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Fluid, Electrolyte, Metabolic and Respiratory Acid-Base Management

A Vimala

Foreword
MA Muthusethupathi

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CHAPTER

3

Sodium Homeostasis and Renal Regulation of Sodium

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OVERVIEW

Sodium is the predominant extracellular cation. Kidney is the main organ regulating the excretion of sodium. ECF volume is determined by the sodium content. Sodium balance is mainly maintained by regulating the excretion of sodium by the kidney. Normally 99% of sodium that is filtered by the glomeruli is reabsorbed. Sodium homeostasis is maintained by regulating excretion of final 1% of filtered sodium. This small change is equivalent to addition or removal of one liter of fluid daily to the ECF volume. To maintain constant sodium balance, sodium intake should be equal to the sodium excretion in the urine. If the daily intake of sodium is 150 millimoles, then 150 millimoles is lost in urine to maintain Na balance. When sodium content increases the ECF volume expands and this is sensed by receptors situated in the arterial and local venous channels. They send signals through renal nerves, hormones and physical changes to the kidneys to increase the excretion of sodium and maintain sodium balance. Similarly, when ECF volume contracts reabsorption of sodium will increase and ECF volume will be maintained.

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RENAL HANDLING OF SODIUM

Normally around 27000 millimoles of sodium is filtered by the glomeruli. Of the filtered sodium more than 99% is reabsorbed and only 0.5–1% is excreted. Maintenance of Sodium Chloride (Na Cl) is absolutely necessary for normal functioning of cells. The glomeruli and tubules interact to maintain Na Cl balance. There are two important physiological mechanisms that maintain the renal blood flow (RBF) and GFR within narrow limits. Glomeruli respond to tubules by tubuloglomerular feedback and tubules respond to glomeruli by glomerulo-tubular balance. When GFR increases or decreases, parallel changes in proximal tubular reabsorbtion occurs.

CONTROL OF PROXIMAL TUBULAR SODIUM REABSORPTION

Glomerulotubular Balance (GTB)

When GFR increases proximal tubular reabsorption of sodium will also increase. This will minimize the variations in fractional proximal fluid absorption. Factors controlling GTB are:

1. Peritubular Capillary Oncotic Pressure

When the GFR increases there will be increasing filtration fraction causing an increase in the oncotic pressure in the postglomerular peritubular capillaries. This will decrease the absolute rate of fluid reabsorption. Other factors controlling the proximal tubular reabsorption are: catecholomines, parathyroid hormone, angiotensin, thyroid hormone, corticosteroids and nitric oxide.

2. Tubuloglomerular Feedback

This is an important mechanism by which GFR is regulated. This is achieved by renin-angiotensin mechanism (Fig. 3.1).

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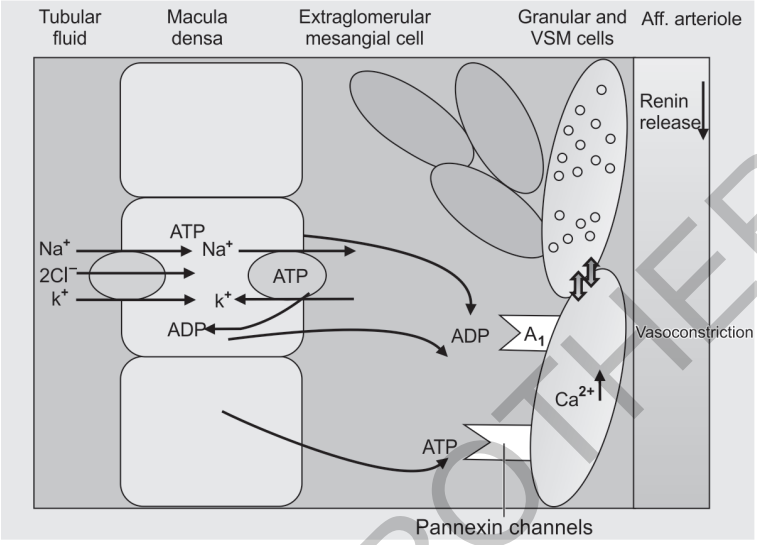

