doi: 10.17116/engneiro201579641-53

Results of Motor Cortex Stimulation in the Treatment of Chronic Pain Syndromes

E.D. ISAGULYAN[1], A.A. TOMSKY[1], A.V. DEKOPOV[1], E.M. SALOVA[1], E.M. TROSHINA, E.V. DOROKHOV[2], V.A. SHABALOV[1]

[1]Burdenko Neurosurgical Institute, Moscow, Russia; [2]Sechenov First Moscow State Medical University, Moscow, Russia

Aim. The article is aimed to demonstrate our experience in motor cortex stimulation (MCS) in patients with chronic neuropathic pain syndromes, assess the clinical efficacy of the technique in short-term and long-term follow-up, and analyze potential predictors of the MCS efficacy. **Material and methods.** Twenty patients were implanted with MCS electrodes at the Burdenko Neurosurgical Institute in the period between 2004 and 2014. The mean age of patients was 52 years (26 to 74 years). The patients suffered from neuropathic pain syndromes of different genesis (post-stroke, multiple sclerosis, atypical facial pain, phantom limb pain, brachial plexus injury, spinal cord injury, complex regional pain syndrome I). All patients underwent neurological examination with verification of neuropathic pain (DN4, Pain Detect, LANSS). The pain intensity and its effect on quality of life were assessed before operation and during follow-up according to 10-point visual-analog scales (modified Brief Pain Inventory). Before surgery, all patients underwent several repetitive transcranial magnetic stimulation (rTMS) sessions. After implantation of epidural electrodes, test MCS was performed. **Results.** Test stimulation was positive in 19 (95%) patients. All these patients were implanted with a chronic MCS system. The mean follow-up was 49.3 months (from 3 to 96 months). In short-term follow-up (fist 6 months), a positive result of MCS was observed in 17 patients, and a reduction in the pain intensity ranged from 37.5% to 90%. In long-term follow up (from 12 to 96 months), 14 patients had positive MCS results, and a reduction in the pain intensity amounted to 25% to 60%. All patients with positive MCS results received significantly decreased doses of opioids and tramadol. Two patients developed infectious complications, but there was no neurological deficit. Analysis of the factors affecting the efficacy of motor cortex stimulation did not reveal a statistically significant effect of rTMS and the presence and intensity of motor deficit. **Conclusion.** Chronic epidural MCS is an effective and safety method for the treatment of some chronic neurogenic medically-refractory pain syndromes. Further research is necessary to specify the patient selection criteria and the MCS efficacy predictors.

Keywords: *motor cortex stimulation, chronic pain, neuropathic pain, clinical efficacy, predictors, post-stroke pain, atypical facial pain, phantom limb pain, spinal cord injury, complex regional pain syndrome I.*

Abbreviations

VAS — visual analog scale
MRI — magnetic resonance imaging
TMS — transcranial magnetic stimulation
ES — electrostimulation
DN4 (Dolour Neuropatique), LANSS (Leeds Assessment of Neuropathic Symptoms and Signs), Pain Detect — questionnaires revealing the nature of neuropathic pain
DREZ-tomy — (dorsal root entry zone) dorsal root entry zone excision
MCS (Motor Cortex Stimulation) — motor cortex stimulation
PQLC (Pain and Quality of Life Card) — pain and quality of life card (a modified brief pain inventory)

Motor cortex stimulation has been used to treat chronic pain syndromes for more than 20 years. To date, more than 1,000 publications devoted to basic and clinical research of the efficacy of motor cortex stimulation in patients with neuropathic pain syndromes have appeared worldwide. In particular, these include 4 randomized controlled trials [1—4] and 3 meta-analyses [5—7].

The indications for motor cortex stimulation are neuropathic pain syndromes when pharmacotherapy and minimally invasive surgery are ineffective. These syndromes include severe post-stroke pain, atypical trigeminal facial neuralgia, phantom pain as well as other severe deafferentation pain syndromes (brachial plexus injury pain, spinal cord injury). At present, some doubts about the MCS efficacy still remain despite the positive results of randomized controlled trials and meta-analyses [8, 9]. This requires further investigation of the efficacy of the technique and ways to improve it.

At the Burdenko Neurosurgical Institute, chronic pain syndromes have been treated using neurostimulation for more than 15 years [10, 11] and motor cortex stimulation for 11 years.

The aim of this publication is to demonstrate our experience in application of motor cortex stimulation in clinical practice, evaluate the MCS efficacy in short-term and long-term follow-up, and analyze potential predictors of the MCS efficacy.

Material and Methods

At the Burdenko Neurosurgical Institute, motor cortex stimulation was used in 20 patients (10 males and 10 females) aged 26 to 74 years (mean age 52 years) in the period between 2004 and 2014. The mean duration of pain syndrome before surgery was 5 years. In all cases, the patients had persistent neurogenic pain refractory to analgesics, specific analgesic

© Group of authors, 2015

e-mail: EIsagulyan@nis.ru

psychotropic pharmacotherapy, physiotherapy treatments, and acupuncture. The pain syndrome characteristics for each patient, along with the patient's gender and age, are shown in **Table 1**.

Below is a more detailed characterization of the clinical cases. In 4 patients, the cause for seeking treatment was the central post-stroke pain syndrome (**Table 1**: cases 13, 15, 19, 20). In this case, three of these patients had hemorrhagic stroke (13, 19, 20), and one patient (15) had ischemic stroke.

Among the hemorrhagic stroke patients, hemorrhage occurred directly in the thalamus in 2 patients (13, 19) and in the basal ganglia, including the thalamus, in 1 patient (20).

In one patient (10), the central pain syndrome in the left arm and left half face was associated with multiple sclerosis.

The main complaint in 4 more patients (2, 6, 9, 18) was severe facial pain. In 2 females (2, 9), facial pain developed in association with multiple sclerosis, with the pain being localized in the right half face, mainly along the 2nd and 3rd branches of the trigeminal nerve. The pain was constant, with paroxysmal aggravation. In one patient (6), facial pain appeared after dental treatment in the lower jaw. The 4th patient (19) presented with the classical clinical picture of trigeminal neuralgia on the right; however, the pain syndrome changed after pain microvascular decompression: constant background pain with paroxysmal aggravation developed.

Two patients (12, 16) suffered from phantom limb pain. One of them had traumatic amputation of the left limbs in a car accident, with the phantom pain developed both in the arm and in the leg. The second patient had a severe soft tissue burn of the left arm due to electrical injury. The phantom limb pain developed after exarticulation of the left shoulder.

In another patient (4), phantom limb pain appeared due to post-traumatic avulsion of the primary trunks of the left brachial plexus. The pain manifested as a sensation of an "extra" left arm and constant pressing, tightening, and twisting pain in the "arm".

Severe deafferentation pain syndromes associated with brachial plexus trunk injury were observed in 4 more patients (1, 3, 8, 17). In one case, a patient (1) with preganglionic avulsion of the brachial plexus trunks underwent neurolysis of the secondary trunks of the brachial plexus and neurotization of the musculocutaneous nerve. Later, stereotactic implantation of electrodes was performed for neurostimulation to the thalamic sensory nuclei and periaqueductal gray matter. These operations had a short-term benefit.

In the 2nd case, a patient (3) had a traumatic injury of the right brachial plexus with the development of total paralysis in the arm. Suspension arthroplasty of the right shoulder joint using a lavsan tape and external neurolysis of the primary and secondary trunks of the right brachial plexus as well as selective neurotization of the musculocutaneous nerve with the 2nd and 3rd intercostal nerves were performed. The pain syndrome persisted after all operations.

In the 3rd case, a patient (8) after an injury underwent neurolysis of the primary trunks of the brachial plexus, then neurolysis of the median and ulnar nerves, and later orthopedic correction of the hand and plasty of the finger flexors.

In the 4th case (17), pain had the form of complex regional pain syndrome type II; a patient underwent surgery for the cervical spine. It is noteworthy that the patient was first implanted with a system for chronic epidural electrical stimulation of the spinal cord at the cervical thickening level as analgesic treatment. The analgesic effect of the stimulation was neutralized within several months despite repeated re-programming of the system and the use of various ES modes.

