Chapter 2
Introduction to Bioelectricity

Yong Jeong

2.1 Introduction

It can be said that the use of electricity by biological systems as a signal between the nerves and muscles was first discovered in 1789 in a frog leg when the Italian physicist Luigi Galvani touched an exposed sciatic nerve with a charged metal scalpel and observed the dead frog's leg flex as if it were alive. This finding provided the basis for the current understanding that electrical energy is the impetus behind muscle movement and also the driving force in other systems. This work was reported in the *Proceedings of the Bologna Academy* in 1791. At that time, Galvani believed that the muscular contractions were due to electrical energy emanating from the animal. However, Allesandro Volta was convinced that the electricity in Galvani's experiments originated from the presence of the dissimilar metals. Both of these interpretations represent the two different aspects of electrical potential in biological system, the action potential and the steady source of electrical potential [1, 2].

Bioelectricity is the electrical phenomenon of life processes. The basic unit of this phenomenon is a cell which is polarized by certain processes using energy. Specialized classes of cells that have electrically excitable membranes such as neurons or muscle cells have additional capabilities of developing action potentials. Many biomedical instruments such as electroencephalography, electrocardiography or electromyography measure the compounds of these action potentials from the brain, heart, and muscle, respectively.

In this chapter, the basic biological mechanisms behind bioelectricity and their applications will be introduced.

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2.2 Electrical Properties of the Human body

The electrical properties of the human body follow the laws of nature. The main chemical components of our body is water, salts (or their ions) and some organic chemicals such as proteins, lipids and so on. These components show different electrical characteristics, however, we can build a circuit model using a combination of resistors, capacitors and/or generators. The main difference between this model from the actual human body is that current flow is caused not by the movement of electrons but by that of ions dissolved in water.

The human body exhibits many levels of structural complexity. It is composed of various organ systems which can be grouped into functional units. These are the integumentary system, skeletal system, muscular system, nervous system, endocrine system, cardiovascular system, respiratory system, digestive system, urinary system, and reproductive system. An organ is a structure composed of several tissue types, which performs specific functions. Again, tissues consist of a group of similar cells that have a common function. Cells are the smallest units of all living things. Thus, even if different systems or organs perform different function, they consist of the same building blocks, the cell and cement (the extracellular matrix).

This means that each organ shares common features including electrical properties. Some variations exist in terms of the chemical composition in the cytoplasm (intracellular compartment), the cell membrane and extracellular components depending on cell or tissue type. These variations, however, has little effect on electrical properties. The main factor which determines the electrical properties of the tissue is the distribution pattern of ion channels on the cell membrane. The amount and composition of lipids can also influence the electrical properties of human body by acting as a capacitor but the capacitance value is almost the same across the cell.

2.2.1 Cell Membrane

Cells are basic building blocks of living organisms. The boundary of animal cells is a plasma membrane composed of thin lipid bilayer and proteins embedded in it (Fig. 2.1). The main role of the cell membrane is to regulate the exchange of chemical substances. Both the lipid bi-layer and some of the embedded proteins play critical roles in the electrical properties of the cell using this exchange. The plasma (fluid in inner space of cells) and interstitial fluids (fluid in outer space) are composed of ions or electrolytes of different species which are unequally distributed across the membrane. This membrane prevents water molecules and ions from diffusing across it. The most common electrolytes are Na^+ (sodium), K^+ (potassium), Cl^- (chloride) and Ca^{++} (calcium). Other components such as H^+ (hydrogen), $HCO_3{}^-$ (bicarbonate), $NH_4{}^+$ (ammonium) or phosphate ions contribute minimally to membrane potential. Protein components endow the membrane with a selective permeability to some ions. The driving force of this exchange is initially a difference in concentration between the inside and outside of the cell. This difference or concentration gradient is maintained mainly by Na^+/K^+ pumps that move Na^+ out of the cell and K^+ into the cell using energy. Selective permeability is also determined

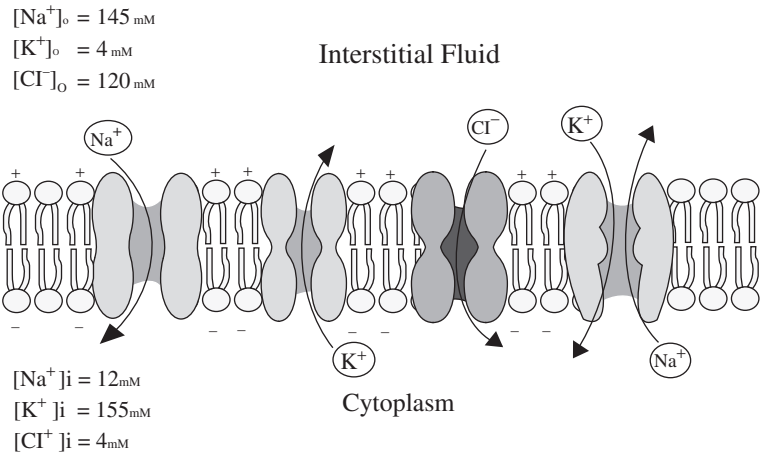

Fig. 2.1 Structure of the plasma membrane. Membrane is composed of a lipid bilayer with embedded proteins. The proteins shown in the figure are ion channels and Na^+/K^+ pumps as illustrated, however there are other proteins embedded in the membrane that act as receptors, transporters and serve other functions

by ion channels. Ions pass through channels that are selective for that specific ion. There are four major ion channels, Na^+ channel, K^+channel, Cl^- channel, and Ca^{++} channel. Figure 2.1 represents a plasma membrane with ion channels and a Na^+/K^+ pump with typical ion concentrations of each side of the membrane. The flow of ions in response to concentration gradients is limited by the selectively permeable cell membrane and the resultant electrical field [3, 4, 5].

