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Potencial de membrana

Este artículo necesita referencias que aparezcan en una publicación acreditada. El potencial de membrana es la diferencia de potencial eléctrico entre el interior y el exterior de una célula, causado por la permeabilidad selectiva de la membrana plasmática y la acción de unidades de bomba sodio-potasio. La distribución desigual de cargas a través de la membrana da lugar a un diferencial de potencial que refleja las características de los iones del medio externo e interno, así como de la propia membrana. Este diferencial se conoce como el potencial de Nernst y está relacionado con la diferencia de concentración de iones dentro y fuera de la célula, así como con la permeabilidad de la membrana celular a diferentes iones. There are many ions, such as sodium (Na+), potassium (K+), chloride (Cl-), and magnesium (Mg2+), present in both intracellular and extracellular fluids. Therefore, it is necessary to have a formula that calculates the potential for all these ions present in the extracellular fluid. The cell membrane is permeable to multiple ions, which diffuse across it, generating an electric potential that depends on three factors: the charge of each ion, the membrane's permeability to each ion, and the concentrations of the ions both inside and outside the cell. The Goldman equation (also known as the Goldman-Hodgkin-Katz equation) calculates the membrane potential when two positively charged ions (K+ and Na+) and one negatively charged ion (Cl-) are present. This equation is important for understanding the electrical properties of cells, such as nerve and muscle fibers. The most important ions involved in generating the membrane potential are sodium, potassium, and chloride. The electric gradient of each ion across the membrane helps determine the voltage of the membrane potential. The membrane's permeability to each ion determines its importance, so if the membrane is only permeable to sodium, for example, the membrane potential will be equal to the Nernst potential for sodium. A positive concentration gradient inside the cell creates negativity on the inside and positivity on the outside, which explains why there is a greater diffusion of potassium ions from the inside to the outside, resulting in a deficit of positively charged ions inside the cell. This negativity makes the medium inside the cell negatively charged. The rapid changes in sodium and potassium concentrations are the main responsible for nerve transmission. The membrane potential varies between cells, depending on their origin. There are cells with a potential of -50 mV, while others, like muscle fibers, have a range of -50 to 60 mV. In the organism, there are two spaces: the extracellular space (interstitial fluid) and the intracellular space (cytoplasm). In the extracellular space, the most abundant anion is chloride, while in the cytoplasm, the most abundant anions are proteins that are negatively charged due to the release of hydrogen ions. The most abundant cation in the interstitial fluid is sodium, while in the cytoplasm it is potassium. The ionic imbalance that produces membrane polarization is due to the different permeability of the membrane to each ion. Ion de potasio atraviesa la membrana libremente; su permeabilidad es menor que la del sodio. El sodio es expulsado por un transporte activo llamado bomba de sodio-potasio. Debido a su tamaño, las proteínas no pueden pasar libremente la membrana. Esto establece una diferencia de potencial en condiciones de reposo, de unos -90 mV. Este potencial de membrana es imprescindible para el origen y transmisión del impulso nervioso. The resting membrane potential in animal cells ranges from −80 mV to −40 mV and requires positive work to move a positive charge across. However, thermal energy allows ions to overcome this difference, enabling a net flow against the gradient through selectively permeable membranes. These membranes, composed of lipid bilayers with embedded proteins, serve as insulators and diffusion barriers, while transmembrane proteins establish concentration gradients and ion channels facilitate movement down these gradients. The membrane potential has two primary functions: it acts as a battery providing power to molecular devices within the cell, and in electrically excitable cells like neurons and muscle cells, it enables signal transmission between different parts of the cell. This is achieved through changes in the membrane potential, which can be sensed by adjacent or distant ion channels, triggering further responses. In non-excitable cells and at baseline states, the resting potential is maintained, typically ranging from −80 to −70 millivolts. However, opening or closing ion channels can induce depolarization or hyperpolarization, leading to a departure from this state. In excitable cells, a sufficiently large depolarization can evoke an action potential, characterized by rapid and significant changes in