Fig. 3.1: Tubuloglomerular feedback

Macular densa is a collection of densely packed cells at the junction of thick ascending limb and early distal tubule. This is set at an angle between afferent arteriole and efferent arteriole. Macular densa senses rapidly changes in the composition of fluid flowing through thick ascending limb (TAL). Increased Na Cl delivery to distal nephron is an indicator of increased GFR whereas low sodium and chloride delivery is an indicator of decreased GFR. Macular densa senses the Na Cl by the apical $Na^{-}k^{-}$ 2Cl for transport. Signaling molecules are released. This brings appropriate changes in GFR. This is based on purinergic signalling. ATP is released through pannexin channels from cells. Extracellular ATP is converted to Adenosine. This binds to Adenosine A^1 receptors on extraglomerular mesangial cells. This triggers a rise in intracellular Ca levels. The calcium signal is propagated through gap junctions of adjacent cells including granular cells of juxtaglomerular apparatus and vascular smooth muscle cells of afferent arteriole and decrease release of renin. This decreases GFR.

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Sodium Handling in Different Segments of Nephron (Table 3.1)

Proximal Convoluted Tubules (PCT)

In PCT, reabsorbtion of sodium and water is isosmotic and around 18000 millimoles (2/3rd) of sodium is reabsorbed in this segment. Na enters the cell through apical membrane by two mechanisms, this is coupled to reabsorption of chloride and secretion of H^+ ions. Second mechanism is independent entry of Sodium. For these two mechanisms the driving force is electrochemical gradient. The driving force for the sodium transport from the cell to the blood is by Na^+K^+ATPase pump in the basolateral membrane.

Loop of Henle

Reabsorption and secretion of water and electrolytes occurs as the filtrate traverses the loop of Henle. The dissociation of salt and water absorption by the loop of Henle is responsible for the capacity of the kidney to concentrate or dilute the urine. The descending limb of loop of Henle is permeable only to water and is impermeable to electrolytes and as a result osmolality of tubular fluid increases progressively and the maximum osmolality of 1200–1400 milliosmoles is achieved at the tip of the descending limb. The ascending limb of loop of Henle is permeable only to electrolytes and is impermeable to water. In the ascending limb 50% of sodium is reabsorbed via luminal $Na^+K^+2CI^-$ cotransporter and the driving force is

Table 3.1: Sodium reabsorption by the kidney

Nephron site	*Na reabsorption*	*Remaining*	
PCT	18000	9000	150/L
Ascending limb of loop of Henle	6000	3000	45/L
DCT	1600	1400	100/L
Cortical collecting duct	800	600	100/L
Medullary collecting duct	450	150	150/L

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by Na^+K^+ATPase situated in basolateral membrane. Of 3000 millimoles of sodium reabsorbed, 1500 millimoles of sodium is reabsorbed via $Na^+K^+2Cl^-$ cotransporter and the remaining 1500 millimoles of sodium is reabsorbed passively via paracellular path way. The exit of Na^+ and Cl^- is an energy requiring process against a concentration gradient and the driving force is by Na^+K^+ATPase. Reabsorption is stimulated by ADH and inhibited by diuretics (Fig. 3.2).

Distal Convoluted Tubule (DCT)

In DCT sodium is reabsorbed along with chloride and is sparingly permeable to water.

Collecting Duct

Sodium reabsorption is linked to chloride reabsorption and to secretion of potassium and H^+ions. Sodium channel is stimulated by increase in distal blood flow. This is also mediated through aldosterone. In the medulla along with

