Approach to Fluid Therapy in Neonates

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Fluid Therapy in Neonates

- Reasons for intravenous fluid therapy
- Fluid therapy in neonatal hypovolemia

  Septic shock
- Fluid therapy for glucose support
- Fluid therapy maintenance requirements

  Holliday-Segar formula
- Fluid therapy sodium considerations

  Other electrolytes

Reasons for Intravenous Fluid Therapy

- Fluids – crystalloid or colloid
  - Volume repletion (ECF)
    - Correct hypoperfusion
  - Correct dehydration (ICF)
    - Cellular resuscitation
  - Maintenance fluid needs (global)
- Blood
  - Correct anemia
- Plasma
  - Restore oncotic pressure
    - Treat hypovolemia
  - ↑ Buffer Base
  - Immunotherapy
  - Coagulation normalization
  - Nutrition

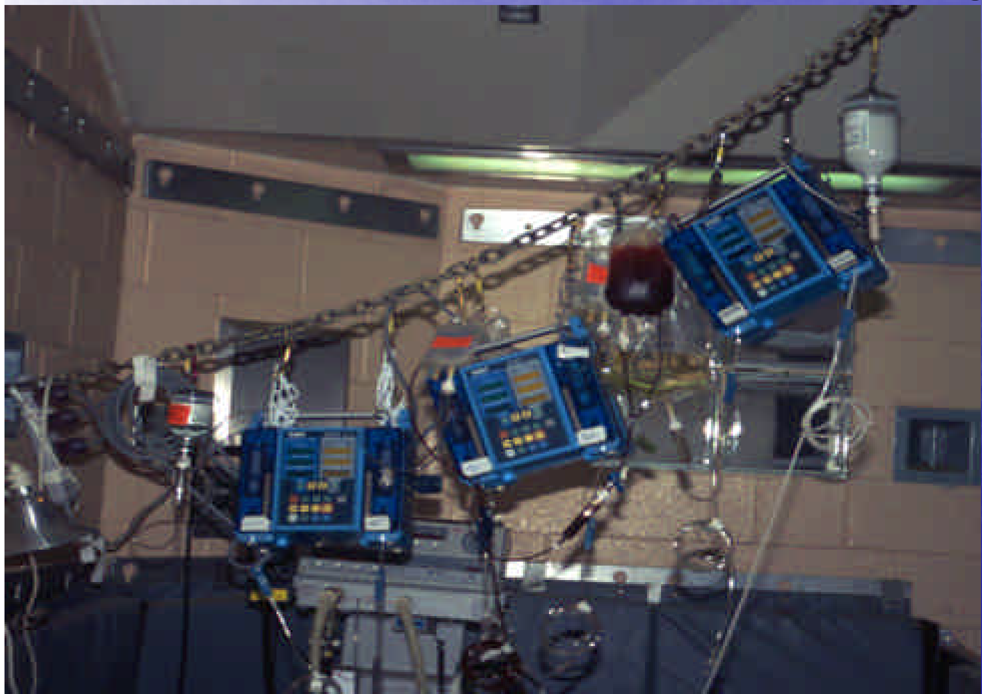
Fluid Therapy Plan in the Neonate

- Understanding of
  - Neonatal physiology
  - Acid-base dynamics
  - Special electrolyte considerations
- Clear understanding of the goals
  - Treatment of hypovolemia
  - Treatment of dehydration
  - Maintenance fluid therapy
- Special needs/limitations of the neonate

Fluid Therapy in the Neonate Considerations

- Insure volemia
- Insure hydration
- Maintenance needs
  - Water
  - Na
  - Energy

Fluid Therapy in the Neonate Hypovolemia - Septic Shock



- Fluid choice
  - Balance crystalloid
    - Saline – acidic
    - Fluid – balanced SID similar to blood
  - Colloids
    - Plasma
    - Whole blood
    - Synthetic
- Considerations
  - Lack intravascular retention

Fluid Therapy in the Neonate Hypovolemia - Septic Shock

- Fluid boluses
  - 20 ml/kg over 5 to 20 minutes
  - Re-evaluation tissue (regional) perfusion after each bolus
    - Improved pulse quality
    - Warm legs
      - Core : peripheral temperature gradient
    - Return of borborygmi
    - Urine production
    - Improved mental status
- Repeat fluid boluses are usually required
  - If > 60-80 ml/kg is required, inopressor therapy
  - May require up to 200 ml/kg – first 1 to 2 hrs
- Avoid fluids > immediate needs
  - Reassessing the patient after each bolus

