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USE OF THERMOELECTRIC HEAT METERS IN LOCOMOTOR THERAPY FOR THE REHABILITATION OF PATIENTS WITH LUMBOSACRAL SPINE INJURIES

The study presents the results of using thermoelectric heat meters in locomotor therapy for the rehabilitation of patients with lumbosacral spine injuries. The conducted clinical studies enable the diagnosis of inflammatory processes, particularly in neurological manifestations of spinal osteochondrosis, and allow monitoring the effectiveness of conservative treatment for degenerative-dystrophic diseases of the lumbosacral spine. The effectiveness of thermoelectric heat meters in medical diagnostics has been confirmed. Bibl. 45, Figs. 4, Tabl. 2.

Key words: thermoelectric heat meter, heat flux density, temperature, thermometric indicators, spinal osteochondrosis, locomotor therapy

Introduction

General problem overview. According to WHO experts, vertebrogenic pain syndromes are highly prevalent worldwide today, becoming one of the most significant medical and social issues. Dorsopathy is a leading cause of disability, significantly affecting patients' quality of life and work capacity, and remains a primary reason for seeking medical care at any age [1].

Back pain is one of the most common complaints prompting patients to seek medical attention. According to some foreign authors, outpatient visits due to lower back pain (LBP) rank second among all medical consultations, surpassed only by respiratory diseases [2]. Studies have shown that in developed countries, 60–90% of the population experience LBP at least once in their lifetime, with an annual increase of 5% [3]. Diagnosing and treating LBP is often challenging due to the etiological heterogeneity of the condition.

Most cases of LBP are benign and of musculoskeletal origin. This type of LBP is referred to as non-specific, in contrast to specific LBP, which is caused by a confirmed primary pathology (e.g., infection, tumor, deformity, osteoporotic or traumatic vertebral fracture, inflammatory process, radicular syndrome, spinal canal stenosis, etc.). Although there is no precise data on the ratio of specific to non-specific LBP, it is generally accepted that 95% of cases fall into the non-specific category [4–30]. More pronounced back pain is observed in individuals aged 50–64 years. It is predicted that in the next 10–15 years, LBP associated with degenerative-dystrophic spinal pathology may become the leading cause of disability among the adult population of Ukraine.

This issue has become especially relevant today, as hundreds of thousands of Ukrainian soldiers are defending their homeland with weapons in hand. The load of 40 to 60 kg that they are forced to carry adds additional strain on the spine. Long-lasting static-dynamic loads also play a role in the onset of pain in the lumbosacral region of the spine.

It should be noted that semiconductor thermoelectric heat flux sensors are promising for studying local heat emissions in humans. These sensors combine miniaturization, high sensitivity, parameter stability over a wide operating temperature range, and compatibility with modern recording equipment [31–41]. The use of such sensors enables high localization and accuracy in thermometric measurements. This makes it possible to obtain detailed information about the heat emission of a specific area of the human body and analyze it thoroughly to detect inflammatory processes in the body at early stages.

Therefore, *the aim of this study* is to investigate thermometric indicators in patients with chronic lower back pain and pain syndrome associated with degenerative-dystrophic diseases of the lumbosacral spine using thermoelectric heat meters in locomotor therapy.

Materials and Methods of Clinical Research

The clinical studies were conducted in the laboratory of neuroorthopedics and pain problems, and in the rehabilitation department of the State Institution "Institute of Traumatology and Orthopedics of the National Academy of Medical Sciences of Ukraine." The following tasks were set during these studies:

- To study the changes in the neurological status of patients with lumbar spine osteochondrosis with spinal canal stenosis at this level in the preoperative period, who were diagnosed with acute or chronic pain syndrome;
- To identify a clinical marker of pain syndrome chronification in patients at the preoperative preparation stage;
- To examine patients with chronic pain syndrome who have linear instability in the lumbosacral spine, and clinically and paraclinically, using thermoelectric thermometers, perform measurements of temperature and heat flux density in the studied areas of the human body;
- To investigate changes in thermometric parameters in patients in the lumbar region and lower limbs in cases of degenerative-dystrophic pathology of the lumbosacral spine.

A total of 62 patients were examined, all of whom were diagnosed with stenosis of the spinal canal at the lumbosacral level and developed pain syndrome. Among them, 45 patients were of young age, and 17 were of middle age. All underwent surgery using the biportal endoscopic microdiscectomy method. The majority of these patients had central stenosis of the spinal canal with moderate disc hernias and protrusions. A comparison group consisted of 15 patients who received conservative reflexotherapy treatment.

In the studied patients, both upon hospitalization and during the course of treatment, anamnesis, subjective, and objective data were examined. When gathering the anamnesis and performing objective examinations, the following information was taken into account: the patient's sex and age; duration of

the disease and the age at onset; duration and nature of the most recent exacerbation; provoking factors that aggravated or alleviated pain in the back and leg; clinical characteristics of the first exacerbation; the patient's constitutional type; type of vertebral deformity; the nature of surgical treatment and its extent. All patients underwent a detailed clinical and neurological examination.

To objectify the data, the following indicators were determined in the patients:

- The severity of the pain syndrome and its qualitative indicators;
- Tension of the paravertebral muscles;
- Lasègue's symptom coefficient;
- Sensory disturbances and the nature of paresthesia.

The Lasègue's sign was assessed on a five-point scale [42, 43]. Grade I corresponds to the ability to raise the leg to 90º, but with mild pain along the posterior surface of the lower limb. Grade II is characterized by moderate pain when raising the leg at an angle of 75–89º. Grade III involves moderate pain when raising the leg at an angle of 45–74º. Grade IV is characterized by severe pain when raising the leg at an angle of up to 45º. Grade V involves sharp pain when the leg is extended, with the patient adopting a forced position –lying with the knee bent.