In 2 patients (5, 11), pain arose after resection of a spinal cord tumor: an intradural extramedullary neuroma at the C5—T2 level was removed in the first case, and a nerve root neuroma at the C6—C7 level was resected in the second case. The first patient underwent DREZ-tomy for the pain syndrome, after which the pain initially reduced, but after 1 month began to increase again. The second patient underwent stereotactic thalamotomy, after which pain regression was observed within 3 weeks.

In one female patient (14), the cause of complex regional pain syndrome type I was long-term compression of the right arm and compression of the ulnar and median nerves. She underwent decompression of the nerves at the lower third forearm level and in the Guyon's canal that had a short-term benefit.

A patient with a cervical spinal cord injury (7) presented with tetrasyndrome with moderate upper limb paresis (deep in the distal segments), spastic lower deep paraparesis, and dysfunction of the pelvic organs (involuntary urination and stool retention). However, the patient's quality of life was mostly affected by pronounced deafferentation pain, mainly of the conductive nature, in the arms, chest wall, and legs as well as severe spasticity in the legs.

Preoperative examination

All patients underwent a neurological examination with assessment of pain syndrome using DN4, Pain Detect, and LANSS scales (neuropathic pain syndrome was confirmed in all patients). The assessment of the pain syndrome intensity was performed before surgery, in the postoperative period, and during follow-up using PQLC that included 10-point visual analog scales (VAS). We assessed the maximum and minimum intensity of background and/or paroxysmal pain, mean daily pain intensity, rate of pain episodes, need for analgesics as well as impact of pain on various aspects of everyday life (general condition, mood, daily activity, passive recreation, self-care, communication with others, sleep, sexual activity).

To select patients and assess the pain syndrome intensity, we used a multi-dimensional verbal-color pain test developed at the Institute of Reflexology of the Federal Research Clinical and Experimental Center of Traditional Methods of Diagnosis and Treatment [12]. This test determines the intensity of pain components using factor scales and provides an integrated quantitative (score/percentage) and qualitative estimate that reflect individual's conscious and unconscious pain experience. The test results are conveniently presented in the graphical format. The test comprises seven scales. The first three scales are the pain intensity, pain frequency, and pain duration. The pain intensity scale is compared to the color choice: patients' color preferences and rejections according to their own internal pain sensations are analyzed (pain intensity and pain pattern). The scale of emotional pain perception provides a quantitative and qualitative estimate of the subjective attitude to pain. The neurotization scale evaluates the level of neurotization and the degree of involvement of behavioral components in the severity of the internal picture of patient's disease. The adaptability scale identifies environmental factors affecting pain worsening. The lie scale determines the sincerity of patient's responses. If the lie scale score is 5—6, the test results are recognized unreliable.

All patients underwent brain TMS, as a test procedure, in the motor cortex projection, over the area of planned

Table 1. **Characterization of pain syndrome in patients**

No	Gender	Age, years	Diagnosis	Pain duration, years
1	M	42	Differentiation pain syndrome after avulsion of the left brachial plexus nerve roots	8
2	F	64	Atypical facial pain. Multiple sclerosis	3
3	F	45	Right brachial plexopathy	2
4	F	56	Pain syndrome after resection of an intradural extramedullary tumor of the spinal cord	3
5	F	42	Left brachial plexopathy and phantom limb pain	2
6	F	39	Atypical facial pain. Facial anesthesia dolorosa	2
7	F	54	Pain syndrome after cervical cord injury	7
8	M	42	Brachial plexopathy	7
9	F	26	Atypical facial pain. Multiple sclerosis	8
10	M	50	Central neurogenic pain. Multiple sclerosis	2
11	F	51	Pain syndrome after resection of a spinal cord meningioma at the cervical level	6
12	M	46	Phantom limb pain (left)	6
13	M	61	Central pain syndrome after stroke in the right hemisphere	2
14	F	46	Complex regional pain syndrome type 2, neuropathy of the median and ulnar nerves	2
15	M	59	Central pain syndrome after stroke in the right hemisphere	5
16	M	60	Phantom pain of the left arm	7
17	M	60	Right brachial plexopathy	12
18	M	73	Atypical facial pain	4
19	F	59	Central pain syndrome after stroke in the right hemisphere	2
20	M	74	Central pain syndrome after stroke in the right hemisphere	6

implantation of electrodes. The efficacy criterion was a reduction in pain by 50% or more at the threshold pulse values after two stimulation series of 10 bursts.

In a patient (7) with a cervical spinal cord injury and bilateral pain, the implantation side was determined by TMS. Alternative stimulation on the left and right sides was performed during outpatient clinic visits for TMS (total of 10 sessions). On this basis, a significant prevalence of bilateral analgesic and anti-spasmodic effects of TMS upon right-sided stimulation was revealed. Therefore, electrodes were implanted on the right side only.

Surgical technique

Preoperatively, all patients underwent brain MRI with 3D-reconstruction and functional MRI to determine the representation of pain region (arm, leg, or face) in the motor cortex (**Fig. 1a**), on the contralateral side with respect to the pain localization. For this purpose, patients during tests were asked to make movements in an appropriate part of the body. In the absence of movement in the extremities, the patients were asked to make virtual movements.

The data on pain area representation and 3D-reconstructed MRI images of the brain were loaded into the memory of a navigation station (StealthStation, Medtronic, USA or Brain Lab, USA) (**Fig. 1b, c)** where identification of anatomical coordinates and landmarks of the electrode implantation area was performed by combining these data.

Surgery was performed under total intravenous anesthesia and mechanical ventilation. To obtain adequate motor responses, muscle relaxants were restrictedly used, and the depth of anesthesia was monitored (bispectral index was calculated based on a continuously recorded electro-encephalogram).

The projection of an appropriate motor cortex area and the carniotomy site were marked up on the patient's head using the navigation station **(Fig. 1d, e)**.

Craniotomy was performed with the formation of a free bone flap of 5×5 cm. The dura mater was not opened. The site of final implantation of two four-contact flat electrodes was identified based on the data of intraoperative electrostimulation at the subthreshold levels with detection of motor evoked potentials **(Fig. 2)**.

After getting the motor response, the electrodes were fixed to the dura mater in such a way that two cranial contacts of each electrode were positioned anteriorly to the central sulcus, 2 caudal contacts were positioned posteriorly to the sulcus, and electrodes themselves overlapped the projection of an appropriate pain area **(Fig. 3a, b)**. The bone flap was placed back and fixed, and soft tissues were tightly sutured. Electrode ends were tunneled out through an adapter to the skin (**Fig. 3c, d).** At this point, the first stage of implantation was completed.

After implantation of electrodes, the test stimulation period began that lasted for 1—2 weeks. Before its onset, subthreshold levels of the stimulation amplitude were determined by monitoring of motor evoked potentials. The appropriate electrode polarity was determined in the same way. If a stable analgesic effect of electrical stimulation (reducing the pain intensity by 50% or more) was achieved throughout the test period, the second stage (implantation of a system for chronic ES) was performed.

The second stage was also performed under intravenous anesthesia and mechanical ventilation. Electrode ends were connected through subcutaneous adapters to a pulse generator implanted subcutaneously in the subclavian area. The pulse generator was programmed in accordance with parameters of the test stimulation period. The patient was handed a desk for self-control of stimulation (switching on, switching off, and switching among programs). In the case of a negative result of the test period, epidural electrodes were removed.

Postoperative and long-term follow-up

Postoperatively, all patients were monitored for the neurological status and pain intensity level using PQLC. In the long-term period, all patients were examined at intervals of 3—6 months. Pain intensity control, correction of a stimulation program, and, if necessary, correction of pharmacotherapy were performed.

Methods of statistical data processing

In this publication, statistical data are presented as frequencies and percentages. A paired t-test was used to compare pain levels in patients before and after surgery. All statistical calculations were performed using the PASW Statistics software package, version 22.0, (SPSS: IBM, Chicago, IL, USA). Graphical diagrams were plotted using the Excel software from the Office Professional Plus 2013 package (Microsoft, USA).

Results and Discussion

According to the literature (randomized trials and meta-analyses), 36 to 80% of patients are satisfied with the motor cortex stimulation treatment [1—7].

The treatment efficacy varies for different pain syndromes. It amounts to 60—80% for the central post-stroke pain syndrome, 75—76% for atypical facial pain, 36—45% for brachial plexus injury pain, and 56—60% for spinal cord injury pain [5—7].

