ELECTROPHYSIOLOGICAL CHARACTERISTICS OF THE EXTERNAL OCULAR MUSCLES OF THE FROG

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Evidence of differences in the fibers of the inferior rectus muscle of the frog as regards the type of its electrical activity was obtained by a microelectrophysiological method. A constant tonic activity, consisting of polymorphic postsynaptic potentials, was observed in most fibers. Individual fibers responded by a series of action potentials to the depolarization produced by insertion of the microelectrode; this response is characteristic of transitional skeletal fibers. The remaining fibers were inactive and some of them, with a high membrane potential, can be classed among the phasic system.

KEY WORDS: ocular muscles; skeletal fibers.

Investigations of the electrophysiological characteristics of the oculomotor apparatus (OMA) of mammals have shown [4, 8] the presence of tonic fibers analogous to those described [3] in the skeletal muscles of amphibians. Fibers of the amphibian ocular muscles can be presumed to be similar to their skeletal muscle fibers and they can be regarded as phylogenetic precursors of the tonic fibers of the mammalian OMA. There are extremely few electrophysiological data on the external ocular muscles of the frog [2], and it is impossible from them to make a reliable functional assessment of their fiber composition, although there is morphological evidence [1, 9] of specialization of the muscle fibers of the frog OMA.

The electrical activity of fibers of the frog inferior rectus muscle is described in this paper.

EXPERIMENTAL METHOD

Frogs of the species Rana temporaria were used. To immobilize the animals the spinal cord was destroyed and in some experiments superficial urethane anesthesia was used (1-2 ml of 10% urethane solution injected intraperitoneally). Access to the inferior rectus muscle of the eye was obtained through the oral cavity. The electrical activity of the muscle fibers was recorded intracellularly by means of glass microelectrodes filled with 3 M KCl solution. The resistance of the electrodes was 5-15 mΩ. To amplify the recorded activity the UBP1-02 amplifier was used and the potentials were recorded on the N-102 loop oscillograph.

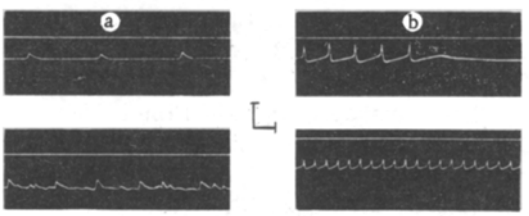

Fig. 1. Activity of tonic (a) and intermediate (b) types of fibers of frog inferior rectus muscle. Top line shows level of zero potential. Calibration: amplitude 50 mV, time 35 msec.

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TABLE 1. Parameters of PSPs and MPs of Frog Inferior Rectus Muscle Fibers

Fibers	Statistical index	MP (in mV)	Amplitude of PSPs (in mV)	Duration of ascending phase of PSPs (msec)	Half-decay period of PSPs (msec)	Frequency (Hz)
Tonic	Range of variation	—	1—20	1—14	1—35	—
	Mode	—	2—10	2—5	3—16	—
	Mean	54,16±1,52	7,36	4,00	7,91	—
Intermediate	Range of variation	—	—	—	—	15—50
	Mean	53,8±1,67	—	—	—	36,36±3,76
Silent	Range of variation	20—99	—	—	—	—
	Mode	70—85	—	—	—	—
	Mean	65,00±3,12	—	—	—	—

EXPERIMENTAL RESULTS AND DISCUSSION

Among the 165 fibers of the inferior rectus muscle of the frog investigated 110 fibers possessed natural tonic activity. Thirteen fibers responded to insertion of the microelectrode by the appearance of regular action potentials (APs). In 42 fibers no visible fluctuations of membrane potential (MP) were observed.

Tonic Activity. Electrical activity recorded from fibers with activity of tonic type consisted of an assortment of polymorphic postsynaptic potentials (PSPs; Fig. 1a). These PSPs succeeded each other at high frequency and were superposed to such a degree that it was impossible to determine the frequency of the individual types of PSPs. The mean MP of these fibers was 54 mV. The temporal and amplitude characteristics of the PSPs varied widely. The amplitude of the PSPs was mainly 2-10 mV, but in some cases it reached 20 mV (Fig. 2b). The range of variation of the duration of the ascending phase of the PSPs was 1-14 msec, the more usual values being 1-5 msec (Fig. 2a). Most values of the half-decay time of the PSPs lay within the range 2-16 msec (Table 1). The amplitude of some PSPs fell to half their value over a longer period, up to 46 msec (Fig. 2c). The distributions of the parameters of the PSPs (Fig. 2a, b, c) were skew and monomodal.

