AIM OF THE WORK

The aim of this work is to review the causes of electrolyte imbalance in critically ill patients and shows the recent lines of management of this problem in the ICU.

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Shawky Sayed Mahmoud

I-Sodium physiology

Sodium is the most abundant cation in the body, averaging approximately 60 mEq/kg of body weight. Most of the body's sodium is in the ECF compartment (135 to 145 mEq/ L), with only a small amount (10 to 14 mEq/ L) located in the ICF compartment ***(Porth and Matfin, 2008)***.

A-Sodium function:

Sodium functions mainly in regulating extracellular and vascular volume. As the major cation in the ECF compartment, Na^+ and its attendant anions (Cl^- and HCo^{3-}) account for approximately 90% to 95% of the osmotic activity in the ECF. Because sodium is part of the sodium bicarbonate molecule, it is important in regulating acid-base balance. Also it contributes to the function of the nervous system and other excitable tissues ***(Porth and Matfin, 2008)***.

B-Gains and Losses:

Sodium normally enters the body through the gastrointestinal tract and is eliminated by the kidneys or lost from the gastrointestinal tract or skin. Sodium intake normally is derived from dietary sources. Body needs for sodium usually

can be met by as little as 500 mg/day. Other sources of sodium are intravenous saline infusions and medications that contain sodium ***(Guyton and Hall, 2006).***

Sodium is reabsorbed along the mammalian nephron (**figure 1**): About 25 moles of Na^+ in 180 L of fluid daily is delivered into the glomerular filtrate of a normal person. About 60% of this load is reabsorbed along the proximal tubule, about 25% along the loop of Henle, including the thick ascending limb, about 5% to 7% along the distal convoluted tubule and 3% to 5% along the collecting duct system ***(Guyton and Hall, 2006).***

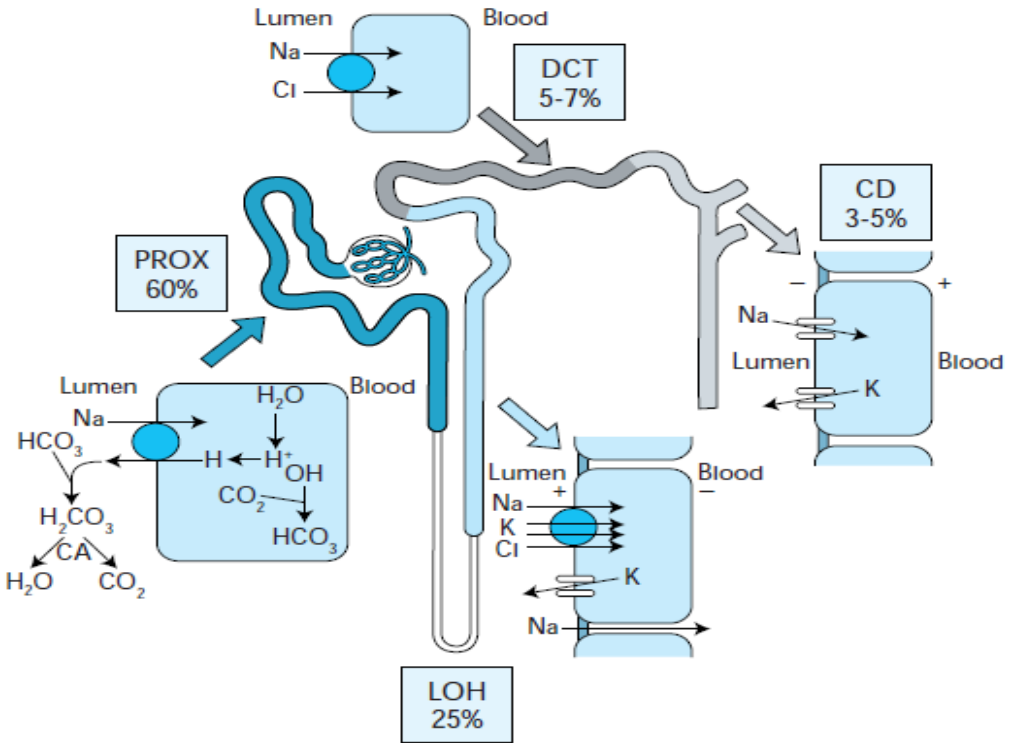

Figure 1: Sodium handeling in the kidney; (CA) carbonic anhydrase ;(Cl^-) chloride ;(CO_2) carbon dioxide; (H) hydrogen; (H_2CO_3) carbonic acid ;(HCO_3) bicarbonate ;(K^+) Potassium; (OH^-) hydroxyl ion ***(Guyton and Hall, 2006).***

