Fluid Management in Neurosurgery

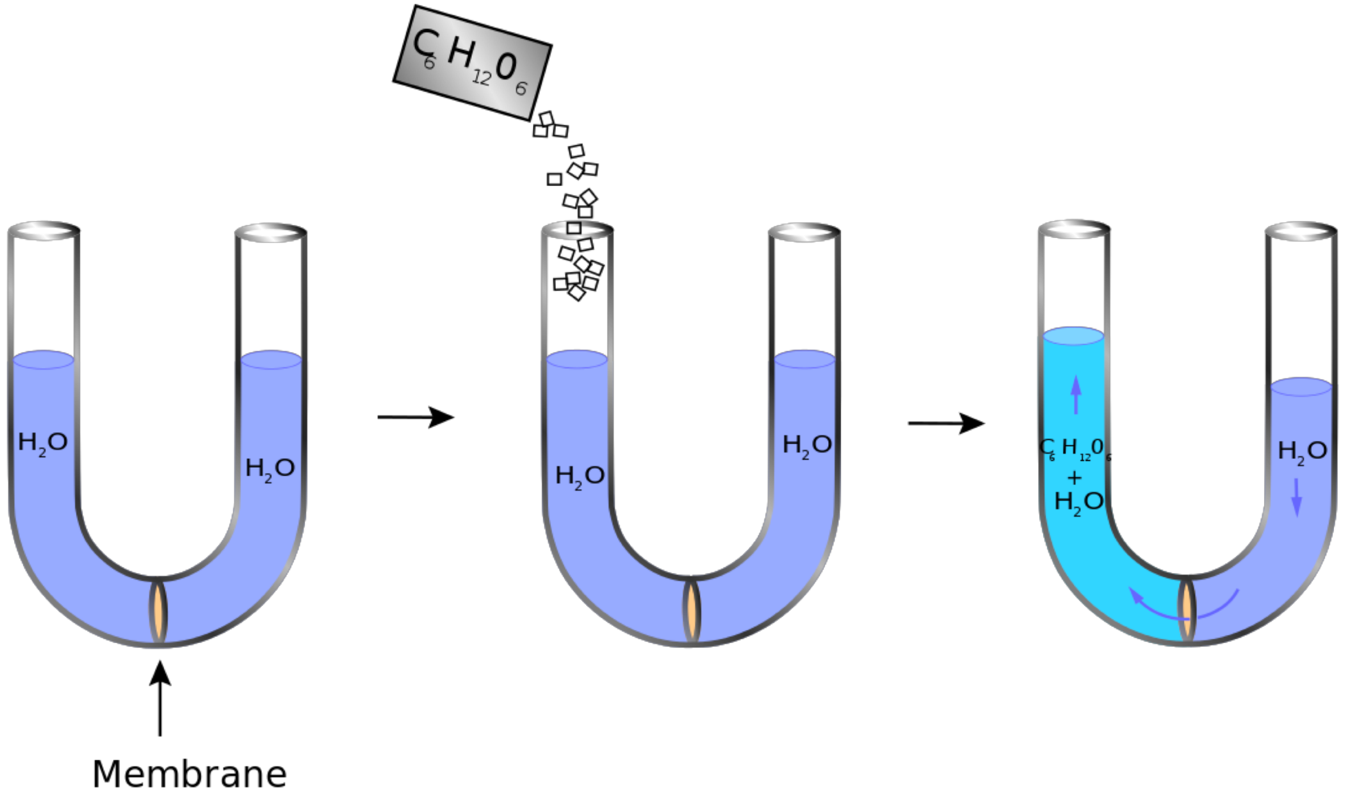
A brief review

Fluid management in neurosurgical patients can be tricky…

- Mannitol, hypertonic saline to reduce ICP
- Intraoperatively, you may battle hypotension from vasodilation due to inhalational anesthetics, severe blood loss
- Development of diabetes insipidus or SIADH
- What’s a neuroanesthesiologist to do???

