CONTRACTILE PROPERTIES OF THE HUMAN TIBIALIS ANTERIOR MUSCLE AT DIFFERENT STAGES OF DENERVATION AND REINNERVATION

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Electromyographic investigations in recent years have led to significant progress in the study of nerve–muscle relations in peripheral motor neuron lesions in man [15]. Electromyograms of stages of denervation and reinnervation have been distinguished [2] and the phenomenon of active reconstruction of the architectonics of the motor units (MU) in lesions of nerves and neurons has been described [3]. Meanwhile, the contractile properties of muscles associated with a peripheral motor neuron lesion in man have been inadequately studied, and there have been only isolated investigations undertaken [11-13] without taking into consideration the different variants of the stages of restructuring of MU in these lesions. This state of affairs may perhaps explain some of the conflicting results of the investigations cited. Reorganization of the architectonics of MU in the course of denervation and reinnervation assumes staggered changes in the many-sided nervous regulation of the contractile properties of the muscle in the course of this process. Experimental investigations have provided some basis for this hypothesis [14].

In the investigation described below contractile properties of human muscles were studied at different stages, identified electromyographically, of denervation and reinnervation following a nerve lesion.

EXPERIMENTAL METHOD

Altogether 27 patients with unilateral radiculopathy of L5 of vertebrogenic origin, alone or together with a lesion of roots L4 and S1 were investigated. The duration of the most recent exacerbation ranged from 1 to 11 months. The contractile properties of the tibialis anterior muscle (TAM), whose innervation in man is mainly derived from root L5, were studied. Electromyography was carried out with the aid of standard concentric needle electrodes. The results were analyzed as in [2] and the corresponding stages were distinguished. To record isometric contraction of TAM in response to single supramaximal stimulation in the region of its motor point and to tetanic stimulation through the lateral popliteal nerve, the apparatus, conditions [10], and technique [4] described previously were used. The following parameters of the isometric evoked contraction were determined: P_t) the force of a single contraction (SC, in kg); PTP) post-tetanic potentiation of the force of SC in percent of its initial value (determined immediately after indirect supramaximal stimulation for 5 sec with a frequency of 40 Hz); CT) the time from the beginning of SC to the point when maximal force was reached (in msec); $^1/_2$ RT) the half-relaxation time (in msec); T_1) the time from the beginning to reaching half the maximal force of SC (in msec); T_2) the time from reaching half the force until the maximum force of SC (in msec); V_1) the average rate of development of half the force of SC ($^1/_2 P_t/T_1$, in kg/msec); V_2) the average rate of reaching the maximal force of SC (P_t/CT, in kg/msec); V_3) the average rate of half-decay of the force of SC ($^1/_2P_t/^1/_2$RT, in kg/msec). We introduced the last five parameters on the basis of data reflecting the informativeness of a fractional analysis of the phases of rise and fall of the isometric contraction curve [6]. As the control, TAM of the opposite, "sound" limb was studied. Statistical analysis of the data was carried out by the method of comparison of sets with tied pairs [1]. On

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TABLE 1. Contractile Properties and Characteristics of Human TAM at Different Stages of Denervation and Reinnervation, Considered as a Single Process

Group of patients	Age, years	Side	Statistical parameter	P_t	PTP	CT	½ RT	T_1	T_2	V_1	V_2	V_3	Average duration of MUP, msec	Average amplitude of MUP, μV
1-	50,7±3,5	C	*M*	2,15	182	88,0	98,0	29,0	59,0	0,037	0,025	0,011	14,25	
			±*m*	0,44	13	4,12	5,18	2,45	3,63	0,007	0,005	0,002	0,19	
		P	*M*	2,46*	176	84,0	93,0	32,0	52,0**	0,040	0,030*	0,013*	10,42***	604
			±*m*	0,50	16	3,46	8,81	1,62	2,67	0,009	0,006	0,003	0,27	59
2-	38,0±3,4	C	*M*	2,70	159	76,0	78,0	29,0	48,0	0,057	0,042	0,018	13,52	
			±*m*	0,71	6	3,37	3,60	2,05	2,29	0,019	0,015	0,005	0,18	
		P	*M*	2,29	174	74,0	83,0	27,0	47,0	0,049	0,032	0,015	13,90	585
			±*m*	0,60	12	2,18	5,53	1,45	1,56	0,016	0,009	0,004	0,28	34
3-	54,3±2,2	C	*M*	3,92	137	75,0	79,0	25,0	50,0	0,085	0,063	0,027	14,23	
			±*m*	1,29	10	6,71	5,23	1,29	6,19	0,031	0,025	0,009	0,22	7
		P	*M*	1,89*	127	76,0	87,0	28,0	48,0	0,035**	0,025*	0,011*	20,25***	104***
			±*m*	0,87	8	11,21	12,82	4,23	7,03	0,016	0,011	0,005	0,52	95

