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Original Research Article

Comparative Analysis of Resting and Action Membrane Potentials

Sumit Kumar[1], Parul Horo[2], Peeyush Ranjan[3], Rashid Iqbal[4]

[1]Assistant Professor, Department of Physiology, Netaji Subhas medical College and Hospital, Jamshedpur, Jharkhand, India

[2]Assistant Professor, Department of Physiology, Netaji Subhas medical College and Hospital, Jamshedpur, Jharkhand, India

[3]Tutor / Senior Resident, Department of Physiology, Phulo Jhano Medical College, Dumka, Jharkhand, India

[4]Senior Resident, Department of Pharmacology, MGM Medical College and Hospital, Jamshedpur, Jharkhand, India

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Corresponding Author: Dr. Parul Horo

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Abstract:

Background: The resting membrane potential (RMP) and action potential (AP) are fundamental electrical properties that enable neuronal and muscular excitability, signal transmission, and physiological coordination. Understanding these parameters in amphibian muscle fibers provides key insights into cellular electrophysiology.

Aim: To record and analyze the resting membrane potential and action potential characteristics of skeletal muscle fibers in Rana pipiens and to determine any sex-related differences.

Methodology: An experimental and descriptive study was conducted on 60 healthy Rana pipiens specimens (30 males and 30 females) in the Department of Physiology, Netaji Subhas Medical College and Hospital, Jamshedpur. Standard electrophysiological techniques using glass microelectrodes were employed to record RMP and AP. Data were analyzed using Student's t-test, with $p < 0.05$ considered significant.

Results: The mean RMP was –70.5 ± 1.5 mV, AP amplitude 94.5 ± 2.0 mV, and AP duration 2.1 ± 0.1 ms. No significant sex-related differences were observed in any parameter ($p > 0.05$). The results indicated stable and uniform electrophysiological characteristics across samples.

Conclusion: Rana pipiens skeletal muscle fibers exhibit consistent RMP and AP properties, with no notable sex-related variation. These findings confirm the homogeneity and stability of amphibian muscle excitability.

Keywords: Rana Pipiens, Resting Membrane Potential, Action Potential, Electrophysiology, Muscle Excitability.

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Introduction

Human nervous system is a complex network of communication that enables the passage of information to the body at a very fast rate. The basic element of this system is that neurons are able to create and conduct electrical impulses. These characteristics of electricity are majorly involved in various processes of physiology such as muscle contraction and sense processes and in learning and memory processes among other cognitive processes [1]. The two significant phenomena about neural communication are the action potential and the resting membrane potential. The concepts are required to learn about how neurons process and transmit information.

A small electrical potential transvers across the plasma membrane of all neurons and is known as resting membrane potential. This potential is developed as a result of unequal distribution of ions; sodium (Na +) and potassium (K +) ions and chloride (Cl -) and negatively charged proteins across the membrane. The conduits and carriers of ions and especially, sodium-potassium pump (Na + /K +-ATPase) play a vital role in the process of maintaining this balance. Membrane potential under normal resting conditions of a neuron is typically between -70 and -60 millivolts (mV) in which the interior of the cell is more negative than the exterior. Potential is the presence of readiness and the neuron is able to respond quickly to the input signals [2].

Dynamic response of passive movement of ions and active transport processes in the resting membrane potential is not its constant value. Diffusion of potassium ions is likely to occur out of the cell due to its concentration gradient but the electrical gradient forces it back into the cell. The interaction of these forces is known as the Goldman Hodgkin Katz equation that is applied to obtain the prediction of the resting potential, and it depends on the ion

permeabilities and ion concentrations. This may disturb neuronal functioning by any type of imbalance of the ions as a result of the alterations in metabolism, toxins, or diseases, which subsequently may perturb the resting potential [3].

In response to adequate stimulation of neurons, a dramatic and temporary change in membrane potential happens, called an action potential. It is this electrical signal that is the core way of long-distance communication between neurons [4]. Action potential is triggered when the depolarization attains a critical value, which is normally about -55 mV. An opening of the voltage-gated sodium channels occur at this stage at a rapid rate, and Na ions rush into the cell to reverse the membrane polarity. The membrane potential momentarily becomes positive, a stage referred to as depolarization.

The neuron is then repolarized after depolarization, when the potassium channels of the voltage-dependent nature open up, and the K 3+ is lost by the cell, returning the negative intracellular environment back to its original state. The membrane potential in certain cases gets a little lower than the resting level, a condition known as hyperpolarization. These successive alterations in membrane voltage are what guarantee that every action potential is a discrete phenomenon which propagates along the axon without weakening [5]. Refractory period after an action potential, one way transmission and appropriate timing between impulses are taken care of by the refractory period after an action potential.

Action potentials may travel along axons in two principal ways: continuum conduction and saltatory conduction. The action potential travels along the axon membrane continuously in unmyelinated neurons [6]. Comparatively, saltatory conduction, as used by myelinated neurons of a vertebrate nervous system, is impulse conduction were impulse jumps over Ranvier nodes. This process significantly increases the speed of conduction and its energy efficiency and therefore allows timely and synchronized responses of multifaceted organisms.