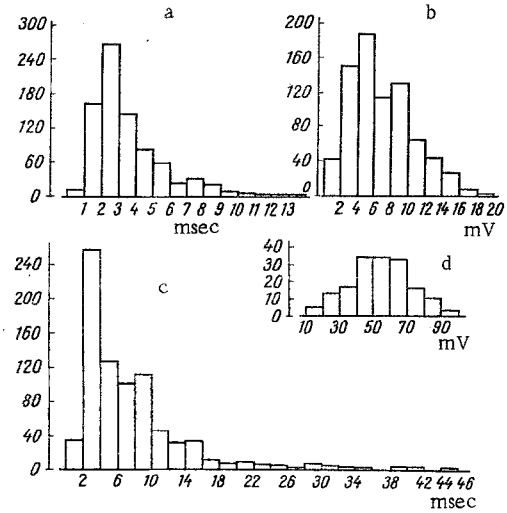

Fig. 2. Histograms of parameters of PSPs and MPs of fibers of frog inferior rectus muscle: a) duration of ascending phase of PSPs; b) amplitude of PSPs; c) half-decay periods of PSPs; d) MPs of fibers of inferior rectus muscle. Abscissa: in a, c) temporal parameters (in msec), in b, d) amplitude parameters (in mV); ordinates: number of observations.

Action Potentials. In 13 fibers insertion of the microelectrode evoked a brief response consisting of APs without overshoots (Fig. 1b). Not more than 2.5 sec after the beginning of recording the fibers ceased to generate APs. A distinguishing feature of this activity was that each AP arose against a background of slowly increasing depolarization (prepotential). The APs had a phase of after-hyperpolarization. The mean value of MP of the fibers was 54 mV. The frequency of the APs was 15-50 Hz (Table 1).

Silent Fibers. In 42 fibers electrical activity was absent. The MP of these silent fibers varied from 20 to 99 mV, with a mean value of 65.0 ± 3.1 mV. The limits of the modal class were 70-85 mV (Table 1).

Fibers of the frog OMA which had natural electrical activity can be classed with the tonic type. The form of activity was similar to that described [10] for tonic fibers of frog skeletal muscles, although the temporal characteristics of PSPs of the frog external ocular muscle fibers were shorter (especially the half-decay period of the PSPs), so that they resembled more closely the fibers of the tonic system of the mammalian OMA. However, no clear regular sequence of the PSPs could be found in the tonic fibers of frog OMA, nor were there any of the "spike-like" PSPs characteristic of the electrical picture of the tonic fibers of the rabbit OMA [5, 6].

The activity consisting of low-amplitude APs with prepotentials observed in 13 fibers evidently arose in fibers of intermediate type. The intermediate fibers of frog skeletal muscles are known to have low accomodative power and pacemaker activity [1], which often arises in response to depolarization created by insertion of the microelectrode into the fiber (traumatic action).

The silent fibers had correspondingly greater powers of accomodation. Considering that in half (46%) of these fibers the MP exceeded 70 mV, it can be assumed that most of these fibers belonged to the phasic type.

The range of variation of the MPs of all the fibers tested was considerable (17-99 mV). The width of the scatter of the MP values in the frog inferior rectus muscle was mentioned by Zhdanov [1]; the distribution of MPs obtained by him was bimodal (with maxima at 58 and 73 mV). According to the present experiments, MPs of between 40 and 70 mV were found with about equal frequency (Fig. 2d). In the fiber population studied, to judge from the electrophysiological picture, tonic fibers predominated (67%); this may account for the shift in the lower limit of the MP distribution into the region of low values. In addition, injury to the fibers of the frog OMA by the microelectrode is a probability, for they are much thinner than skeletal muscle fibers [2].

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