Osmolality & Osmolarity

- Osmolality = # of milliosmoles (mOsm) per kg of solvent
- Osmolarity = # of mOsm per liter of solution, determines fluid movement between body compartments
- Movement continues until solutions attain equal osmolality on the two sides of the membrane



Osmotic Pressure

- Osmotic pressure is the hydrostatic force which acts to equalize the concentration of water on both sides of a membrane that is impermeable to solutes dissolved in that water

Colloid Oncotic Pressure

- Osmotic pressure generated by large molecules (e.g. albumin, hetastarch, dextran)
- Clinically significant in vascular membranes that are permeable to small ions but not large molecules

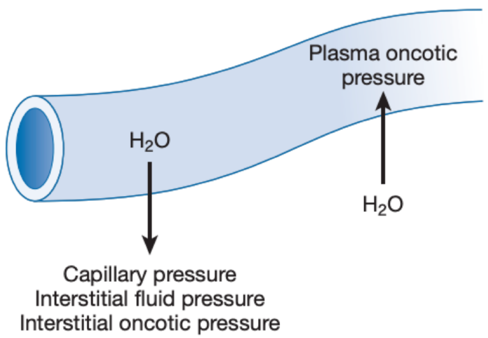
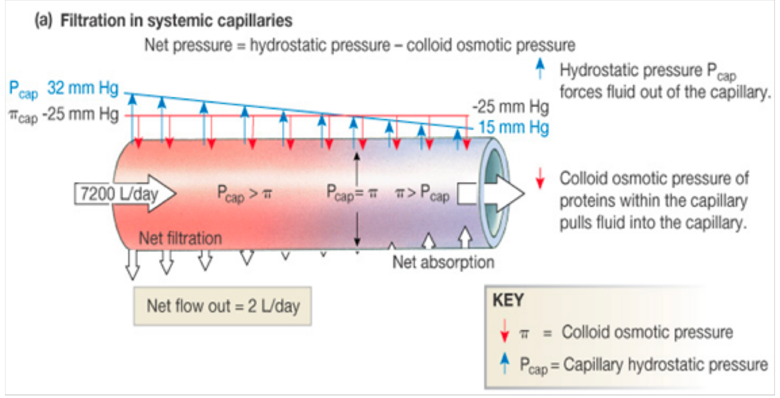


Fig. 9.3 In peripheral tissues, four forces act on intravascular water: capillary hydrostatic pressure, interstitial fluid pressure (negative in most tissues), and interstitial oncotic pressure (exerted by proteins in the interstitial space) act to draw water from the intravascular space into the interstitium. The only force that acts to maintain intravascular volume is plasma oncotic pressure. This last force is produced by the presence in plasma of high-molecular-weight proteins that cannot cross the capillary wall.



Ernest Starling, British physiologist

- Ernest Starling studied how water moves between tissue and the intravascular space
- The amount of fluid movement is proportional to the hydrostatic pressure gradient minus the osmotic gradient across a vessel wall

$$\mathbf{Q_f = K_f S\,[(P_c - P_t) - \sigma\,(\pi_c - \pi_t)]}$$

- Q_f = fluid movement
- K_f = filtration coefficient of the capillary wall (leakiness determinant)
- S = surface area of the capillary membrane
- P_c = hydrostatic pressure in capillary lumen
- P_t = hydrostatic pressure in interstitial space
- $\sigma =$ coefficient of relfection
- π_c = oncotic pressure of plasma
- π_t = oncotic pressure of fluid in extracellular space