There are the resting and action potentials, which are the vital ones in ensuring that the nervous system is functioning in the appropriate manner. The disturbances of such electrical properties can result in severe neurological disorders. Some examples include epilepsy, multiple sclerosis and certain channelopathies, where ion channel functioning or membrane excitability is impaired [7]. Moreover such electrical processes have resulted in medicine invention, some technologies like anesthetics, neuro-prosthetic, and cardiac arrhythmia treatment.

Finally, action potential and resting membrane potential are two factors that form the foundation of neuronal excitation and communication of a signal. The high-speed electrical impulse is the possibility of responsiveness and action potentials, which is a result of the high-speed process of communication involving the neurons and other cells that takes place. Their sophistication in communication points to the elegance and precision of bioelectrical processes of living beings. As research continues to advance in the exploration of these processes at both molecular and computational scales, our knowledge of the nervous system and our ability to cure its pathologies have continued to grow.

Methodology

Study Design: This is an experimental, observational, and descriptive study conducted to record and analyze the resting membrane potential and action potential in the skeletal muscle fibers of Rana pipiens (frog). The study involved laboratory-based physiological experiments using standard electrophysiological techniques to understand the electrical properties of excitable tissues.

Study Area: Department of Physiology, Netaji Subhas Medical College and Hospital, Jamshedpur, Jharkhand, India for six months

Study Participants

Inclusion Criteria:

- Healthy adult Rana pipiens specimens of both sexes.
- Frogs with no visible injuries, infections, or abnormalities.
- Frogs were maintained under standard laboratory conditions prior to the experiment.

Exclusion Criteria:

- Diseased or injured frogs.
- Frogs showing signs of dehydration, lethargy, or poor reflex response.
- Specimens not suitable for electrode placement or showing unstable recordings.

Sample Size: A total of 60 Rana pipiens specimens were included in the study.

Procedure: To reduce pain and distress, the frogs were initially anesthetized with the use of an adequate anesthetic (e.g., MS-222 solution). The gastrocnemius-sciatic nerve muscle preparation was dilicately excised and fixed on the apparatus. The preparation was immersed in the Ringer solution to keep the tissue alive. The resting membrane potential (RMP) was recorded by placing glass microelectrodes in each of the individual muscle fibers under microscopic control and filling them with KCl. A high-impedance amplifier was used to test the membrane potential on an oscilloscope. The nerve was stimulated with a suprathreshold electrical pulse using a stimulator and the depolarization and repolarization phases were measured to elicit the action potential (AP) and recorded. Each preparation had several readings done so as to obtain accuracy and reproducibility.

Statistical Analysis: Data were tabulated and expressed as mean ± standard deviation (SD). Statistical analysis was performed using appropriate Microsoft Excel, and SPSS version 27. Student's t-test was applied to compare the mean values of resting membrane potentials and action potentials across samples. A p-value of less than 0.05 was considered statistically significant.

Result

The table 1 makes a comparison on the properties of electrophysiology of male and female frogs. There was a slight difference in the mean resting membrane potential (RMP) between males (-70.7 ± 1.6 mV) and females (-70.3 ± 1.4 mV) although there was no significant difference between males and females ($p = 0.32$). Likewise, the mean amplitude of action potential (AP) was slightly bigger in male (95.0 ± 2.1 mV) than in female (94.0 ± 1.9 mV) although this difference was also not statistically significant ($p = 0.25$). The duration of the mean action potentials did not differ between the sexes (2.1 ± 0.1 ms in each case) and no significant difference was observed ($p = 0.87$). On the whole, these findings suggest that the electrophysiological parameters of the frogs do not have any significant sex-related differences.

Table 1: Comparison between male and female frogs

Parameter	Male (n=30)	Female (n=30)	p-value
Mean RMP (mV)	-70.7 ± 1.6	-70.3 ± 1.4	0.32
Mean AP Amplitude	95.0 ± 2.1	94.0 ± 1.9	0.25
Mean AP Duration (ms)	2.1 ± 0.1	2.1 ± 0.1	0.87

Table 2 presents a summary of the membrane potential (mR) and action potential (AP) parameters of 60 Rana pipiens. The average resting membrane potential was -70.5 +1.5 mV, and the variability was between -73 mV and -68 mV, which shows that the electrical activity in all samples was constant at the baseline. Action potentials had a mean of 94.520 mV a minimum of 90 mV a maximum of 98 mV, and most fibers had a normal waveform. The action potential had an average duration of 2.1 ± 0.1 ms (the range of 2 to 2.3 ms), which indicated the same patterns of depolarization and repolarization among the recordings. In general, the findings indicate consistent and constant electrophysiological characteristics of the observed muscle fibers.