2.2.2 Membrane Potential

To understand membrane potential better consider an environment with only one ion species, for example, K^+ is present in solution. If the solution is divided into two compartments by a membrane with K^+ channels, and the concentration of K^+ is higher in one compartment, then there will be a net flux from the compartment with higher concentration to the lower one (extracellular interstitial fluid). For this situation, the flux due to concentration gradient (diffusion) tends to push K^+ to compartment with low concentration (outside of the cell) and is given by

$$J_K\,(\text{diffusion}) = -Dd[\mathrm{K}^+]/dx$$

from Fick's law where D is the diffusivity constant.
The flux of K^+ will lead to a positive charge accumulation outside of the cell. The flux due to electrical field (drift) tends to push K^+ inside the cell and is given by

$$J_K\,(\text{drift}) = -\mu Z[\mathrm{K}^+]dv/dt$$

from Ohm's law where μ is mobility in m^2/sV, Z is ionic valence and v is voltage across the membrane.

Thus, the net flow is

$$J_K = J_K\,(\text{diffusion}) + J_K\,(\text{drift}) = -Dd[\mathrm{K}^+]/dxJ_K - \mu \mathrm{Z}[\mathrm{K}^+]dv/dt$$

Using the Einstein relation, $D = \mathrm{K}T\mu/q$, the total flow is given by

$$J_K = -RT/q\mu d[\mathrm{K}^+]/dx - \mu Z[\mathrm{K}^+]dv/dt$$

where R is Boltzmann's constant, T is the absolute temperature in degrees Kelvin, and q is the magnitude of the electric charge.

At equilibrium when the flow of K^+ into the cell is balanced by the flow out of the cell thus

$$RT/q\mu d[\mathrm{K}^+]/dx - \mu \mathrm{Z}[\mathrm{K}^+]dv/dt = 0$$

Integrating this equation from outside the cell to inside

$$\int_{v_o}^{v_i} dv = -\frac{KT}{q}\int_{[\mathrm{K}^+]_o}^{[\mathrm{K}^+]_i} \frac{d[\mathrm{K}^+]}{[\mathrm{K}^+]}$$

where v_o and v_i are the voltages outside and inside the membrane and $[K^+]_o$ and $[K^+]_i$ are the concentrations of K^+ outside and inside the membrane. Thus,

$$vi - vo = -\frac{KT}{q}\ln\frac{[\mathrm{K}^+]_i}{[\mathrm{K}^+]_o} = \frac{KT}{q}\mathrm{In}\frac{[\mathrm{K}^+]_o}{[\mathrm{K}^+]_i}$$

This equation is known as the Nernst equation, and we can obtain K^+ equilibrium potential,

$$E_K = v_i - v_o = \mathrm{RT}\ln[\mathrm{K}^+]_o/[\mathrm{K}^+]_i\,\mathrm{mV}$$

In the same way Na^+ and Cl^- equilibrium potentials are

$$E_\mathrm{Na} = \mathrm{RT}\ln[\mathrm{Na}^+]_o/[\mathrm{Na}^+]_i\,\mathrm{mV}$$

$$E_\mathrm{Cl} = -\mathrm{RT}\ln[\mathrm{C1}^-]_o/[\mathrm{Cl}^+]_i\mathrm{mV}, \text{respectively.}$$

In a real system, however, all ions coexist together and the membrane potential (V_m) is given by the Goldmann equation for K^+, Na^+, and Cl^- can be derived as

$$\mathrm{V}m = \frac{KT}{q}\ln\left(\frac{P_\mathrm{K}[\mathrm{K}^+]_o + P_\mathrm{Na}[\mathrm{Na}^+]_\mathrm{o} + P_\mathrm{Cl}[\mathrm{Cl}^-]_i}{P_\mathrm{K}[\mathrm{K}^+]_i + P_\mathrm{Na}[\mathrm{Na}^+]_i + P_\mathrm{Cl}[\mathrm{Cl}^-]_o}\right)$$

where P is the relative membrane permeability of each ion.

2.2.3 Equivalent Circuit Model for the Plasma Membrane

Developing of an equivalent circuit model of the cell membrane is helpful for understanding membrane potential. The membrane is a lipid bilayer that is embedded with different types of ion channels. Ion channels act as a resister however, since they are characterized as being open or closed, thus they are variable resisters. Equilibrium potential for each ion is the electrical potential difference across the channel and is modeled as batteries.

There is a steady outflow of K^+ ions and an inflow of Na^+ ions, thus when left alone, this would drive the membrane potential toward 0. To prevent this, Na^+/K^+ pumps are used in equal and opposite directions to these passive currents and can be modeled as generators.

The cytoplasm and interstitial fluid are the electrical conductors and they are separated by the lipid bilayer of the membrane which has an insulating property. This feature can be modeled as capacitor. Capacitance for a cell membrane is approximately 1 $\mu F/cm^2$.

By combining the above ion channels as resistors, Na^+/K^+ pumps as generator, and lipid bilayer as capacitors, one can develop an integrated model of the cell membrane as shown in Fig. 2.2.