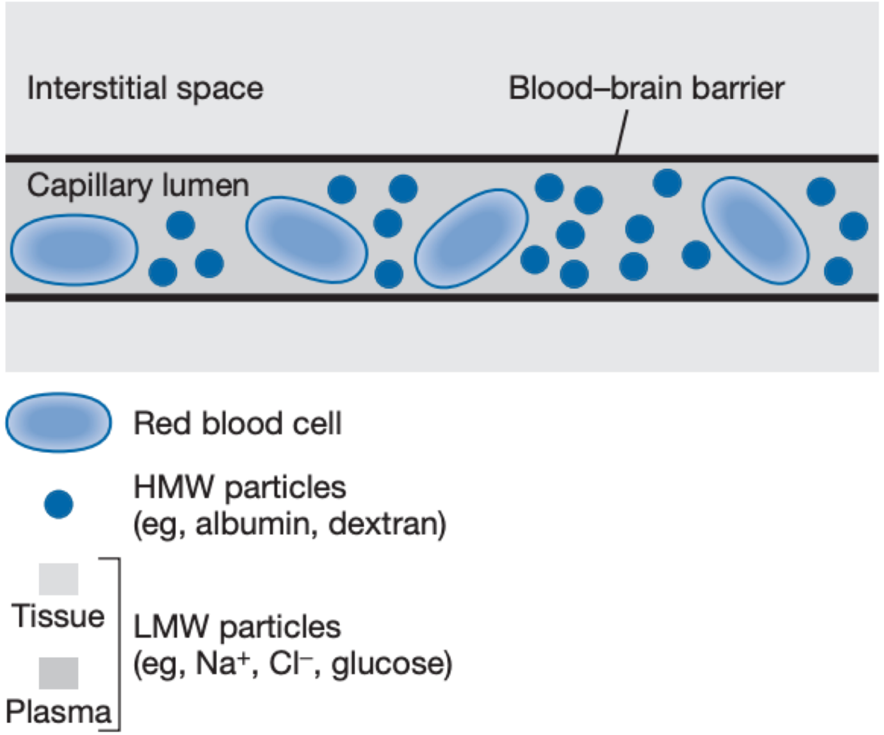


Fig. 9.5 In cerebral capillaries, the blood–brain barrier (estimated pore size of 7–9 Å) prevents movement of even very small particles between the capillary lumen and the brain's interstitial space. Increasing plasma osmolality by intravenous infusion of mannitol or hypertonic saline can, therefore, establish an osmotic gradient between the brain and intravascular space that acts to move water from the brain into capillaries. HMW, high-molecular-weight; LMW, low-molecular-weight.

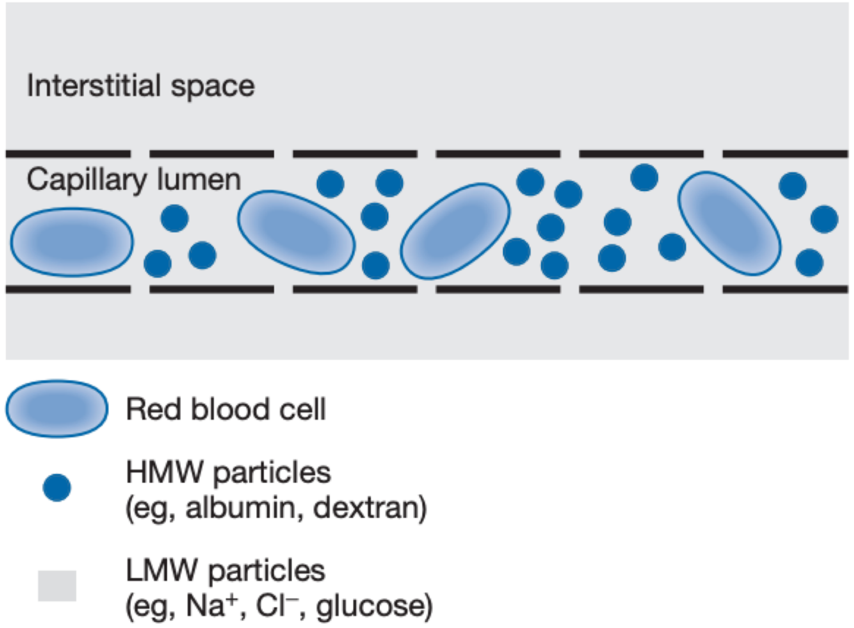
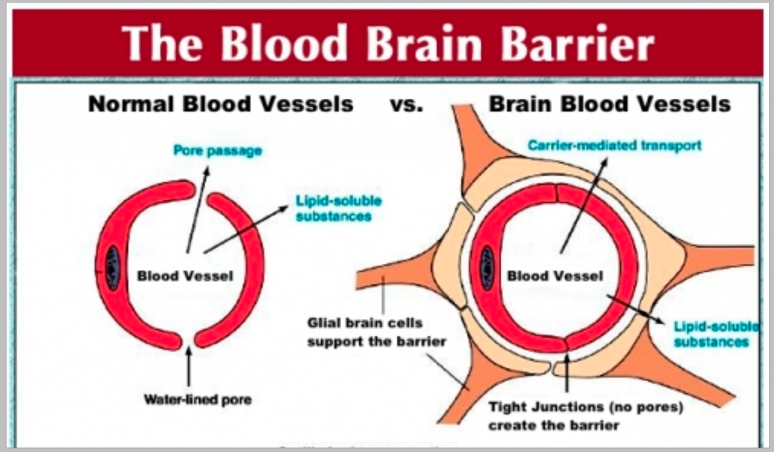
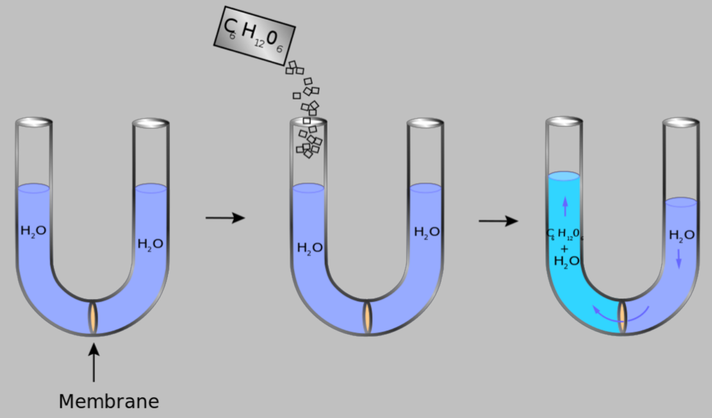