In this study, test stimulation had a positive effect in 19 (95%) of 20 patients implanted with epidural electrodes for motor cortex stimulation. In one patient (6), a significant decrease in the analgesic efficacy of ES was observed by the end of the test period. Despite attempts of reprogramming, the analgesic effect was not restored. For this reason, electrodes were removed.

Therefore, only 19 patients aged 26 to 74 years were implanted with a system for chronic electrical stimulation of the motor cortex (**Table 2**).

The mean follow-up was 49.3 months (3 to 96 months). In the short-term follow-up (within the first 6 months after implantation), the mean pain intensity decreased from 7±0.4 to 3±0.4 points ($p<0.05$, paired t-test) in 17 (89.5%) patients, with the regression level ranging from 37.5 to 90%. In the long-term follow-up (12 to 96 months), positive results were observed in 14 (73.7%) patients. The mean pain intensity decreased from 7±0.4 to 4.5±0.4 points ($p<0.05$, paired t-test); the pain regression level amounted to 25—60%.

In addition to the mean pain intensity, the patients had a statistically significant decrease in both the minimum and maximum pain intensity. There was a significant decrease in the rate and intensity of pain paroxysms. These episodes were not usually scored above 5—6 on VAS (instead of 9—10 before surgery) and were even stopped within 10—30 min upon increasing the stimulation amplitude in several patients (2, 11, 13, 15).

Stimulation parameters used in the study were as follows: amplitude: 1.0—5.5 V; frequency: 20—50 Hz; pulse width: 60—210 μs. The literature data [13, 14] are generally in accordance with ours.

The need for analgesics was significantly reduced in many patients. One patient (3) with traumatic injury of the brachial plexus trunks completely refused medication; 4 other patients (5, 9, 13, 19) reduced administration of anticonvulsants 3 times and completely refused opioid analgesics. A patient (11) with a cervical nerve root injury due to neurinoma resection reduced the tramadol dose 2 times and completely refused morphine. A patient (7) with a spinal injury reduced the dose of tramadol and sibazon 2 times. It is worth noting that all patients in whom stimulation was effective either refused or significantly reduced a dose of narcotic analgesics and tramadol.

Table 3 presents the data of medication therapy for pain syndrome that was performed before stimulation and in association with motor cortex stimulation.

All patients had a decrease in the impact of pain on various aspects of the life quality (in particular, on daily activity) **(Fig. 4)**.

Below, we describe the results of the multi-dimensional verbal-color pain test. Before surgery, all patients had maximum scores for the rate and duration of pain (5—6). That is the pain in all patients was constant. According to the pain intensity scale, most of the patients assessed their pain as intolerable. Only one female patient (3) assessed her pain as very severe (score of 5). All examined patients, except a patient 6, were not detected with perversions of color, which indicated that a psychogenic pain component was not dominant in them. According to the scale of sensory pain perception, all patients demonstrated high pain sensitivity. Indicators of the emotional pain perception scale were very high in all patients. Two patients (3, 6) demonstrated a particularly high neurotization level (up to a score of 6). Both of them were ill for several years, and the first examination revealed their extreme fixation on their painful feelings and painful experiences. Given the specificity of our patients, of greatest importance to them were factors associated with motion and rest (posture, postural change, walking, standing, sitting, etc.) as well as with a change in the weather. Factors associated with eating, type of food, and smoking were scarcely mentioned. The lie scale score was not higher than 4 in all patients.

It should be noted that despite certain fluctuations in the ES efficacy in the early postoperative period, the analgesic effect in most patients was stable in the long-term follow-up. For example, the neurostimulation efficacy in a patient 11 in the early postoperative period (1 month after discharge) decreased by 20% compared to the baseline level, but further remained stable. At the same time, the neurostimulation efficacy in a patient 3 increased by 10% compared to the baseline level due to independent searching for an optimal stimulation program and periodical changing the ES frequency. In general, our data are in agreement with the literature data [13, 14].

Negative results

The stimulation system was removed in 3 patients due to loss of efficacy. For example, the stimulation efficacy in 2 patients with pain after brachial plexus root avulsion reduced significantly and did not result in a satisfactory regression of the pain syndrome. This occurred 5 and 10 months after implantation in cases 17 and 1, respectively. In the patient 1, a reduction in the pain intensity was achieved after a repeated (third) DREZ-tomy. In a patient (8) with a cervical spinal cord injury, stimulation significantly reduced the intensity of both pain and spastic syndromes; however, the duration and intensity of the effect decreased significantly within the next two years. In all cases, there were attempts to reprogram the system, but they did not improve the results.

In 2 more patients, follow-up was interrupted. One patient (2) with multiple sclerosis died from the underlying disease 5

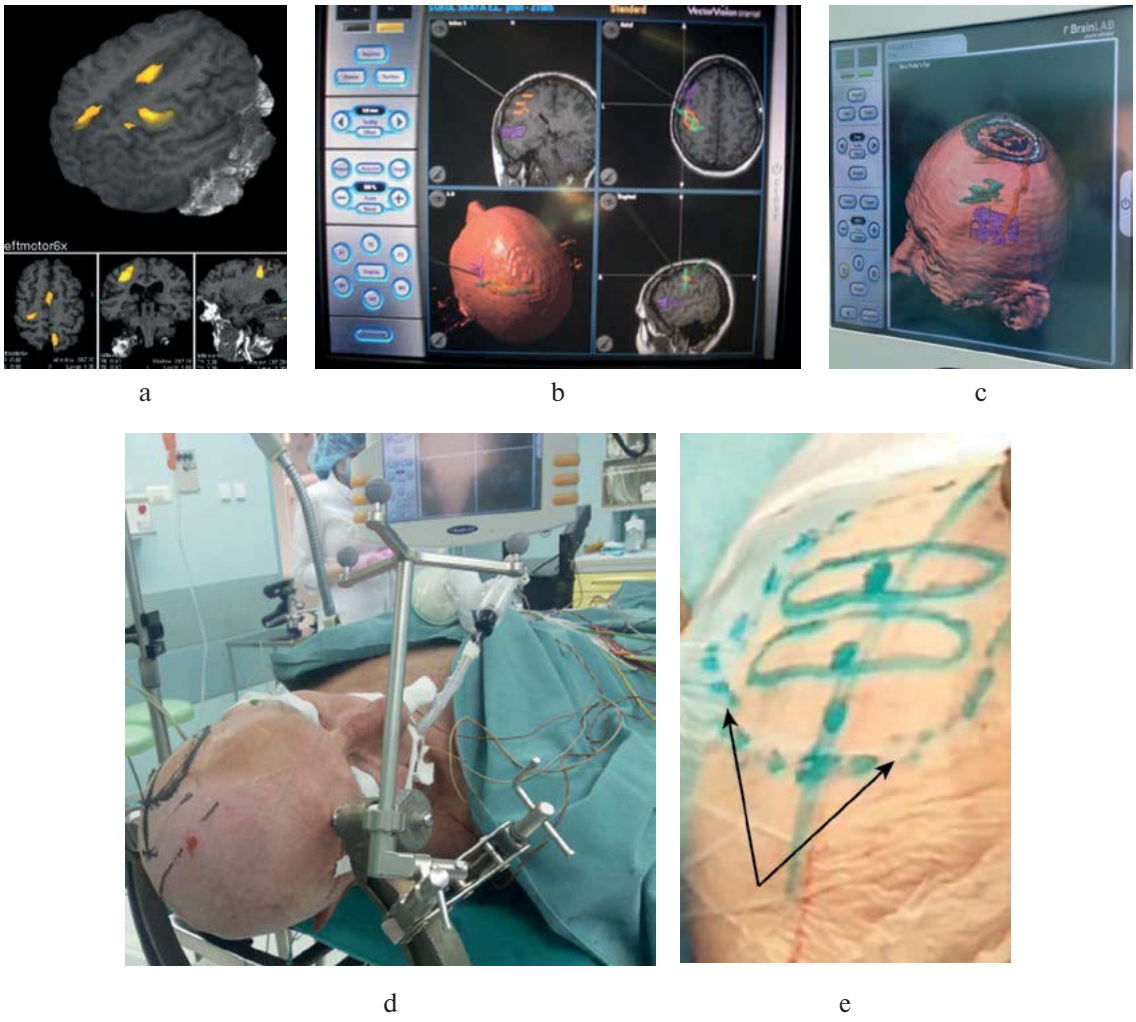


Fig. 1. **Electrode implantation technique.**

a — functional MRI with 3D-reconstruction; b, c — identification of the craniotomy site using a navigation station; d, e — mapping for craniotomy and a view of the navigation station.