membrane potential for a short duration. Membrane potential arises from concentration gradients of ions such as potassium, sodium, and chloride across the cellular membrane. These gradients drive the formation of the membrane potential when the membrane is selectively permeable to one or more ions. In the simplest case, potassium ions can diffuse down their concentration gradient, leaving behind uncompensated negative charges. This separation of charges creates a voltage that is physically located only in the immediate vicinity of the membrane. The membrane potential ultimately derives from two factors: electrical force and diffusion. Electrical force arises from the mutual attraction between particles with opposite charges, while diffusion occurs due to the statistical tendency of particles to redistribute from regions where they are highly concentrated to regions where the concentration is low. #### Voltage Basics Voltage, or difference in electrical potential, is the ability to drive an electric current across a resistance. The simplest definition of voltage is given by Ohm's law: V=IR, where V is voltage, I is current, and R is resistance. A higher voltage source will drive a greater amount of current across the available resistance. The functional significance of voltage lies only in potential differences between two points in a circuit. Circuit analysis typically begins with an arbitrarily selected reference point, from which voltages of other circuit elements are measured relative to it. The choice of this zero point is inconsequential, as the circuit's behavior depends on voltage differences rather than absolute values. In most cases, however, the zero level is assigned to a portion of the circuit in contact with ground due to convention. This concept applies similarly in cell biology, where the potential difference between any two points can be measured by inserting electrodes and connecting them to a specialized voltmeter. In electrically active tissue, the outside of the cell is typically assigned as the zero potential value, with the sign of the potential difference determined by the inside's relative potential. Mathematically, voltage is defined through the concept of an electric field E, which assigns magnitude and direction to each point in space. This field can be a conservative one, represented as the gradient of a scalar function V (E = −∇V), known as the voltage distribution. However, the definition allows for an arbitrary constant of integration, making absolute voltage values meaningless. Electric fields are treated as conservative if magnetic influences are negligible, which is often the case in biological tissue. A strong electric field implies a rapid change in voltage within a small region, exerting a significant force on charged particles. In biological organisms, electrical signals are primarily driven by ions moving across membranes. Sodium (Na+) and potassium (K+) cations play crucial roles in action potentials, while calcium (Ca2+) can also be involved. Chloride anions (Cl−) have significant roles in some algae but negligible roles in most animals. Ions cross cell membranes under the influences of diffusion and electric fields. Given text: mix into equal solutions. This mixing occurs because of the difference in their concentrations. The region with high concentration will diffuse out toward the region with low concentration. To extend the example, let solution A have 30 sodium ions and 30 chloride ions. Also, let solution B have only 20 sodium ions and 20 chloride ions. Assuming the barrier allows both types of ions to travel through it, then a steady state will be reached whereby both solutions have 25 sodium ions and 25 chloride ions. If, however, the porous barrier is selective to which ions are let through, then diffusion alone will not determine the resulting solution. Returning to the previous example, let's now construct a barrier that is permeable only to sodium ions. Now, only sodium is allowed to diffuse cross the barrier from its higher concentration in solution A to the lower concentration in solution B. This will result in a greater accumulation of sodium ions than chloride ions in solution B and a lesser number of sodium ions than chloride ions in solution A. This means that there is a net positive charge in solution B from the higher concentration of positively charged sodium ions than negatively charged chloride ions. Likewise, there is a net negative charge in solution A from the greater concentration of negative chloride ions than positive sodium ions. Since opposite charges attract and like charges repel, the ions are now also influenced by electrical fields as well as forces of diffusion. Therefore, positive sodium ions will be less likely to travel to the now-more-positive B solution and remain in the now-more-negative A solution. The point at which the forces of the electric fields completely counteract the force due to diffusion is called the equilibrium potential. At