To assess the mobility of the lumbar spine, the Schober test and the finger-to-floor test (FFT) were performed. The Schober test involved marking the spinous process of the L_V vertebra while the patient stood upright. A 10 cm distance was measured upwards from this point, and a second mark was made. After the patient performed a maximum forward bend, the distance between the two marks was measured again, and the increase was assessed. Normally, the increase should be 4–5 cm.

The finger-to-floor test (FFT) was conducted with straight knees. The patient was asked to reach down and touch the floor with their fingers, and the distance from the tip of the third finger of the outstretched hand to the floor was measured at the maximum forward bend. Normally, this distance should be between 0 and 10 cm [44, 45].

One of the established factors of pain chronification is the emergence and prolonged presence of a neuropathic component of pain, which has specific characteristics (descriptors, sensory disturbances in the area of innervation of a certain nerve). The DN4 questionnaire was used to assess the presence of the neuropathic component of pain, which is a crucial criterion for the involvement of central mechanisms in the development of the pain syndrome. It includes 7 items related to sensory symptoms (burning, cold sensations, electric shock feeling, tingling, crawling sensation, prickling, numbness, itching) and 3 items related to neurological examination (hypesthesia to touch with the hand, hypesthesia to pinprick, allodynia). Each item was scored as 1 or 0. If the total score was four or more out of ten, it indicated the presence of a neuropathic component of the pain syndrome.

The strength of the muscles, both paravertebral and lower limb muscles, was assessed using a five-point scale, where the strength of an intact muscle was assigned 5 points.

The assessment of the intensity of paravertebral muscle tension was carried out in three degrees [42, 45]. In grade I, the muscle tension is soft, the finger easily sinks into it, and only swelling of the muscle is noted. In grade II, the muscle has moderate density, it bulges, and the finger can only sink into it with some effort. In grade III, the muscle has a stone-like density and is almost impossible or absolutely impossible to deform during palpation.

For a comprehensive assessment and comparison of the pain syndrome between groups, both qualitative (descriptors) and quantitative (intensity and severity) evaluations were conducted. The quantitative assessment involved evaluating the patient's subjective judgment of their pain sensations, for which the visual analogue scale (VAS) was used. This scale consists of a 10 cm line marked from 0 to 10, where 0 represents no pain and 10 represents the most intense pain the patient has ever felt. The

subjective pain assessment was classified as follows: 1–3 points for mild pain, 4–5 points for moderate pain, 6–7 points for strong pain, 8–10 points for unbearable pain.

For the qualitative assessment of pain, the McGill Pain Questionnaire was used, which contains 78 descriptors that characterize the nature of the pain. The descriptors are divided into three classes, increasing in meaning. The first class (items 1–13) covers the sensory characteristics of pain, the second class (items 14–18) addresses the psychoemotional aspects, and the third class (item 20) represents the verbal scale of pain intensity. The patient was asked to choose one word from each class that best reflected their pain sensations. The result of the survey was used to determine two main indicators: the rank pain index (the sum of the ordinal numbers of the chosen words or their average value) and the number of selected words. The obtained data do not have absolute values and are subject to statistical interpretation. These data were used to assess not only the pain but also the psychoemotional experience associated with the pain.

At the next stage, we conducted research on the thermal and thermometric indicators of the skin surface in the lower back area and the injured leg in civilians with degenerative-dystrophic pathology of the lumbosacral spine, without signs of spinal canal stenosis at this spinal level. The study was conducted using a multichannel thermoelectric thermometer developed at the Institute of Thermoelectricity of the National Academy of Sciences and the Ministry of Education and Science of Ukraine [31–41]. The device is designed for simultaneous measurement of temperature and heat flux density on the surface of the human body using a contact method. To process the data from the electronic recorder, store, and reproduce them in a specified form on a personal computer, the specialized software "TermoMonitor" was used, which allows real-time monitoring of the human temperature and thermal state.

In the room where the patients were examined, the temperature was constantly maintained within the range of 20–25°C, with relative humidity of 50–60%. There were no sources of infrared radiation. Prior to the examination, all physiotherapeutic and warming procedures were discontinued for the patients; they were also instructed to stop taking anti-inflammatory, antipyretic, vasodilatory, or vasoconstrictive medications. Patients were asked to refrain from smoking for 3–4 hours before the examination. Two to three hours before the examination, any topical ointment applications were removed, and the skin surface was degreased with a mixture of 40% ethyl alcohol and ether (in a 4:1 ratio). Immediately before the examination, patients underwent a 15–20 minutes temperature adaptation period. During this time, they remained in a state of physical rest, with no static or dynamic muscle tension. Thermometric measurements on the patient's skin surface were conducted in real time for 3 minutes. The following were noted: the time of thermal adaptation (in seconds) – t (how long it took from the start of the examination until the main indicators reached the thermal “plateau”), temperature and heat flux density values at the height of this “plateau”, and the shape of the curves themselves. The thermoelectric sensors were symmetrically placed on both sides, para-vertebrally at the level of the spinous processes of the L4–L5 vertebrae.

The patients were examined in a state of physiological rest, with the room temperature maintained between 18–22°C, from 9:00 AM to 12:00 PM. In addition to measuring thermometric indicators, the variability of the heart rate was simultaneously assessed, as both of these parameters are regulated by the autonomic nervous system. The main centers for regulating thermal exchange and vascular tone are located in close proximity within the brainstem.

Results of Clinical Research and Discussion

For the analysis of differences and comparison of the clinical course after admission to the hospital and the start of treatment, patients were divided into either the acute pain group (with a pain syndrome duration of up to 3 months) or the chronic pain group (with a duration of more than 3 months).