Fluid Bolus

- Example: 50 kg foal
  20 mg/kg = 1000 ml
  over 10 – 20 min

Fluid Therapy
Glucose Support

- All compromise neonates
  - Will benefit from exogenous glucose support
  - Decrease catabolic state
  - Support their recovery
- Blood glucose interpretation
  - Not relate directly to adequate glucose stores
  - Summation of glucose mobilization/utilization
  - Hypoglycemia
  - Normoglycemia
  - Hyperglycemia

Fluid Therapy
Glucose Support

- Placental glucose delivery to fetus

  Glucose transfer rate between 4 and 8 mg/kg/min

  - fetal foal 6.8 mg/kg/min
  - fetal calf 5 mg/kg/min

  Varies between species

  Varies with energy intake on dam

Fluid Therapy
Glucose Support

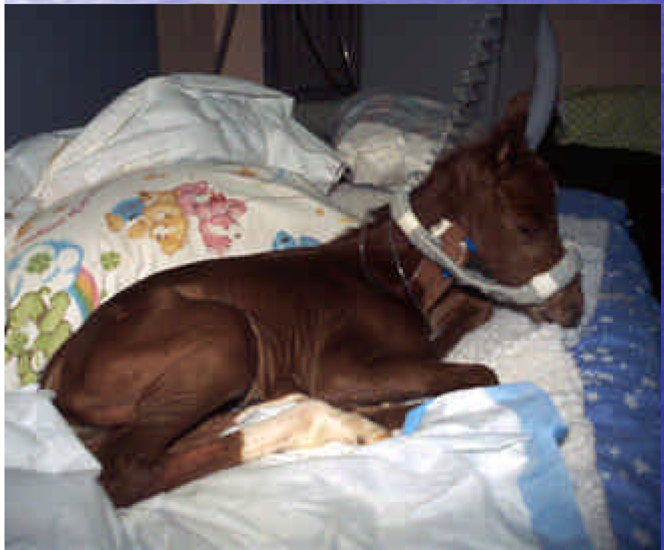
- Birth - glucogensis
  - Normal fetus is born before gluconeogenesis begins
  - Low birth blood glucose
    - Neonatal foal 25-35 mg/dl
    - Birth stress can modulate – calves
    - If dam is hyperglycemic – $\uparrow$neonates birth glucose level
  - Continues to drop for the first few hours of life
    - Until gluconeogenesis is initiated
    - Until entral nutrition provides a source of glucose
  - Low point of blood glucose levels
    - Is usually 2 to 4 hours after birth

Fluid Therapy
Glucose Support

- Established fetal distress
  - Placentitis or lack of nutrient transfer from the dam
  - Fetus begin active glucogenesis
    - Precocious glucogenesis
- Late term/perinatal fetal distress
  - Failure of metabolic transition
  - Neonate suffering from perinatal disease
    - May not make the transition to glucogenesis
    - May become dangerously hypoglycemic
    - Compounding the other neonatal problems
  - Normal birth blood glucose level
    - Drops to < detectable within hours
    - No glucogensis

Fluid Therapy
Glucose Support

- Response to exogenous glucose support
  - Varies with neonate's physiologic response
  - Normal neonates adapt readily
  - Neonates with perinatal challenges may not
- Response patterns of compromised neonates
  - Hyperglycemia
    - Slow insulin response
    - Continued glucogenesis despite exogenous source
    - Stress glucogensis
    - Metabolic anarchy - failure of metabolic transition
  - Hypoglycemia
    - SIRS response
    - Hypermetabolism
    - Metabolic anarchy - failure of metabolic transition



Fluid Therapy
Glucose Support

- Glucose infusion rate
  - Do not think in terms of % glucose delivered but mg delivered
  - 4 to 8 mg/kg/min
    - Placental transfer rate
    - Neonatal liver glucogenesis rate
  - Begin 4 mg/kg/min
    - Increase over the first hours of therapy to 8 mg/kg/min
      - Repeated blood glucose measurements
  - Even with blood glucose levels too low to measure
    - Begin with 4 mg/kg/min
    - But be prepared to raise infusion rate rapidly dictated by BG
- Most foals tolerate 8 mg/kg/min

Fluid Therapy
Glucose Support

- Foals with severe sepsis/septic shock

  Infusion rate as high as 20 mg/kg/min

- With high exogenous glucose loads

  Addition of thiamine to the fluids

  may help ensure proper metabolism

Fluid Therapy
Glucose Support – 50 kg foal

- 4 mg/kg/min
  - 50 kg X 4 mg/kg/min = 200 mg/min
  - 200 mg/min X 60 min/hr = 12000 mg/hr
  - 5% dextrose = 50 mg/ml
  - Fluid infusion rate = 240 ml/hr of D5W
- 6 mg/kg/min.
  - Infuse 240 ml/hour of 7.5% dextrose
- 8 mg/kg/min
  - Infuse 240 ml/hour of 10% dextrose