Fig. 9.4 In peripheral capillaries, free movement of most low-molecular-weight (LMW) particles (including sodium and chloride ions, glucose, and mannitol) occurs between the capillary lumen and the interstitial space. Intravenous administration of LMW solutes cannot affect the movement of water between the interstitium and vasculature because no osmotic gradient can be established. In contrast, a rise in plasma oncotic pressure from the administration of concentrated albumin, hetastarch, or dextran may draw water from the interstitium into the vessels because these high-molecular-weight (HMW) particles are precluded from passing through the capillary wall. Hypertonic saline solutions create an osmotic gradient across cell membranes and thus transfer fluid from the intracellular to the extracellular compartment, including the intravascular space.

- Cerebral capillaries have a very small pore size 7-9 A (0.7 – 0.9 nm)
  - Prevents movement of proteins and ions
- Fluid movement across the BBB is determined by total osmotic gradient generated by both large molecules and small ions
  - Normal BBB, with decrease of plasma osmolality, the osmotic gradient drives the water into the brain tissue
  - Damaged BBB, variable response to changes in plasma osmotic/oncotic pressure





Fluids for IV Administration

- Crystalloids
  - Contain small molecules that pass freely through cell membranes and vascular walls
  - Oncotic pressure = 0
  - Can be:
    - Hypo-osmolar
    - Iso-osmolar
    - Hypo-osmolar

Hypo-osmolar (D5W, ½ NS)

- Reduce plasma osmolality
- Causes movement across BBB into cerebral tissue
- Increases brain water content and edema, resulting in increased ICP

Iso-osmolar (Normosol, Plasmalyte, NS)

- Osmolality of 300 mOsm/L
- Does not change plasma osmolality, no increase in brain water content

Hyper-osmolar (hypertonic saline, mannitol)

- Pull water from brain to the intravascular space
- Used to decrease ICP, brain water content

Fluids for IV Administration

- Colloids
  - Albumin, plasma, hetastarch, pentastarch, dextrans
- Composed of large molecules which are relatively impermeable to capillary membranes
- HES affects coagulation; factor VIII depletion can cause kidney injury an increased mortality in critically ill patients

Fluids for IV Administration

- Glucose Solutions - salt free solutions containing glucose are avoided in brain and spc injuries for several reasons
  - Metabolized glucose in 5% dextrose releases only free water remains which reduces serum osmolality and increases brain water content
  - Glucose administration can increase neurologic damage and worsen outcomes for ischemia due to enhanced glucose metabolism and resultant tissue acidosis