The acute pain group consisted of 15 patients (all male, with an average age of 39.8 ± 1.2 years), while the chronic pain group consisted of 47 patients (also male, with an average age of 52.1 ± 1.7 years). The control group also included 15 patients with acute pain syndrome (with an average age of 42.4 ± 0.9 years).

The average duration of chronic pain in individuals with chronic pain syndrome was 19.5 ± 1.2 months. In the acute pain group, the duration of the pain in BNCS reached 1.6 ± 0.8 months. In the control group, these figures were 1.1 ± 0.4 months.

Upon evaluating clinical symptoms, lower back pain was recorded in 91.6% of the acute pain group and in 100% of patients in the chronic pain group. Pain radiation to the leg before treatment was present in 100% of patients in the acute pain syndrome group. In individuals with chronic pain, it was noted in 45.1% of patients. Muscle tension in the back was diagnosed in patients from both clinical groups. In individuals with acute pain during the preoperative period, severe muscle tension was observed in 29.4% of patients, moderate tension in 66.9%, and mild tension in 3.7%. In the chronic pain group, severe paravertebral muscle tension was observed in 20.8% of cases, moderate in 69.4%, and mild in 9.8%. Antalgic scoliosis was found in 60.2% of individuals with acute pain and in 24.5% with chronic pain. The difference was statistically significant ($p < 0.05$). The Lasègue sign was present in 96.2% of individuals with acute pain and in 44.7% with chronic pain ($p < 0.05$). However, regarding the degree measurement, its intensity did not differ between the groups, being 40.4 ± 3.7° in the acute pain group and 44.9 ± 2.5° in the chronic pain group ($p > 0.05$).

At the next stage, sensory disturbances at the levels of L5–S1 on both legs were checked. In patients with acute pain, sensory disturbances were found on the homolateral leg, in the form of hypoalgesia to needle pricking in 54.7% of individuals and allodynia to brush touch in 12.7% of cases. In individuals with chronic pain, hypoalgesia to needle touch was observed in 32.1% of individuals, and allodynia to brush touch was found in 38.5% of patients.

In patients from both pain groups, changes in the reflex sphere of the lower limbs were observed. A tendency for decreased knee reflexes on the side of pain was observed in 10.2% of individuals with chronic pain and in 4.5% of individuals with acute pain. Unilateral reduction (or loss) of the Achilles reflex was almost equally common in individuals with acute pain (56.3%) and chronic pain (49.5%).

In patients with acute pain, the Lasègue sign, antalgic scoliosis, and radiation of pain to one or both lower limbs were more commonly observed. In patients with chronic pain, the intensity of pain slightly decreased, but the tension in the paravertebral muscles, particularly in the lumbar region, increased. The angle of the antalgic scoliosis decreased, but it remained constant. The pain increased with the frequency and intensity of physical activity.

It is well-known that limited spinal mobility can worsen treatment outcomes, restrict daily activities, and contribute to the chronicity of pain [45]. Therefore, in our research, we used active tests to assess the static-locomotor function of the spine: the Schober test and the fingertip-to-floor test.

As the studies showed, the Schober test proved to be of limited informativeness (Table 1). However, the fingertip-to-floor test allowed us to clearly differentiate between acute and chronic pain.

As the clinical studies showed, for patients with acute vertebrogenic pain in the lower back, which developed against the background of spinal canal stenosis, the most characteristic symptom was intolerable pain in this region of the spine, radiating to the lower limbs. They also exhibited a positive Lasegue's sign and a decrease or absence of knee and/or Achilles reflexes on the side of the pain. For patients with chronic pain, a more characteristic finding was moderate or severe vertebrogenic pain.

According to the McGill Pain Questionnaire, which provided a qualitative characterization of the pain syndrome, the following was found.

The most commonly encountered pain descriptors were:

- *Burning* – in 38.9% (control group) and in 40% for acute vertebrogenic pain against the background of spinal canal stenosis; in 55.1% for chronic vertebrogenic pain;
- *Stabbing* – in 31.4% (acute pain) and in 30.0% (control group); in 31.6% in individuals with signs of chronic pain;
- *Twisting* – in 35.9% (acute pain group) and in 36.4% of the control group; in 46.4% – in patients from the clinical group with chronic vertebrogenic pain*;*
- *Piercing* – in 40.1% of individuals with acute pain and in 39.7% of the control group; in 43.4% of patients with chronic vertebrogenic pain;
- *Constricting* – in 19.9% of patients with acute vertebrogenic pain and in 21.1% of the control group; in 16.5% of patients with chronic vertebrogenic pain*;*
- *Pulling* – in 31.5% of patients with acute vertebrogenic pain and in 29.4% of patients in the control group; in 59.9% of patients with chronic vertebrogenic pain.

Table 1

Assessment of Static-Locomotor Function of the Spine in Patients with Spinal Canal Stenosis and Different Pain Manifestations

Parameter	Group		
	Control (n = 15)	Acute pain (n = 15)	Chronic pain (n = 47)
Schober's test, cm	5.9 ±0.21	3.4 ± 0.32 P_c >0.05	4.6 ±0.42 P_c >0.05 P_a >0.05
Fingertip-to-floor test, cm	11.2 ± 3.11	22.18 ± 3.41 P_c <0.05	27.4 ± 2.19 P_c <0.05 P_a <0.05

Notes:
P_c – Probability of the difference of the corresponding indicator in the control group;
P_a – Probability of the difference of the corresponding indicator in the acute pain group.

According to the survey results, the descriptor selection index (DSI) was calculated, representing the number (sum) of selected words, as well as the pain rank index (PRI) i.e., the sum of the ordinal numbers of descriptors within subclasses. The indicators were calculated separately for the sensory and affective scales.

