Induced Auxotonic Muscle Contractions in Animals with Lateral Spinal Cord Hemisection under Various Cooling Regimens

V. I. Babinkov, Z. A. Cherkashina, V. G. Germanov, and N. K. Khitrov

Translated from *Byulleten' Eksperimental'noi Biologii i Meditsiny*, Vol. 128, No. 9, pp. 270-273, September, 1999
Original article submitted June 3, 1998

We studied the effects of long-term moderate hypothermia on induced auxotonic contractions of dog hindlimb extensor muscle after lateral hemisection of the spinal cord at the thoracolumbar region (T_{XII}-L_{I-II}) during the early and late postoperative periods (1-2 and 3-5 weeks, respectively). The mechanisms of antispastic effects of moderate hypothermia are different: the immediate effect was due to cold blockade of spinal neurons, while delayed effects resulted from activation of descending bilateral oversegmental motor apparatus.

Key Words: spinal cord; hemisection; hypothermia

Temperature regimens of moderate local hypothermia (MHT) of the spinal cord improving the state of animals and their limbs have been described elsewhere [9,10]. MLH reduced spastic paresis after spinal cord hemisection at the T_{XII}-L_{I-II} level. In animals without hemisection, single deep hypothermia (DHT) induced hindlimb paralysis and damage to spinal neurons.

Therapeutic effect of hypothermia (HT) is associated with its antiedemic and antihemorrhagic effects on the spinal cord and surrounding tissues [7,8]. Spinal effects on neuromuscular structures during HT received little attention.

Here we studied functional characteristics of extensor muscles of both hindlimbs in animals with spinal cord hemisection at various postoperative periods and under different regimens of spinal cord cooling.

MATERIALS AND METHODS

Experiments were performed on 23 male and female dogs. Induced auxotonic contractions of hindlimb extensor muscles were studied. All dogs were divided into 5 groups. Animals of groups 1 and 2 were subjected to moderate long-term intra- and postoperative hypothermia and then examined during the early (1-2 weeks) and late (3-5 weeks) postoperative periods, respectively; group 3 animals were not subjected to hypothermia; group 4 included narcotized dogs; and group 5 animals were exposed to single DHT.

During MHT modeling, the temperature in the surgical wound was decreased to 9-11°C for 2 h with 2-h intervals over 24 h postoperation. During DHT, the temperature in the surgical wound decreased to 6-8°C for 2 h postoperation. Lateral hemisection of the spinal cord was performed subarachnoidally (dorsal access) under thiopental-hexenal anesthesia. Before cooling, group 5 dogs were subjected to the same surgery without hemisection.

We determined functional parameters of hindlimb extensors (the lateral and medial heads of the gastrocnemius muscle and the anterior and lateral heads of the quadriceps muscle).

The muscles were examined using a stimulatory impedance myograph [1]. Experimental animals were narcotized with thiopental and hexenal, and muscles were locally stimulated with pulses (1 Hz) of increasing current via an implanted needle electrode. Induced auxotonic muscle contractions were recorded using a

I. M. Sechenov Moscow Medical Academy

0007-4888/99/0009-0892$22.00

heat paper electrocardiograph. The strength of stimulating pulses gradually increased to a maximum response (MR), and threshold current and the amplitude of MR were determined. The amplitude of induced contractions was calibrated in resistance units (Ω). In groups 1 and 2, the amplitude/duration ratio was calculated. Histograms were constructed from current thresholds and MR amplitude distributing these values in 3 intervals. Mean values of threshold current were estimated (mA). The results were analyzed by Student's t and χ^2 tests.

RESULTS

A significant increase in the excitability threshold and a decrease in the number of high-amplitude muscle contractions (Fig. 1, *e*) accompanied DHT-induced structural changes in the spinal cord tissue (group 5). A decrease in muscle excitability was noted in group 3 dogs subjected to hemisection without HT (Fig. 1, *c*). In all groups, muscle contractility was determined by excitability of muscle fibers and, therefore, changes in histograms of excitability thresholds and MR were similar.

By contrast, group 1 dogs were characterized by high muscle excitability and prevalence of low-amplitude induced contractions (Fig. 1, *a*). This peculiarity disappeared 3-5 weeks postoperation (group 2), and high muscle excitability was accompanied by prevalence of high-amplitude contractions (Fig. 1, *b*). The number of high-amplitude contractions in group 2 dogs 1.7-fold surpassed that in group 1.

