

The Significance of Sodium-Potassium Pump (Na^+ , K^+ -ATPase) in Neural Signaling

Yunyan Ma

Miss Hall's School, Pittsfield MA, 01201, USA

Abstract. Neural signaling is the significant process that allows the human brain to pass down cell signals across the body. The neurons inhibit in the brain and pass down information from the axons on one neuron to the dendrites on another. This process is enabled through the concentration gradient regulating effect of the sodium/ potassium pump (the Na/ K pump). Facilitating the flow of Na^+ and K^+ ions, the concentration gradient generated creates an action potential. The neurons open and close their voltage gated channels to change voltage potentials, de- and repolarise local membranes and secrete neurotransmitters. The series of processes collectively allows the transmission of information through the human body (Stillwell 431). Understanding the process of neural signaling brings new insights into how our brains communicate information to our body and essentially dictates our day to day life.

Keywords: Neural signaling, neural transmitting, intercellular transportation, action potential, sodium/ potassium pump.

1. Introduction

The human brain dictates the way we interact with the external world. Through responding to stimuli and passing interpreted information through our bodies, what we “know” all depends on specific configurations of connections between the trillions of neurons that inhabit our brains (Churchland 42).

Neurons, or nerve cells, are the building blocks of the brain. They pass down information to the rest of our body through transmitting impulses over single axons and receiving the impulses over numerous dendrites (Stevens 55). In the process of neural signaling, one Na/ K pump splits one phosphate from the energy-storing adenosine triphosphate (ATP) to move three sodium ions out of the cells in exchange for two potassium ions into the cell (Stein 263). This regulates the concentration gradient within the neurons and produces an action potential that gets passed on from one chemical synapse to another through the release of neurotransmitters. The process of neural signaling is what essentially allows us, as humans, to communicate information from one part of our body to another, control our actions, and ultimately interact and understand the world we reside in.

2. The Structure of a Neuron

To understand this process, it is essential to first understand the anatomy of each neuron.

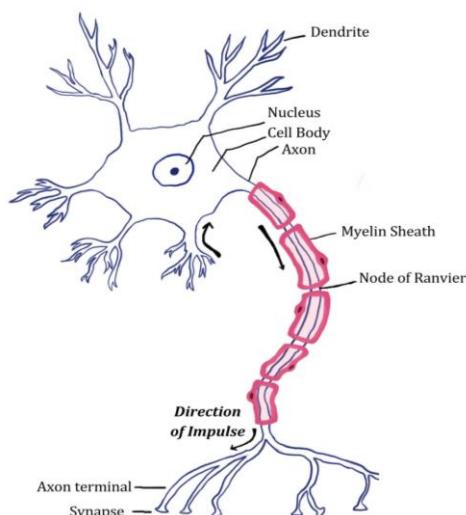


Fig. 1 Anatomy of each neuron

There are three significant parts in a neuron: the cell body, the dendrites, and the axon (Stevens 54). Within the cell body, neurons are observed to have single prominent nucleoli within their cytoplasm (Palay and Palade 72). Along with the nucleus and cytoplasm, neurons also have various organelles and other cell structures, such as the mitochondria, like any other human body cells. The neurons and their synapses project long, thin processes that can invaginate neighboring neuronal or glial cells. The invaginating projections, majorly axons and dendrites, play important parts in enabling the precise mechanism for communication between one neuron and another (Pestralia et al. 211). Axons are long nerve processes that extend outwards from the cell to convey signals emitted from the cell to various areas (Ludwig et al. 1). Dendrites are responsible for inputting information from one neuron to another. They are usually shorter, more numerous, and heavily branched than the axons. They have many synapses to receive signaling messages from nearby cells (Stevens 54).

3. The Cell Membrane and Intermembrane Transportation

The sodium-potassium pump plays an essential role in generating action potentials that then translate into electrical signals that are communicated through the nervous system. This is made possible through the concentration gradient Na^+ , K^+ -ATPases established across the cell membranes (Ogawa et al. 13742). The pump maintains the concentration gradient through active transport.

The process of active transport, along with passive transport, consists of the two major ways for molecules to move across the cell membrane. To understand intermembrane transportation of molecules, it is important to first establish an understanding towards the cell membrane.

