MOTOR REHABILITATION OF PATIENTS WITH CONSEQUENCES OF SPINAL CORD INJURY USING NONINVASIVE ELECTRICAL STIMULATION OF THE SPINAL CORD COMBINED WITH MECHANOTHERAPY

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The paper presents a clinical case of a patient with the consequences of spinal cord injury treated with the use of noninvasive electrical stimulation of the spinal cord in combination with mechanotherapy.
Key Words: noninvasive electrical stimulation of the spinal cord, spine and spinal cord injury, rehabilitation, mechanotherapy, stimulation of foot support zones.

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Rehabilitation of a patient with spinal cord injury is one of the urgent problems of modern medicine. The importance and significance of this treatment is dictated by the high rate of spinal cord injuries accompanied by complex pathogenesis of traumatic disease of the spinal cord and the insufficient effectiveness of various rehabilitation procedures [1, 2, 4, 5]. Electrical stimulation of the spinal cord aimed at generating imitation of normal walking movements in the lower limbs is one of the methods that allows one to achieve good outcomes in recovery of the motor function in patients with spinal cord injury. Invasiveness is the drawback of the treatment method being proposed as the stimulating electrodes are implanted directly on the surface of the spinal dura mater, thus requiring surgical interventions. Furthermore, identically to all surgical manipulations, it is associated with a number of risks and possible complications. Transcutaneous electrical spinal cord stimulation (tESCS), which induces locomotor movements in humans and animals, has been designed several years ago [6]. The essence of the method consists in generating complex-shaped electrical pulses instead of the regular rectangular ones. The special shape of the stimulating pulses makes high-intensity currents required to provide efficient impact on the spinal cord painless for humans with normal sensitivity. It started to be used simultaneously in several clinics for motor rehabilitation of patients with spinal cord injuries. These studies have demonstrated that noninvasive electric stimulation of the spinal cord increases muscular strength, improves tactile and pain sensitivity, recovers spontaneous movement activity and the body balance [7–9].

However, no studies devoted to noninvasive stimulation of the spinal cord combined with mechanotherapy in patients after spinal cord injury using this procedure have been published thus far. The aim of our work was to analyze the outcomes of rehabilitation treatment of a patient with spinal cord injury.

A 17-year-old patient V. had a spine and spinal cord injury after a car accident over 7 years ago. The patient had burst fractures of the T6–T9 vertebral bodies resulting in formation of a kyphotic deformity at this level and spinal cord contusion. Surgical intervention was performed 3 months after the injury. The surgery involved single-stage correction of the posttraumatic kyphotic deformity in the thoracic spine using a multi-screw fixation system combined with posterior fusion using an autobone graft through the dorsal approach and discectomy at the T6–T9 level with fusion using a cortical autograft (Fig. 1).

Patient's neurological symptoms included severe lower extremity paraparesis accentuated on the left side (score 0–1) and sensory impairments starting at the T9 level. After surgical management, the child was receiving in- and outpatient courses of drug therapy and rehabilitation treatment on a regular basis: remedial gymnastics, massage of the extremities, and robotic-assisted mechanotherapy using the Lokomat system. Despite the numerous courses of treatment for seven years, no positive dynamics in recovery from neurological deficit have been observed.

Patient's condition upon admission to hospital was critical. Nerve conduction impairment started at the T8–T9 level (mosaic pattern with sensitivity better preserved on the right side). Bathesthesia was preserved. Decreased muscle strength in the lower extremities was observed: score 0–1 on the right side; score 0 on the left side. Intense sporadic movements in the lower extremities were observed: the patient was able to contract hip muscles (to a better extent on the right side); make the minimal, low-amplitude movements by toes of the right foot; hold the bent-knee right lower extremity for 4–5 s with the foot supported on the plane (Fig. 2). Muscle hypotrophy of the lower extremities was also observed.

