Chapter 2 / Capítulo 2

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Hydroelectrolyte Regulation: Physiological Mechanisms

Regulación hidroelectrolítica: mecanismos fisiológicos

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Objectives:

- Determine the mechanisms of osmolarity regulation.
- Identify the determinants of osmoregulation and volume regulation.
- Describe the hormonal mechanisms of hydroelectrolytic regulation.

INTRODUCTION

Hydroelectrolytic regulation is a fundamental process for maintaining homeostasis in the organism. It refers to the distribution and concentration of water and electrolytes within the body compartments, such as the intracellular and extracellular spaces.

Renal function

The kidneys regulate the excretion of water and electrolytes through glomerular filtration and tubular reabsorption, using hormones such as aldosterone and antidiuretic hormone (ADH) to adjust sodium and water reabsorption.

Hormonal mechanisms

Aldosterone increases sodium reabsorption, while ADH promotes water reabsorption in the renal tubules, helping maintain the proper concentration of electrolytes in the plasma. Dysregulation of this balance can lead to serious conditions such as dehydration or hyponatremia, which affect cellular function and the overall state of the organism. Therefore, these mechanisms are essential for the proper functioning of cells and tissues, as well as for nerve impulse transmission and muscle contraction.

Water and sodium

The balance between water and sodium requires a series of distinct and highly sensitive pathways. Osmoregulation controls plasma osmolality, primarily mediated by sodium concentration. Volumetric regulation, meanwhile, maintains effective circulating volume. This regulation triggers changes in response to certain stimuli:

- Too much water → Hyponatremia.
- Too little water → Hypernatremia.
- Too much sodium → Volume expansion (edema).
- Too little sodium → Volume depletion.

Osmotic pressure and water distribution

Osmotic pressure is the force generated by solutes that do not cross membranes and that drives the movement of water. Effective solutes generate osmotic pressure (Na^+, proteins). Ineffective solutes do not generate it (urea, ethanol).

The distribution of water between the intracellular and extracellular compartments depends on osmotic balance:

- K^+ predominates intracellularly.
- Na^+ predominates extracellularly.
- Proteins (such as albumin) predominate in the plasma → oncotic pressure.

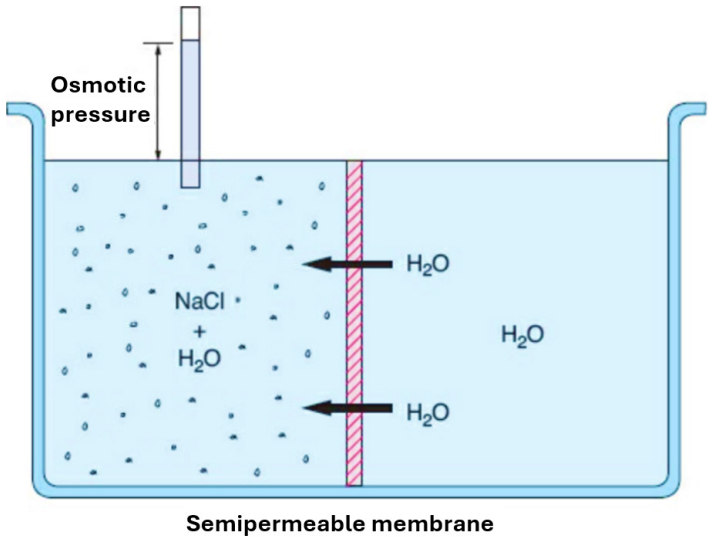

Figure 2.1. Osmotic effect

Relationship between osmolality and sodium

The estimated plasma osmolality can be calculated using the formula:

$$\text{Osmolality} = (2 \times Na^+) + (\text{Glucose}/18) + (\text{BUN}/2{,}8)$$

Urea does not affect effective osmotic pressure because it crosses membranes freely. Effective osmolality depends primarily on Na^+.

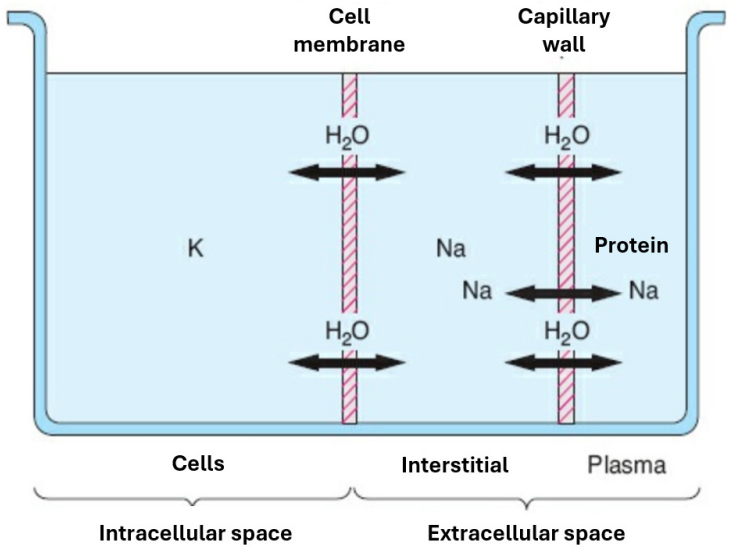

Figure 2.2. Cell membrane and capillary membrane

Osmoregulation vs volume regulation

- Osmoregulation: regulated by ADH and thirst → affects osmolality and plasma Na^+.
- Volume regulation: regulated by the renin–angiotensin–aldosterone system (RAAS), ANP, and ADH (only in severe hypovolemia).