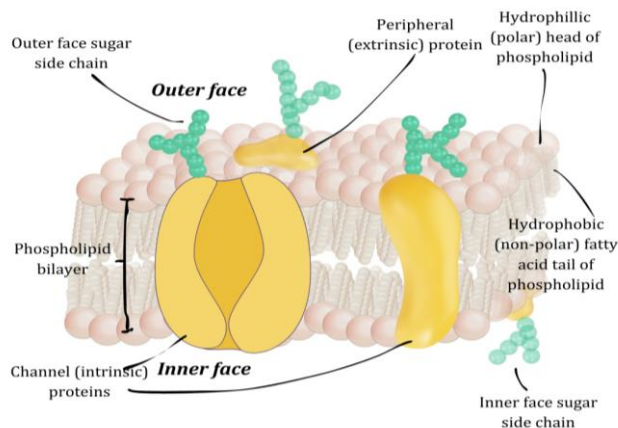


Fig. 2 Intermembrane transport of molecules

The cellular membrane consists mainly of lipids and proteins. Its fundamental structure is the phospholipid bilayer. The bilayer membrane consists of two layers of phosphate groups that arrange according to their hydrophilicity. The hydrophilic head of the phosphate group faces outwards to the aqueous environment, while the hydrophobic fatty acid tails arrange inwards towards the bilayer structure. Most membranes are permeable for certain ions and molecules such as water molecules while remaining impermeable for other solutes such as the various biochemicals and salts in the surrounding environment (Stillwell 429). This is why there are also proteins that embed in the phospholipid bilayer that is responsible for moving certain molecules through the layers.

There are two major ways for molecules to move across the membrane: passive diffusion and active transportation. While passive diffusion moves molecules across the membrane along the concentration gradient of the environment, active transport moves molecules against the gradient (Pardee 279; Stillwell 427) and therefore requires energy to take place. This energy is usually acquired by breaking ATP molecules into ADP by removing the phosphate group on the end of their structures. Active transport also requires the presence of carrier proteins and enzymes (Stillwell 435).

4. Sodium-Potassium Pumps and Neural Signaling

The sodium-potassium pumps are the most important active transport proteins (Stillwell 436). Through constantly transporting sodium and potassium ions across the membrane, the pump controls the concentration of its cell, keeping sodium concentration low inside and potassium concentration high on the outside (Stillwell 437). This sustained concentration gradient is crucial for maintaining osmotic equilibrium and resting membrane potential across the cells. It also plays an important role in regulating cell volume as well as intracellular signal transduction.

During the initial depolarization phase of action potentials, sodium ions have a much higher concentration outside of the membrane. They are attracted to the negatively charged inside the membrane. As they flow into the cells, they create a more inside-positive membrane potential. Both attracted by the opposite charge and pushed by the concentration gradient, potassium ions move out of the cell after a potential spike. This process during the cell repolarisation leaves behind trapped anions (usually Cl^-) and restores a more negative membrane potential.

Leak channels support this ion diffusion across the membrane. Many of these leak channels are ion-selective. Only certain ions are permeable while others stay impermeable through the membrane. For example, potassium ions can diffuse out of the cell through certain leak channels, leaving the impermeable anions behind hence creating a membrane potential (Stillwell 429). Until equilibrium is reached, the magnitude of the membrane potential increases. The potassium ions flow outwards at a constant rate as the potential difference in concentration and the amount of the ion is great and the channels are very small.

Because of this electrical potential difference, the electrical gradient of potassium ions causes them to flow from the outside to the inside, while the concentration gradient causes them to move in the opposite direction.

When transmitting a signal, the neuron creates an action potential which is mediated by the opening of voltage-gated sodium channels. This opening allows sodium to enter the neuron, neutralising the charge and depolarizing the membrane of that local area. The action potential would travel down the axon. This is when the neurons depolarize the membrane through closing and inactivating the voltage-gated sodium channels. The potassium channels then open as they start to exit from the inside of the cell through the opening potassium channels, lowering the voltage across the membrane. As the region depolarises, voltage-gated calcium channels would also open, allowing the calcium ions to rush into the terminal. This increase of calcium in the synaptic bouton induces the secretion of various neurosecretory vesicles. (Stillwell 431)