Black arrows indicate the craniotomy borders. The vertical green line in the middle of the planned craniotomy corresponds (according to the navigation station data) to the central sulcus. Internal green ovals are planned sites for implantation of two flat electrodes, the middle point of the ovals are their geometric isocenters.

years after system implantation. One patient (9) stopped communicating in 2010. However, the patients in both cases reported a good efficacy of stimulation as long as they maintained contact.

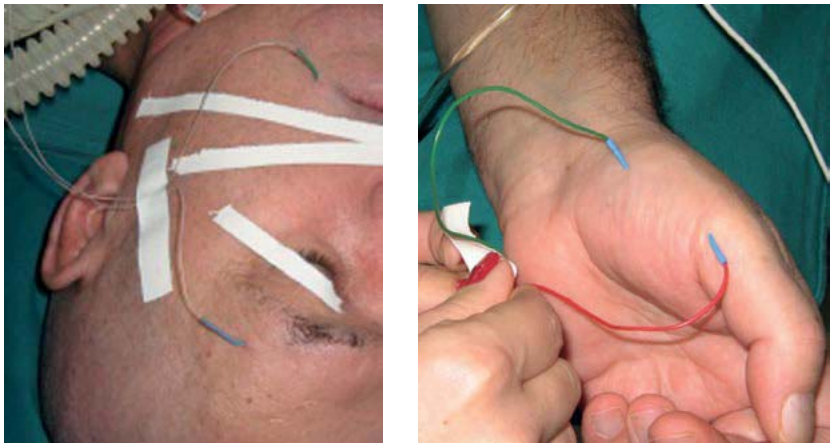
Complications

According to the literature [14], the rate of complications of motor cortex stimulation is no more than 5%, on average. The most common complications of motor cortex stimulation are technical (electrode break and system failure; their cumulative rate is 5.7%) and infectious complications that are mainly associated with the wound or implantation site of a subcutaneous part of the system: their rate is 5.1% [6, 14].

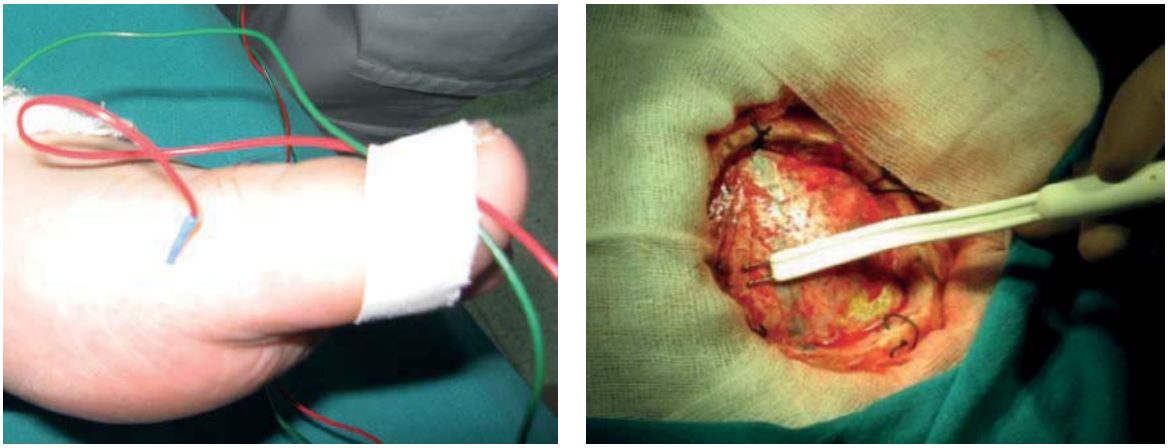
A special place among complications of motor cortex stimulation is held by epileptic seizures that usually occur during intraoperative or test stimulation. Their rate is 12% [6, 14], but they occur more often in the case of subdural stimulation [6]. The most severe complications of cortical electrode implantation are epidural or subdural hematomas (depending on the electrode location) that may lead to death, but their rate is less than 1%. Also, the literature [6] reports single cases of a neurological deficit, regressing within one day or a few months after implantation of the entire system.

In our series of the 19 patients implanted with electrodes for epidural motor cortex stimulation, postoperative complications developed in 2 (10.5%) patients. In both cases, these were infectious complications that did not lead to a sensory or motor deficit or worsening of pain. Three months after implantation of the system, a patient 20 developed purulent inflammation in the pulse generator pocket and a decubitus ulcer over the connector implantation site. The system was removed despite a good analgesic effect. In another patient (12), a decubitus ulcer formed at the site of pulse generator implantation 3 years after surgery, which required removal of the generator together with connectors.

While discussing the results, we should note that the present study has several limitations precluding us from making comprehensive conclusions. The sample of patients was not



a b



c d



e f

Fig. 2. **Electrode implantation technique.**

Intraoperative electrophysiological monitoring.

a, b, c — location of needle electrodes in the muscles of the face, hand, and feet; d — intraoperative stimulation; e — M-response from the facial muscles; f — response from the hand.