Table 2.1. Regulation

Situation	Plasma Osmolality	Plasma Na^+	Extracellular Volume
Salt without water	Increases	Increases (hypernatremia)	Increases
Water without salt	Decreases	Decreases (hyponatremia)	Increases
Isotonic saline	No change	No change	Increases

Source: Own elaboration

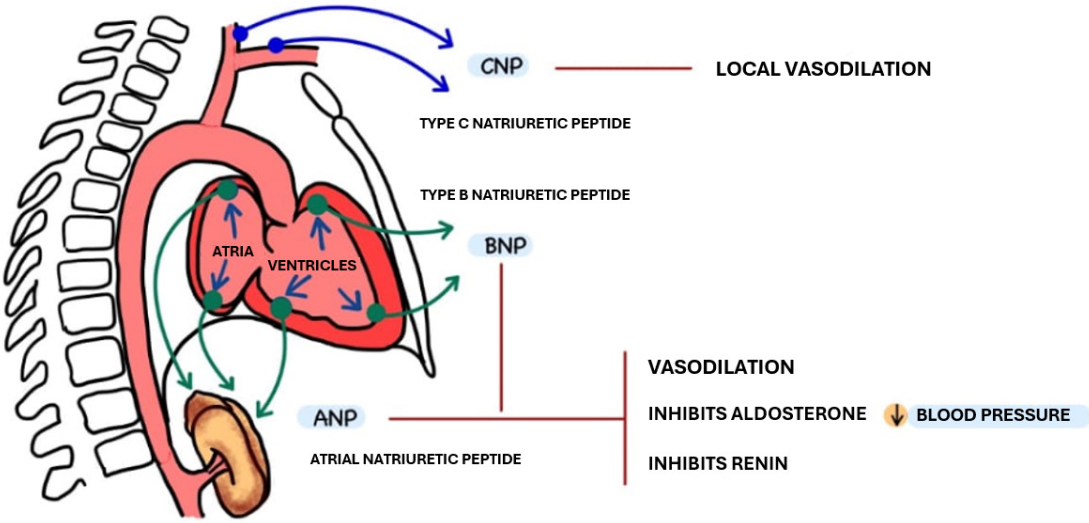

Figure 2.3. Volume regulation

Hormonal regulation

Antidiuretic hormone (ADH)

- Released from the hypothalamus (supraoptic and paraventricular nuclei).
- Acts on the collecting tubules through V2 receptors → inserts type 2 aquaporins (AQP2) → reabsorbs water.
- Stimuli for its release:
  - Hyperosmolality
  - Significant hypovolemia (>10 %)
- Absence of ADH → dilute urine (30–50 mOsm/kg)
- Presence of ADH → concentrated urine (up to 1200 mOsm/kg)
- Inhibited by prostaglandins (PGE_2, PGI_2) - Thirst
- Stimulated by slight increases in osmolality (~2–3 mOsm/kg).
- Crucial for preventing hypernatremia in individuals with free access to water.

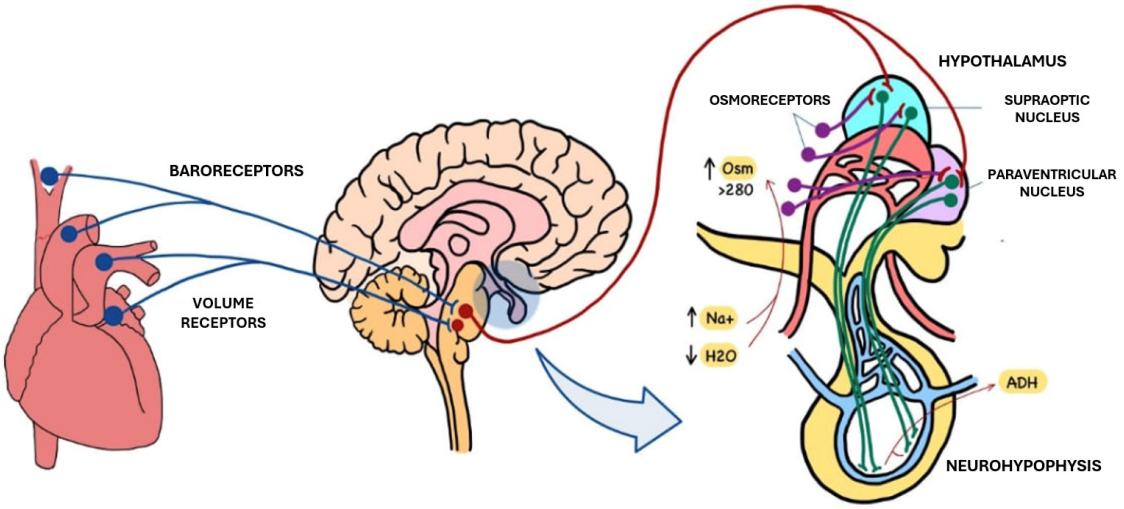

Figure 2.4. Hypothalamus-Hypophysis and ADH

Regulatory receptors

Table 2.2. Regulatory receptors

Type of regulation	Main sensors	Hormonal effectors
Osmoregulation	Hypothalamic osmoreceptors	ADH and thirst
Volume regulation	Macula densa, afferent arteriole, atria, carotid sinus	RAAS, ANP, ADH (only with severe hypovolemia), norepinephrine

Source: Own elaboration

Effective circulating volume

Effective circulating volume is the portion of extracellular fluid volume that effectively perfuses tissues. It is affected by true hypovolemia and relative hypovolemia (CHF, cirrhosis, vasodilation). It does not directly correlate with plasma volume or cardiac output.

Clinical marker

Urinary Na^+ < 25 mEq/L indicates activation of sodium-retaining mechanisms.

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