The descriptor selection index for the sensory scale was 2.27±0.06 for individuals with acute vertebrogenic pain and 4.02±0.07 for those with chronic pain (p<0.05). The index for the affective scale was 3.04±0.08 for acute pain and 3.40±0.05 for chronic pain, respectively (p>0.05). The pain rank index for the sensory scale was 14.09±1.81 in the acute pain group and 28.15±2.13 in the chronic pain group (p<0.05). For the affective scale, the values were 16.91±3.08 for acute pain and 21.98±1.04 for chronic pain (p<0.05).

Patients with signs of chronic pain gave a more emotional assessment of their pain sensations and, therefore, chose more emotionally charged descriptors. Additionally, the number of selected descriptors was greater in individuals with chronic vertebrogenic pain compared to those with acute pain.

A significant positive correlation was found between the visual analog scale (VAS) and the pain rank index (PRI) for the acute pain group (p<0.05), and a strong correlation for the chronic pain group

(p<0.05). As the pain intensity increased, the significance of the corresponding descriptor also increased in both pain groups.

According to the McGill questionnaire, patients in the chronic pain groups gave a more emotional assessment of their pain sensations, as they chose more emotionally colored descriptors, which were rated with higher scores (p<0.05). The number of selected descriptors was significantly higher in the chronic pain syndrome group (p<0.05).

In the next stage of the research, a survey was conducted with thematic patients to identify the neuropathic component of pain using the DN4 questionnaire [9]. The DN4 questionnaire includes 7 items related to sensory symptoms (burning, cold sensation, electric shock, tingling, crawling sensation, prickling, numbness, itching), as well as 3 items related to neurological examination (hypesthesia to touch with the hand (brush), hypesthesia to pricking, allodynia). Each item was rated 1 or 0 points. If the total score was 4 or more out of 10, it indicated the presence of a neuropathic component in the pain syndrome. It was found that in the control group, the neuropathic component was 2.15 ± 0.91 points; in patients with acute vertebrogenic pain, it was 4.50 ± 1.01 points ($p < 0.05$); in the group of patients with chronic vertebrogenic pain, it reached 7.02 ± 0.80 points ($p < 0.005$).

The neuropathic component in the group of patients with acute vertebrogenic pain was identified in 26.9% of cases. These patients more frequently reported descriptors such as numbness in the leg, burning sensation, electric shock-like feeling, and shooting pain. In individuals with chronic vertebrogenic pain against the background of spinal canal stenosis, the neuropathic component was found in 68.5% of cases. Patients in this group more often complained of tingling/prickling sensations in the leg, occasional numbness in the homolateral side of the leg, cold sensation, and itching. No significant difference in the prevalence of sensory phenomena (allodynia, hypesthesia, or hypoalgesia) between the groups was observed.

At the next stage of the research, measurements of the thermal flux density and skin surface temperature were conducted in the symmetrical paravertebral areas of the lumbar spine and the innervation zone of the L5–S1 nerve roots on the skin surfaces of the thigh, lower leg, and foot. These measurements were taken on both the pain side and the intact opposite leg in patients, predominantly young and middle-aged male individuals. This group consisted of 71 patients aged 39 to 69 years: 20 with signs of lumbosciatica due to intervertebral disc herniations, 20 with lumbosciatica due to intervertebral disc herniations combined with vertebral instability in this area, 11 with spinal canal stenosis, and 20 without pain in the lumbar region but with intervertebral disc herniations and protrusions in the same spinal segment (these individuals formed the control group in this study in relation to those with vertebrogenic pain syndrome).

As the studies showed, in the control group, fluctuations in the main thermometric indicators in the paravertebral areas were symmetrical and practically did not differ according to the "left/right" test. Heat and thermoadaptation of the skin areas in contact with the thermoelectric sensors occurred simultaneously and followed a gradual curve with a clearly visible saturation point. Additionally, in all individuals of the control group, the full range of motion in the lumbosacral spine was preserved, there were no pain sensations in the spinous processes and paravertebral areas in the lumbosacral zone, and no signs of sensory disturbances or reflex changes in the relevant areas were observed. In the control group, the time to reach thermal "saturation" was 45.3±0.3 seconds. The skin temperature in the paravertebral areas was within 34.6±0.5 °C, and the heat flux density was 17.1 ± 0.1 mW/cm².

During the clinical examination of patients with signs of lumbosciatica, caused by the presence of hernias or protrusions in the lumbosacral spine, the following was observed. The patients complained of burning sensations and pain in the lower back and lower limbs, as well as trophic disorders. Their spine

was fixed in a bent position. Unilateral tension symptoms were positive, and 20% of patients exhibited a cross Lasègue's sign. There was a decrease in the range of motion in the lumbar spine, muscle tension in the lumbar area, pain upon palpation and percussion of the paravertebral points, and a sharp restriction of side bending toward the affected side. In the supine position with the lower limbs bent at the hip joints, the pain decreased. The pain was of a pulling nature and was accompanied by coldness, numbness, and tingling in the lower limbs. The skin was pale, cold to the touch, dry (especially in the area of the shin and foot), with signs of hyperkeratosis. White dermographism was noted. Parallel fluctuations in temperature and heat flux density were observed on the painful side, with lower values on the intact side (Fig. 1).