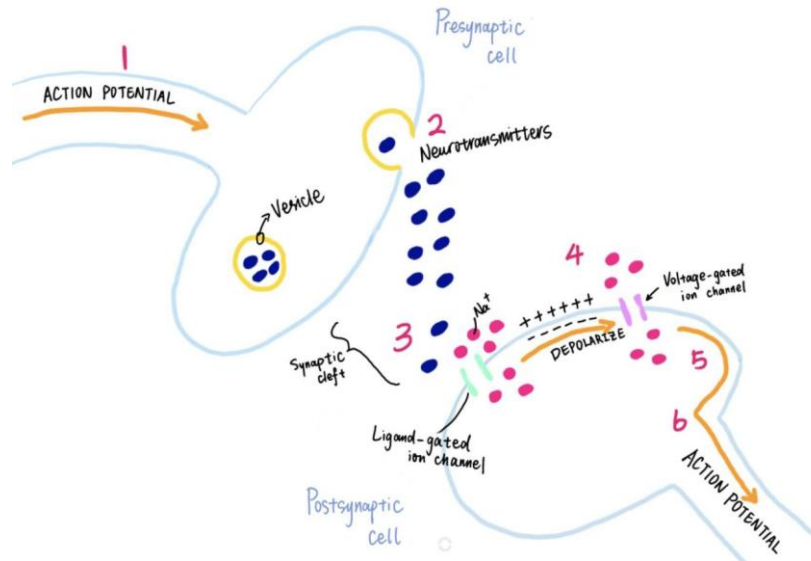


Figure 3. Legend

As the neurotransmitters are being secreted with the opening calcium channels, they diffuse across the synaptic cleft to receptors on the postsynaptic cell. The binding of neurotransmitters to the receptors results in an altering of their properties and conformation, causing the channels to open. The ions then flow into the postsynaptic cell. Depending on the ion, the channel opening leads to either depolarization or hyperpolarisation. If sufficient depolarization occurs, an action potential will result in the postsynaptic cell with the action potential produced. After the signal is finished, the locations of ions have been reversed. This reverses not only the concentration but the relative voltage across the membrane. With each of the pumping cycles, the transport protein embedded in the cell membrane transports two potassium ions into the cell and three sodium ions to the outside of the cell. Since the pump moves the ions against their initial concentration gradient, they require ATP to provide them with the necessary energy for each of the cycles.

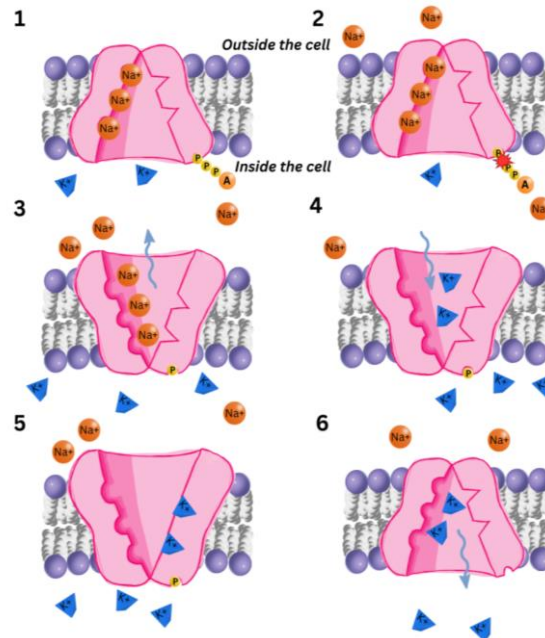


Figure 4. Legend 2

5. Conclusion

Sodium-potassium pump is an important protein pump which exists in a large amount in human cells. About one-third of the ATP produced by human cells every day is used to power this cycle (Berman et al., 235). Sodium and potassium pumps play an important role in nerve signal transduction,

using ATP as an energy source to transfer sodium and potassium against the concentration gradient of sodium and potassium ions. With the flow of Na⁺ and K⁺ ions, a concentration gradient is generated, which in turn generates an action potential. Through action potentials, neurons open and close their voltage gated channels to change voltage potentials, depolarize or repolarize local membranes, and secrete neurotransmitters, ultimately transmitting information from one neuron to another through the human body (Stillwell 431), making it possible for us to respond to and interact with the world that surrounds us.

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