The neurological status was assessed using the ASIA impairment scale, the international standard neurological and functional classification of spinal cord injuries. This classification allows one to reduce the subjective evaluations of the neurological status and makes examination results unbiased and reliable. Score of motor activity assessed using the ASIA impairment scale was 53; for pain and tactile sensitivity, 42.

An electroneuromyography (ENMG) study was performed using a four-channel electroneuromyograph: the conduction velocity and bilateral evaluation of the amplitudes of sensory and motor responses was assessed during stimulation of the tibial, peroneal, and sural nerves on the basis of F waves and H-reflexes using the standard routine [3]. The somatosensory evoked potentials were recorded during bilateral stimulation of *n. tibialis* (SSEPs of *n. tibialis*) to evaluate the functional state of the spinal tracts; the potentials corresponding to lumbar enlargement P20-N22 and the cortical potential P38-N46 were registered with allowance for the amplitudes, the absolute and interpeak latencies. The ENMG data showed a significant decrease in amplitudes of M responses during left-sided stimulation of the tibial nerve (2 mV), no sensory potentials when examining the sensory fibers of the left lower extremity, being indicative of damage to motor neurons of the spinal cord on the left side at the S1–S2 level and peripheral sensory fibers of the left lower extremity. No signs of right-sided damage to the peripheral sensory and motor fibers of the right lower extrem-