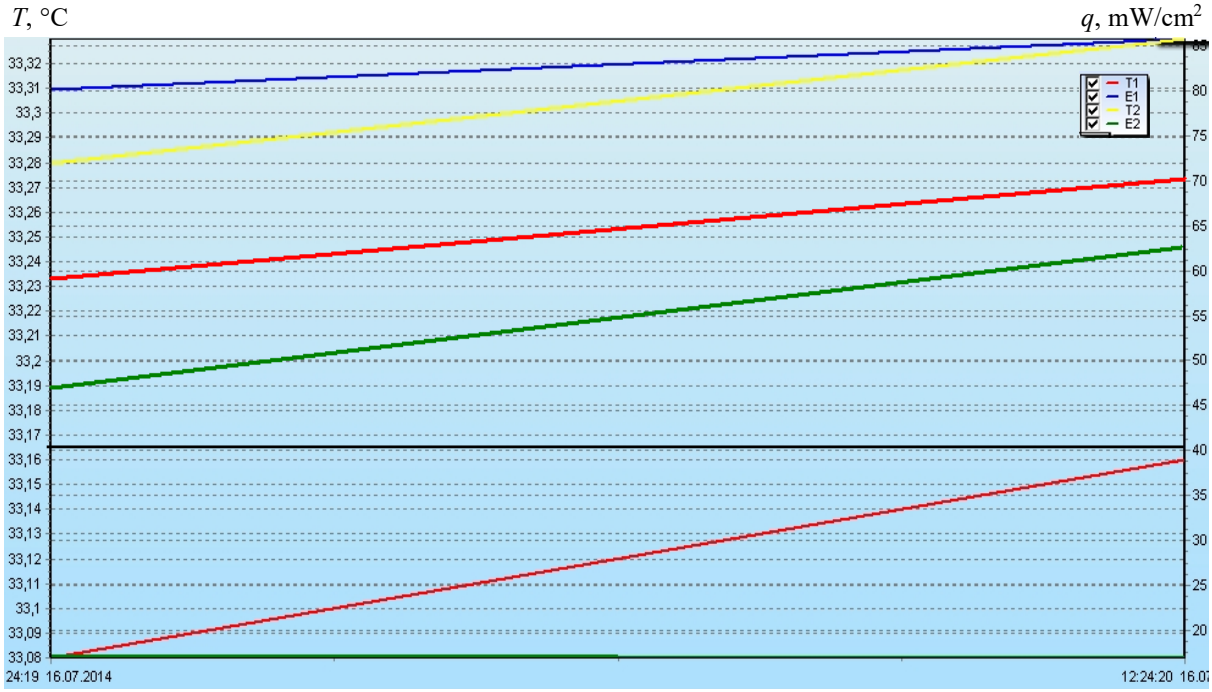

Fig. 1. Graphical representation of temperature and heat flux density indicators in the control group (Patient Ch., 41 years old, medical record No. 526475)

The skin temperature indicators on the painful side were 34.8±0.5 °C, and the heat flux density was 101.6±0.3 mW/cm², while on the intact side, the temperature was 30.6±0.7 °C, and the heat flux density was 71.8±0.4 mW/cm². The time to reach thermal "saturation" was 40.1±0.2 seconds (Fig. 2).

In individuals with signs of lumbosciatica, which occurred against the background of intervertebral disc herniations and protrusions combined with instability in the lumbosacral spine, the pain was bilateral, worsening during flexion or extension of the spine and prolonged sitting, and decreasing with rest. Movements in the lumbar spine were not restricted but painful, especially during flexion. The straight leg raise test provoked bilateral pain in the lower back. Pale skin, a burning sensation, a feeling of fullness, and asymmetry of the white and red dermographism were noted in the lower extremities. Cyanosis and "mottling" of the skin, particularly in the feet, were observed. Associated diseases such as varicose veins in the lower extremities and hemorrhoidal veins were detected, indicating systemic weakness of the venous apparatus.

During thermometric studies in this group of patients, a tendency towards the "scissors" symptom on the side of pain was observed: a sharp increase in thermal flux density to 85.4 ± 0.6 mW/cm² with almost unchanged skin temperature on the painful side (34.7 ± 0.2°C); the time to reach thermal "saturation" was reduced to 39.8 ± 0.8 seconds. On the opposite side, in the paravertebral zone, minor fluctuations in thermometric parameters were observed, which did not exceed physiological norms (Fig. 3).

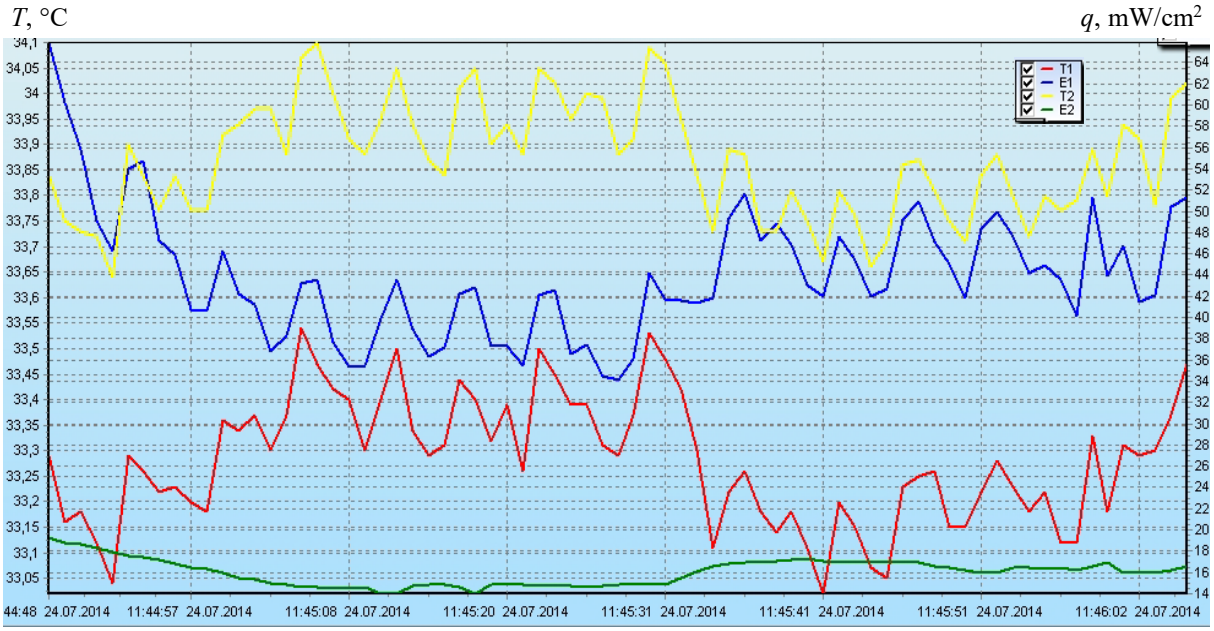

Fig. 2. Graphical representation of the temperature and heat flux density indicators in patients with signs of lumbosciatica due to intervertebral disc herniations and protrusions, without signs of instability in the lumbosacral spine (Patient S., 36 years old, medical history No. 563818)

