EFFECT OF THE DISCHARGE OF A HIGH-VOLTAGE CAPACITOR ON THE VOLT-AMPERE CHARACTERISTICS OF A CELL MEMBRANE MODEL

I. P. Arleevskii and V. K. Bezuglov

UDC 615.846.7.015

Investigations on models of the cell membrane have shown that a high-voltage discharge sharply alters the volt-ampere characteristic curve of the frog skin, increasing the angle of the curve and displacing it toward negative values of potential. The action of the discharge is determined by the ionic composition of the surrounding medium. Adrenalin, dinitrophenol, strophanthin, and acetylcholine modify the volt-ampere characteristic curve of the skin and also affect the magnitude of the changes in its parameters during the action of the discharge. The authors attribute the effect described to the influence of the high-voltage discharge on permeability of cell membranes.

Investigations on models of the cell membrane, using the frog skin for this purpose, have shown that the electric pulse induces stepwise changes in resting potential, the concentration of sodium and potassium solutions on either side of the skin having a marked influence on this process. The suggestion has been made that the effect observed is based on a momentary increase in permeability of the cell membranes, with rapid translocation of ions leading to changes in the electrical parameters of the skin [1].

To confirm this hypothesis a series of experiments was carried out to study the effect of a defibrillator discharge on the volt-ampere characteristic curve (VACC) of the frog's skin. Investigations have shown that the VACC can be used as an indicator of the intensity and direction of ionic fluxes determined by the degree of permeability of cell membranes [2, 3].

EXPERIMENTAL METHOD

The VACC was plotted from results obtained by an apparatus whose block-diagram is given in Fig. 1. As a prelude to the study of the action of various compounds, the skin was kept for 15 min before the experiment in a solution of the corresponding substances (using Ringer's solution as the solvent), after which it was rinsed with distilled water. During application of the discharge the electrolytic terminals were removed, while after the discharge they were immersed in the corresponding compartments of the cell. The experiments were carried out at 18-20°C.

EXPERIMENTAL RESULTS AND DISCUSSION

The electric pulse led to changes in VACC whose magnitude depended on the intensity of the discharge and the character of the ionic medium (Figs. 2 and 3). These changes consisted of an increase in the gradient of the straight lines, accompanied by their displacement toward negative potential values.

No. 1 Department of Internal Medicine, V. I. Lenin Kazan' Postgraduate Medical Institute. Laboratory of Biophysics, V. I. Lenin Kazan' University. (Presented by Academician of the Academy of Medical Sciences of the USSR A. A. Vishnevskii.) Translated from Byulleten' Éksperimental'noi Biologii i Meditsiny, Vol. 74, No. 12, pp. 9-12, December, 1972. Original article submitted September 21, 1971.

TABLE 1. Changes in Volt-Ampere Characteristics under the Influence of High-Voltage Discharges of Different Intensity

Intensity of discharge (in kV)	Parameters of equations									
	K_{16}*		Na_{16}		K_{350}		Na_{350}		Ringer's solution	
	a	*b*	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*
0 (control)	0,19	1,9	0,35	—1,3	1,08	4,1	1,21	—22,2	1,07	6,2
0,5	0,58	9,9	0,45	2,3	2,38	—13,0	4,03	—41,3	8,0	28,8
1,0	0,79	6,6	0,64	0,2	4,05	—31,1	4,50	—27,0	11,7	23,5
2,0	0,85	8,6	0,80	4,4	4,45	—60,0	12,25	—104,0	14,0	96,4
3,0	1,00	4,3	0,81	8,5	10,0	—145,0	13,50	—81,0	15,3	98,2
4,0	1,10	8,8	0,91	6,9	9,25	—92,5	13,40	—19,2	—27,7	—590

*Here and later concentrations (K and Na) are given in mg%.

TABLE 2. Volt-Ampere Characteristics in Relation to Ion Concentration

Concentration of ions (in mg%)	Parameters of equations			
	K		Na	
	a	*b*	*a*	*b*
1	0,19	4,2	0,24	3,6
4	0,24	6,7	0,19	3,1
8	0,20	4,6	0,20	3,2
16	0,25	3,6	0,21	1,8
64	0,51	—9,0	0,40	—2,2
350	2,08	—36,2	4,14	—11,8

TABLE 3. Changes in Volt-Ampere Characteristics with Time under Constant Conditions

Time (in min)	Parameters of equations					
	before discharge				after discharge	
	K_{16}		Na_{16}		Na_{16}	
	a	*b*	*a*	*b*	*a*	*b*
0	0,15	3,5	0,28	4,8	0,97	10,6
5	0,14	2,7	0,26	4,0	0,97	5,2
10	0,13	2,0	0,24	3,2	0,97	3,8
15	0,13	1,5	0,23	2,0	0,97	2,8
20	0,13	1,1	0,21	1,5	0,97	2,5

TABLE 4. Changes in Volt-Ampere Characteristics under the Combined Influence of a Discharge and of Various Substances

Experimental conditions	Parameters of equations			
	before discharge		after discharge	
	a	*b*	*a*	*b*
Control	1,29	—32,5	6,14	—52,8
Adrenalin	6,96	—52,0	7,06	42,0
Acetylcholine	4,82	—24,0	7,60	63,0
Strophanthin	1,43	—17,2	4,40	—30,0
Dinitrophenol	9,65	—63,8	11,80	—38,2