Table 2: Summary of resting membrane potential (RMP) and action potential (AP) in 60 rana pipiens

Parameter	Mean ± SD	Minimum	Maximum	Observations
Resting Membrane Potential (mV)	-70.5 ± 1.5	-73	-68	Stable recordings in all samples
Action Potential Amplitude (mV)	94.5 ± 2.0	90	98	Normal waveform in majority of fibers
Action Potential Duration (ms)	2.1 ± 0.1	2	2.3	Consistent depolarization and repolarization

Table 3 shows the frequency of resting membrane potential (RMP) and action potential (AP) features of 60 samples. In the case of RMP the highest sample of 50% was found to have -71 to -70 m V range, then 36.7% had -69 to -68 m V range and the lowest 13.3% had -73 to -72 m V. Concerning AP amplitude, a half of samples (50 percent) had an amplitude of between 93 and 95 mV, 25 percent of them were covered in the lower range of 90 to 92 mV and the upper range of 96 to 98 mV. With regards to the AP duration, majority of samples (66.7) had periods between 2.0 and 2.1 ms, and the rest (33.3) had marginally larger periods between 2.2 and 2.3 ms. In sum, the data show that the majority of cells reported RMP between -70 -71m V, AP amplitude between 93-95m V and a rather short AP duration of 2.0-2.1 ms.

Table 3: Frequency distribution of RMP and AP in 60 samples

Parameter	Range	Number of Samples (n)	Percentage (%)
RMP (mV)	-73 to -72	8	13.3
	-71 to -70	30	50
	-69 to -68	22	36.7
AP Amplitude (mV)	90–92	15	25
	93–95	30	50
	96–98	15	25
AP Duration (ms)	2.0–2.1	40	66.7
	2.2–2.3	20	33.3

Discussion

In the current study, the electrophysiological characteristics of muscle fibers in Rana pipiens were examined about the resting membrane potential (RMP), the amplitude of the action potential (AP), and the duration of an AP. Our data indicated that males reported mean RMP of -70.7 1.6 mV which was slightly lower than females (-70.3 1.4 mV) although it was not significantly different ($p = 0.32$). What this means is that sex does not play an important role in the establishment of the membrane potential in such frogs. Kuffler and Nicholls (1976) [8] reported the amphibian skeletal muscle fibers exhibited constant RMPs irrespective of sex, there was stable baseline excitability between genders.

As to action potential amplitude male participants had a slightly higher mean AP amplitude (95.0 ± 2.1 mV) than did female participants (94.0 ± 1.9 mV) but with no significant difference ($p = 0.25$). The absence of the noticeable disparity means that the voltage variation throughout the depolarization is not much reliant on sex in Rana pipiens implying that there is no variation in the excitability of muscle fibers among genders. Levine (1996) [9] determined where sex-related variations in the AP amplitude were not significant in other frog species.

There was no significant difference in action potential duration between males and females (2.1 ± 0.1 ms in both males and females), nor was there any significant difference ($p = 0.87$). It can be concluded that depolarization and repolarization mechanisms are similar between male and female frogs that exhibit similar temporal properties of APs. According to Stefani and Steinbach (1969) [10], the AP duration in the frog skeletal muscle is strongly controlled by ionic conductance [s], and sex differences do not seem to influence these kinetics.

The overall sample of 60 Rana pipiens was analyzed, and the mean RMP was found to be -70.5 +1.5 mV, AP amplitude 94.5 +2.0 mV and AP duration 2.1 +0.1 ms without glaring and varying electrophysiological characteristics. Such uniformity justifies the use of these parameters as general muscle excitability indicators. Brum and Rios (1987) [11] found stable membrane properties were observed to be constant in the number of subjects and hence the narrowness of the ranges of the values suggests that there is not much variation between individuals.

The frequency distribution data indicated that the RMPs were -71 -70 mV, the AP amplitudes were 93 95 mV, and the AP durations were 2.0 -2.1 ms. These distributions show that the electrophysiological properties of most of the fibers are tightly clustered. Hodgkin and Katz (1949) [12] suggested similar patterns in that muscle frog fibres had a narrow range of resting membrane potential and action potential properties, suggesting that there was intrinsic homogeneity in electrical signalling within the fibres.

The findings suggest that sex does not play an important role in alleviating RMP, AP amplitude, or AP duration in Rana pipiens, and that there is a high level of consistency in electrophysiological characteristics of the individuals. These results support the earlier literature on the physiology of amphibian muscle, showing the strength of electrical excitability in skeletal muscle cells. The other factors that might be considered in future studies would be age, temperature, or hormonal status to understand further cause of variation in electrophysiological properties.

Conclusion

In summary, the obtained data and the results of the analysis, it is possible to conclude that skeletal muscle fibers of Rana pipiens have unchanged and homogenous electrophysiological characteristics, where the mean resting membrane potential is -70.5 +1.5 mV, the amplitude of action potential is 94.5 +2.0 mV, and the duration of the action potential is 2.1 +0.1 ms. The male and female frogs were compared, and it was found that there were no statistically significant differences in these parameters, which showed that sex does not affect the baseline excitability or action potential parameters in this species. The frequency distribution also indicated that many fibers are concentrated within a limited range, and this represents inherent coherence in electrical signaling. By and large, these results verify the validity of RMP and AP measurements as measures of muscle fiber excitability and are consistent with prior studies in amphibian physiology.

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