A comparison of excitability thresholds and the ratio between the amplitude and duration of contractions for ipsi- and contralateral muscles revealed no quantitative differences between the left and right

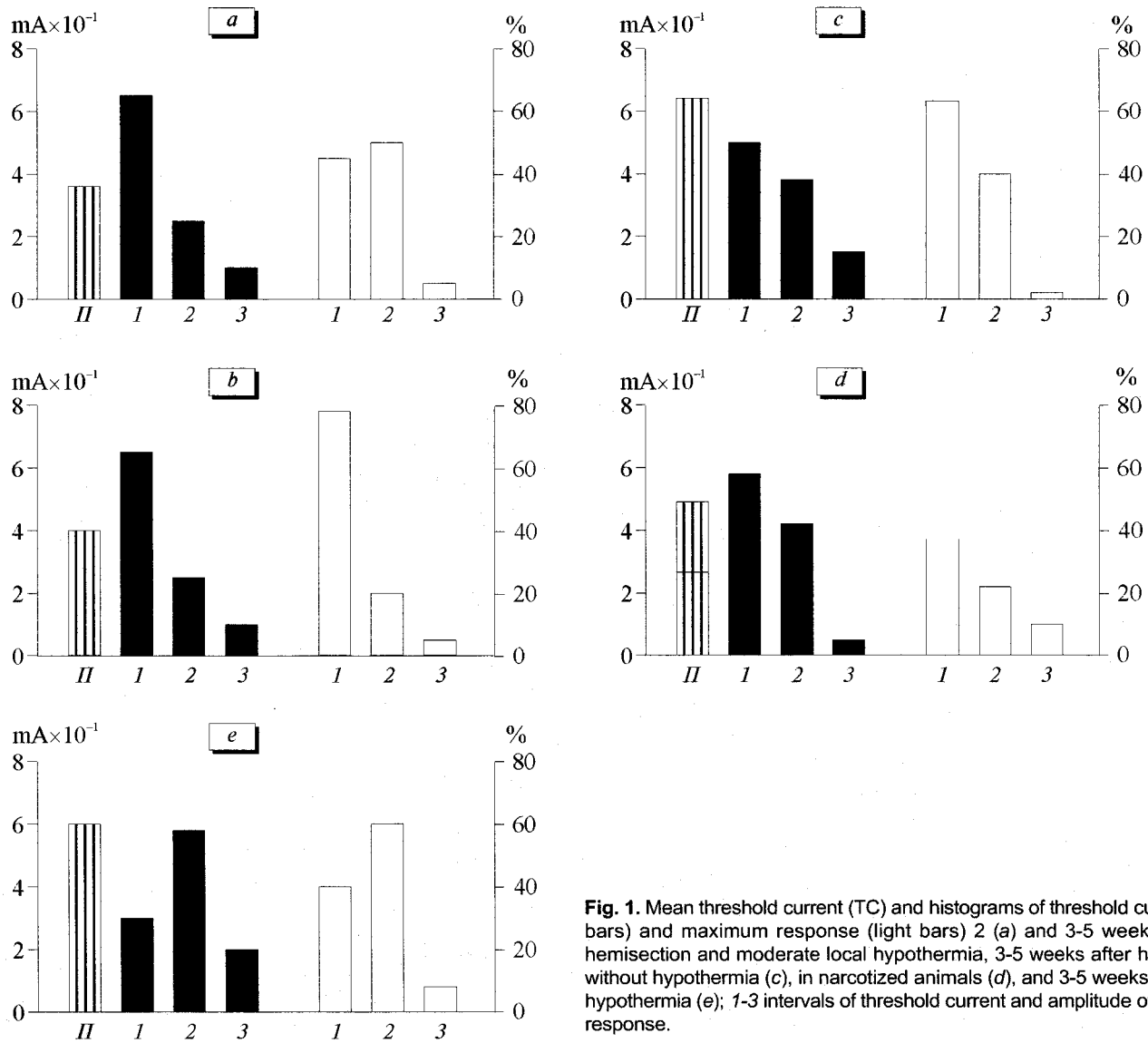

Fig. 1. Mean threshold current (TC) and histograms of threshold current (dark bars) and maximum response (light bars) 2 (*a*) and 3-5 weeks (*b*) after hemisection and moderate local hypothermia, 3-5 weeks after hemisection without hypothermia (*c*), in narcotized animals (*d*), and 3-5 weeks after deep hypothermia (*e*); *1-3* intervals of threshold current and amplitude of maximum response.

sides: the amplitude of contractions tended to increase.

