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Water and Electrolyte Balance

Biochemistry

Body water distribution, sodium, potassium, calcium, chloride and phosphate balance, osmosis, diffusion, fluid regulation and biochemical importance.

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CHAPTER 15

Water and Electrolyte Balance

Body fluids, osmosis, diffusion, electrolyte homeostasis and clinical importance

1. Body water distribution

Total body water (TBW) commonly represents around 50-60% of adult body mass. Infants have a higher proportion; older age and higher adiposity reduce it. Approximately two-thirds of TBW is intracellular (ICF) and one-third extracellular (ECF). ECF includes plasma and interstitial fluid, plus small specialized compartments. An illustrative 70-kg adult with 60% TBW has 42 L water: 28 L ICF and 14 L ECF, including roughly 3-3.5 L plasma. Actual values vary.

2. Movement of water and solutes

Diffusion moves solute down its concentration gradient; facilitated diffusion uses transport proteins. Osmosis is movement of water across a semipermeable membrane in response to effective solute concentration. Filtration is pressure-driven fluid movement; active transport requires energy. Osmolality measures particles per kg of solvent; tonicity depends on effective osmoles that drive water shifts across cell membranes. Hypertonic fluid tends to shrink cells; hypotonic fluid tends to swell them. Na+/K+-ATPase maintains gradients by transporting 3 Na+ out and 2 K+ in per ATP.

3. Fluid regulation

- ADH increases collecting-duct water permeability through aquaporin-2; thirst promotes intake.
- RAAS: renin -> angiotensin II -> aldosterone, supporting perfusion and sodium retention.
- Natriuretic peptides promote sodium excretion and oppose volume-retaining mechanisms.
- Kidneys match water and electrolyte losses to intake; skin, lungs and GI tract contribute to losses.

Estimated serum osmolality (mOsm/kg) 2 x Na (mmol/L) + glucose (mg/dL)/18 + BUN (mg/dL)/2.8. Typical measured osmolality is ~275-295 mOsm/kg; effective osmolality excludes urea.

4. Major electrolytes and typical adult serum ranges

Electrolyte	Typical range	Function
Sodium	135-145 mmol/L	ECF volume, water balance and nerve activity
Potassium	3.5-5.0 mmol/L	Resting membrane potential, muscle and heart function

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Chloride	98-106 mmol/L	Electroneutrality, fluid and acid-base balance
Total calcium	8.5-10.5 mg/dL	Contraction, coagulation, bone and signalling
Magnesium	1.7-2.2 mg/dL	Enzyme, cardiac and neuromuscular function
Phosphate	2.5-4.5 mg/dL	ATP, bone, nucleic acids and buffering

5. Electrolyte disturbances

Disturbance	Common causes and manifestations
Hyponatraemia	Water excess, diuretics, sodium loss; headache, confusion, seizures when severe
Hypernatraemia	Water deficit or sodium gain; thirst, altered consciousness
Hypokalaemia	GI losses, diuretics, shifts into cells; weakness, ECG changes
Hyperkalaemia	Renal impairment, medications, cell breakdown; dangerous arrhythmias
Hypocalcaemia	Vitamin D deficiency, hypoparathyroidism, critical illness; tingling, tetany
Hypercalcaemia	Hyperparathyroidism, malignancy; constipation, weakness, confusion
Hypophosphataemia	Refeeding, renal losses; muscle and respiratory weakness
Hypomagnesaemia	GI or renal losses; tremor, arrhythmias and refractory hypokalaemia

6. Fluid imbalance and replacement

Dehydration is water deficit; extracellular volume depletion may result from salt and water loss. Fluid overload may occur with heart or renal dysfunction. Assess weight, intake/output, perfusion, oedema, lungs and laboratory trends. Isotonic crystalloids support extracellular expansion when clinically appropriate; hypotonic fluids and hypertonic saline have specific indications. Dextrose 5% in water behaves mainly as free water after metabolism. Treatment and correction rates must be prescribed and monitored; overly rapid sodium correction can cause serious neurological harm.