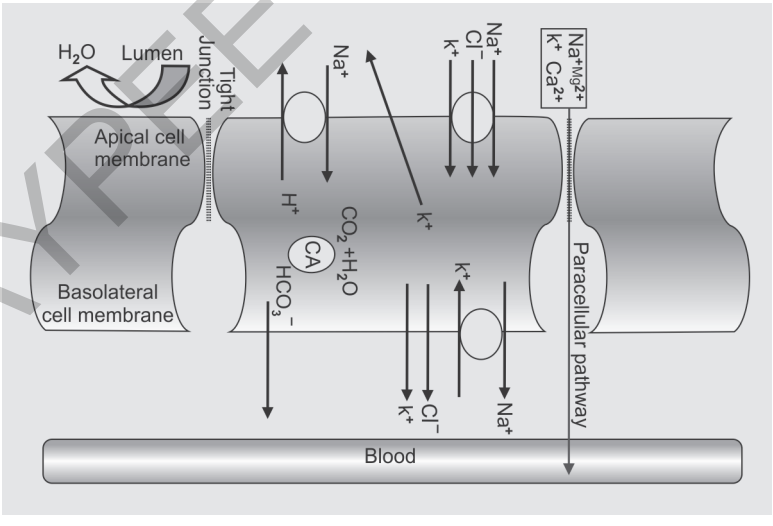

Fig. 3.2: Na reabsorption in proximal tubule

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sodium balance, concentration of urine and ammonium excretion occurs. Atrial natriuretic factor acts for regulation of sodium reabsorption.

Factors Regulating Na+ Excretion

Maintenance of Sodium Chloride (Na Cl) is absolutely necessary for normal functioning of cells. The glomeruli and tubules interact to maintain Na Cl balance. There are two important physiological mechanisms that maintain the renal blood flow (RBF) and GFR within narrow limits. Glomeruli respond to tubules by tubuloglomerular feedback and tubules respond to glomeruli by glomerulotubular balance.

ECF Volume

When ECF volume is contracted urine is free of Na^+ and Cl^- and when expanded urine Na will be increased. Thus, there are no normal values for urinary Na and Cl and should be interpreted relative to the fluid status of the patient and dietary intake.

Anions

The normal anion reabsorbed or excreted along with sodium is chloride. In pathologic states like vomiting there is loss of chloride in gastric juice hence only less chloride will be available for reabsorption along with sodium. Sodium is reabsorbed with other anion HCO_3 and this generates metabolic alkalosis. The quantity of bicarbonate delivered to the kidney is also increased. When the reabsorptive capacity of tubules is exceeded, the bicarbonate will be lost with sodium in urine.

Hormones (Aldosterone)

5% of sodium reabsorption occurs in the distal nephron and is under the influence of aldosterone [Discussed in detail under K balance].

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Angiotensin 11

Angiotensin is released from juxtaglomerular apparatus. Hypovolemia, low renal perfusion pressure, increased sympathetic activity and rise in beta adrenergic agonists will stimulate angiotensin release. Angiotensin 11 will increase the reabsorption of sodium in PCT along with water.

This leads to increase in chloride concentration in the lumen which is passively reabsorbed. Angiotensin 11 is a powerful efferent arteriolar constrictor and will increase the intraglomerular pressure and increases GFR. Increased filtrate in the PCT lumen will increase the reabsorption of Na and solute.

KEY POINTS

- Reabsorption of Na is isoosmotic in Proximal tubule.
- 50% of Na is reabsorbed via luminal $Na^+K^+2Cl^-$ cotransporter.
- In collecting duct sodium reabsorption is linked to chloride reabsorption and to secretion of potassium and H^+ ions.

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Fluid, Electrolyte, Metabolic and Respiratory Acid-Base Management

This educative book discusses electrolyte and acid-base abnormalities encountered in intensive care. The purpose of this book is to guide the postgraduates in various disciplines of medicine, practicing medical professionals, nephrologists and intensivists in the management of critically ill patients.

In effect, the book highlights:

- Comprehensive approach to fluid therapy including calculation of maintenance fluid, assessment of fluid status, composition and distribution of commonly used parenteral fluids.
- Simplified approach to analysis of metabolic and respiratory acid-base abnormalities. The text covers discussion on Stewart ion approach and ventilator management and up-to-date advances in the field.
- Problem-based clinical approach to electrolyte and acid-base abnormalities using patient scenarios.



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Shelving Recommendation
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