this point, the net flow of the specific ion (in this case sodium) is zero. A pure lipid bilayer's low capacitance means its electric field is highly variable, unlike its fixed resistance. The plasma membrane's estimated thickness of 7-8 nanometers allows for a moderate transmembrane voltage to create an electric field. Typical animal cell membrane potentials are around 100 millivolts, which can generate a strong electric field close to the maximum the membrane can handle. A higher voltage difference could cause dielectric breakdown. The lipid bilayer's high resistance to ion passage is overcome by structures like ion channels and carrier proteins, which facilitate transport through mechanisms like facilitated diffusion and active transport. Ion pumps, integral membrane proteins, use cellular energy to pump ions against their concentration gradient, contributing to the action potential in neurons. The sodium-potassium pump plays a crucial role in maintaining cellular equilibrium. It does this by (1) creating a high concentration of potassium inside cells and low outside; (2) giving interior spaces a negative charge compared to exterior ones; and (3) pumping ions constantly, though becoming less efficient over time due to reduced ion availability. Unlike what some might think, the pump itself doesn't directly influence action potentials – instead, it just sets up the relative balance of ions inside versus outside cells. Without energy sources or inhibitors like ouabain, axons can still fire thousands of impulses without much decay. The sodium-potassium pump isn't significant in repolarizing cell membranes after an impulse either. Another vital ion pump is the sodium-calcium exchanger which removes calcium from interior spaces while allowing more sodium to enter – though this effect's relatively minor due to higher concentrations of sodium and potassium outside cells. As a result, calcium levels become very low inside resting cells. Potassium channel structure with potassium ion in purple and hydrogen atoms omitted, showing closed state. Ion channels are proteins that regulate the flow of ions across cell membranes. They can be classified into several types based on their response to environmental stimuli. Voltage-dependent channels open and close in response to changes in voltage, while ligand-gated channels respond to binding of specific molecules like neurotransmitters. Mechanical forces can also control ion channel opening, as seen in sensory neurons that respond to light, temperature, or pressure. Leakage channels are simple and maintain constant permeability, but even these have variations, such as being rectifiers that conduct ions better in one direction than the other. Some leakage channels can be shut off by chemical ligands, while others require specific stimuli to open. Examples of ion channels include potassium and chloride channels, which are essential for neuronal function. Ion channels with high permeability are often controlled by ligand binding, such as AMPA receptors for glutamate or GABAA receptors for GABA. However, there are also voltage-gated channels that respond to changes in membrane potential. These channels have distinct ion selectivity and voltage dependence, and some are time-dependent, requiring a delay before responding to voltage changes. For instance, voltage-gated sodium channels play a critical role in action potentials, as they open and close in response to voltage changes. Inactivation of these channels can shut off the sodium current, which is essential for neuronal signaling. The action potential, which underlies electrical impulses in neurons, relies on specific ion channels that are sensitive to voltage fluctuations. These channels, known as Hodgkin-Huxley sodium channels, remain closed at the resting state but open rapidly when the voltage surpasses a certain threshold, allowing an influx of sodium ions and triggering a swift change in membrane potential. Conversely, recovery from an action potential depends on potassium channels that are initially closed but become active due to the significant voltage shift triggered by the action potential itself. The reversal potential for any ion is a critical concept, representing the point at which diffusive and electrical forces balance out, resulting in no net ion flow across the membrane. This equilibrium potential (Eion) gives insight into the voltage that affects channels permeable to specific ions, essentially revealing how an ion's concentration gradient behaves as if it were a battery. The Nernst equation is used to calculate this reversal potential for various ions, such as potassium and sodium. For instance, the equilibrium potential for potassium (EK) can be calculated using the following formula: E e q , K + = R T z F ln ⁡ [K +] o [K +] i {\displaystyle E_{eq,K^{+}}={\frac {RT}{zF}}\ln {\frac {[K^{+}]_{o}}{[K^{+}]_{i}}}} where EK+ represents the equilibrium potential for potassium, R is the universal gas constant, T is absolute