Legend. P) Characteristics of TAM on "pathological" side; C) control data; *p < 0.05; **p < 0.01; ***p < 0.001. Mean amplitude of MUP in groups 2 and 3 was compared with that in group 1. Significance of differences of remaining parameters was estimated relative to C.

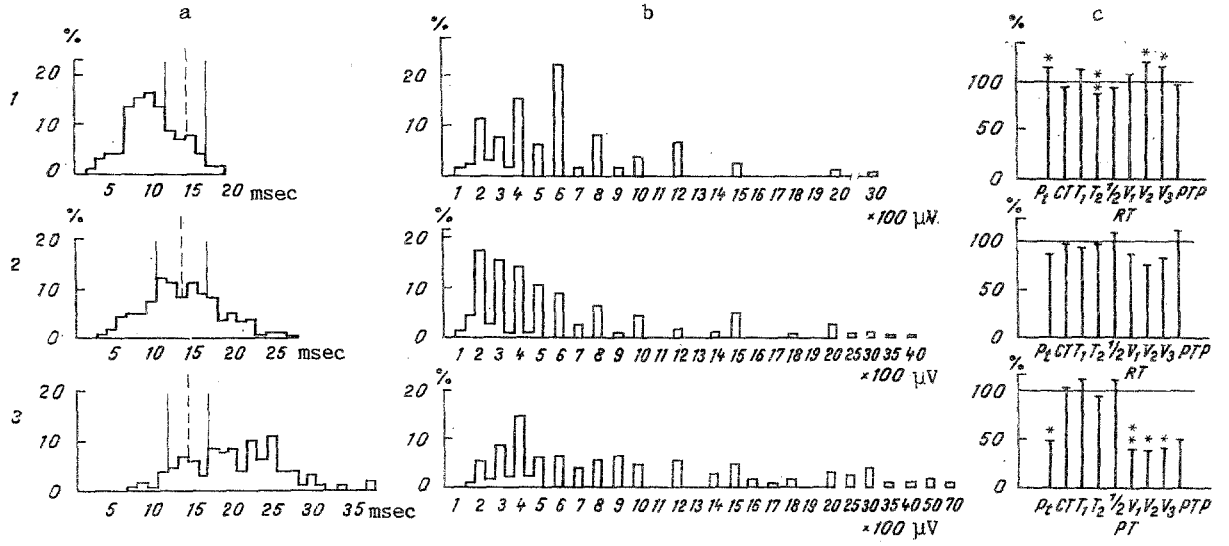

Fig. 1. Histograms of distribution of MUP by duration and amplitude and relative percentages of changes in contractile characteristics in patients of groups 1-3. a) Histograms of distribution of MUP by duration. Abscissa, duration of MUP (in msec); ordinate, number of MUP of a given duration (in % of total number of MUP tested). Vertical lines indicate boundaries of distribution of duration in normal subjects; broken lines indicate average duration under normal conditions; b) histograms of distribution of MUP by amplitude (in μV); c) changes in contractile characteristics (in % relative to control). Number of MUP studied was 168 in patients of group 1 (at least 20 in each muscle), 275 in group 2, and 127 in group 3.

the basis of the electromyographic data the patients were divided into the following groups, depending on the stage of the denervation–reinnervation process [2]: 1) with stages I and II in TAM (n = 8), 2) with stages IIIA and IIIB (n = 13), and 3) those with stages IV and V (n = 6).