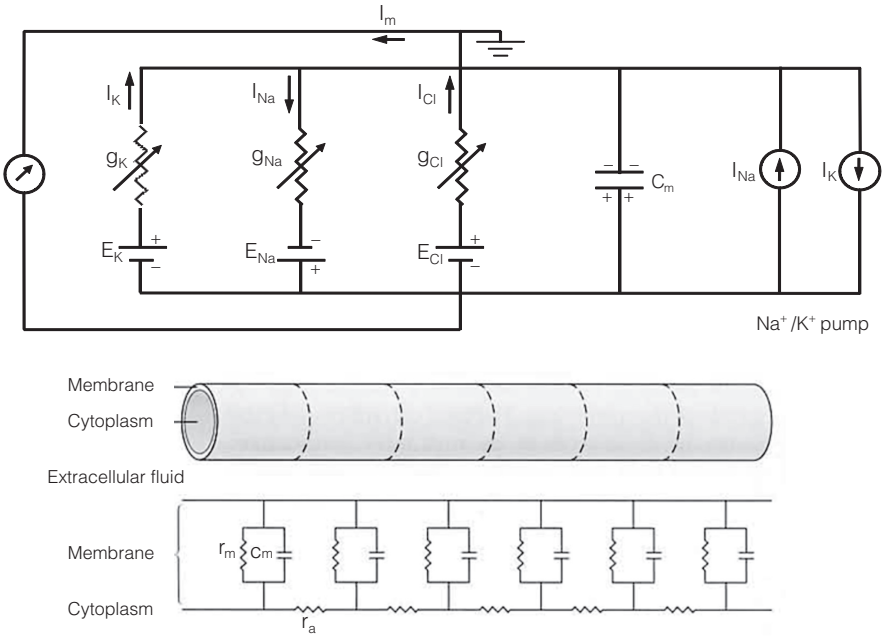

Fig. 2.2 Equivalent circuit model of the plasma membrane. Lipid bilayer acts as a capacitor and each ion channel acts as a variable resister. Na^+/K^+ pump acting as a generator is also illustrated

2.2.4 Graded Response of Membrane Potential

Changes in the open probability of sets of ion channels cause membrane potential change in limited areas. The change can depolarize or hyperpolarize the membrane potential. For example, either a decrease of K^+ permeability or an increase of Na^+ permeability will cause the membrane potential to move closer to the sodium equilibrium potential (depolarization). Opening either sodium channels or nonselective cation channels will lead inward movement of Na^+ thus causes depolarization by moving the membrane potential toward some value roughly midway between the sodium equilibrium potential and the potassium equilibrium potential. This graded potential spreads along the membrane by changing the charge on the membrane capacitance and by flowing through opened channels which are equivalent to a resistor. This structure is equivalent to a RC circuit and in this case a step change in current flow causes an exponential change in membrane potential. The time it takes for the membrane potential to reach about 63% ($1 - 1/e$) of its final value is the time constant (τ) of the membrane. The time constant can be calculated by multiplying the resistance and the capacitance of the membrane (Fig. 2.3).

As the current flows along the membrane, some of the current leaks through open channels in the neighboring areas. As a result the membrane potential progressively decreases with increasing distance from a current source. This spatial pattern is exponential and the distance where the voltage change to 37% ($1/e$) of its original value is the length constant (λ) (Fig. 2.4).

These grade responses can interact with each other and can be spatially or temporally summated. Two successive grade responses will add to each other with a degree of temporal summation. Two stimuli at neighboring sites also add to each other with a degree of spatial summation (Fig. 2.5).

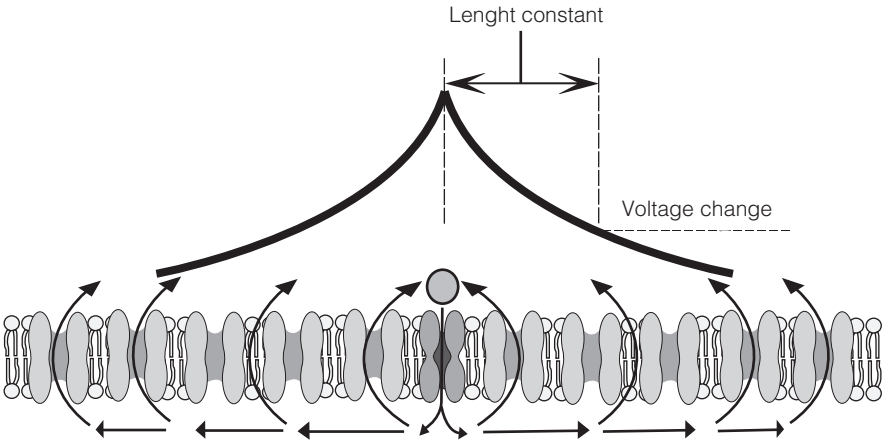

Fig. 2.3 An injection of current at one point causes a voltage decline exponentially along with distance. The distance where the voltage reaches about 37% of its original value is the length constant

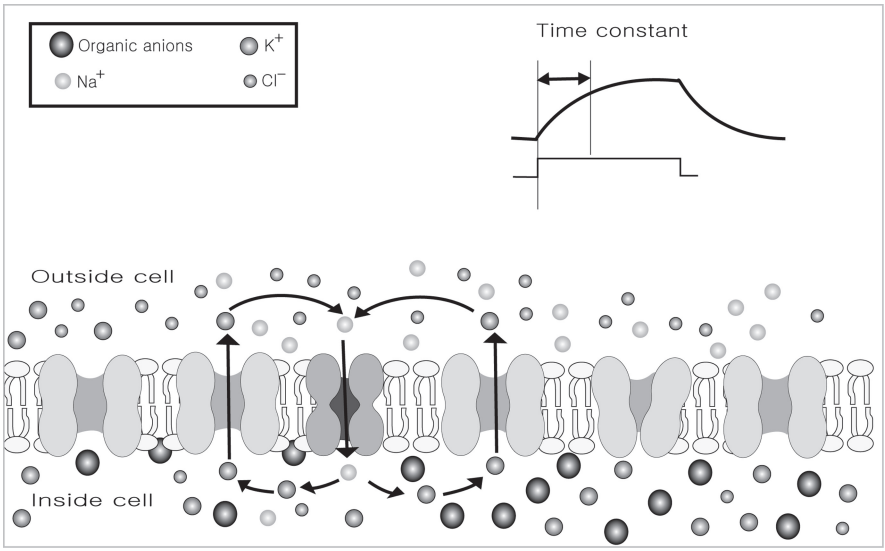

Fig. 2.4 An injection of square wave causes an exponential voltage change due to the parallel resistance and capacitance of the membrane. The time when the voltage reaches about 63% of its final value is the time constant