Glucose Support
Glucose Intolerance

- Administering exogenous glucose
  - Spare endogenous stores
- Hyperglycemia
  - Continued glucogenesis
  - Glucose administration is in excess of utilization
    - Absence of an adequate insulin response
  - Iatrogenic glucose overload
    - Errors in calculations
    - Administration of glucose boluses
  - SIRS/Sepsis/stress
- Failure to adapt to the exogenous glucose load
- Insulin response sluggish in the neonate
  - After significant perinatal stress

Glucose Support
Glucose Intolerance

- Hyperglycemic neonate
  - Check the infusion rate
  - Is intolerance secondary to sepsis?
  - Be patient, allow time for insulin response

Glucose Support
Glucose Intolerance

- Consequences of hyperglycemia
  - Without an insulin response
    - Selective cellular dehydration
  - Glucose diuresis with subsequent fluid and electrolyte wasting
- Mild hyperglycemic (< 250 mg/dl)
  - No glucose diuresis
    - Give the neonate time (hours) to develop insulin response
  - Glucose diuresis, blood dextrose is persistently high without apparent adaptation
    - Initiate insulin therapy
    - Decrease glucose infusion

Glucose Support
Renal Glucose Threshold

- Glucose threshold higher in neonate
  - Marked variation between species
- Immature kidney
  - Increased glucose reabsorption capacity
  - *Low Affinity High-capacity Transport*
    - Only mechanism in adult kidney some species
    - Usually less efficient in neonate
  - *High Affinity Low-capacity Transport*
    - Compensates for what other transport mechanisms miss
    - Higher affinity in neonates
      - Not present in adults of all species

Glucose Support
Renal Glucose Threshold

- High glucose threshold in neonate/fetus
  - Lower GFR
    - Complete reabsorption more likely
  - ↑ efficiency of high affinity low capacity transport mechanisms
- Threshold varies between individuals
  - Foals – 180 to 200 mg/dl
  - Crias – 200 to 230 mg/dl

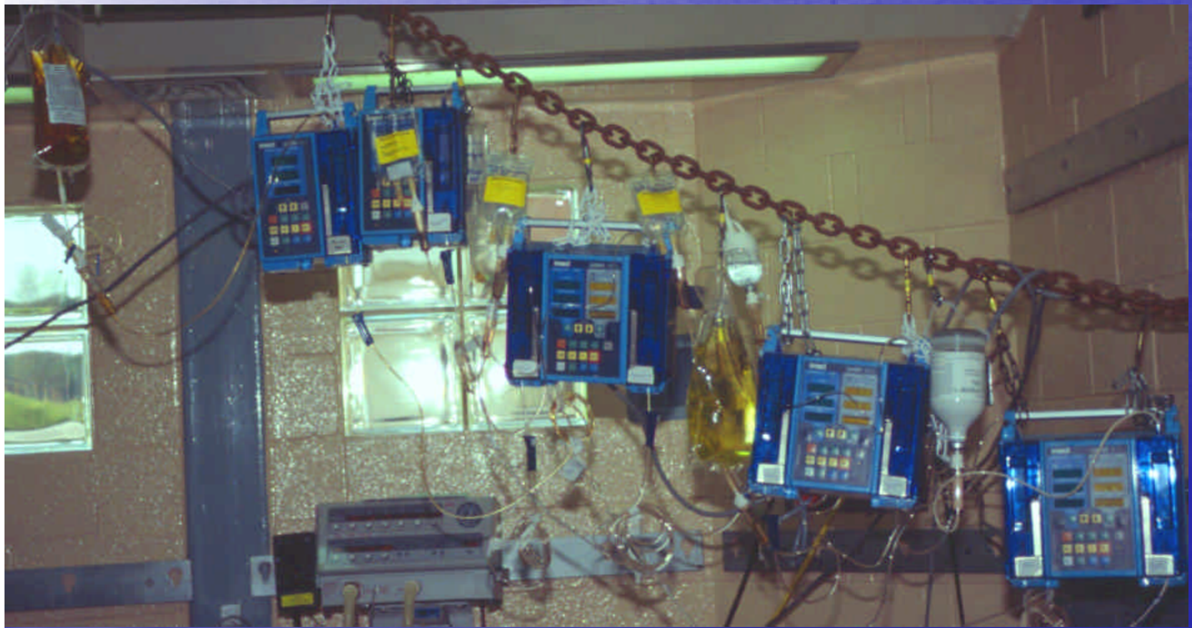
Glucose Support
Regular Insulin therapy

- Continuous infusion of regular insulin
  - Well tolerated by most neonates
  - Allows more control of glucose kinetics
- Most cases insulin deficiency
  - Not resistance
  - Respond to low insulin levels
  - Even in the face of sepsis
  - Reflect slow adaptation to regulation
    - Neonatal Metabolic Maladaptation