The absence of differences disagrees with general concept of the Brown-Sequard syndrome caused by unilateral injuries to the spinal cord in humans [3]. These similar changes in both hindlimbs can not be caused by cold injury (as in group 5 dogs), because tissue damage in animals of groups 1 and 2 was minimum. Thus, the absence of differences can be related to bilateral tonic influences of supraspinal systems through intact descending pathways of the contralateral side.

Pyramidal and extrapyramidal conduction disorders are accompanied by activation of spinal reflexes not only at the side of spinal cord injury but also at the contralateral side [3]. Structural markers of enhanced neuronal activity are observed at the intact side. Patients with central hemipareses demonstrate enhanced cross-influences between the right and left segments [2]. The structures devoid of afferent impulses acquire properties of dominant centers, and their effects on functionally related structures are activated [4,6].

Thus, spinal cord lesions are characterized by spatial and temporal changes in the activity of motoneurons associated with their alteration and plastic rearrangements modulating the state of the corresponding muscles.

The mechanisms of HT-induced antispastic effects at the neuronal level are still not clearly understood. Decreased tonic activity of spinal motoneurons is probably related to reversible cold block of excitation conduction at the level of interneuron [5]. However, phase changes in peripheral neuromuscular structures induced by cold exposure, their mechanisms, and temporal parameters received little attention.

Our experiments revealed 2 stages of MHT-induced antispastic effects, which are characterized by prevalence of low- (stage 1) and high-amplitude (stage 2) auxotonic contractions.

Reduced excitation thresholds attest to high impulse activity of spinal motoneurons facilitating excitation of peripheral structures. This accounts for muscle spasms during alteration of supraspinal influences.

However during stage 1, some motoneurons or their axons are in the state of cold block. This attenuates spastic muscle hypertonia and, therefore, decreases the amplitude of MR: a dissociation between high excitability and low contractility is observed. Parameters of induced auxotonic contractions during stage 2 also confirm the absence of muscle spasms, because high-amplitude induced auxotonic contractions cannot be induced in spastically contracted muscles. Taking into account similar characteristics of ipsi- and contralateral muscles after cold block, we assume that the decrease in spastic muscular tone during stage 2 is associated with activation of compensatory mechanisms, because intact contralateral descending pathways of the spinal cord promote recovery of integrating bilateral supraspinal influences on muscles and interrelations between the phasic and tonic systems. The decrease in muscular tone reduces the amplitude of induced auxotonic contractions.

Thus, MHT activates compensatory processes and decreases edema and inflammation of the spinal cord and adjacent tissues.

DHT impairs muscle excitability and contractility due to irreversible damage to spinal motoneurons.

In animals subjected to hemisection without HT, these changes in functional characteristics of muscle were less pronounced but attested to impaired tonic activity of spinal motoneurons.

REFERENCES

1. V. I. Babinkov, N. V. Yakovenko, N. I. Losev, *et al.*, *Pat. Fiziol.*, No. 6, 28-31 (1988).
2. L. O. Badalyan and I. A. Skvortsov, *Clinical Electroneuromyography* [in Russian], Moscow (1986).
3. P. Duus, *Topic Diagnosis in Neurology* [in Russian], Moscow (1995).
4. G. N. Kryzhanovskii, *Determinant Structures in Pathology of the Nervous System* [in Russian], Moscow (1980).
5. A. V. Livshits, *Spinal Cord Surgery* [in Russian], Moscow (1990).
6. V. P. Podachin, G. G. Musalov, and I. I. Nezlina, *Structural and Functional Bases of Functional Compensation after Spinal Cord Injury* [in Russian], Moscow (1983).
7. V. T. Pustovoitenko, *Clinical Liquorology of Spinal Cord Injury* [in Russian], Minsk (1992).
8. A. P. Romadanov, V. S. Mikhailovskii, and R. L. Andreiko, *Vopr. Neirokhir.*, No. 2, 9-13 (1979).
9. Z. A. Cherkashina, *Effects of Local Hypothermia on Spinal Cord during Complicated Backbone Injury (Experimental and Clinical Examinations)*, Abstract of Doct. Med. Sci. Dissertation, Moscow (1991).
10. G. S. Yumashev and Z. A. Cherkashina, *Current Approaches in Diagnostics and Therapy of Spinal Injuries* [in Russian], Moscow (1993), p. 15.