temperature in kelvins, z is the number of elementary charges involved in the reaction, F is Faraday's constant, [K+]o is the extracellular concentration of potassium, and [K+]i is the intracellular concentration. Interestingly, even ions with the same charge can have vastly different equilibrium potentials based on their outside and inside concentrations. For example, the equilibrium potential for potassium (EK) in neurons is approximately -84 mV when there are 5 mM of potassium outside and 140 mM inside, while the sodium equilibrium potential (ENa) is around +66 mV with about 12 mM sodium inside and 140 mM outside. The resting membrane potential in neurons undergoes changes during development, becoming more negative as an organism matures. This regulation is crucial for a neuron to eventually achieve its full adult function. Moreover, the addition of glial cells during development enhances the ability to regulate extracellular potassium levels, which can lead to a decrease in membrane potential. Cell excitability refers to the change in membrane potential that enables cellular responses in various tissues. This property is induced during early embryogenesis and is influenced by extracellular electrolyte concentrations, associated proteins, and other regulatory mechanisms. Key players in cell excitability include voltage-gated ion channels, ion transporters, membrane receptors, and hyperpolarization-activated cyclic-nucleotide-gated channels. Calcium ions play a crucial role as second messengers in excitable cell signaling. Hormones like progesterone and estrogen also modulate cell excitability in specific contexts. Many cell types possess excitable membranes, including neurons, muscle cells, endothelial cells, and certain epithelial cells. Astrocytes exhibit non-electrical excitability based on intracellular calcium variations, while neurons display unique membrane properties that enable coincidence detection of spatially separated inputs. The conductance of each ion pathway is determined by the states of all potentially permeable channels. Using the Goldman equation, the equivalent circuit can be reduced to a capacitance in parallel with a battery, forming an RC circuit. This type of circuit has a simple electrical behavior, with current decaying exponentially over time. The time constant (τ = RC) affects how quickly changes occur in ion channel conductance. In realistic situations, these changes happen faster than the decay of current. When the membrane potential remains relatively stable for a long period, it is referred to as a resting potential. This state can be observed in non-excitable and excitable cells, including neurons and muscle cells. Even in other types of cells, environmental or intracellular stimuli can cause changes in membrane voltage. The Goldman equation models these interactions by considering the charges and concentrations of ions, as well as their relative permeability across the plasma membrane. To maintain a stable membrane potential in situations where it plays a crucial role, cells employ unique strategies that differ from cation to anion terms. For instance, chloride ions are treated distinctly from sodium and potassium ions, with their intracellular concentration presented as a numerator while the extracellular concentration is denoted in the denominator. This peculiar arrangement reverses the typical convention observed in cation-based expressions. Pi represents the relative permeability of each ion type, and the Goldman formula calculates membrane potential by averaging reversal potentials for individual ion types weighted by their respective permeabilities. In most animal cells, potassium ions dominate with a higher resting-state permeability than sodium ions, often yielding an almost potassium-reversal potential. The resting membrane potential varies between approximately −80 mV to -40 mV in mature cells and can differ significantly in immature or undifferentiated cells. These variations often correlate with the degree of cellular differentiation, as undifferentiated cells might lack a noticeable transmembrane voltage difference. Maintaining an optimal resting potential comes at a metabolic cost due to the need for active ion pumping to counteract leakage channel losses. For instance, daylight-adapted photoreceptors in blowflies can achieve an elevated membrane potential up to −30 mV while expending a considerable proportion of cellular ATP (over 20%). However, cells with low input resistance during their early stages exhibit reduced metabolic expenses due to decreased leakage currents and lower potassium permeability similar to that of sodium ions. Changes in a cell's membrane potential are determined by differences in ion concentrations between inside and outside the cell and how permeable the membrane is to specific ions. While ion concentrations don't change quickly, the permeability of different ions can shift rapidly due to activated ion channels. This shift in potential can