Glucose Support
Regular Insulin therapy

- Dose regular insulin – CRI
  - Range – 0.00125-0.2 U/kg/hr
  - Began at 0.0025 U/kg/hr
  - Double rate every 4 to 6 hr
    - until the glucose controlled
    - or the infusion rate is > 0.04 u/kg/hr
- Response to the infusion
  - Not seen immediately
  - Avoid the "glucose rollercoaster"

Glucose Support
Preparing Regular Insulin Infusion



- Use Regular Insulin
- Insulin <3 months old
- Insulin is a suspension

  To resuspend

  - Gently rock or roll
  - Never shake
- For neonates

  0.1 U/ml solution

  - In 100-150 mls of saline

Glucose Support
Preparing Regular Insulin Infusion

- Insulin adheres to glass and plastic
  - Blocked with albumin containing solutions
  - Blocked with careful pretreatment of IV lines
    - Insulin solution in final dilution
    - Running 40-60 ml through line
      - Carefully flush
    - Use lines after plasma transfusion
  - Insulin should be diluted in saline in a glass bottle
    - Infusing into the saline
    - Do not allow undiluted insulin to run down the glass
  - If lines are not pretreated (line change)
    - Insulin kinetics may be erratic
    - Sudden increase in delivery once the sites are occupied

Fluid therapy
Maintenance Requirements

- Fluid requirements

  Metabolic rate

  Degree this metabolism is supported by catabolism

  - Increase osmotic load
  - Result in production of metabolic water

  Insensible water loss

  - Humidity
  - Respiratory rate
  - Ambient temperature
  - Surface to mass ratio

Fluid therapy
Maintenance Requirements

- Fluid requirements (cont)
  - Gastrointestinal water loss
  - Urine osmotic load
    - Increased with many medications
    - Increased with hyperglycemia
  - Ability of the kidneys
    - to concentrate this osmotic load
- There is no "correct maintenance fluid rate"
  - Maintenance needs vary from patient to patient

Fluid therapy
Maintenance Requirements

- Holliday-Segar philosophy (1957)

  Maintenance fluid needs are related to basal metabolism

  Metabolism produces

  - Heat

    Dissipated by insensible evaporation

  - Solute

    Byproducts excreted in urine

Fluid therapy
Maintenance Requirements

- Basal Metabolic Rate

  Higher per kg in neonate

  Higher per kg in smaller animal

  Varies with size

  Growing neonate based on wt $MR^{0.75}$

  Between species based on wt $MR^{0.75}$

  BMR can be estimated

  - Based on surface area
  - Based on experimental info in tables
  - Based on age formulas (humans)
  - Using Holliday-Segar formula

Fluid therapy
Holliday-Segar Formula

- Developed to estimate kcal for BM
- But … fluid required in ml = kcal

  For each 100 kcal for BM require 100 ml fluid
    - Insensible loss – 40-50 ml
    - Urinary excretion 50-60 ml

      U_{sg} = 1.010
- Holliday-Segar Formula (wt < 100 kg)
  - 1-10 kg wt = 100 ml/kg/day
    - 4 ml/kg/hr
  - 11-20 kg wt = 1000 ml + 50 ml/each kg >10kg/day
    - 40 + 2 ml/each kg >10kg/hr
  - > 20 kg = 1500 ml + 25 ml/each kg > 20/day
    - 60 + 1 ml/each kg > 20/hr

Fluid therapy Maintenance Fluids

- Example: 50 kg foal
- First 10 kg weight = 1000 ml/day
- Second 10 kg weight = 500 ml/day
- Remaining 30 kg weight = 750 ml/day
- Total: 2250 mls/day or 94 ml/hr.

Fluid therapy
Maintenance Fluids

- Using H-S formula
  - Half calculated rate = insensible loss
  - Useful with anuric renal conditions
- INs – insensible losses = OUTs
  - Helps gauge renal function
  - Detect excessive urine output
  - Help match INs with OUTs
    - Beware: correction of fluid overload
      - O>I

Fluid therapy
Maintenance Support

- "Dry maintenance rate"
  - Somewhat fluid restricting
- Neonates
  - If don't have excessive fluid loss
  - Can have trouble handling fluid overload
  - Dry maintenance rate helpful
- Glucose infusion rate
  - For the 50 kg neonate > 2.5 calculated fluid maintenance rate
    - Larger the foal the greater the difference
  - It is more important to deliver glucose needs