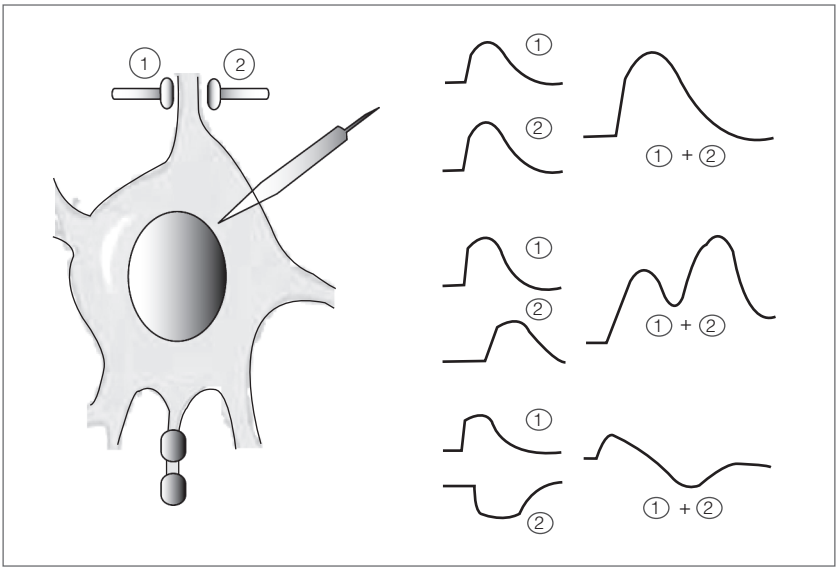

Fig. 2.5 Temporal and spatial summation. *Upper*: Simultaneous activation of two synapses results in spatial summation. *Middle*: Sequential activation of two synapses results in both spatial and temporal summation. *Low*: Spatial summation can occur with excitatory and inhibitory synaptic input

2.2.5 Action Potential

As most neurons or muscle cells are much longer than their length constants, the grade responses disappear when flowing along the cell, thus the responses cannot deliver signal from one end to the other in the cell. Excitable cells are distinguished by their ability to generate action potentials that can propagate without losing their amplitude.

The core structures for generating action potential are voltage-gated ion channels, mainly voltage-gated Na^+ and K^+ channels.

Depolarization by synaptic input or by receptor potential causes the opening of both channels; however Na^+ channels open faster and are responsible for the rising phase of action potential. Since they are voltage-gated, the opening of Na^+ channel will depolarize the membrane potential which will then cause more Na^+ channels to open. The membrane then becomes overwhelmingly permeable to Na^+ causing the membrane potential to approach Na^+ equilibrium potential. This phenomenon can be calculated using the Goldmann's equation described before. Once open, however, the Na^+ channels spontaneously close by inactivation gate and they cannot open again until the membrane potential returns to resting membrane potential. Closing of Na^+ channels causes the membrane potential to return to its resting level. In addition, K^+ channel start to open slowly and this facilitates the falling phase. The permeability of K^+ in this stage dominates and the membrane potential first approaches resting membrane potential then approaches K+ equilibrium potential (after hyperpolarization) (Fig. 2.6).

The all-or-none feature of action potential implies that stimulus less than certain level (threshold) of depolarization results in a graded response which would not be transferred. However a stimulus big enough to move the membrane potential beyond the threshold will generate action a potential that can propagate to distant regions of the cell. In neurons, the axon hillock (initial point of axon) has the lowest threshold with relatively high densities of Na^+ channels and is thought to be the principal trigger zone. The graded responses produced throughout the dendrites or cell body is summed spatially and temporally, and if the summed response is large enough to pass the threshold, an action potential will be generated at axon hillock. At this point the amount of response determines the frequency of action potential. Thus the function of the axon hillock is similar to that of an analogue-digital converter.

After generating an axon potential at trigger zone, it begin to propagate to neighboring segments of the membrane and depolarize them to threshold triggering action potentials in the next neighboring area and so on. This propagation is unidirectional, from axon hillock to axon terminal because in the case of the neuron, the proximal segment just traversed by the action potential enters a refractory period and thus becomes inexcitable. The velocity is a function of the length constant, that is, the longer the length constant the further an action potential can travel down axon segment before it decreases to subthreshold levels. To deliver the action potential faster, invertebrates have thick axon fibers, up to hundreds of micrometers in width, to increase the length constant. Vertebrates on the other hand have myelinated axons which allow rapid conduction with thin axons. Myelin acts as an insulating