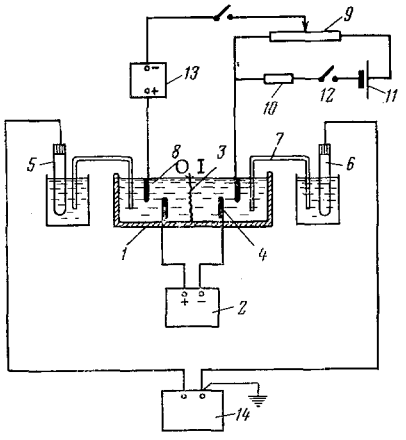

Fig. 1. Scheme of apparatus for determining volt-ampere characteristic curve of frog's skin: 1) cell; 2) defibrillator; 3) skin; O) outer surface of skin; I) inner surface of skin; 4) nickel electrode; 5) measuring electrode; 6) auxiliary electrode; 7) electrolytic terminal; 8) nickel electrode; 9) variable resistor; 10) fixed resistor; 11) dry cell; 12) key; 13) microammeter; 14) LPU-01.

As the graphs show, the VACC of frog's skin consists as a rule of a series of straight lines inclined at a certain angle to the abscissa and intercepting part of the ordinate. For analysis they can be described by the equation for a straight line $y = ax + b$, where y is the current, x the potential on the membrane, b the intercept on the ordinate (the current at zero potential), and a the tangent of the angle of inclination of the straight line to the abscissa. This equation is more convenient for analysis and illustration.

The changes in VACC under the influence of discharges of different intensity are shown in this form in Table 1.

In Table 1 the strictly regular increase in the tangent of the angle of inclination with an increase in intensity of the discharge will be noted. This suggests that differences in the gradient of the VAAC depending on intensity are connected with the degree of change in permeability of the membranes and, correspondingly, with the quantitative difference in the shifts of ionic gradients. This view is confirmed to some extent by the results of investigations in which the effect of various concentrations of ions on the VAAC was studied (Table 2).

Analysis of these results shows that the parameters of the equations are definitely dependent upon the concentration within the range of concentrations from 16 to 350 mg%. The changes in VAAC within the range of electrolyte concentrations from 1 to 16 mg% were not significant.

To evaluate and disprove the effect of processes taking place in the skin during the experiment, changes in the VAAC with time, while the conditions were kept constant, were determined (Table 3).

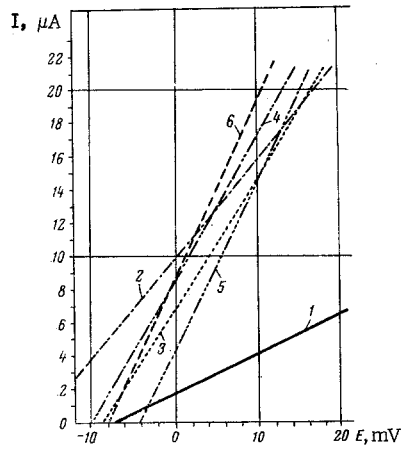

Fig. 2

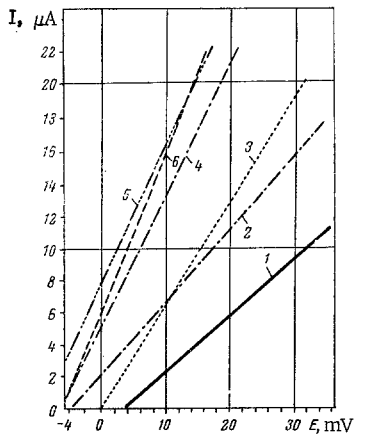

Fig. 3

Fig. 2. Changes in VACC of frog skin under the influence of a high-voltage discharge of increasing intensity ($KCl : H_2O$; K 16 mg%). 1) Control; 2) 0.5 kV, 3) 1 kV, 4) 2 kV, 5) 3 kV, 6) 4 kV.

Fig. 3. Change in VACC of frog skin under the influence of a high-voltage discharge of increasing intensity ($NaCl : H_2O$; Na 16 mg%). 1) Control, 2) 0.5 kV, 3) 1 kV, 4) 2 kV, 5) 3 kV, 6) 4 kV.

These changes were found to be not significant, and their direction was opposite to that of the action of the discharge and of increasing concentrations of electrolytes.

Changes occurred in the VAAC also when Ringer's solution was present on both sides of the skin. Under these conditions it could be used to study the action of the electric pulse in conjunction with the effect of various substances (Table 4).

The results indicate that these substances, by changing the VAAC, have some influence on the permeability of the skin for the ions tested. The action of the electric pulse was to increase the parameter a, and the degree by which this was done was determined by the properties of the compound. The increase in this parameter was most marked for the control (Ringer–Ringer). Under experimental conditions the changes were less marked, especially during the action of adrenalin. It can therefore be concluded that the compounds studied have a "protective" effect.

LITERATURE CITED

1. I. P. Arleevskii and V. K. Bezuglov, in: Atherosclerosis and Essential Hypertension [in Russian], Kazan' (1970), p. 13.
2. E. P. Buzhinskii, V. A. Gotlib, and A. A. Lev, in: Mitochondria [in Russian], Moscow (1968), p. 141.
3. G. N. Mozhaeva, Biofizika, No. 1, 68 (1969).