7. Biochemical functions of key ions

Ion	Important function
Sodium	Extracellular osmolality, membrane transport and nerve impulses
Potassium	Resting membrane potential, muscle and cardiac excitability

Chloride	Electrical neutrality, gastric acid production and acid-base balance
Calcium	Contraction, coagulation, signalling and mineralization
Magnesium	ATP-associated reactions and neuromuscular regulation
Phosphate	Energy transfer, membranes, nucleic acids and buffers

8. Fluid balance monitoring

Intake includes oral, enteral and intravenous fluids; measurable output includes urine, drainage, vomit and stool when quantified. Insensible loss through skin and breathing is less directly measured. Compare trends in weight, intake-output records, perfusion, oedema and laboratory results. An abrupt weight increase may reflect fluid retention, but the clinical context matters.

9. Nursing applications

Use accurate intake/output charts and daily weights when indicated; monitor infusion rates, IV site and ECG in high-risk cases. A haemolysed specimen may cause pseudohyperkalaemia, but a possible critical result requires prompt assessment and confirmation. Never give concentrated potassium by direct IV push; follow local infusion safety protocols.

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10. Important Examination Questions

Long Answer Questions

1. 1. Explain body fluid distribution and electrolyte regulation.
2. 2. Describe body water compartments and mechanisms of fluid movement.
3. 3. Discuss the biochemical functions and clinical disturbances of major electrolytes.

Short Answer Questions

1. 1. Write a short note on Osmosis vs diffusion.
2. 2. Write a short note on ADH.
3. 3. Write a short note on RAAS.
4. 4. Write a short note on sodium and potassium disturbances.

Very Short Answer Questions

1. 1. Which is the major extracellular cation? - Sodium.
2. 2. Which is the major intracellular cation? - Potassium.
3. 3. What is osmosis? - Net water movement across a selectively permeable membrane due to osmotic differences.
4. 4. What hormone increases water permeability in collecting ducts? - ADH.

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Additional objective question

Principal extracellular cation? - Sodium.

11. Quick Revision

- Roughly two-thirds of total body water is intracellular.
- ADH promotes water reabsorption; aldosterone affects sodium and potassium handling.
- Ionized calcium is biologically active; total calcium depends partly on albumin.
- Sodium and potassium disturbances can cause neurological and cardiac complications.

Conclusion

Water and electrolyte regulation maintains volume, membrane function and circulation; safe management requires individualized monitoring and prescribed correction.

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Practice questions

Choose one best answer. The answer key and explanations follow the questions.

1. Approximately what fraction of total body water is intracellular?

A. Two-thirds
B. One-third
C. One-tenth
D. One-quarter

2. What is the usual effect of a hypertonic fluid on cells?

A. Cell swelling
B. Cell shrinkage
C. Cell volume remains unchanged
D. Cell swelling followed by lysis

3. How many sodium and potassium ions does Na+/K+-ATPase transport per ATP?

A. 2 Na+ out and 3 K+ in
B. 3 Na+ in and 2 K+ out
C. 3 Na+ out and 2 K+ in
D. 1 Na+ out and 1 K+ in

4. A patient with renal impairment has potassium 6.8 mmol/L and new ECG abnormalities. What is the priority response?

A. Offer a potassium-rich drink
B. Wait for the next routine blood test without escalation
C. Encourage unmonitored exercise to lower the potassium
D. Urgently escalate for monitored assessment and treatment of hyperkalaemia

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Answer key and explanations

1. A - Two-thirds

About two-thirds of total body water is intracellular.

2. B - Cell shrinkage

Hypertonic fluid draws water out of cells, tending to shrink them.

3. C - 3 Na+ out and 2 K+ in

The pump exports three sodium ions and imports two potassium ions per ATP.

4. D - Urgently escalate for monitored assessment and treatment of hyperkalaemia

Severe hyperkalaemia with ECG changes carries a risk of dangerous arrhythmia. It requires urgent monitored assessment and treatment; the nurse follows the emergency protocol and prescribed care.

Reference:
https://www.ukkidney.org/clinical-resources/aki-guide-resources/primary-care/recognising-and-responding-to-aki-in-primary-care/

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