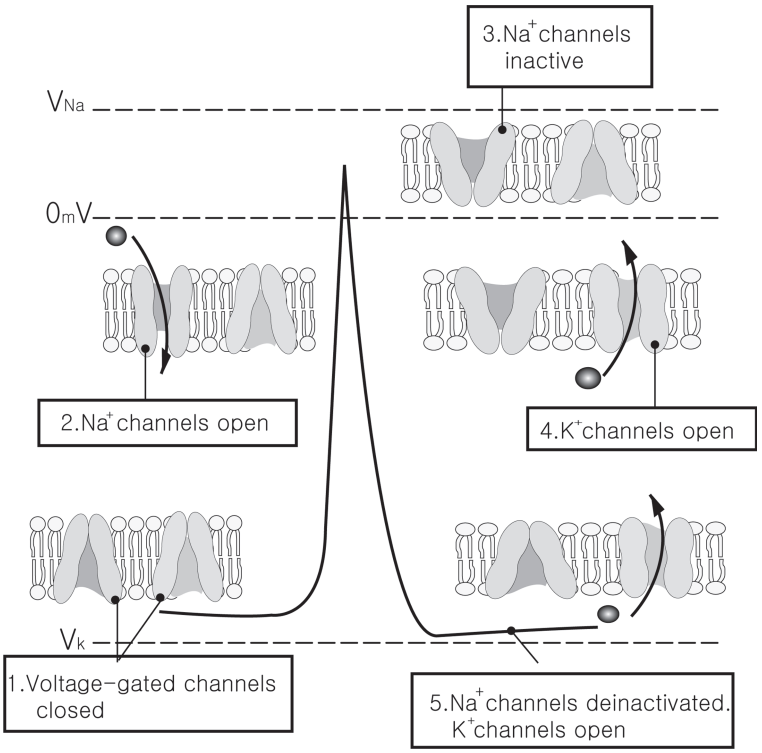

Fig. 2.6 Na^+ and K^+ channel opening and closing underlie action potential development. E_{Na}: sodium equilibrium potential, E_K: potassium equilibrium potential, V_m: membrane potential

sheath, allowing an action potential to spread along the axon until it gets to a node of Ranvier, which is a bare portion of axon without myelin. As a result, action potentials jump from one node to the next and so on. This conduction is called saltatory conduction. Saltatory conduction not only functions as a method of fast conduction of action potentials, but it also has the function of verifying information by ensuring that the frequency of action potential is correct (Fig. 2.7).

2.2.6 Synaptic Transmission

One of the main functions of neurons is transferring information form one neuron to another. The synapse is the place where this process occurs. There are two types of synaptic transmissions; electrical and chemical synapses transmissions. Electrical synapses refer gap junctions between two cells. These synapses separate two adjoining neurons by a few nanometers. The cytoplasm of one cell is connected to the next cell through channels named connexons. Current can flow through these channels either way, thus depolarization and hyperpolarization can spread from one cell

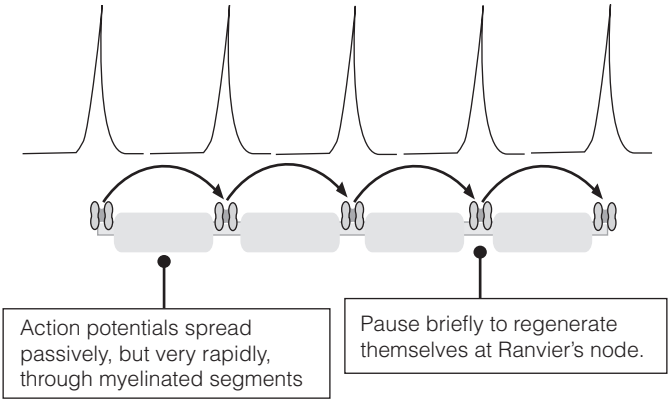

Fig. 2.7 Saltatory conduction of action potential along a myelinated axon

to next cell instantaneously and form an electrical syncitium. The electrical properties of this channel thus follow that of a graded response. These synapses are present only in a limited population of neurons. Gap junctions are good at spreading electrical signals through networks of interconnected neurons, and are effective in developing synchronic activity in clusters of neurons.

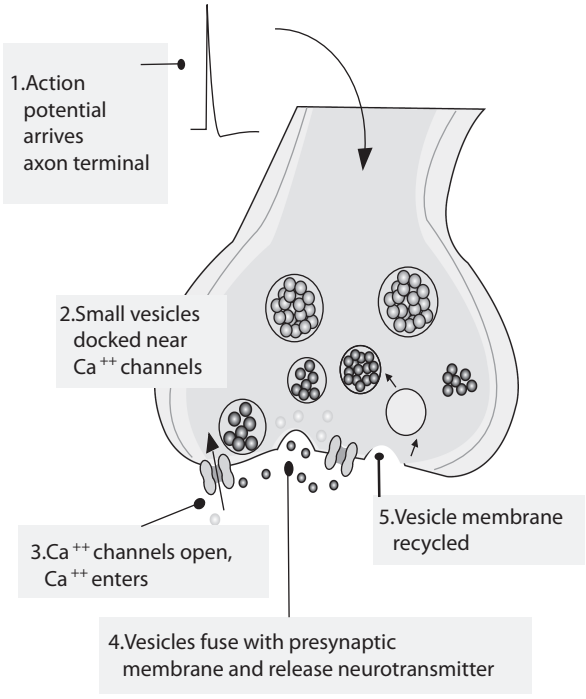

Fig. 2.8 Release of neurotransmitter

Chemical synapses are the main measure of inter-cellular communication and are different from electrical synapses. There is no continuity of cytoplasm at all and the direction of signal transmission is unidirectional (There are some exceptions. However, main frame is unidirectional). The gap between two cells is extracellular space and named the synaptic cleft. When the action potential reaches the axon terminal, intracellular Ca^{++} increases by opening of voltage dependent Ca^{++} channels. The increased Ca^{++} levels triggers fusion of synaptic vesicles wherein neurotransmitters are stored within neuronal membrane (Fig. 2.8). Glutamate, GABA, acetylcholine, dopamine, and several other chemicals are used as neurotransmitters. The released neurotransmitters bind to specific receptors of the post-synaptic cell membrane and change the membrane potential. Chemical synapses are similar to digital to analogue converter. They have much more signaling flexibility than electrical synapses thus allows for more room for plastic changes of synaptic transmission which is thought be the basis of learning and memory.