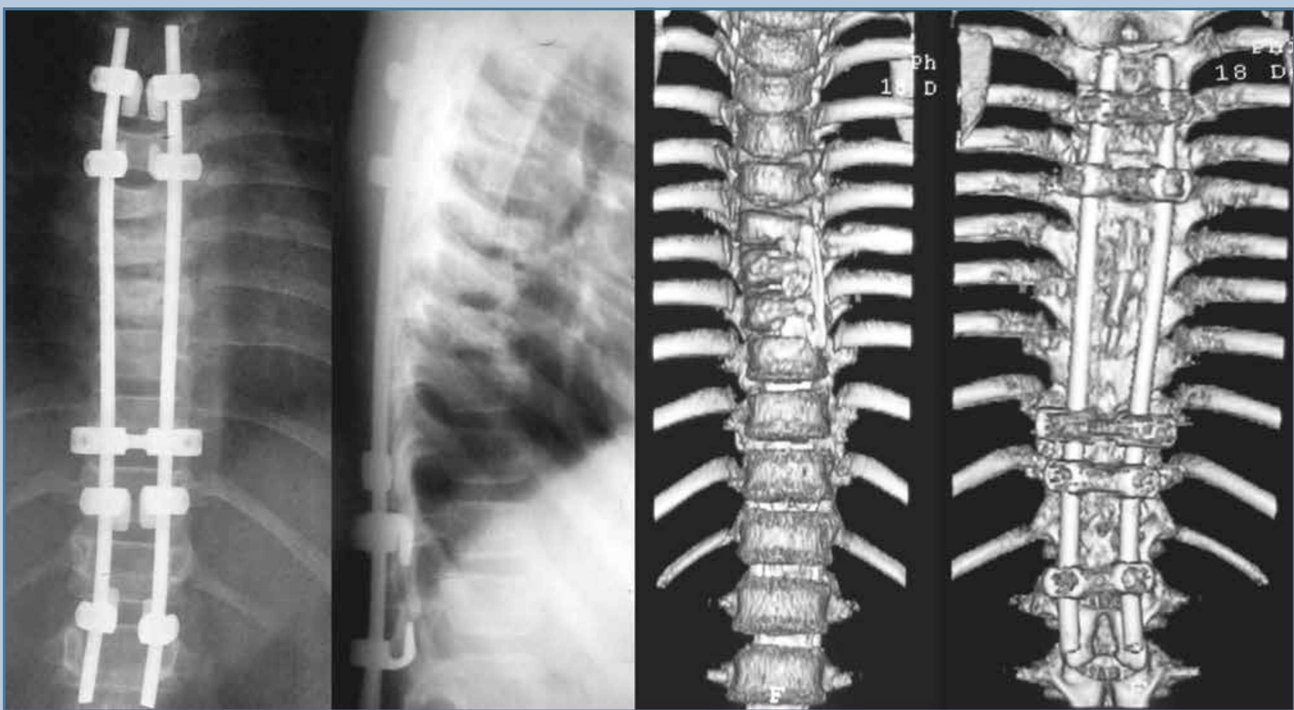

Fig. 1
X-ray films and CT scans of 9-year-old patient V. with a burst fracture of the T6–T9 vertebrae and spinal cord contusion after surgical treatment

ity or motor neurons of the spinal cord at the lumbar enlargement level were observed. The amplitude of the H-reflex was increased to 35%, being indicative of the reduced suprasegmental control of muscle activity. Investigation of the SSEPs of *n. tibialis* upon right-sided stimulation showed only the potential of lumbar enlargement P20-N22, while to P38-N46 was detected, thus indicating that somatosensory afferent conduction along the spinal tract was completely disturbed above the level of lumbar enlargement. P20-N22 was not detected when investigating the SSEPs of *n. tibialis* on the left side, which was attributed to disturbed conduction along sensory fibers at the peripheral level (Fig. 3).

The patient underwent 20 tESCS sessions within 2 weeks: 2 sessions a day, 5 days a week. Each session lasted 30 min. tESCS was performed simultaneously for two spinal cord levels using a Kulon-2 stimulator (State University of Aerospace Instrumentation, Russia). The electrodes (the cathode) were placed between spinous processes of the T11–T12 and L1–L2 vertebrae (round-shaped electrodes with an adhesive layer, ~3 cm in diameter, BF-4, LEAD-LOC, Inc.); the indifferent electrode (anode) was placed above the iliac crests (oval-shaped electrodes with an adhesive layer, 10 cm long along the major axis, SS-3). Stimulation frequency was 30 Hz; pulse duration, 1 ms. Current intensity was selected during a session depending on patient's sensations: until lower extremity muscles started to contract or the patient started to have unpleasant sensations. Current parameters were reduced at this point. Current amplitude was increased during each session; the operating current was varied between 30 and 140 mA. The tESCS sessions were carried out simultaneously with one or two types of mechanotherapy; the mechanotherapy types were strictly altered. In one case, the patient was placed in the supine position and received stimulation of foot support zones using a Korvit device (OOO VIT, Russia). In the second case, the patient was placed in the sitting position, with his legs making cycling movements using a Thera-fit plus trainer for the active and passive rehabilitation of the lower extremities. Patient's response to load was controlled during the entire rehabilitation course.

Fig. 2
Maintaining the knee-bent right lower extremity with support on the plane in the patient in supine position; stimulation off

Positive dynamics in patient's subjective feelings appeared two weeks after stimulation, manifesting as increased tolerance to the tESCS procedure. The instrumental methods and neurological evaluation showed that the function of the lower extremities was improved. The patient had a subjective feeling of increased muscle strength and greater tolerance to higher-intensity electrical stimulation of the spinal cord during the sessions. Time of maintaining the knee-bent right lower extremity with support onto the plane increased up to 15 s immediately and 7 days after the stimulation course. Muscle strength of the lower extremities increased by 1 point (locomotor activity, 54 points; sensitivity, 42 points). The dynamics of the functional state of the spinal cord was evaluated by ENMG and recording the SSEPs of *n. tibialis* 7 days after the stimulation course was finished. ENMG of the lower extremities showed no significant changes compared to the outcomes before the tESCS course. The changes observed had no qualitative significance for rehabilitation and did not affect the patient's neurological status. Recording the SSEPs of *n. tibialis* after right-sided stimulation showed improved afferent conduction in the spinal cord above the lumbar enlargement manifesting as emergence of the cortical potential P38-N46 with significantly reduced amplitude (0.6 μV). The N22-P38 interpeak interval was not higher than the normal parameters (14 ms; Fig. 3). No SSEPs were recorded for the left lower extremity, identically to the situation before the electrical stimulation course, because of the completely disturbed afferent conduction at the level of peripheral sensory nerves.