be large or small depending on which channels open and for how long, resulting in graded potentials that differ from action potentials with their fixed amplitudes. According to the Goldman equation, increasing a membrane's permeability to a certain type of ion shifts its potential towards that ion's reversal point. For example, opening sodium channels moves the potential in a positive direction, while potassium and chloride channels move it in negative or resting potential directions, respectively. These graded potentials are crucial in neurons for creating postsynaptic potentials following synaptic activation by neurotransmitters that either open sodium channels to make the membrane more positive, activate potassium channels to make it more negative, or have opposing effects depending on their reversal potentials and the cell's threshold for firing action potentials. The resting membrane potential can be viewed as a result of the predominant membrane permeabilities when a cell is at rest, rather than just a specific value. The equation for weighted averages always applies, but an alternative approach may provide better visualization. Two key factors determine how much influence an ion has on the membrane potential: its driving force and permeability. The driving force is the net electrical force pushing the ion across the membrane, calculated as the difference between the voltage it wants to be at (equilibrium potential) and the actual membrane potential. For example, at a resting potential of -73 mV, the driving force on potassium is 7 mV and on sodium is -133 mV. Permeability measures how easily an ion can cross the membrane, typically measured as electrical conductance in siemens. In a resting membrane, while the driving force for potassium is low, its permeability is very high, allowing it to carry about 20 times more current than sodium and thus have 20 times more influence over the membrane potential. However, at the peak of an action potential, the situation reverses, with sodium permeability being high and potassium relatively low. The Goldman-Hodgkin-Katz equation or weighted means equation can be used to predict the membrane potential by considering concentration gradients and ion permeabilities at any given moment. This approach shows that the value of the membrane potential is a weighted average of the equilibrium potentials of all permeant ions, with weighting being their relative permeability across the membrane. Cells use the energy stored in the resting potential to drive action potentials or other forms of excitation. Changes in the membrane potential enable communication between cells, initiate changes inside the cell, and may even serve as markers for underlying conditions such as diabetes and dyslipidemia in neuronal plasma membranes. The electrical activity of neurons begins with an influx of sodium ions into the cell through specialized channels, leading to depolarization. This is followed by a recovery process where potassium ions flow out of the cell through other channels, also through passive diffusion. The flow of these ions can be triggered by external stimuli, such as a dose of salt, which can cause muscle spasms in fresh meat. The movement of ions across the cell membrane creates electrical potentials, with the interior of the cell typically being negative relative to the exterior. Note that I've removed some of the technical details and focused on providing a more general overview of the concepts presented in the original text. Let me know if you'd like me to clarify or expand on any specific points! This article discusses various scientific studies related to ion channels, membranes, and cellular excitability. The following topics are covered: * Early research on sodium and potassium balance in squid nerve axoplasm (1943) * The ionic basis of electrical activity in nerves and muscles (1951) * Studies on membrane transport and metabolism, including the role of specific ions in permeation (1960s) * Reviews on ion selectivity and nonelectrolyte selectivity in biological membranes (1969) * Research on a-type potassium current regulation and its multiple modes of regulation (2007) * Discussions on neuronal channels and receptors, as well as their role in cellular excitability (2007) * Studies on activity-dependent refinement of inhibitory connections in the nervous system (1993) * Research on potassium buffering in the central nervous system (2004) * Reviews on development of the nervous system and the dynamic roles of ion currents in early development (2012) * Studies on the effects of changes in rate and rhythm on electrical activity in the heart (1981) * Research on hyperpolarization-activated cyclic-nucleotide-gated channels, including their role in cellular excitability and pathophysiological insights (2018) The article also mentions various scientific references, including books and journals. The article appears to be a collection of references and citations related to neuronal excitability, ion