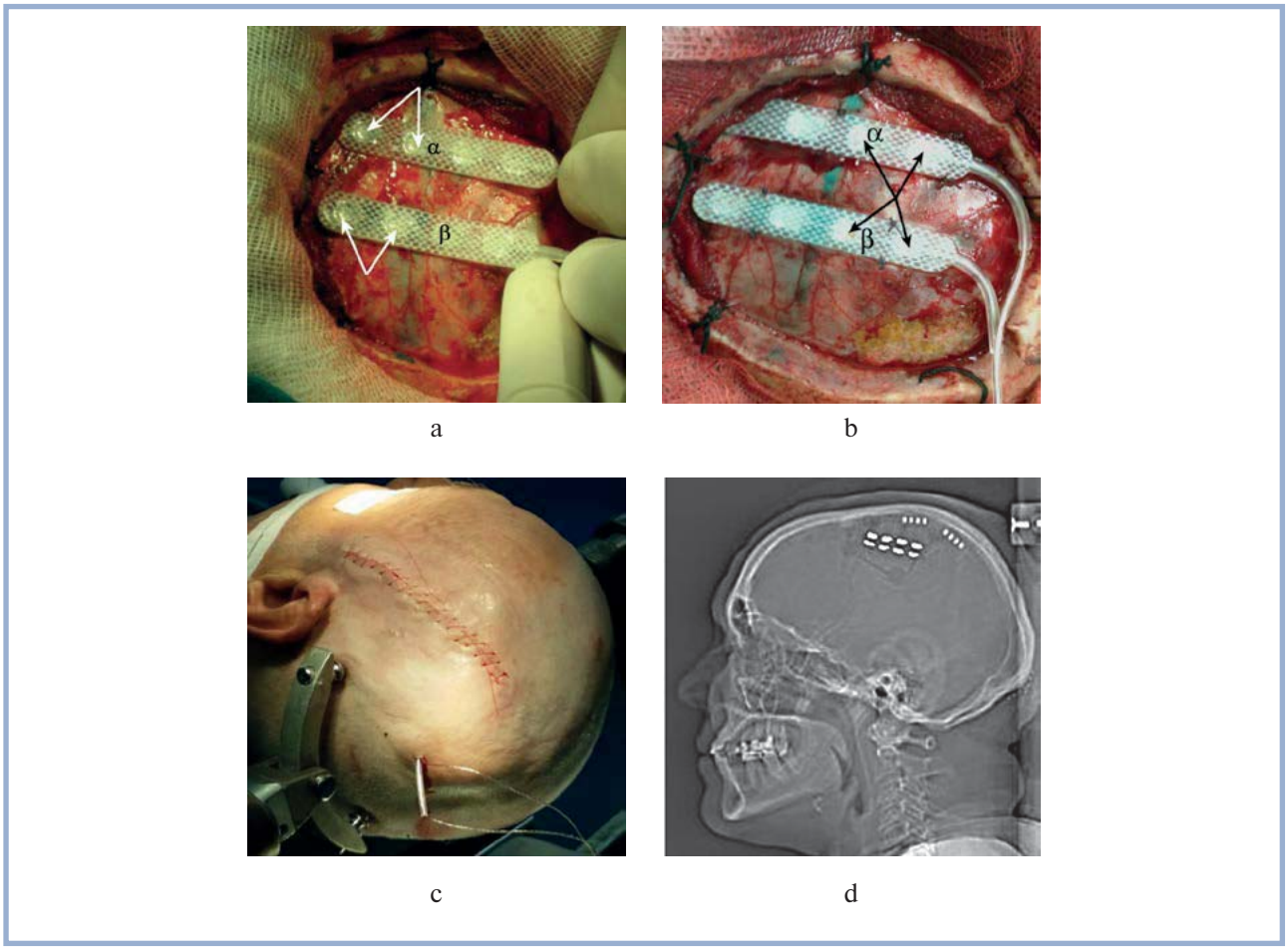


Fig. 3. **Electrode implantation technique.**

a, b — location of electrodes in a bone window, epidurally, over a certain area of the central cortex. The lower electrode (α) is located in the face area; the upper electrode (β) is located in the hand area. The green line is the central sulcus projection. Anteriorly to the sulcus, two contacts of each electrode (cathodes), denoted by white arrows, are situated in the projection of the motor cortex. Two rear contacts of each electrode (polarized as anodes), denoted by black arrows, are located posteriorly to the central sulcus, in the sensory area; c — a postoperative wound; temporary adapters tunneled out through a counteropening are seen; d — a view of electrodes on a radiographic image after surgery.

large enough (n=20). In addition, the genesis of pain in all patients was clearly different (central pain syndrome in some patients, while both central and peripheral pain syndrome in others) despite the common features (deafferentation pain). This limits us in making general conclusions for all patients. At the same time, allocating the patients into disease subgroups is impractical due to the small sample size. However, it should be noted that the number of patients in many international trials conducted at a single clinical site did not exceed 30 patients even for a 10-year period [1, 3, 15—17]. Large samples (over 100 patients) usually occur only in multicenter trials and meta-analyses [5—7]. This problem is associated with a strict limitation on the range of diseases that serve indications for motor cortex stimulation as well as with their relatively low prevalence.

In the present study, like in most other studies [15, 17], no placebo-controlled stimulation was performed. Particular attention should be paid to the past medical history of our patients, in particular to the availability of adequate medical treatment. This need stems from the fact that an important indication for motor cortex stimulation, along with pathogenesis and a clinical form of pain syndrome, is resistance to pharmacotherapy. Meanwhile, a study conducted in Europe [18] showed that the real drug-resistant neuropathic pain, as defined by international experts, is found only in 5% of patients. A significant proportion of patients with persistent neuropathic pain syndromes have no adequate therapy.

Analysis of the data on conservative treatment in our patients (**Table 3**) reveals that there were patients who received adequate pharmacological treatment with some delay (1, 3, 6, 8, 11, 13—18, 20) or did not receive it at all (5, 7). For example, a patient 17 was immediately prescribed with tramadol in tablets and injections. He had taken the medication for at least 10 years, after which attempts of adequate treatment using anticonvulsants and antidepressants failed. In addition, the patient underwent a destructive intervention for the cervical roots and thoracic sympathectomy in the absence of adequate medical treatment. The efficacy of motor cortex stimulation in this patient quickly decreased (within 5 months after implantation).

Investigation of predictors for the motor cortex stimulation efficacy in treatment of neuropathic pain syndromes is of great significance. The literature provides ambiguous data on this problem [14]. Criteria that have been used for a long time since

Table 2. **Demographic indicators and results of stimulation in long-term follow-up**

Demographic indicator	
Mean age, years	53±12
Gender ratio, m/f	1/1
Duration of pain history, years	5±3
Positive test stimulation *(n)*, %	19 (95%)
Negative test stimulation *(n)*, %	1 (5%)
Duration of long-term follow-up, months	65±22
Stimulation results	
Percentage of regression of the mean pain intensity in long-term follow-up	4.3±1.1 (p<0.05)
Decrease in the maximum pain intensity during follow-up, VAS score	2.7±1.3 (p<0.05)
Decrease in the minimum pain intensity during follow-up, VAS score	3.6±1.4 (p<0.05)
Decrease in the rate of paroxismal pain aggravation during follow-up, VAS score	3.2±1.6 (p<0.05)
Decrease in the need for medication during follow-up, VAS score	3.1±1.5 (p<0.05)
Decrease in the impact of pain during follow-up (VAS score) on:	
general condition	4.1±1.7 (p<0.05)
mood	4.5±1.2 (p<0.05)
attitude to others	3.4±1.4 (p<0.05)
daily activity	3.5±1.1 (p<0.05)
passive recreation	3.1±1.5 (p<0.05)
self-care	3.7±1.0 (p<0.05)
sleep	3.5±1.3 (p<0.05)
sexual activity	2.8±2.0 (p<0.05)

the introduction of motor cortex stimulation to treatment of neuropathic pain are now argued. For example, an initially supposed direct correlation between the degree of motor function preservation and the efficacy of motor cortex stimulation [19, 20] was disproved later [15, 21]. The TMS efficacy is not clearly recognized as a reliable prognostic factor [14, 21]. Recent studies have shown that this criterion has a high reliability (according to various data, 79 to 90%) in predicting the positive result of epidural cortical stimulation and a significantly lower reliability (35 to 67%) in predicting the negative result of MCS [16, 22]. Earlier publications also considered a regression of pain in response to thiopental [23] and ketamine [24] administration as a predictor of the motor cortex stimulation efficacy; however, these criteria were not put into widespread practice.

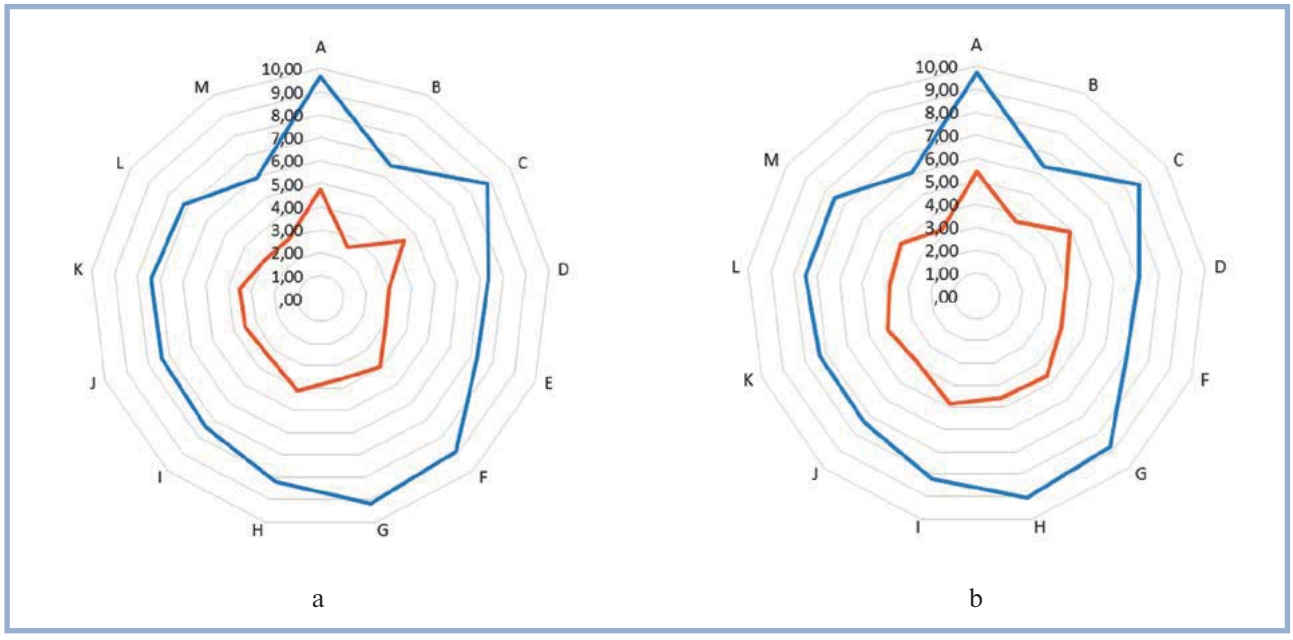


Fig. 4. **The mean profile of pain and quality of life for patients in the short-term (a) and long-term (b) follow-up.**

The external outline is a condition before surgery, the internal outline is a condition after surgery.
A — maximum pain intensity; B — minimum pain intensity; C — rate of pain episodes; D — mean pain intensity; E — need for analgesics; F-M — effect of pain on the overall health (F), mood (G), motor activity (H), passive recreation (I), self-care (J), attitude to others (K), sleep (L), and sexual activity (M).