2.3 Equivalent Circuit Model of Tissues and Organs

The electrical properties of tissues and organs are basically the combination of the electrical properties of cells that make up the tissue or the organ. As shown in Fig. 2.9, one can make a model of a body segment, which contains skin, fat, muscle, bone and extracellular fluid (ECF) components. This model represents typical limbs [6]. Nerves and vessels components can be added, however their proportion is small in terms of the magnitude of resistance and capacitance. Modeling of the trunk portion of the human body is also possible by adding other components, for example an air component in case of a lung or gut. The values of resistance and capacitance of each component are sum of the composing cells.

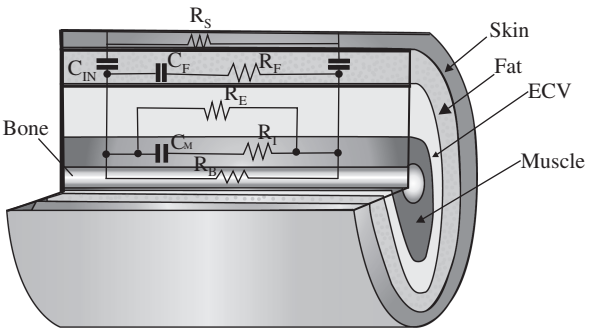

Fig. 2.9 The equivalent model of segmental body composition with the components of skin, fat, muscle, extracellular and intracellular fluid volume and bone. R_S: skin resistance, C_{In}: connect capacitance between skin and fat, C_F: capacitance of the fat, R_F: resistance of the fat, C_M: capacitance of the muscle cell membrane, R_I: resistance of the sarcoplasmic fluid, R_E: resistance of the extracellular fluid, R_M: resistance of muscle, R_B: resistance of bone (modified from Ref. [3])

When measuring the electrical properties of the body, the main problem is the impedance developed between electrodes and skin. This issue is beyond the scope of this chapter. Detailed information on this subject can be found elsewhere [7].

2.4 Biomedical Devices

The main sources of bioelectrical signals are generated by muscles, the heart or the brain. Chemical or mechanical signals also can be measured after being converted to electrical signals. The initial point of measuring is called the sensor. The outputs of the sensor are analog signals, which are amplified, filtered, conditioned, and converted to digital signals through a processor and digital converter. Once the analog signals are converted to digital signals, they can be stored and processed by many different methods [5].

Although the electrical signals that different instruments measure do not look the same, they share the same underlying mechanisms. All instrument systems also have an output display device, a storage device, a calibrating system and feedback elements. The display device enables users to view signals numerically or graphically in a discrete or continuous way. The storage device allows operators to carry out further analysis after obtaining the data.

This chapter will introduce basic mechanisms and applications of major biomedical instruments.

2.4.1 Electrocardiography

Electrocardiography (ECG or EKG) is routinely performed in clinical practices to measure the heart function. With ECG doctors can detect many clinical situations such as arrhythmia, cardiac hypertrophy, ischemic heart disease and even electrolyte imbalances. The biological source of ECG rhythm is the sum of action potentials in heart muscle cells. Serial propagation of action potential from sino-atrial node (pace maker) through atrio-ventricular node, Bundle of His, bundle branches and finally to ventricular muscle cells creates a typical shape for ECG rhythm (Fig. 2.10). The first wave, P is developed when the atrium is excited. The PR interval is when the action potentials stay for 100–200 ms to ensure time for blood flow from atrium to ventricle. The second QRS complex happens mainly when ventricle is excited and the third T wave is when the ventricle is relaxed. Thus, changes in the shape, timing or amplitude of each wave can imply a certain dysfunction in the heart.

Conventional ECG examination use 12 channels with 9 skin surface electrodes and a reference electrode. One electrode is attached to each limb and among those electrodes three are for picking up ECG signal and the remaining one (right leg) is a reference electrode. Six chest electrodes are connected on the thoracic surface at defined positions near the heart (Fig. 2.11).

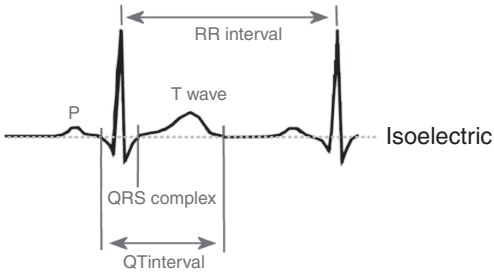

Fig. 2.10 Typical ECG rhythm

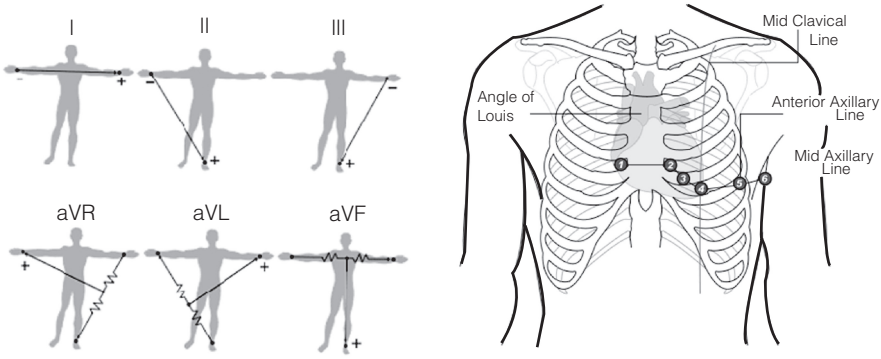

Fig. 2.11 Leads in electrocardiography recording. Six limb leads (*left*) and six chest leads are illustrated

Four electrodes are attached to each limb; right arm (RA), left arm (LA), and left leg (LL) for measuring the signal and right leg (RL) for reference. Three bipolar electrodes (I, II, III) measure the voltage difference between RA-LA in channel I, RA-LL in channel II, LA-LL in channel III. Einthoven, the inventor of the first practical ECG found the following difference among the electrodes: $u_{II} = u_I + u_{III}$. The three unipolar electrodes (aVR, aVL, aVF) are voltage differences between one limb and sum of the other two limbs. Signals from these electrodes have a higher voltage, and they are called augmented electrodes. Interestingly the vector leads of the augmented leads interlace the vector angle of lead I, II and III (0°, 60°, 120°) so that each 30° is covered. Six chest electrodes are for measuring the cardiac electrical activities in transverse plane. The electrodes are unipolar with reference of RA or the sum of three limb leads. With these 12 electrodes one can detect the cardiac vectors both in coronal and transverse plane.