C-Regulation:

Water is an important biological solvent that provides an ideal environment for biochemical reactions. It moves freely across the cell membranes from low to high solute concentration.

The Na^+-K^+ -ATPase pump is a membrane bound enzyme that carries out the active electrogenic translocation of Na^+ and

K^+ ions across the plasma membrane of most cells ***(Patel, 2009).***

Factors of regulation:

(1) Low pressure (volume) sensors

Low pressure sensors signal the medulla and result in a decrease in sympathetic activity in response to the increased BV. The opposite occurs if hypovolemia develops. Also in the presence of hypovolemia and hypotension, low pressure sensors also mediate anti diuretic hormone (ADH) release via vagal afferents to the medulla.

(2) ***High Pressure sensors***

In response to fluctuations in the mean arterial blood pressure, baroreceptors in the carotid sinus and aortic arch send signals to the medulla to modulate autonomic nervous system activity rapidly. These high pressure receptors also influence ADH release if ECF loss is severe enough to affect the blood pressure ***(Patel, 2009).***

II-Potassium physiology

Potassium is the second most abundant cation in the body and the major cation in the ICF compartment. The intracellular concentration of potassium ranges from 140 to 150 mEq/L. While the potassium content of the ECF (3.5 to 5.0 mEq/ L) ***(Hoskote et al., 2008).***

A-Gains and Losses:

In healthy persons, potassium balance usually can be maintained by a daily dietary intake of 50 to 100 mEq. Additional amounts of potassium are needed during periods of trauma and stress. The kidneys are the main source of potassium loss. Approximately 80% to 90% of potassium losses occur in the urine, with the remainder being lost in stools or sweat **(*Fink et al., 2005).***

B-Regulation :

Plasma potassium is largely regulated through two mechanisms: **(1)** renal mechanisms that conserve or eliminate potassium, and **(2)** a transcellular shift between the intracellular and extracellular compartments. Normally, it takes 6 to 8 hours to eliminate 50% of potassium intake ***(Kumar and Clark, 2009a).***

(1)Renal mechanism

The major route for potassium elimination is the kidney. Potassium is filtered in the glomerulus, reabsorbed along with sodium and water in the proximal tubule and with sodium and chloride in the thick ascending loop of Henle, and then secreted into the late distal and cortical collecting tubules for elimination in the urine **(*Fink et al., 2005).***

Aldosterone plays an essential role in regulating potassium elimination by the kidney. The effects of aldosterone on potassium elimination are mediated through a sodium–potassium exchange system located in the late distal and cortical collecting tubules of the kidney. In the presence of aldosterone, sodium is transported back into the blood, and potassium is secreted in the tubular filtrate for elimination in the urine ***(Guyton and Hall, 2006).***

(2)Extracellular–Intracellular Shifts

The exchange of K^+ and H^+ ions between the ICF and ECF plays a significant role in regulating the ECF concentration of both ions. In acidosis, H^+ ions move into the cell as a means of preventing large changes in ECF pH. As H^+ ions move into the cell, other positively charged ions, such as K^+, must move out

as a means of maintaining electrical neutrality ***(Guyton and Hall, 2006).***

III-Calcium physiology

Calcium is one of the major cations in the body. Approximately 99% of body calcium is found in bone. Most of the remaining calcium is located inside cells, and only approximately 0.1% to 0.2% (approximately 8.5 to 10.5 mg/dL) of the remaining calcium is present in the ECF ***(Peacock et al., 2010).***

A-Gains and Losses:

The major sources of calcium are milk and milk products. Only 30% to 50% of dietary calcium is absorbed from the duodenum and upper jejunum; the remainder is eliminated in the stool. There is a calcium influx of approximately 150 mg/day into the intestine from the blood **(*Peacock et al., 2010).***