Solution	Osmolarity	pH	Na^+	Cl^-	K^+	Ca^{2+}	Glucose	Other
NS	308	6.0	154	154	-	-	-	-
½ NS	154	6.0	77	77	-	-	-	-
3% NS	1026	5.0	513	513	-	-	-	-
LR	273	6.5	130	109	4	3	-	lactate 28
Plasmalyte	294	7.4	140	98	5	3	-	acetate 27 gluconate 23
D_5W	253	4.5	-	-	-	-	50	-
D_5W ½ NS	432	4.0	77	77	-	-	50	-
D_5W LR	525	5.0	130	109	4	3	50	lactate 28
7.5% $NaHCO_3$	1786	8.0	893	-	-	-	-	HCO_3 893
Albumin 5%	330	7.4	~145	-	≤2	-	-	albumin 50
Albumin 25%	330	7.4	~145	-	≤2	-	-	albumin 250
10% Dextran 40 in NS	308	4.0	154	154	-	-	-	dextran 100
Hetastarch 6% in NS	308	5.9	154	154	-	-	-	hetastarch 60

Hypotonic

Isotonic

Hypertonic

Osmolarity = mOsm/L

Electrolytes = mEq/L

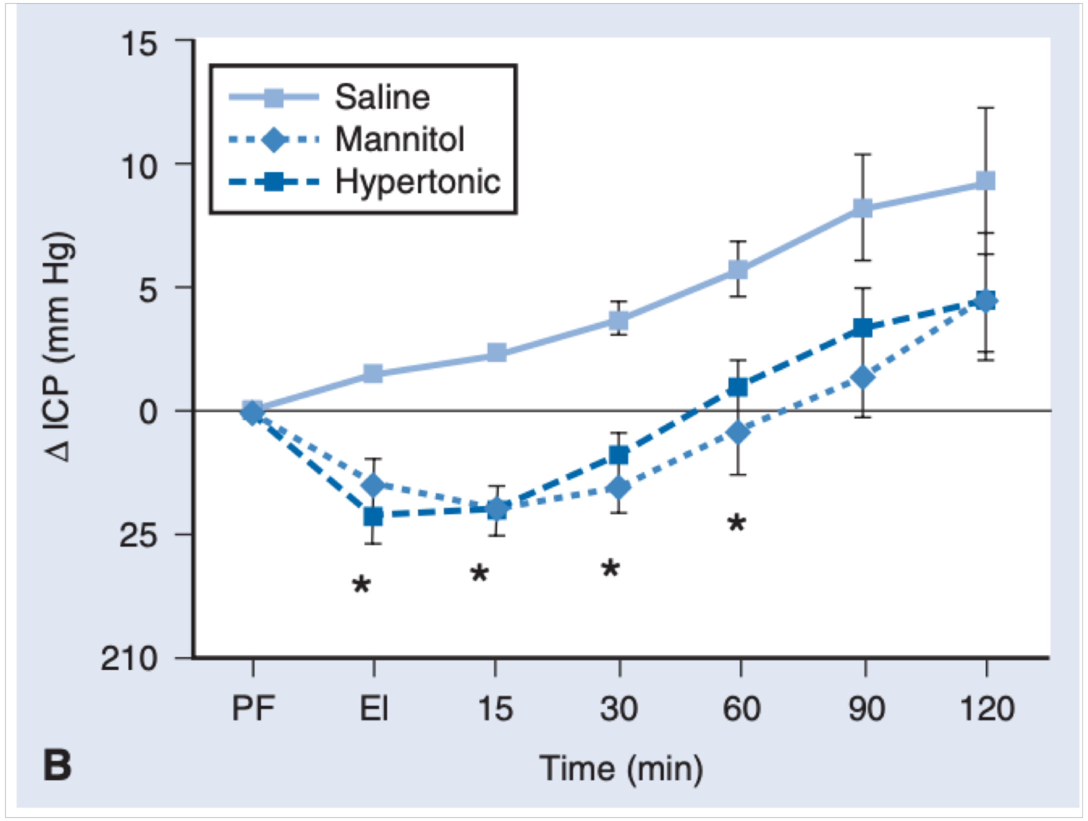
Glucose, albumin = g/L

*Though sometimes used interchangeably, molarity and molality are not the same. The units for molarity are moles/liters versus the units for osmolality are moles/kilogram.