Table 3. **Pharmacotherapy of pain before stimulation and in association with motor cortex stimulation**

№	Pain history, years	Onset of treatment, years	Treatment before stimulation	Treatment in association with stimulation
1	8	3	AMT, 50 μg/day; GBP, 900 μg/day; TRM, 1.0 up to 4—6 times per day	MPT, 37.5 μg/day; CLZ, 1.0 μg/day; CBZ, 600 μg/day; TRM, 1.0 once a day
2	3	0	CBZ, 1,200 μg/day	CLZ, 2.0 μg/day; CBZ, 600 μg/day
3	2	1	AMT, 75 μg/day; GBP, 900 μg/day; TRD, 1.0 up to 4—6 μg/day	GBP, 600 μg/day; CLZ, 1.0 μg/day; TRD — dr
4	3	0	AMT, 75 μg/day; GBP, 900 μg/day; DZP, 10 μg + CP, 100 μg once a day; TRD, up to 400 μg/day	GBP, 600 μg/day; HXZ, 25 μg/day; TRD, 1.0 once a day
5	2	0	NSAIDs and TRD, up to 4 times per day. After application to the Institute: AMT, 20 μg/day; GBP, 900 μg/day; TRD, up to 400 μg/day	Initially, the patient refused analgesics; later: AMT, 30 μg/day; CLZ, 1.0 μg/day
6	2	1	CBZ, 1,200 μg/day	CBZ, 600 μg/day; GBP, 900 μg/day
7	7	0	TZD, 24 μg/day; CTD, 600 μg/day; TRD, 150 μg/day	CBZ, 300 μg/day; PRX, 20 μg/day. Doses of CTD, TRD, and TZD
8	7	2	GBP, 1,800 μg/day; CLZ, 2.0 μg/day; TRD, 400 μg/day	GBP, up to 900 μg/day; CLZ, 1.0 μg/day; TRD — dr
9	8	0	CBZ, 600 μg/day; AMT, 75 μg/day; GBP, 1,800 μg/day; TRD, up to 1 g/day	AMT, GBP, and TRD — dr. CBZ, 600 μg/day; CLZ, 1.0 μg/day
10	2	0	CBZ, up to 1,400 μg/day; GBP, up to 1,800 μg/day; DLX, up to 60 μg/day; TRD, up to 600 μg/day	TRD — dr. GBP, up to 900 μg/day; CLZ, 1.5 μg/day
11	6	3	PGB, up to 600 μg/day; AMT, 75 μg/day; CLZ, 2.0 μg/day; TRD, i/m, up to 4 times per day	CLZ, 2.0 μg/day; PGB, up to 300 μg/day; AMT, up to 50 μg/day; TRD — dr
12	6	3	GBP, up to 1,800 μg/day; TRD, tabs and i/m, up to 8 times per day; AMT, up to 150 μg/day	GBP, up to 900 μg/day; TRD, up to 400 μg/day; AMT, up to 75 μg/day
13	2	1	CBZ, up to 600 μg/day; CTP, 10 μg/day; CLZ, 2.0 μg/day; ANF, 50 μg/day; PGB, 600 μg/day; TRD, PGB, up to 600 μg/day;	PGB, up to 450 μg/day; ANF, 50 μg/day; TRD — dr
14	2	0.5	TRD, up to 400 μg/day; CBZ, 600 μg/day; AMT, 75 μg/day; narcotic analgesics	GBP, 900 μg/day; AMT, 75 μg/day; TRD, 1.0 i/m, up to 2 times per day; narcotic analgesics — dr
15	5	2	GBP, up to 1,800 μg/day; AMT, 75 μg/day; TRD, i/m, up to 4 times per day	GBP, up to 900 μg/day; AMT, 59 μg/day; TRD, 0.01 up to 2 times per day
16	7	2	AMT, 50 μg/day; PGB, up to 600 μg/day; CBZ, up to 600 μg/day; TRD, i/m, up to 10 times per day; BTP, i/m, up to 10 times per day	PGB, up to 300 μg/day; AMT, 75 μg/day; CLZ, 1.0 μg/day; TRD, 1.0 i/m, 1—2 times per day
17	12	10	TRD, KTR, MRP. During last 2 years: CBZ, 1,200 μg/day; AMT, 75 μg/day	In the period of effective stimulation: TRD, 1.0 i/m, up to 3 times per day; CBZ, up to 1,000 μg/day; AMT, 75 μg/day
18	4	0	CBZ, 1,000 μg/day; PGB, 600 μg/day;	Refusal of medications
19	2	2	CLZ, up to 2.0 μg/day; PGB, up to 600 μg/day; no AMT	AMT, up to 50 μg/day; CLZ, up to 2.0 μg/day
20	6	2	AMT, 75 μg/day; GBP, up to 1,800 μg/day	In the period of effective stimulation: ANF, 75 μg/day; GBP, up to 600 μg/day

Footnote. GBP — gabapentin, PGB — pregabalin, CBZ — carbamazepine, AMT — amitriptyline, ANF — anafranil, MPT — maprotiline, DLX — duloxetine, CTP — citalopram, PRX — paroxetine, HXZ — hydroxyzine, CLZ — clonazepam, DZP — diazepam, TZD — tizanidine, KTR — ketorol, MRP — morphine, TRD — tramadol, BTP — butorphanol, NSAIDs — non-steroid anti-inflammatory drugs, dr — drug refusal/dose reduction.

In not all cases of the present study, we were able to find a direct relationship between the motor function preservation or TMS efficacy and the result of chronic motor cortex stimulation; however, this correlation was present in most cases. The state of motor function and the results of transcranial magnetic stimulation and epidural cortical stimulation during follow-up are presented in **Table 4**.

All patients were admitted to implantation of cortical electrodes based on positive results of repetitive transcranial magnetic stimulation. For example, a patient 3 with flaccid peripheral paresis of the right arm, worsening to plegia in the distal arm, noted a good and relatively stable analgesic effect associated with chronic ES. In the same patient, we also observed a distinct analgesic effect of TMS that lasted several hours.

A patient 7 with central tetraparesis after a spinal cord injury at the cervical level had a positive result of TMS; a good effect of stimulation lasted for 3 years, and not only pain but also spasticity regressed. A further reduction in the analgesic effect of ES was accompanied by a parallel increase in the

Table 4. **Motor function and outcomes of transcranial magnetic stimulation and epidural cortical stimulation during follow-up**