Calcium is stored in bone and excreted by the kidney, Approximately 60% to 65% of filtered calcium is passively reabsorbed in the thick ascending loop of Henle, and 5% to 10% is reabsorbed in the distal convoluted tubule. PTH and possibly vitamin D stimulate calcium reabsorption in this segment of the nephron. Other factors that may influence calcium reabsorption in the distal convoluted tubule are phosphate levels and glucose and insulin levels. Thiazide

diuretics, which exert their effects in the distal convoluted tubule, enhance calcium reabsorption ***(Raoof et al., 2009).***

B-Calcium function:

Calcium plays a key role in a wide range of biologic functions, either in the form of its free ion or bound complexes. One of the most important functions as bound calcium is in skeletal mineralization. The vast majority of total body calcium (>99%) is present in the skeleton as calcium-phosphate complexes . Non-bone calcium represents <1% of total body calcium (About 10 g in an adult), and is responsible for a wide range of essential functions, including extra- and intracellular signaling, nerve impulse transmission, and muscle contraction ***(Peacock et al., 2010).***

C-**Regulation:**

Role of parathyroid hormone:

The main function of PTH is to maintain the calcium concentration of the ECF. It performs this function by promoting the release of calcium from bone, increasing the activation of vitamin D as a mean of enhancing intestinal absorption of calcium, and stimulating calcium conservation by

the kidney while increasing phosphate excretion **(*Fink et al., 2005).***

Types of Hyperparathyroidism

1- Primary Hyperparathyroidism:

Common causes of parathyroid problems include benign growths on the gland and enlargement of at least two glands. In rare cases, a cancerous tumor causes this condition. primary hyperparathyroidism is more likely in people over the age of 60 and occurs most often in women. An increased risk of developing primary hyperparathyroidism also occurs in people who have certain inherited disorders that affect several glands throughout the body, such as multiple endocrine neoplasia, or have a long history of calcium and vitamin D deficiencies, or have been exposed to radiation from cancer treatment or have taken a drug called lithium.

2- Secondary Hyperparathyroidism:

This type occurs when an underlying condition causes calcium levels to be abnormally low. Most cases of secondary hyperparathyroidism are caused by chronic kidney failure that result in low vitamin D and calcium levels.

3- Tertiary Hyperparathyroidism:

This type occurs when parathyroid glands keep making too much PTH even when your calcium levels return to normal. This type usually occurs in people with kidney problems ***(Fink et al., 2005).***

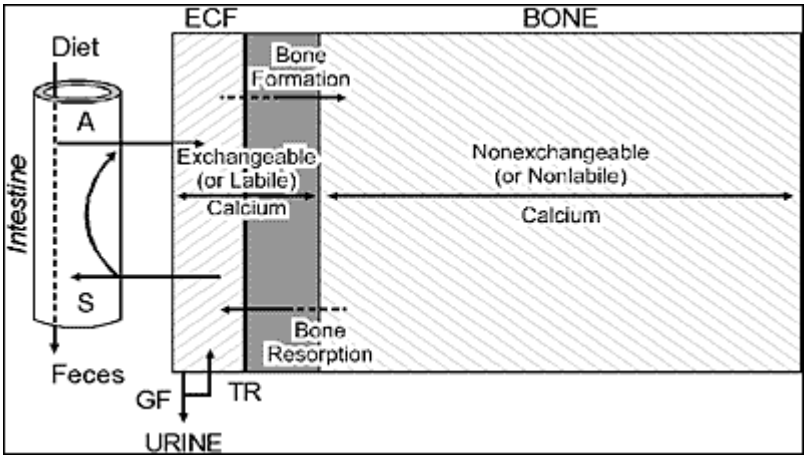

Figure 2 : Schematic Representation of Calcium and Skeletal Metabolism. Abbreviations: A, absorption; S, secretion; ECF, extracellular fluid; GF, glomerular filtration; TR, tubular reabsorption.The dark vertical line between bone and ECF represents bone surface and bone-lining cells. Shaded area represents labile skeletal calcium (Deftos, 2010).