Fluid therapy
Maintenance Support

- Parental nutrition
  - Fluids can readily be decreased to this dry maintenance rate
- Sufficient oral nutrition
  - Delivers more than fluid needs
- “Dry fluid rate”
  - Spares kidneys during recovery period
  - Renal pathology common in the neonate
    - $\downarrow$ GFR
    - Significant tubular epithelial dysfunction
    - Compounds neonate’s fluid handling challenges

Fluid therapy
Maintenance Support

- Maintenance fluid choice
  - 5% dextrose in water
    - Rehydration of all fluid compartments
    - Not just increase interstitial fluids
    - Sick neonates tend to have an osmolar gap
  - Selected electrolytes added
    - Na restriction
  - Parenteral nutrition
    - D5W - deliver maintenance water requirements
      - Isotonic fluids (252 mOsm/L) without excessive sodium

Fluid Therapy
Sodium considerations

- Neonates easily sodium overloaded
  - Perinatal disease compounds Na handling problems
  - Sodium overload common sequela
    - Indiscriminate fluid therapy
- Normal foal
  - Nursing 10 - 20% of its body weight in mare's milk
  - Receives 1 - 3 mEq Na/kg/day
    - Colostrum 4.9 mEq Na/kg/day
- Neonate will use ~ 1 mEq Na/kg/day in growth
  - Interstitial expansion
  - Increase cellular mass
  - Bone growth

Fluid Therapy
Sodium considerations

- Goal - limit daily Na intake to < 3 mEq/kg/day
  - 1 liter of Na based crystalloids – 50 kg neonate
  - 1 liter of plasma – 50 kg neonate
  - Drug infusions
    - Inopressors
    - Insulin
    - Antimicrobials
    - CRIs
  - Parenteral nutrition
    - Most amino acid sources
      - 2 gm/kg/day amino acids
      - Delivers approximately 1 mEq Na/kg/day.

Fluid Therapy
Sodium considerations

- Neonatal nephropathy

  Common neonatal problem

  - Hypoxic ischemic disease
  - SIRS – cytokine associated
- Na wasting

  Higher Na requirement

Fluid Therapy
Sodium considerations

- Clinically

  Urine is only source of Na loss

  - Without reflux
  - Without diarrhea (dysmotiliy)
  - After growth requirements considered

  Match Ins to urine loss

  - + 1-2 mEq/kg (growth)

Fluid Therapy
Sodium considerations

- Urinary Na loss

  Total urine collection

  - Total daily Na excretion monitored

  Not have total urine collection

  - Na requirements can be estimated from urine Na concentrations
  - Fxna

- Na overload avoided

  while Na requirements are met

Fluid Therapy
Electrolyte Considerations

- K requirements
  - Difficult to estimate
    - Renal loss
    - Growth requirements (anabolic)
    - Catabolic K release
    - K release from sepsis
  - Any neonate not consuming milk will require
- Supplemental K
  - When delivering glucose (4-8 mg/kg/min.)
    - empirical supplementation - 10-40 mEq/l fluids
  - When delivering fluids
    - Dry maintenance rate
    - 20-60 mEq/liter may be required

Fluid Therapy
Electrolyte Considerations

- Ca, Mg and PO_4
  - Incomplete ossification
  - Delay until full enteral feeding
  - Cases of hypocalcemia
- Compatibility
  - Parenteral nutrition
  - Continuous rate infusion drugs
  - Ca level
    - Not high enough to cause incompatibilities

Fluid Therapy
Electrolyte Considerations

- Formula per liter

  30 ml/l 23% Ca gluconate (0.642 mg/ml)

  + 1.2 ml/l K_2PO_4 (0.1 mg/ml PO_4)

  + 0.15 ml/l 50% $MgSO_4$ (0.075 mg/ml)

- Maintenance fluids

  Run at the dry fluid rate for a typical 50 kg foal

  29 mg Ca/kg/day (1.45 mEq Ca/kg/day)

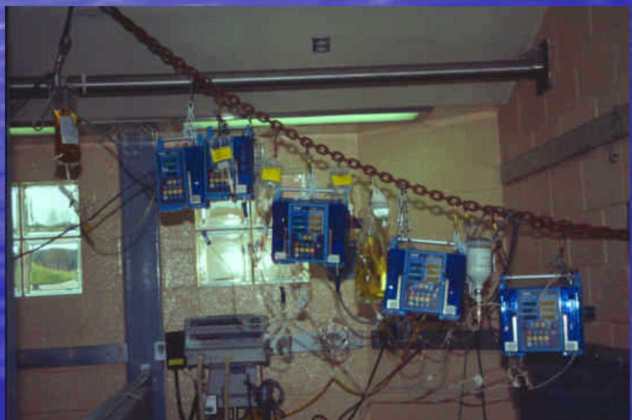
  5 mg P/kg/day (0.16 mEq P/kg/day)