Fluids to control Intracranial Pressure

- Mannitol
  - Increases plasma osmolality, osmotic gradient is established between the intravascular compartment and the cerebral parenchyma
  - Mannitol is less effective with larger lesions or anytime the BBB is interrupted
    - Mannitol may go down its concentration gradient into the brain leading to a rebound phenomenon of increased brain edema and ICP
  - Administration of mannitol causes a triphasic hemodynamic response
    - Transient hypotension (1-2 min)
    - Increase in blood volume, cardiac index, and PCWP
    - After 30 minutes, blood volume returns to normal

mannitol groups at any time during the study. **B,** Effect of hypertonic saline and mannitol on intracranial pressure. Both of these osmotic agents produced transient decreases in intracranial pressure when compared with an equal volume of 0.9% saline. Δ ICP, change in ICP from PF value; Δ OSM, change in OSM from PF value; EI, end of infusion of 0.9% saline, mannitol, or hypertonic saline; PF, 45 minutes after induction of a cryogenic brain lesion; *, $p < 0.05$ mannitol and hypertonic saline groups vs. 0.9% saline group.) *(From Scheller MS, Zornow MH, Oh YS: A comparison of the cerebral and hemodynamic effects of mannitol and hypertonic saline in a rabbit model of acute cryogenic brain injury. J Neurosurg Anesth 1991;3:291-296.)*



Hypertonic Saline Solutions

- Hypertonic salt solutions lower ICP and improve CPP
- No osmotic diuresis like mannitol, better for perioperative fluid management

Clinical Implications

- Intraoperative volume replacement/resuscitation
  - Should take into account blood loss, urine output, insensible losses
  - Fluids should be administered judiciously to maintain
    - Euvolemia
    - Slightly increased serum osmolarity
    - Normal plasma oncotic pressure
  - Fluid management should be guided in trends in arterial blood pressure and CVP
  - Hypo-osmolar fluids should be avoided as they may reduce the plasma osmolality

Head Injury

- An ideal fluid would maintain intravascular volume and not increase cerebral edema
- NS = ideal, osmolality 308 mOsmol/L; can cause hyperchloremic acidosis if given in large quantities
- Hypertonic saline osmolality 514 mOsmol/L withdraws fluid from tissues and increases intravascular volume, increased CO and systolic BP → improved CPP (remember CPP = MAP – ICP)
- Colloids vs. crystalloid? Limited scientific evidence to support their use
- SAFE study compared saline vs. albumin; no benefit to albumin, found to have increased mortality 2/2 vasogenic edema
- Blood is ideal for resuscitation with > 30% loss of blood volume

Subarachnoid Hemorrhage

Hyponatremia and hypovolemia occur frequently with SAH

- Hyponatremia may be due to cerebral salt wasting syndrome
- Hypovolemia 2/2 bed rest, iatrogenic blood loss, autonomic dysregulation

Neuroscientist task force recommends the following in SAH

- Target euvolemia
- Isotonic crystalloid is preferred agent for volume replacement
- Avoid hypervolemia and aggressive fluid administration

Water & Electrolyte Disturbances

- Diabetes Insipidus (DI)
  - Caused by decreased secretion (central neurogenic DI) or action (nephrogenic DI) of antidiuretic hormone (ADH)
  - Commonly seen after TBI, pituitary/hypothalamic lesions
  - Clinical features: polyuria (>200 mL/h), hypernatremia (145 mmol/L), increased plasma osmolality (>300 mosm/kg)
  - Rx: volume repletion, DDAVP
- SIADH
  - Caused by head injury, excessive release of ADH leading to continuous renal excretion of sodium despite hyponatremia; associated hypoosmolality
  - Urine osmolality is high
  - Rx: fluid restriction
- CSWS
  - Mainly seen with SAH and characterized by hyponatremia, volume contraction and high urine sodium due to release of natriuretic factor from the brain
  - Rx: sodium containing solution

THE END

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