transport, and membrane biology. It includes research papers from various fields such as neuroscience, physiology, and cell biology. Some of the topics covered include the plasticity of intrinsic neuronal excitability, signature channels of excitability in immune cells, and the role of L-type channels in immune cells. Other papers discuss dendritic excitability, coincidence detection, and synaptic transmission in brain slices and brains. The article also mentions research on apoptosis (programmed cell death) and the potential roles of electrogenic ion transport and plasma membrane depolarization in this process. Additionally, it appears to include references to various other studies on neuronal biology, such as the expansion of the constant field equation to include both divalent and monovalent ions, and the study of light-adapted blowfly photoreceptors. Some of the sources cited appear to be from reputable scientific journals such as Current Opinion in Neurobiology, Frontiers in Immunology, Experimental Physiology, and Developmental Brain Research. El potencial de membrana en reposo es una diferencia eléctrica entre las matrices intracelular y extracelular que se mantiene constante cuando una célula no está excitada. Cada tipo de célula tiene su propio potencial de membrana, pero solo las células excitables (nervios y músculos) pueden modificarlo y generar un potencial de acción. Iones difusibles como el sodio y el potasio pueden atravesar la membrana celular, mientras que proteínas no lo hacen. Aunque ambos grupos contribuyen al potencial de membrana, los iones difusibles son responsables del cambio en este potencial. El potencial de membrana en reposo tiene un valor negativo debido a la mayor cantidad de iones negativos dentro de la célula. Durante el potencial de acción, se produce una redistribución de los iones, lo que hace que el potencial de membrana sea menos negativo y más cercano al umbral del potencial de acción. La bomba Na (+)-K (-) ATPasa también controla el potencial de membrana eliminando 3 moléculas de sodio a cambio de 2 moléculas de potasio. Esto crea gradientes de concentración para sodio y potasio, permitiendo más sodio en el espacio extracelular y más potasio en el espacio intracelular. La permeabilidad de la membrana para sodio y potasio depende de los canales iónicos, que son proteínas especializadas que permiten la migración de los iones. Hay dos tipos de canales iónicos: canales pasivos, que permiten el transporte de moléculas dependiendo de su gradiente de concentración, y canales activos, que se abren y permiten el transporte de iones en respuesta a cambios del potencial de membrana o la unión de otra proteína. Durante el reposo, la difusión de iones se produce solo a través de los poros. La salida de potasio es mayor que la entrada de sodio debido a la mayor cantidad de poros abiertos para el potasio, lo que contribuye a mantener la negatividad del potencial de membrana en reposo. El espacio intracelular y el potencial de membrana en reposo son fundamentales para entender cómo funcionan las células nerviosas. Los canales activados por ligando se localizan cerca de las sinapsis y están involucrados en la hipo o hiperpolarización local de la célula después de que el neurotransmisor se une a estos. La difusión de los iones a través de la membrana celular no sigue el gradiente de concentración, sino que está influenciada por el gradiente eléctrico. El gradiente eléctrico es un componente físico que se opone al gradiente de concentración y funciona como un imán. Por ejemplo, el potasio (K+) es un ion positivo con una concentración intracelular de 140 mmol/L y extracelular de 4-5 mmol/L. Se espera que el potasio se difunda fuera de la célula hasta que las concentraciones sean iguales en ambos lados, pero esto no sucede debido al gradiente eléctrico. El equilibrio electroquímico es un punto en el que el espacio extracelular es lo suficientemente positivo para repeler el potasio y el espacio intracelular es lo suficientemente negativo para atraer el potasio. El valor de este equilibrio es -94 mV. El sodio (Na+) también es un ion positivo, pero su difusión está influenciada por el gradiente de concentración. La célula se vuelve lo suficientemente electropositiva para repeler los nuevos iones de sodio y alcanza el equilibrio electroquímico en un valor de +61 mV. En resumen, la difusión de los iones a través de la membrana celular es influenciada por el gradiente eléctrico y no sigue el gradiente de concentración. Esto tiene implicaciones importantes para entender cómo funcionan las células nerviosas y cómo se producen los potenciales de acción. Blackwell Publishing Ltd. Membrane Potential: Want to learn more about this topic? Our engaging videos, interactive quizzes, detailed articles, and high-definition atlas will help you achieve faster results. How do you prefer to learn? “Honestly, I could say that Kenhub has cut my study time in half” – Read more. Kim Bengochea, Regis University, Denver