No.	Gender	Age, years	Pain history, years	Motor function	TMS outcome: pain regression level (VAS score and duration)	Outcome of epidural cortical stimulation during follow-up
1	M	42	8	Peripheral monoparesis, up to 2—3 points	>50%, >1 h	Negative effect after 10 months
2	F	64	3	No paresis	70%, several hours	Positive. The patient died after 3 years
3	F	45	2	Peripheral monoparesis of the right arm, up to 3 points in the proximal arm and up to plegia in the distal arm	Not less than 30%, several hours	Positive
4	F	56	3	Peripheral monoparesis of the left arm, up to 3 points, and central monoparesis of the left leg, up to 4 points	>50%, 2 days	Positive
5	F	42	2	Monoplegia of the left arm	Not less than 30%, several hours	Positive
6	F	39	2	No pareses	Less than 30%, up to 1 hour	Negative test stimulation
7	F	54	7	Spastic tetraparesis, up to 1—2 points, in the distal parts and up to 3 points in the proximal parts	Pain regression by 50% (VAS); spasticity regression by 2 points (Ashworth); few hours	Stimulation effect disappeared after 3 years
8	M	42	7	Peripheral monoparesis of the right arm, up to 3 points	>50%, several hours	Positive. Communication with the patient was lost
9	F	26	8	No paresis	>50%, 3 h	Positive
10	M	50	2	No paresis	90%, several hours	Positive
11	F	51	6	No apparent paresis	>30%, 1 h	Positive
12	M	46	6	Functional stumps. No paresis	>70%, 6 h	A system was removed due to complications
13	M	61	2	Left-sided central hemipares, up to 4 points	>50%, 2 h	Positive
14	F	46	2	Peripheral monoparesis of the right arm, up to 2—3 points	>50%, 2 h	Positive
15	M	59	5	Left-sided central hemipares, up to 4 points	>50%, 1 day	Positive
16	M	60	7	A stump is functional	>50%, 1 h	Positive
17	M	60	12	Peripheral monoparesis of the right arm, up to 4 points in the proximal arm and up to plegia in the distal arm	>50%, 1 h	Negative effect after 5 months
18	M	73	4	No paresis	90%, 1 day	Positive
19	F	59	2	No paresis	>50%, 1 day	Positive
20	M	74	6	Central left-sided hemiparesis, up to 4 points in the arm and up to 3 points in the leg	30%, 30 min	Positive. A stimulator was removed because of complications

neurotization level on the background of dramatic events in the patient family life. It should also be noted that the antispasmodic effect of ES, in contrast to the analgesic effect, remained stable. In a patient 6 without motor dysfunction and with a positive result of TMS, the stimulation efficacy vanished in the test period. It is noteworthy that another, more significant prognostic factor — the intensity of a psychogenic pain component that we were not able to identify before test stimulation, prevailed in this case. A patient 12 with severe phantom pain in the left limbs noted significant pain relief associated with stimulation for a long time, until the development of a complication (see above), so he was able to work. Most likely, the absence of the limb in the case of phantom pain and the lack or gross limitation of movements in the "formally" existing limb are not prognostically equivalent. This is indicated by both the positive results of chronic ES of the motor cortex in the case of phantom limb pain, which are described in the current literature, and the positive results in all patients with phantom limb pain in our small series. With all things being equal, the intensity of a psychogenic pain component and a high neurotization level are the key predictor for motor cortex ES in particular and for any of the neurostimulation techniques in general.

Apparently, some uncertainty of the patient selection criteria and predictors for the efficacy of motor cortex stimulation in the treatment of chronic pain syndromes is associated with the fact that the mechanisms of cortical stimulation still remain unclear [14, 25]. Today, the most prevailing theory is activation of structures of the antinociceptive system [14, 25, 26]. In recent animal studies [28, 30, 31, 39], it was hypothesized that a prolonged analgesic effect of MCS may be due to activation of the descending antinociceptive system, including periaqueductal gray matter, as well as activation-associated changes in protein synthesis and increased secretion of inflammatory mediators at the segmental level. N. Reyns et

al. [32] demonstrated that motor cortex stimulation affects the beta rhythm changes characteristic of neuropathic pain.

Therefore, despite the common view on the mechanism of motor cortex stimulation in general, more detailed neurophysiological and neurobiochemical effects underlying the mechanism still remain poorly understood.

Conclusion

Chronic epidural ES of the motor cortex is an effective treatment for a variety of severe drug-resistant neurogenic pain syndromes. If the effect reduces during the follow-up period, it can be restored by a periodic variation of the ES parameters.

The positive result of transcranial magnetic stimulation may be a predictor of a good result of chronic motor cortex stimulation, but implantation of the entire system for stimulation is advisable to perform after a test period of 10—14 days. A pronounced psychogenic component in the chronic pain picture and a high neurotization level are predictors of a negative result of chronic neurostimulation in the case of long-term follow-up.

Enhancing the MCS efficacy can be achieved by repeated re-programming of a system, improvement of neurostimulators and electrodes, and clarification of ideas about the mechanisms of motor cortex stimulation and the principles of patient selection. Further research is needed to clarify the criteria for patient selection and predictors of the long-term efficacy of MCS in the treatment of neuropathic pain syndromes.

Authors declare no conflict of interest.

REFERENCES

1. Rasche DI, Ruppolt M, Stippich C, Unterberg A, Tronnier VM. Motor cortex stimulation for long-term relief of chronic neuropathic pain: a 10 year experience. *Pain*. 2006;121(1-2):43-52.
2. Nguyen JP, Velasco F, Brugières P, Velasco M, Keravel Y, Boleaga B, Brito F, Lefaucheur JP. Treatment of chronic neuropathic pain by motor cortex stimulation: results of a bicentric controlled crossover trial. *Brain Stimulation*. 2008;1(2):89-96.
   doi: 10.1016/j.brs.2008.03.007.
3. Velasco F, Argüelles C, Carrillo-Ruiz JD, Castro G, Velasco AL, Jiménez F, Velasco M. Efficacy of motor cortex stimulation in the treatment of neuropathic pain: a randomised double-blind trial. *Journal Of Neurosurgery*. 2008;108(4):698-706.
   doi: 10.3171/JNS/2008/108/4/0698.
4. Lefaucheur JP, Drouot X, Cunin P, Bruckert R, Lepetit H, Créange A, Wolkenstein P, Maison P, Keravel Y, Nguyen JP. Motor cortex stimulation for the treatment of refractory peripheral neuropathic pain. *Brain*. 2009;132(6):1463-1471.
   doi: 10.1093/brain/awp035.
5. Lima MC, Fregni F. Motor cortex stimulation for chronic pain: systematic review and meta-analysis of the literature. *Neurology*. 2008;70(24):2329-2337.
   doi: 10.1212/01.wnl.0000314649.38527.93.
6. Fontaine D, Hamani C, Lozano A. Efficacy and safety of motor cortex stimulation for chronic neuropathic pain: critical review of the literature. *Journal of Neurosurgery*. 2009;110(2):251-256.
   doi: 10.3171/2008.6.17602.
7. Nguyen JP, Lefaucheur JP, Raoul S. et al. Motor cortex stimulation for the treatment of neuropathic pain. In: *Neuromodulation*. Eds. Krames ES, Peckham PH, Rezai AR. Amsterdam: Elsevier. 2009;515-526.
8. Levy RM. Motor cortex stimulation for chronic pain: panacea or placebo? *Neuromodulation*. 2014;17(4):295-299.
   doi: 10.1111/ner.12209.
9. Sachs AJ, Babu H, Su Y-F, Miller KJ, Henderson JM. Lack of Efficacy of Motor Cortex Stimulation for the Treatment of Neuropathic Pain in 14 Patients. *Neuromodulation*. 2014;17(4):303-310.
   doi: 10.1111/ner.12181.
10. Isagulyan E. *Chronic electrical stimulation of the spinal cord and brain in treatment of neurogenic pain syndromes [dissertation]*. Moscow; 2006. Available at: http://dlib.rsl.ru/01004299840. Accessed 12.12.2014. (In Russ.).
11. Isagulyan E, Shabalov V. Surgical treatment of central pain syndromes. *Neyrokhirurgiya*. 2009;3:8-16. (In Russ.).
12. Adashinskaya G, Enikolopov S, Meyzerov E. Pain and color. *Psikhologicheskiy Zhurnal*. 2005;26(3):74-80. (In Russ.).
13. Henderson JM, Boongird A, Rosenow JM, LaPresto E, Rezai AR. Recovery of pain control by intensive reprogramming after loss of benefit from motor cortex stimulation for neuropathic pain. *Stereotactic And Functional Neurosurgery*. 2004;82:207-213.
14. Ostergrad T, Munyon C, Miller JP. Motor cortex stimulation for chronic pain. *Neurosurgery clinics of North America*. 2014;25(4):693-698.
   doi: 10.1016/j.nec.2014.06.004.
15. Nuti C, Peyron R, Garcia-Larrea L, Brunon J, Laurent B, Sindou M, Mertens P. Motor cortex stimulation for refractory neuropathic pain: four year outcome and predictors of efficacy. *Pain*. 2005;118(1-2):43-52.
16. André-Obadia N, Mertens P, Lelekov-Boissard T, Magnin M, Garcia-Larrea L. Is Life Better After Motor Cortex Stimulation for Pain Control? Results at Long-Term and their Prediction by Preoperative rTMS. *Pain Physician*. 2014;17(1):53-62.
17. Son BC, Kim DR, Kim HS, Lee SW. Simultaneous Trial of Deep Brain and Motor Cortex Stimulation in Chronic Intractable Neuropathic Pain. *Stereotactic and Functional Neurosurgery*. 2014;92(4):218-226.
   doi: 10.1159/000362933.
18. Torrance NI, Ferguson JA, Afolabi E, Bennett MI, Serpell MG, Dunn KM, Smith BH. Neuropathic pain in the community: More under-treated than refractory? *Pain*. 2013;154:690-699.
   doi: 10.1016/j.pain.2012.12.022.
19. Carroll DI, Joint C, Maartens N, Shlugman D, Stein J, Aziz TZ. Motor cortex stimulation for chronic neuropathic pain: a preliminary study of 10 cases. *Pain*. 2000;84:431-437.
20. Katayama Y, Fukaya C, Yamamoto T. Poststroke pain control by chronic motor cortex stimulation: neurological characteristics predicting a favorable response. *Journal of Neurosurgery*. 1998;89:585-591.
21. Nguyen JP, Nizard J, Keravel Y, Lefaucheur JP. Invasive brain stimulation for the treatment of neuropathic pain. *Nature Reviews Neurology*. 2011;7(12):699-709.
   doi: 10.1038/nrneurol.2011.138.
22. Lefaucheur JP, Ménard-Lefaucheur I, Goujon C, Keravel Y, Nguyen JP. Predictive value of rTMS in the identification of responders to epidural motor cortex stimulation therapy for pain. *Journal of Pain*. 2011;12(10):1102-1111.
   doi: 10.1016/j.jpain.2011.05.004.
23. Yamamoto T, Katayama Y, Hirayama T, Tsubokawa T. Pharmacological classification of central post-stroke pain: comparison with the results of chronic motor cortex stimulation therapy. *Pain*. 1997;72:5-12.
24. Saitoh Y, Kato A, Ninomiya H, Baba T, Shibata M, Mashimo T, Yoshimine T. Primary motor cortex stimulation within the central sulcus for treating deafferentation pain. *Acta Neurochirurgica Supplement*. 2003;87:149-152.
25. Sukul VV, Slavin KV. Deep Brain and Motor Cortex Stimulation. *Current Pain and Headache Reports*. 2014;18(7):427.
   doi: 10.1007/s11916-014-0427-2.
26. Garcia-Larrea L, Peyron R. Motor cortex stimulation for neuropathic pain: from phenomenology to mechanisms. *Neuroimage*. 2007;37:Suppl 1:71-79.
27. Lefaucheur JP, Holsheimer J, Goujon C, Keravel Y, Nguyen JP. Descending volleys generated by efficacious epidural motor cortex stimulation in patients with chronic neuropathic pain. *Experimental Neurology*. 2010;223(2):609-614.
   doi: 10.1016/j.expneurol.2010.02.008.