  3.4 mg Mg/kg/day (0.28 mEq Mg/kg/day)

Fluid Therapy
Electrolyte Considerations

- Ca, Mg and PO_4 formula
  - These amounts
    - Are small when compared to
      - Amounts ingested from mare's milk
    - Generally enough to prevent
      - Hypocalcemia and hypomagnesemia
    - Balanced for bone deposition
    - Compatible with
      - Most continuous rate infusions (CRI)
      - Parenteral nutrition





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Practical Approach to Fluid Therapy in Neonates

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Forming a practical approach to fluid therapy in the neonate requires an understanding of neonatal physiology, a clear understanding of the goals of fluid therapy (treatment of hypovolemia, dehydration or maintenance fluid therapy) and an understanding of the special electrolyte needs and limitations of the neonate.

Fluid Therapy for Hypovolemia (Septic Shock)

Sodium containing crystalloids or colloids are usually chosen to expand vascular volume. Some clinicians use saline, but I prefer to use a fluid with a balanced strong ion difference similar to blood. Normal saline is an acidic solution since when large quantities are given a significant hyperchloremic acidosis can occur. Although somewhat expensive, plasma can serve as a replacement colloid solution.

When treating septic shock, fluid boluses of 20 ml/kg over 5 to 20 minutes should be given with re-evaluation after each bolus to decide if the therapeutic goal has been reached. In this case, the goal is adequate tissue perfusion has assessed by signs of adequate regional perfusion. Improved pulse quality, warm legs, return of borborygmi, urine production and improved mental status are all signs of adequate perfusion. Repeat fluid boluses are usually required. If more than 60-80 ml/kg is required, serious consideration for inopressor therapy should be given. The neonate with severe septic shock may require up to 200 ml/kg of fluids in the first 1 to 2 hours. On the other hand, because of the neonate's difficulty in handling fluid loads, fluids in excess of immediate needs should be strictly avoided. This can be achieved by reassessing the patient after each bolus has been given as opposed to placing a neonate on a high continuous fluid rate.

Example: 50 kg foal – 20 mg/kg = 1000 ml over 10 – 20 min

Fluid therapy for glucose support

All compromise neonates will benefit from exogenous glucose support. The main challenge is convincing the neonate’s physiology to accept exogenous glucose without becoming hyperglycemic. Many clinicians confuse blood dextrose levels with a gauge of adequate glucose stores. Blood glucose levels are a summation of glucose mobilization and glucose utilization. Before birth, the normal fetus is receiving all of their glucose needs through the placenta. Transfer rate of glucose from the placenta to fetus very somewhat between species but generally is between 4 and 8 mg/kg/min. (fetal foal 6.8 mg/kg/min., fetal calf 5 mg/kg/min.). With fetal distress because of placentitis or because of lack of nutrient transfer from the dam, the fetus may begin to have active glucogenesis being born with a high resting glucose. But the normal fetus is born before glucogenesis begins, usually with a low blood glucose (neonatal foal 25-35 mg/dl) which continues to drop for the first few hours of life until either glucogenesis is initiated or entral nutrition provides a source of glucose. The low point of blood glucose levels is usually 2 to 4 hours after birth. The normal foal will begin glucogenesis without a problem, but the neonate suffering from perinatal disease may not make the transition to glucogenesis and may become dangerously hypoglycemic, compounding the neonatal problems. In either case, whether the neonate has precocious glucogenesis or no glucogenesis, supplementing them with exogenous glucose will spare their calories, decrease their catabolic state and support their recovery.

When delivering glucose therapy, a rate of 4 to 8 mg/kg/min should be the goal. Neonates tolerate exogenous glucose best if the infusion is begun at the low rate and gradually increased over the first hours of therapy. Even when the blood glucose is too low to register, I still feel beginning at 4 mg/kg/min is a good starting dose. Blood glucose levels can be followed and the infusion rate of dextrose increased in the first few hours if necessary. In foals with severe sepsis or septic shock the infusion rate often needs to be increased above 8 mg/kg/min and may even need to be as high as 20 mg/kg/min. When giving high exogenous glucose loads, addition of thiamine to the fluids may help ensure proper metabolism.