2.4.2 Electroencephalography

Electroencephalography (EEG) measures the electrical activity of 10^{11} neurons underneath the scalp. In some situations, electrodes are placed on the surface of

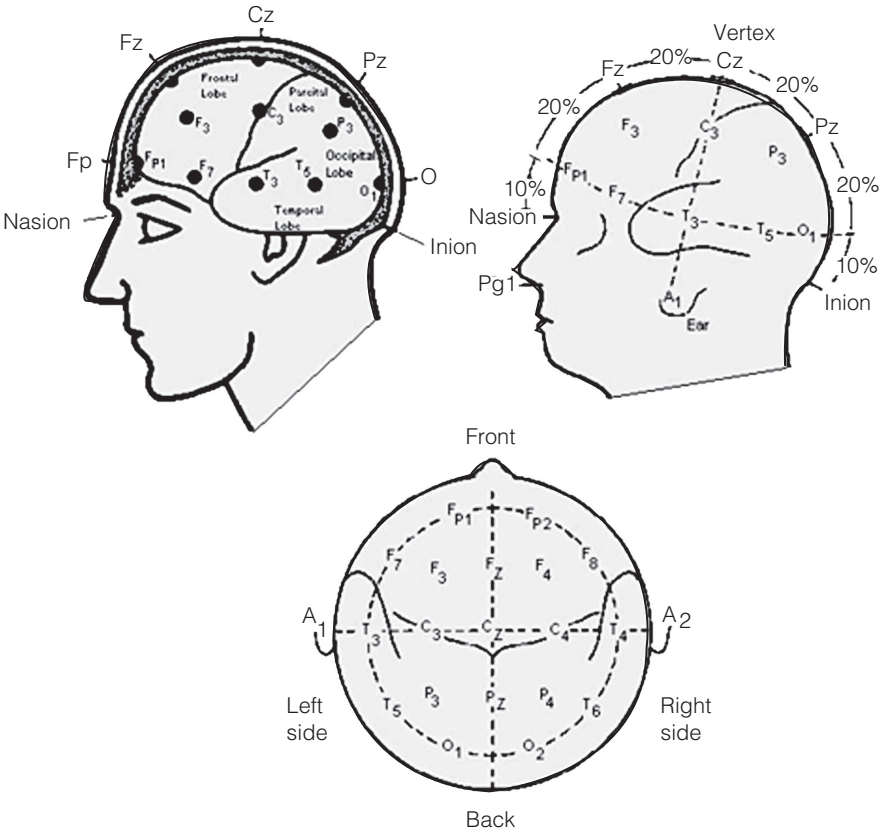

Fig. 2.12 Positioning of international 10–20 EEG electrode system. F: frontal lobe, P: parietal lobe, T: temporal lobe, O: occipital lobe

brain itself after or during surgery. In this case it is called Electrocorticogram (ECoG). Standardized EEG recording uses 21 electrodes (Fig. 2.12). The leads can be bipolar or unipolar according to the montage the operator selects. When recording, one can easily record oscillating electrical activity. The amplitude is on the order of 50 μV and the frequency between 1 and 50 Hz. The waves change markedly according to the status of brain, for example depending on the conscious level of the subject, different brain waves will be recorded by the EEG machine. Some of the changes in EEG waves are characteristic of specific abnormalities of the brain, such as epilepsy or brain death. Others are found in normal people and classified according to frequency level. Alpha waves are rhythmic waves occurring at a frequency between 8 and 13 Hz. They are recorded in almost all people when they are awake in a quiet and resting state. Beta waves in the frequency range from 13 to 30 Hz, and are recorded during mental activities and tension. Theta waves occur at frequencies between 4 and 7 Hz. It is prominent during drowsiness. Delta waves include all the

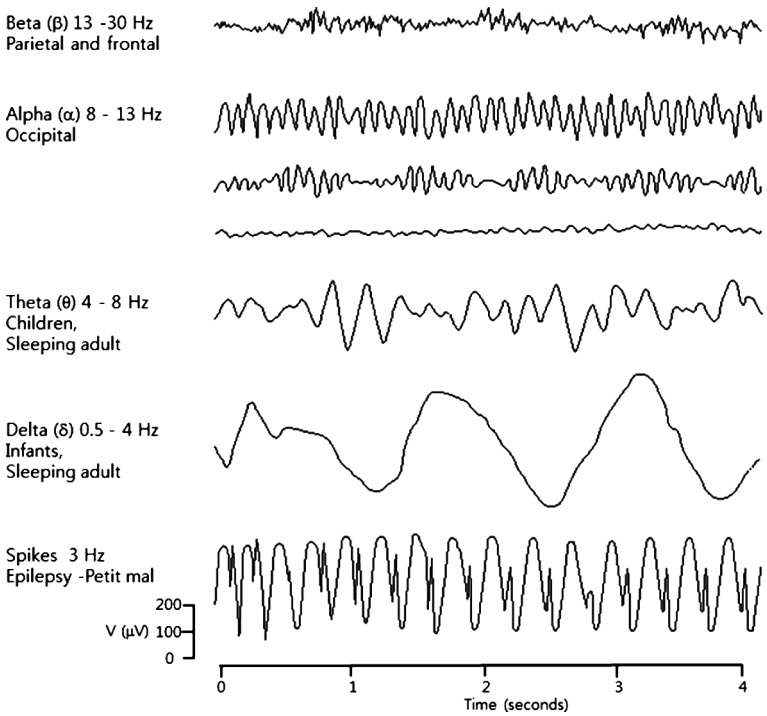

Fig. 2.13 Examples of EEG waves

waves below 3 Hz. It occurs in deep sleep, in babies and in serious organic brain disease (Fig. 2.13).