28. Pagano RL, Fonoff ET, Dale CS, Ballester G, Teixeira MJ, Britto LR. Motor cortex stimulation inhibits thalamic sensory neurons and enhances activity of PAG neurons: Possible pathways for antinociception. *Pain*. 2012;153(12):2359-2369.
doi: 10.1016/j.pain.2012.08.002.

29. Chiou RJ, Chang CW, Kuo CC. Involvement of the periaqueductal gray in the effect of motor cortex stimulation. *Brain Research*. 2013;1500:28-35.
doi: 10.1016/j.brainres.2013.01.022.

30. Kudo K, Takahashi T, Suzuki S. The changes of c-Fos expression by motor cortex stimulation in the deafferentation pain model. *Neurologia Medico-Chirurgica*. 2014;54(7):537-544.

31. Silva GD, Lopes PSS, Fonoff ET, Pagano RL. The spinal anti-inflammatory mechanism of motor cortex stimulation: cause of success and refractoriness in neuropathic pain? *Journal of Neuroinflammation*. 2015;20:12(1):10.

32. Reyns N, Derambure P, Duhamel A, Bourriez JL, Blond S, Houdayer E. Motor cortex stimulation modulates defective central beta rhythms in patients with neuropathic pain. *Clinical Neurophysiology*. 2013;124(4):761-769.
doi: 10.1016/j.clinph.2012.10.011.

Commentary

The review of clinical experience with motor cortex stimulation for treatment of refractory chronic neuropathic pain syndromes is of great interest, and I would congratulate the authors for the excellent results and a detailed analysis of the clinical data.

The presented study is one of the world's largest trials conducted at a single institution. Since the introduction of motor cortex stimulation in the treatment of various neuropathic pain syndromes, researchers and clinicians at various medical centers have tried to establish criteria for selection of ideal candidates for surgery as well as predictors of successful outcomes. But so far, all these attempts have not led to the development of a comprehensive and universal protocol. This fact partly explains why motor cortex stimulation has not become a widespread treatment for pain and has not received official approval in many countries.

In this situation, the authors' experience is even more valuable. In addition to the very detailed and exhaustive review of the literature, the authors collected comprehensive clinical material and compared related series of carefully selected patients who were examined and eventually treated by motor cortex stimulation. The authors analyzed the results of stimulation based on the baseline pain intensity level as well as other factors, such as age, gender, disease duration, results of various clinical and psychological tests, and also results of preoperative test transcranial magnetic stimulation of the cerebral cortex.

In addition to the most understandable presentation of the authors' approach to selection of patients and the detailed description of the surgical technique, the article presents a detailed and very informative description of follow-up in all patients. This detailed information deserves publishing in a peer-reviewed journal to make these data available to other researchers for further analysis.

One of the most important findings in the presented study is the safety of the technique that was confirmed by the lowest possible complication rate and the lack of any serious negative impact on the quality of life of operated patients. This gratifying fact certainly encourages us to recommend using motor cortex stimulation in cases where other treatments do not lead to a significant decrease in the pain intensity.

The treatment success rate varied depending on the individual features of patients, and I agree with the authors that it is impossible to make comprehensive conclusions in the case of a small number of patients in each diagnostic group. However, I support the authors' conclusions on the satisfactory efficacy and safety of motor cortex stimulation. On the basis of my own experience, I continue to use this treatment for some specific indications. In my practice, motor cortex stimulation is used only in patients with post-stroke central deafferentation pain syndromes as well as with facial anesthesia dolorosa after surgery for the trigeminal nerve.

In our practice, we use MRI to localize the motor cortex and integrate the obtained data into a navigation system. We identify the stimulation target by neurophysiological monitoring. Our surgical approach involving high field MRI was presented in a previously published paper [1]. Actually, motor cortex stimulation was indicated in our previously published algorithm for facial pain treatment [2, 3].

I think the most important conclusion of this work is that preoperative transcranial magnetic stimulation is not a predictor for the efficacy of motor cortex stimulation — this problem was previously discussed in the literature. Also, I agree with the authors' idea that preservation of the motor function is not a prerequisite for achieving a significant clinical improvement in patients with motor cortex stimulation.

However, I would like to add to the authors' presentation that, although motor cortex stimulation works even in the absence of movements in the affected part of the body, but preservation of the motor cortex is required. According to our experience, motor cortex stimulation is not effective in patients with central post-stroke pain syndromes in whom the motor pathways were not initially damaged by stroke as well as in patients in whom we were unable to localize the motor cortex using preoperative functional MRI.

Konstantin V. Slavin, Professor, Head of the Section of Stereotactic and Functional Neurosurgery, University of Illinois at Chicago, USA

REFERENCES

1. Slavin KV, Thulborn K. Motor cortex stimulator implantation guided by combination of frameless navigation and intraoperative neurophysiology. 2nd Intl Scient Teleconf «New Technology in Medicine», St-Petersburg, Russia. 2005;72-73.

2. Slavin KV, Nersesyan H, Colpan ME, Munawar N. Current algorithm for the surgical treatment of facial pain. Head Face Med. 2007;3(30):1-8.

3. Slavin KV, Nersesyan H, Colpan ME, Munawar N. Algoritmo para el tratamiento quirúrgico del dolor facial. Neurotarget. 2007;2(3):35-44.