Example: 50 kg foal – to deliver glucose at a rate of 4 mg/kg/min
50 kg X 4 mg/kg/min = 200 mg/min X 60 min/hr = 12000 mg/hr; using 5% dextrose = 50 mg/ml; fluid rate = 240 ml/hr.
For 6 mg/kg/min. infuse 240 ml/hour of 7.5% dextrose; for 8 mg/kg/min. - 240 ml/hour of 10% dextrose

Glucose intolerance may occur because of failure to adapt to the exogenous glucose load. The normal fetus does not need to regulate its glucose level but rather relies on maternal regulation. So another transition that occurs at birth is regulation of glucose levels. The insulin response to high blood glucose levels may be somewhat sluggish in the neonate, especially the neonate who has had significant perinatal stress. The hope of administering exogenous glucose is to spare endogenous stores. Occasionally the neonate will continue glucogenesis despite the delivery of exogenous glucose resulting in hyperglycemia. Hyperglycemia may also occur if glucose administration is in excess of utilization in the absence of an adequate insulin response. A third reason for hyperglycemia is iatrogenic glucose overload because of errors in calculations or administration of glucose containing fluids as boluses. If the neonate becomes hyperglycemic, the clinician should double check the infusion rate, ascertain whether the intolerance might be secondary to sepsis and also be patient, allowing time for the neonate to develop an insulin response. Hyperglycemia without an insulin response may result in a degree of cellular dehydration, but the major adverse effect is a glucose diuresis with subsequent fluid and electrolyte wasting. If the neonate is only mildly hyperglycemic (< 250 mg/dl) and there is not a significant glucose diuresis, I prefer to give the neonate sometime (hours) to develop its own innate insulin response. If there is a glucose diuresis or the blood dextrose is persistently high without apparent adaptation, I prefer to initiate insulin therapy rather than decreasing glucose infusion, since decreasing glucose infusion will not address the energy needs of the neonate.

If exogenous insulin is required, continuous infusion of regular insulin is well tolerated by most neonates and allows more control of glucose kinetics. In most cases, rather than being insulin insensitive, neonates will respond to surprisingly low insulin levels suggesting an insulin deficit as opposed to insulin resistance, even in sepsis. The amount of regular insulin required usually ranges between 0.00125-0.2 u/kg/hr. I usually began at 0.0025 u/kg/hr and double the rate every 4 to 6 hr. until the glucose becomes control or the infusion rate is > 0.04 u/kg/hr at which time I more slowly increase the rate. Care should be taken not to increase the rate too quickly, since the response to the infusion is not seen immediately and it is easy to increase the infusion rate too soon and place the neonate on a glucose roller coaster. When preparing an insulin infusion, special care of should be taken. First, it should be no more than 3 months since the insulin bottle was first used. Insulin is a suspension and should be gently rocked or rolled to resuspend the insulin but never shaken. Insulin adheres to both glass and plastic. Adherence can be decreased with albumin containing solutions or other special carriers or careful pretreatment of IV lines may be used. Insulin should be diluted in saline in a glass bottle, by infusing the insulin into the saline and not allowing the undiluted insulin to run down the glass where it will adhere. I generally make up a 0.1 U/ml solution in 100-150 mls of saline. The insulin containing solution in the final dilution should be used to treat all plastic ware from the insulin line to the neonate by running 40 to 60 mls of the solution through the line and then flushing the line with solutions not containing insulin (some studies suggest that having the insulin retained in the line for 24-72 hrs. may be more efficacious but certainly is not practical). If the insulin is given after a plasma transfusion, albumin in the plasma may have already bound some of the sites on the plastic where insulin would normally adhere. If the lines are not pretreated or if there's a line change and the new lines are not pretreated, the insulin kinetics may be erratic because of lack of delivery as insulin binds to the lines and then a sudden increase in delivery once the sites are occupied.

Fluid therapy for maintenance support

Fluid requirements of any individual (commonly referred to as maintenance fluids) varies depending on metabolic rate (in neonates usually 100 - 120 kcal per kg with some modification of requirements with sepsis, etc. whether the caloric source is endogenous or exogenous), the degree this metabolism is supported by catabolism (which will both increase osmotic load and result in production of metabolic water), insensible water loss (dependent on humidity, ventilatory rate, ambient temperature, surface to mass ratio), gastrointestinal water loss, urine osmotic load (increased with many medications and hyperglycemia) and the ability of the kidneys to concentrate this osmotic load (loss of this ability increases fluid requirements). Because these factors vary from one individual to another there is no "correct fluid maintenance rate." This should be kept in mind when formulating maintenance fluid rates. In an environmentally controlled neonatal intensive care unit, variations in relative humidity and ambient temperature may be controlled. But one factor that will vary with each patient reliably is the surface area to volume ratio resulting in excess evaporative losses from smaller patients and less from larger patients. For this reason, and since neonates presenting to our neonatal service vary in weight from 1.5-80 kg, I use a formula that varies the fluid rate according to body size as follows:

For the first 10 kg of body weight (1-10 kg) -- 100 mls/kg/day
For the second 10 kg of body weight (11 kg-20 kg) -- 50 mls/kg/day
For weight in excess of 20 kg -- 25 ml/kg/day

Example: 50 kg foal
First 10 kg body weight = 1000 ml/day
Second 10 kg body weight = 500 ml/day
Remaining 30 kg body weight = 750 ml/day
Total: 2250 mls/day or 94 ml/hr.