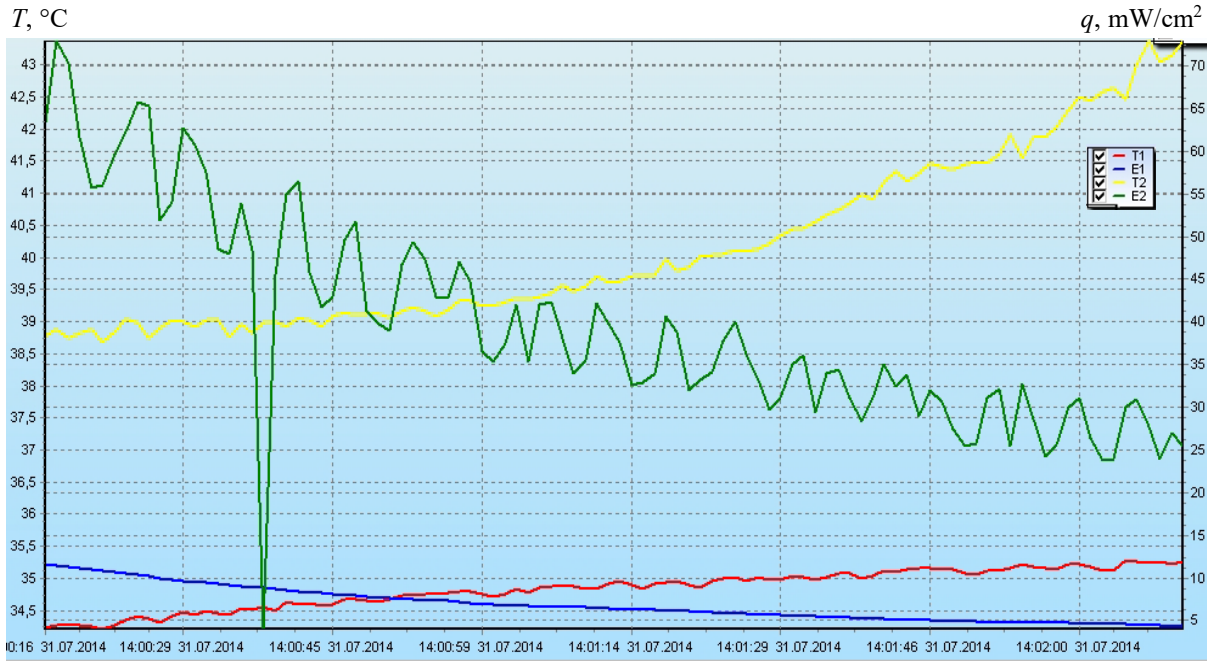

Fig. 3. Graphical representation of temperature and thermal flux density indicators in patients with signs of lumbosciatica due to hernias and protrusions of intervertebral discs in combination with instability in the lumbosacral spine (Patient L., 50 years old, medical history No. 563009).

Patients in whom the pain syndrome developed against the background of spinal canal stenosis in the lumbosacral region noted that the pain persisted for more than two to three months and did not subside with the use of common painkillers and muscle relaxants. Relief was only achieved with the use of epidural adhesiolysis. Upon targeted examination, a decrease in temperature and thermal flux density indicators was found on both sides, but more intensively on the dominant side of the pain (Fig. 4).

