nutrition Solutions

<u>Element</u>	<u>Daily Amount</u>
Sodium	2-5 meq/kg
Potassium	2-5 meq/kg

Chloride 2-5 meq/kg
 Magnesium 0.25-0.5 mEq/kg
 Calcium gluconate* 0.5-2.5 mEq/kg
 Phosphorous 1-2 mmol/kg
 * 110 mg is used in standard pediatric TPN at OHSU; gluconate is the recommended Calcium salt in Parenteral Nutrition solutions since this salt dissociates less than chloride salt.

Iron - is not a standard part of TPN solutions, but may be added to solutions as Iron Dextran when oral iron therapy is precluded by GI problems. Monitor serum ferritin levels. A test dose of iron dextran must be given.

VIII. Multi-Vitamins Pediatric (Used at OHSU)

Infants and children up to 11 years of age receive pediatric multi-vitamins. Above 11 years of age, children receive adult dosage of vitamins for intravenous use.

Vitamin A - 2300 USP units
 Vitamin D - 400 USP units
 Vitamin K - 200 mcg
 Vitamin C - 80 mg
 Folic Acid - 140 mcg
 Niacin - 17 mg
 Vitamin E - 7 mg equals 7 USP units
 Riboflavin - 1.4 mg
 Thiamine - 1.2 mg
 Vitamin B6 - 1.0 mg
 Vitamin B12 - 1 mcg
 Dextranthenol - 5.0 mg
 Biotin - 20 mcg

MVI Pediatric infused at OHSU --- Follow Protocol on Pediatric Parenteral Nutrition Order sheet

< 3 kg 3.25 mls daily
 > 3 kg < 11 years 5 mls daily
 > 11 years = Adult multivitamin

IX. Pediatric Trace Elements mixture at OHSU --- Follow Protocol on Pediatric Parenteral Nutrition Order Sheet (13)

Intravenous trace elements in pediatric patients (not neonates)
 Unless specifically crossed out, the Pediatric Parenteral Nutrition form will always provide trace elements according to our protocol.

Elements	Recommended mcg/kg/day	Dose per out pediatric TPN protocol mcg/kg/day	Max mcg/day
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Zinc	100	100	5000
Copper	20	20	300
Manganese	1 to 10	5	50
Chromium	0.14 to 0.20	0.17	5
Selenium	2	none	30

Dosing - Trace Elements:

T.E.	Intravenous Dosing		Oral Dosing	
	Infant		Pediatric Infant	Pediatric
			Mcg/kg/day (max-mcg/day)	(dose/day)

Zn	250 < 3 mo 100 > 3 mo	100 (5000)	3-5 mg	10-15 mg
Cu	20	20 (300)	0.5-1.0 mg	1-3 mg
Cr	0.2	0.14 to 0.20 (5)	10-40 mcg	20-200 mg
Mn	1	1 to 10 (50)	0.5-1.0 mg	1-5 mg
Se	2	2(30)	10-60 mcg	20-200 mcg

Manganese and copper may be decreased/not used in children with obstructive jaundice.

Molybdenum and selenium are usually present as contaminants in parenteral solutions.

X. Weaning Parenteral Nutrition

- A. Goal is maintenance of optimal nutrition while progressing from parenteral to enteral nutritional support.
- B. Wean parenteral fluid gradually as enteral fluids are being advanced and tolerated; document enteral and parenteral intake via calorie count.
- C. Decrease parenteral calories the same amount enteral calories are increased.
- D. Enteral feeding should be initiated and TPN weaned as soon as possible to decrease the risk of cholestatic liver disease.

- E. Enteral feeds should be initiated in a slow continuous drip with age appropriate elemental formula.

XI. Cyclic TPN

Cyclic TPN is needed for long-term use to increase mobility. Can be used to increase oral intake. Tapering TPN off reduces risk of hyperglycemia and hypoglycemia.

Recommended:

- 1) Taper volume: cut volume in half for 15 minutes then cut reduced volume in half again for 15 minutes to start and stop TPN Taper for neonates and infants over 1 hour
- 2) Target for cyclic TPN:
 - a) neonate - 16-18 hour cycle
 - b) infants - 12 hour cycle
 - c) children - 8-10 hour cycle

XII. Monitoring

A. When TPN is initiated:

1. **Check blood glucose 1 hour after initiation** and 1 hour after each increase in dextrose concentration.

OR

Check urine glucose every shift after starting new TPN solution; if positive check blood glucose.

2. **Check Labs: liver panel, renal panel, lytes, glucose, magnesium.**

3. Check serum **triglycerides** after each change in lipid prescription.

4. **Monitor liver function tests** daily while advancing TPN.

B. After target dextrose, amino acid, and lipid concentrations have been reached, check all of the above weekly and after any change in prescription.

C. **Refeeding syndrome** - Severely malnourished patients who are given adequate calories may develop critical hypophosphatemia and/or hypokalemia in the first few days. Check levels prior to TPN initiation, replete if indicated, and monitor levels closely!!

D. Monitoring for long term TPN (> one month). (12)

1. Every 3 months check: serum ferritin, free carnitine (in children with short gut or chronic diarrhea).
2. Every 6 months check: carnitine, zinc.
3. Annually check: copper, selenium, chromium, manganese.

References

1. Oregon Health & Science University Pharmacy, Portland, Oregon.
2. Mauer E.C., et al. Lipid Emulsion - Use in Neonates and Infants. *Hosp. Pharm* 1987. 22:185-187.
3. Hohnbrink K and Oddlifson N. *Pediatric Nutrition Support*. Aspen 1991.
4. Macfarlan, K, et al. Usage of total parenteral nutrition in pediatric patients. *JPEN* 15:85-88,1991.
5. ASPEN Board of Directors. Guidelines for pediatric nutrition support. *JPEN* 17:(4)305A-495A,1993.
6. Ekuall, S. Pediatric nutrition in chronic diseases and developmental disorders.1993. 36-37.
7. Colomb, V. Liver disease associated with long term Parental Nutrition in Children. *Transplantation Proceedings*. 1994; 26(3);1467.
8. Sapsford, A. Energy, Carbohydrate, Protein, and Fat Nutritional Care for High Risk Newborns. Precept Press Chicago Illinois. 1994;71-87.
9. Fitzgerald, K. et al. Hypermanganesemia in patients receiving total parenteral nutrition. *JPEN*. 1999;23(6):333-6.
10. ASPEN Safe Practices. *JPEN*. 1998; 22: 49-66.
11. Samour, P. Handbook of Pediatric Nutrition. ASPEN Publishers. 1999. 551-588.
12. Mc Donald, et al. Carnitine and cholestasis: Nutritional dilemmas for the parenterally nourished newborn. *Supportline*. April 2003 Vol 25 No 2.
13. Guidelines for the use of parenteral and enteral nutrition. *JPEN* 2002; 26 (1 suppl): 15a-1385A,

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