EXPERIMENTAL RESULTS

In patients of group 1, with reduction of the average duration of the MU potentials (MUP) and a shift of the histogram of distribution of MUP by duration to the left, i.e., with EMG features indicating a decrease in the territory of MU during reconstruction of their architectonics [3], an increase in the force and of the velocity characteristics of SC was found (Table 1, Fig. 1). In the early stages, after experimental denervation of the muscle, some

investigators observed an increase in the force and velocity of isometric contraction, but under those circumstances an increase in the duration of SC also was found [5]. Shortening of the temporal characteristics of contraction, however, was observed by some investigators in a slow muscle [7]. In the patients of group 3, whose average duration and amplitude of MUP were increased, with a shift of the histogram of distribution of MUP by duration and amplitude to the right, i.e., with signs of enlargement of the territories of MU and of an increase in the number of muscle fibers in them, a decrease in the force and velocity characteristics of SC was found. "Slowing" of MU, enlarged due to sprouting after partial denervation, was established previously experimentally [8]. This phenomenon may probably lie at the basis of the observed reduction of the velocity characteristics of SC in the patients of this group, whereas reduction of the strength of SC may be explained by the marked decrease in the number of MU in the muscle. In the patients of group 2, who occupied an intermediate position between groups 1 and 3 and were characterized by flattening of the histograms (indicating the simultaneous presence of MU with reduced and enlarged territories compared with normal), no significant changes in contractile properties were observed. This can be explained by the effect of cancelling out at the level of the whole muscle, for at these stages there are fibers in TAM with opposite tendencies of changes in their contractile properties.

It can be concluded from the results of this investigation that the character of the changes in the contractile properties of the whole muscle depends on the stage of the denervation–reinnervation process. In the initial stages an increase in the force and velocity characteristics of SC was found, but a decrease in the final stages was found. The mechanisms lying at the basis of changes in the contractile properties at different stages of denervation and reinnervation of a muscle are probably different [5, 8, 9, 14]. The results can be used for the formulation of diagnostic criteria and for evaluating the effectiveness of treatment in diseases of muscles of neurogenic origin.

LITERATURE CITED

1. I. P. Ashmarin, N. N. Vasil'ev, and V. A. Ambrosov, Rapid Methods of Statistical Analysis and Planning of Experiments [in Russian], Leningrad (1975).
2. B. M. Gekht, L. F. Kasatkina, and A. V. Kevish, Zh. Nevropatol. Psikhiat., No. 6, 822 (1980).
3. B. M. Gekht, L. F. Kasatkina, and S. S. Nikitin, Byull. Éksp. Biol. Med., No. 4, 16 (1983).
4. Kh. S. Khamitov, É. I. Bogdanov, and E. M. Kats, Fiziol. Zh. SSSR, No. 8, 1113 (1983).
5. H. J. Finol, D. M. Lewis, and R. Owens, J. Physiol. (London), 319, 81 (1981).
6. M. J. Gillespie, T. Gordon, and P. R. Murphy, J. Physiol. (London), 372, 485 (1986).
7. E. Gutmann, J. Milichna, and I. Syrovy, Exp. Neurol., 36, 488 (1972).
8. D. D. Hatcher, A. R. Luff, R. A. Westerman, and D. I. Finkelstein, Exp. Brain Res., 60, 590 (1985).
9. G. J. Herbison, M. M. Jaweed, and J. F. Ditunno, Arch. Phys. Med., 62, 35 (1981).
10. E. Marsh, D. Sale, A. J. McComas, and J. Quinlan, J. Appl. Physiol., 52, 1636 (1982).
11. A. J. McComas, R. E. P. Sica, M. J. Campbell, and A. R. M. Upton, J. Neurol. Neurosurg. Psychiat., 34, 453 (1971).
12. R. G. Miller, Ann. Neurol., 6, 51 (1979).
13. H. S. Milner-Brown, R. B. Stein, and R. G. Lee, J. Neurol. Neurosurg. Psychiat., 37, 670 (1974).
14. M. Narusawa, Tokai J. Exp. Clin. Med., 10, 499 (1985).
15. E. Stalberg, Peripheral Neuropathy, ed. by P. J. Dyck et al., 2nd ed., Philadelphia (1984), pp. 967-980.