This fluid rate is what I term a "dry maintenance rate" since it is somewhat fluid restricting. However my experience shows that most often neonates who don't have excessive fluid loss, have more problems with fluid overload than fluid restriction. Thus I find this dry maintenance rate helpful in maintaining fluid balance. You will note that the fluid administration rate to meet glucose requirements is more than 2.5 that of the calculated fluid maintenance rate for the 50 kg foal. It is more important to deliver glucose needs in a solution that is not overly concentrated than to limit the fluids to this calculated rate initially. But once the foal is on parenteral nutrition or sufficient oral nutrition, fluids can readily be decreased to this dry maintenance rate. I prefer to use 5% dextrose in water as maintenance fluid with selected electrolytes added (see below) since sodium restriction is important in neonates. Even when giving parenteral nutrition, I use 5% dextrose in water as a way to deliver isotonic fluids without excessive sodium while delivering maintenance water requirements.

Sodium considerations

As noted above, neonates have a difficult time handling sodium. This appears to be compounded in the neonatal foal with perinatal disease. Sodium overloading is a common sequela of indiscriminate fluid therapy. The normal foal nursing 20% of its body weight in mare's milk receives 1-1.8 mEq Na /kg/day. Since colostrum is more sodium rich than milk, the same volume of colostrum will result in an intake of 4.9 mEq Na/kg/day. Using these levels as guides, I try to limit daily Na intake to < 3 mEq/kg/day. So, 1 liter of Na based crystalloids or 1 liter of plasma will deliver a 50 kg foal's total sodium requirements for a day. When other medications are being infused in saline such as inotropes, pressors, insulin or antimicrobials, they also will add to the sodium load of the neonate. Most amino acid sources used in parental nutrition will deliver approximately 1 mEq Na/kg/day.

Many neonates, especially foals, who have neonatal nephropathy, may waste sodium in their urine. These neonates will have a higher Na requirement. If urine is being collected, total daily Na excretion can be monitored and Na can be administered at the rate of 1 to 2 mEq/kg/day above the excretion level (for growth requirements). When total urine collection is not possible, Na requirements can be estimated from urine Na concentrations. With some care, Na overload can be avoided while Na requirements can be met.

Other electrolyte considerations

As noted above, the neonate who is not consuming milk will require supplemental K. It is difficult to estimate the K requirements because of the dynamics of renal loss, growth requirements in neonates who are anabolic and K release in neonates who are septic and catabolic. When delivering glucose (4-8 mg/kg/min.) empirical supplementation of 10-40 mEq/liter of fluids is usually adequate. When delivering fluids at the dry maintenance rate, 20-60 mEq/liter may be required.

Where there is incomplete ossification and there may be some delay until full enteral feeding can be achieved or in cases of hypocalcemia, calcium, magnesium and phosphorus may be added to the intravenous fluids. When parenteral nutrition and other drugs are given by continuous rate infusion through the same intravenous line as the calcium containing fluids, care must be taken so that the calcium level is not high enough to cause incompatibilities. The following addition per liter of fluids will result in concentrations which are compatible with most concurrent infusions: 30 ml/l 23% calcium gluconate (0.642 mg/ml) plus 1.2 ml/l potassium phosphate (0.1 mg/ml phosphate) plus 0.15 ml/l 50% $MgSO_4$ (0.075 mg/ml). When added to the maintenance fluids run at the dry fluid rate for a typical 50 kg foal this solution will deliver 29 mg Ca/kg/day (1.45 mEq Ca/kg/day), 5 mg P/kg/day (0.16 mEq P/kg/day) and 3.4 mg Mg/kg/day (0.28 mEq Mg/kg/day). Although these amounts are quite small when compared to the amounts ingested from mare's milk, they are generally enough to prevent hypocalcemia and hypomagnesemia and appear to be balanced for bone deposition and most importantly are not incompatible with most continuous rate infusions (CRI) including parenteral nutrition. The amount of magnesium delivered is much smaller than that administered when Mg is given to treat a hypoxic ischemic encephalopathy (50 mg/kg/hr for the first hour as a loading dose followed by 25 mg/kg/hr as a continuous rate infusion).