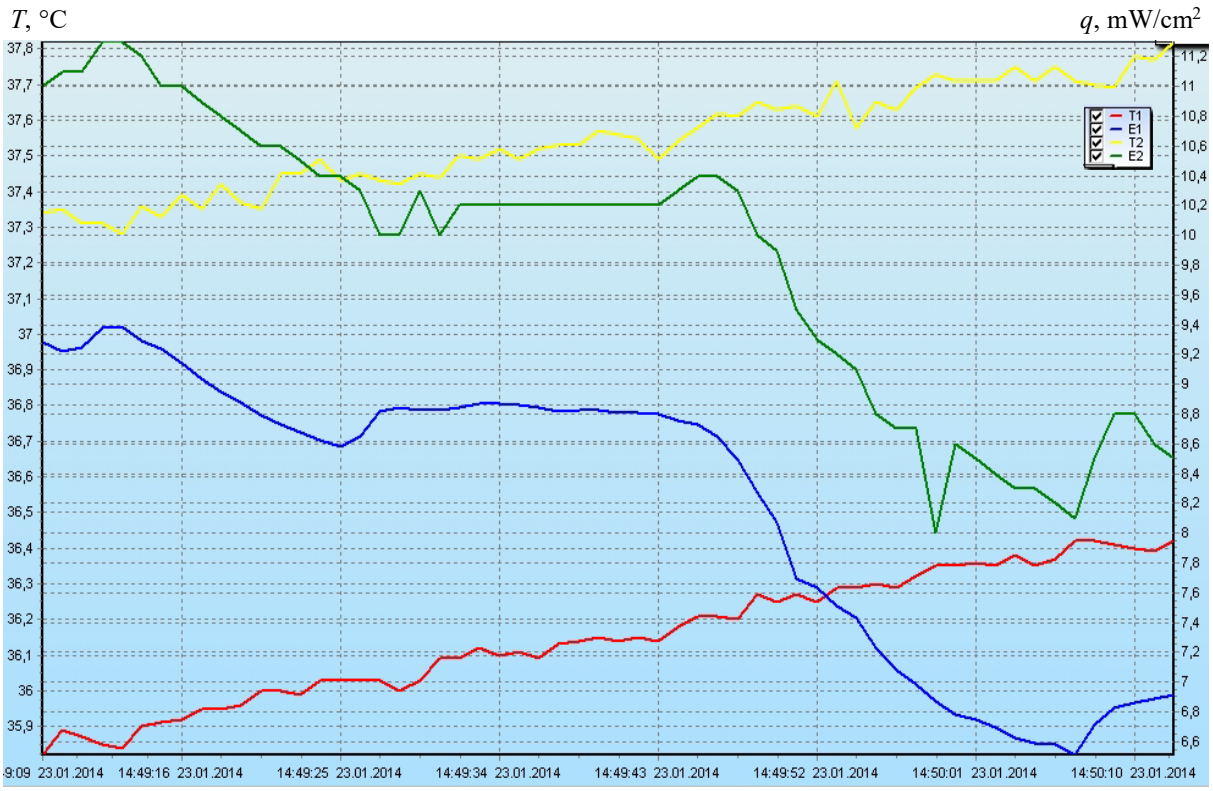

Fig. 4. Graphical representation of the temperature and heat flux density indicators in patients with pain syndrome due to spinal canal stenosis at the lumbosacral level (Patient A., 41 years old, medical history No. 578193).

It should be noted that separately among patients with chronic pain in the lower back are those with linear instability of the vertebrae in this region of the spine. The presence of such a pathology in patients who perform significant physical workloads creates additional strain on the spine, exacerbating pain, especially under conditions of acute stress and nerve strain. Therefore, early detection of this pathology is also of decisive importance.

Thus, the next stage of the study involved examining 55 patients with chronic pain in the lumbosacralregion of the spine caused by pathological mobility of the vertebrae in the lumbosacralsection of the spine. The pain was constant, radiated to one of the lower limbs, significantly limited their daily activities, and intensified at night. In addition to using non-steroidal anti-inflammatory drugs, patients were forced to use anticonvulsants and antidepressants. The duration of the disease ranged from 1 to 5 years. The average age of the patients was 49 ± 3.5 years. All patients were divided into two clinical groups.

The first clinical group consisted of 39 individuals with unilateral lumbosciatica due to the presence of hernias and protrusions of intervertebral discs with signs of linear instability in the lumbosacralsection of the spine, who were undergoing conservative treatment (main group).

The second clinical group included 16 patients with unilateral lumbosciatica due to the presence of hernias and protrusions of intervertebral discs without signs of linear instability in the lumbosacralsection of the spine, who also underwent conservative treatment (comparison group).

The control group consisted of 10 individuals without pain syndrome, despite the presence of hernias and protrusions of intervertebral discs, and without signs of linear instability in the lumbosacralsection of the spine. The average age of the patients was 49 ± 3.5 years.

Patients in the clinical group I complained of burning sensations and pain in the lower back and

lower limbs, as well as trophic disorders. Their backs were fixed in a bent position. Unilateral stretch symptoms were positive, and 20% of patients showed a cross Lasègue sign. Decreased range of motion in the lumbar spine, muscle tension in the lumbar area, pain during palpation and percussion of paravertebral points, and sharp restriction of bending to the affected side were observed. When lying on their backs with bent lower limbs at the hip joints, pain decreased. The pain was of a pulling nature, accompanied by coldness, numbness, and a tingling sensation in the lower limbs. The skin was pale, cold to the touch, dry, and showed signs of hyperkeratosis. White dermographism was observed.

In patients of the clinical group II, the pain was bilateral, intensified during flexion or extension of the spine and prolonged sitting, and decreased at rest. The range of motion in the lumbar spine was not restricted, but painful, especially during flexion. A bilateral pain in the lower back appeared during the stretch test. Pale skin, burning sensations, a feeling of fullness, and asymmetry of white and red dermographism in the lower limbs were noted. Cyanosis and "marmoration" of the skin, mostly on the feet, were observed. Comorbid conditions included varicose veins of the lower limbs and hemorrhoidal veins, indicating a systemic weakness of the venous apparatus.

The conducted clinical studies allowed us to conclude that the spastic type of vascular reactions in the lower back and lower limbs is a direct indication for performing manual therapy in patients; while the dilatation type of vascular reactions in this area of the spine only requires the implementation of certain elements of kinesitherapy in patients.

At the next stage of the research, measurements of thermal and thermometric indicators were conducted in the paravertebral regions and along the nerve roots of L4-S1. The following results of the measurements were obtained.

Control group: The temperature and heat flux density indicators were uniform on both sides within the following ranges: $T = 33.2 \pm 0.5$°C, $Q = 171.3 \pm 0.6$ mW/cm².

In individuals from the first – main group (39 individuals): the "scissors" symptom was observed on the side of pain (temperature and heat flux density intersecting on the side of pain), with a significant decrease in the heat flux density values and a moderate increase in temperature on the affected side. The temperature and heat flux density indicators in the paravertebral area on the side of pain were: $T = 34.19 \pm 1.71$°C, and the heat flux density was within $Q = 26.82 \pm 4.98$ mW/cm².

In the comparison group – the second clinical group (16 individuals) – a moderate decrease in the thermal flux density on the pain side and a slight increase in temperature on the pain side were observed. The values of the thermometric parameters were as follows: $T = 39.8 \pm 6.29$°C, $Q = 120.6 \pm 99.20$ mW/cm².