One application of EEG is sleep studies. When an individual becomes inattentive, drowsy and falls asleep, the alpha rhythm is replaced by slower, larger waves. In deep sleep, large, irregular delta wave appears with bursts of alpha-like activity called sleep spindles. The high-amplitude, slow waves are sometimes replaced by rapid low voltage irregular activity resembling that those obtained in alert subjects. This stage is called paradoxical sleep or rapid-eye-movement (REM) sleep. Other stages are nonrapid-eye-movement, NREM, or slow-wave sleep.

2.4.3 Electromyography

The functional unit of skeletal muscle is the motor unit which includes motor neurons, its axon and muscle fibers innervated by the motor neuron. Cross sectionally, however, the muscle fibers of a motor unit are interspersed with fibers of other motor units. Thus the muscle fiber component of a given motor unit constitutes a distributed electric source located in a volume conductor consisting of all other muscle fibers, both active and inactive. The potential from active fibers has a triphasic form

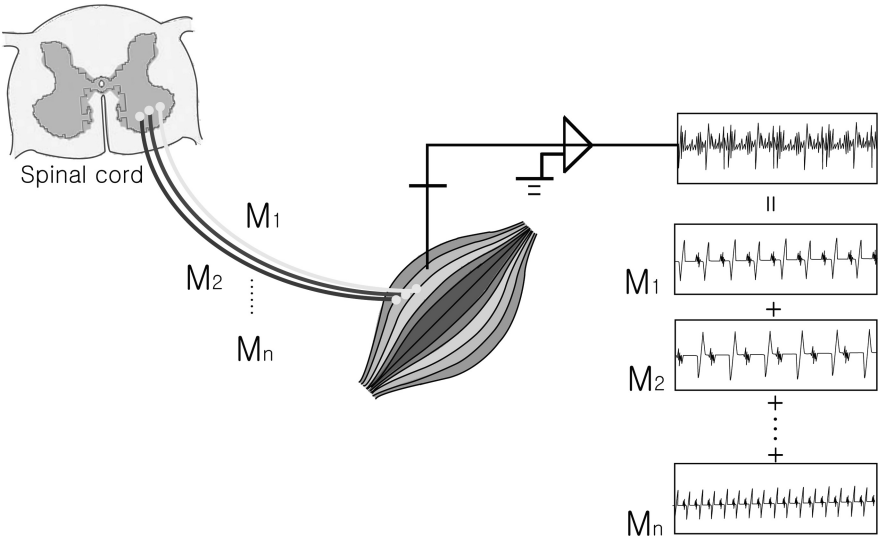

Fig. 2.14 Example of an electromyography recording. Recorded EMG waves are compounded from the action potentials of many motor units (M)

of short duration with an amplitude of 20–2000 μV, depending on the size of the motor unit (Fig. 2.14).

Surface electrodes are convenient but only can detect the activities of surface muscles and have less spatial resolution. Various types of monopolar, bipolar, and multipolar insertion-type electrodes are commonly used for recording the activity of deep muscles and from single motor units.

In clinical studies, the main purpose of EMG is to differentiate whether symptoms such as weakness are from dysfunction of neurons or from the muscles. With neuronal diseases, spontaneous activities and giant muscle unit potentials are observed. In contrast with muscle diseases the amplitude of each motor unit potential is decreased.

2.5 Current Research Trends in Biomedical Electrical Instruments

From the engineering perspective, the technology for biomedical instruments does not need to be either advanced or sophisticated. In terms of technology, the level of currently developed bioelectrical devices seems to have reached their plateau stage. Thus further advances or innovations should be found through different approaches.

One of the directions biomedical instrument device development is headed in is to provide users the interpretation of measured data. By using a certain algorithm, the ECG system provides not only simple data such as the heart rate or irregularity,

it provides many possible clinical situations. Even though physician should verify the interpretation, the accuracy rate is impressive. The EEG system also provides brain mapping solutions thus allowing the physician to detect the source region of abnormal brain waves. This kind of approach is promising since it reduces the clinical burden to doctors, which may result in patients getting better medical service at less financial cost.

Medical instruments are also becoming miniaturized, portable, and designed to use less electrical energy. All these are becoming possible due to the development of microchips and better performing batteries. Also recently developed instruments can be connected to a network. This means patient data can be stored and delivered to a database using a personal computer or even cellular phones. One example of this technology is a hybrid of cell phone with a blood glucose tester. When a diabetic patient checks his or her blood glucose level with tester attached to the cell phone, the results are transmitted to the physician and family to be stored on a PC or database. By using this device the patient can get more dedicated attention and care, and therefore might have better prognosis. This idea can be applied to other devices that can monitor EKG or EEG. By creating hand-held devices that can monitor these things we can predict possible heart attacks or seizures.

Nowadays, all scientific and engineering fields emphasize multi-disciplinary approaches and fusion or converging technology. Electrical engineering for biomedical instruments is no exception. Above all, engineers should have a better understand of anatomy and the physiologic nature of biological systems and clinical needs. With this knowledge, engineer can identify the real problems and can provide novel solutions for unsolved problems. By converging information technology and biological technology we can expect the beginning of a new era in the field of biomedical devices.

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