We are inclined to attribute the insignificant positive effect of this treatment to the age of the injury and the short treatment duration. It is beyond any doubt today that electrical stimulation affects the functional state of neural structures [7–9]. Its effect manifests itself during both direct electrical stimulation of a specific neural structure, when stimulating electrodes are placed on the object being stimulated, and the noninvasive method of delivering electri-

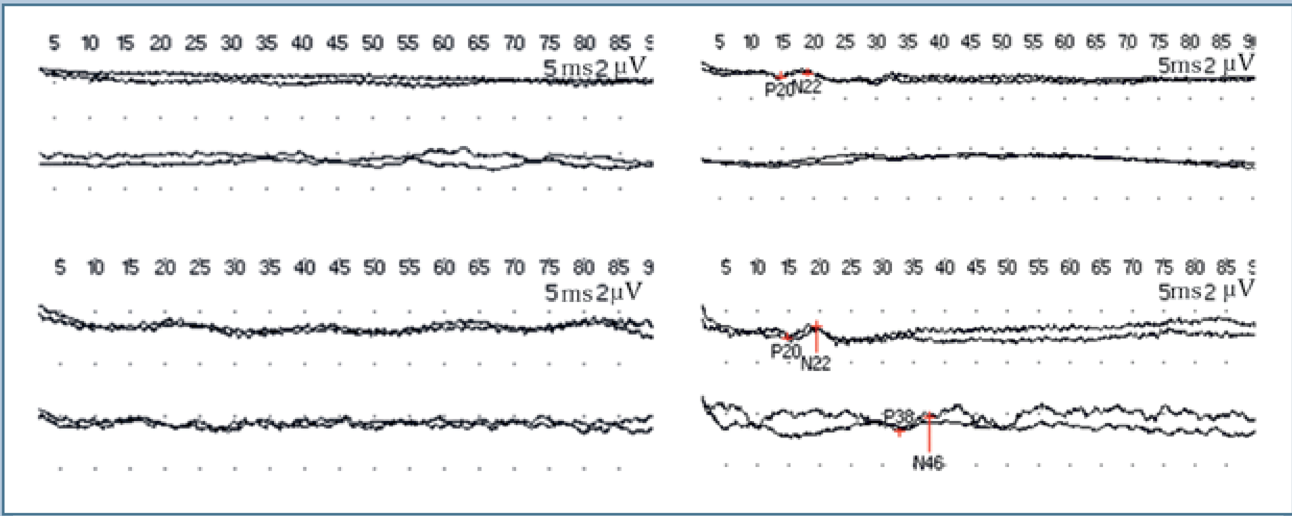

Fig. 3
Maintaining the knee-bent right lower extremity with support on the plane in the patient in supine position; stimulation off *n. tibialis* after right-sided stimulation (before and after electrical stimulation): the upper curves – Lumb 3(2)-I'c, the lower curves – Cz-Fpz; the potential P20-N22corresponding to the lumbar enlargement is reliably recorded on the right side before stimulation; the cortical potential P38-46 emerges after stimulation

cal pulses through electrodes placed on skin. Nevertheless, it is fair to say that the use of the tESCS method combined with mechanotherapy has made it possible to improve the outcome of conservative treatment in the patient with consequences of spinal cord injury and to maintain the achieved outcome 7 days after the procedures.

Today, the research focused on improvement or recovery of the spinal cord function using isolated transcutaneous electrical stimulation or combined with mechanotherapy is considered to hold great promise. However, further studies and justification are needed in order to draw a final conclusion on their effectiveness as well as the effect they have on the spinal cord function and its components.

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