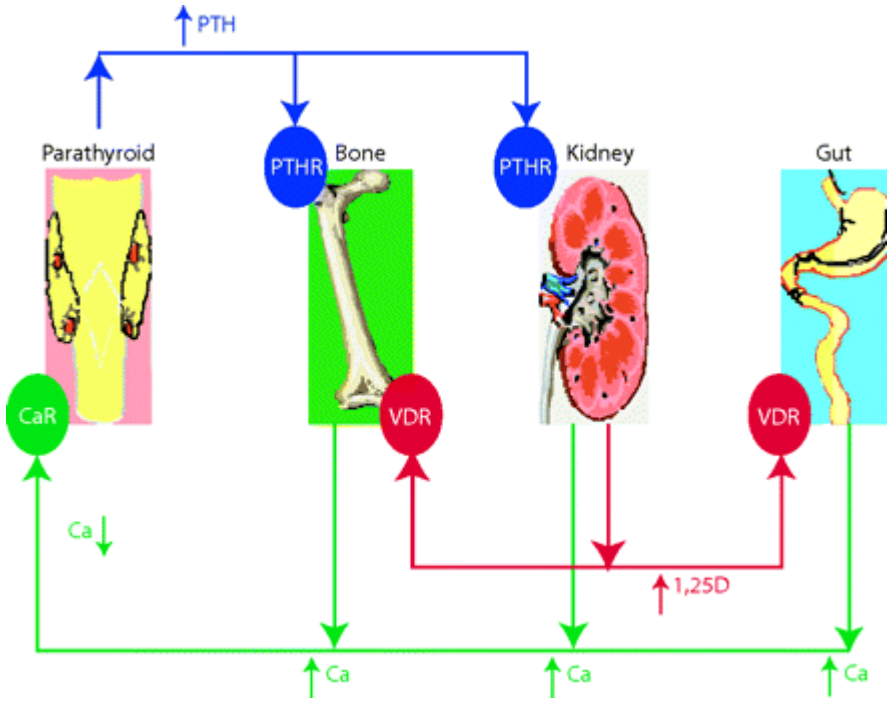

Figure 3: Regulation of serum calcium homeostasis. Serum calcium homeostasis is regulated by a rapid negative feedback hormonal pathway involving the concentration of ionized calcium in serum (Ca, green arrows) and the secretion of parathyroid hormone (PTH, blue arrows) from the parathyroid. A fall in serum calcium (↓ Ca) inactivates the calcium receptor in the parathyroid cell (CaR; green circle) and increases PTH secretion (↑ PTH), which restores serum calcium (↑ Ca) by activating the parathyroid receptor (PTHR; blue circles) in bone, to increase calcium resorption, and in kidney, to increase tubular calcium reabsorption. In kidney, the increased PTH secretion augments its calcium-restorative effect by increasing secretion of 1,25-dihydroxyvitamin D (1,25D; red arrows), which, acting on the vitamin D receptor (VDR, red circles) in gut, increases active calcium absorption and increases calcium resorption in bone ***(Raoof et al.,2009).***

IV-Phosphorus physiology

Phosphorus is mainly an intracellular anion. It is the fourth most abundant element in the body after carbon, nitrogen, and calcium **(*Porth and Matfin, 2008).***

A-Gain and loss:

Phosphate is ingested in the diet and eliminated in the urine. Phosphate is derived from many dietary sources, including milk and meats. Approximately 80% of ingested phosphate is absorbed in the intestine, primarily in the jejunum. Absorption is diminished by concurrent ingestion of substances that bind phosphate, including calcium, magnesium, and aluminum. The overall elimination of phosphate by the kidney involves glomerular filtration and tubular reabsorption. Essentially all of the phosphate that is present in the plasma is filtered in the glomerulus. Renal elimination of phosphate is then regulated by an overflow mechanism in which the amount of phosphate lost in the urine is directly related to phosphate concentrations in the blood ***(Irwin and Rippe, 2006)*.**

Essentially all the filtered phosphate is reabsorbed when phosphate levels are low. When plasma phosphate levels rise above a critical level, the rate of phosphate loss in the urine