At the same time, we studied heart rate variability in all examined patients using the "VegetoSPECTR" device, which allowed us to determine the direction of their autonomic reactions and perform a correlation analysis of these indicators.

The parameters of the spectral and temporal characteristics of the HRV in the examined groups are presented in Table 2.

Thus, for the first time, a direct correlation was established between temperature and thermal flux density indicators and the spectral and temporal characteristics of HRV in Group I of the subjects. Furthermore, the high-frequency (parasympathetic) HF component of the cardiovascular rhythm played a significant role in shaping the thermal flux indicators.

The temperature indicators in this group were also significantly influenced by the levels of humoral regulation and metabolic disturbances.

In the comparison group (II clinical group), all negative weak correlation links between thermal indicators and HRV were found, except for the HFn indicator. This also pointed to the role of

parasympathetic responses in the formation of thermal flux density indicators in patients with signs of lumbosciatica in the absence of linear instability in the lumbar spine.

Table 2

Parameters of autonomic reactions in patients with instability in the lumbosacral region of the spine

N = 39	***M* ± *m***	*T*1 (34.19±1.71)	*Q*1 (26.82±4.98)
Parameter (spectral characteristics)		Correlation coefficient, **r**	
VLF, msec^2	13768.07±7361.08	**0.65**	0.28
LF, msec^2	23417.68±14962.65	**0.76**	**0.37**
HF, msec^2	32919.18±21321.92	**0.84**	**0.44**
LF/HF, cond.unit	2.01±0.55	- 0.15	0
LFn, %	54.86±4.37	- 0.2	**- 0.3**
HFn, %	45.14±4.37	0.2	**0.3**
Parameter (time characteristics)			
SDNN, msec	156.11±61.38	**0.76**	**0.41**
pNN50, %	18.35±7.01	**0.65**	**0.57**
RMSSD. msec	186.58±86.67	**0.81**	**0.46**

Group II

N = 16	***M* ± *m***	*T*2 (39.8±6.29)	*Q*2 (120.6±99.20)
Parameter (spectral characteristics)		Correlation coefficient, ***r***	
VLF, msec^2	21608.2±11315.41	- 0.09	- 0.10
LF, msec^2	60093.9±31361.08	- 0.06	- 0.11
HF, msec^2	114969.2±60523.87	- 0.07	- 0.10
LF/HF, cond.unit	1.0±0.37	- 0.13	- 0.14
LFn, %	37.4±3.57	- 0.17	**- 0.28**
HFn, %	60.5±3.72	0.21	**0.30**
Parameter (time characteristics)			
SDNN, msec	287.5±108.02	- 0.02	- 0.06
pNN50, %	54.0±22.07	0.08	- 0.08
RMSSD, msec	383.7±153.47	- 0.02	- 0.04

It should also be noted that, for the first time, a significant decrease in the production of thermal energy was observed in individuals of the I clinical group, where only functional reflex changes in the peripheral nerve fibers are recorded in the neurological status of the patients.

Experimental studies by foreign scientists have shown that when peripheral nerve fibers are damaged, cold receptors are the first to be affected, and their number is 2 to 2.5 times greater than that of heat receptors. In our opinion, this could explain the emergence of the "scissors" symptom in the examined individuals.

Thus, the statistical set of clinical material will allow in the future introducing the thermoelectric medical thermometer into primary healthcare for patients during the exacerbation period, as well as in rural outpatient clinics and family doctor offices. This will enable automatic diagnosis of individuals with neurological vertebrogenic disorders without the need for expensive radiological diagnostic devices.

This comprehensive approach will improve the methods of complex treatment for the affected patients: in addition to traditional conservative treatment during the preoperative and postoperative periods, which includes the use of nonsteroidal anti-inflammatory drugs, muscle relaxants, and general strengthening therapy, it is recommended to prescribe duloxetine at 60 mg per day for an extended period. This drug belongs to the group of selective serotonin and norepinephrine reuptake inhibitors and will significantly improve the quality of life of patients in the postoperative period.

In summary, the conducted clinical examinations and measurements of various paraclinical indicators in patients with vertebrogenic pain in the lumbar region, along with the results of patient surveys, clearly identified descriptors of acute or chronic vertebrogenic pain in patients with degenerative-dystrophic pathology of the spine. This, in turn, allowed for a more thoughtful approach to the development and improvement of a multi-channel thermoelectric thermometer, followed by the refinement of treatment tactics (surgical or conservative), significantly enhancing the effectiveness of the therapeutic process.

Thus, the preliminary clinical studies provide the opportunity to diagnose inflammatory processes, particularly in the neurological manifestations of spinal osteochondrosis, and to monitor the effectiveness of conservative treatment for degenerative-dystrophic diseases of the lumbosacral spine.

Conclusions

1. The study of changes in thermometric indicators of the skin coverings in the lumbosacral spine region showed that this diagnostic method is highly informative and allows for an accurate examination of these changes depending on the patient's age, sex, and the identification of key trends in their condition over time.
2. The conducted clinical studies allow for the diagnosis of inflammatory processes, particularly in the neurological manifestations of spinal osteochondrosis, and tracking the effectiveness of conservative treatment for degenerative-dystrophic diseases of the lumbosacral spine.
3. It has been established that simultaneous measurement of temperature and thermal flux density in the studied areas of the human body using a thermoelectric medical thermometer allows for the identification of the nature of neurological complications in spinal osteochondrosis at early stages of the inflammatory process, without the need for expensive radiological diagnostic devices.
4. The determination of thermometric indicators in the lumbosacral region of the spine in individuals with chronic pain syndrome against the background of degenerative-dystrophic spinal pathology, in the presence of herniated and protruded intervertebral discs, allows for improved diagnosis of the neurological manifestations of this pathology, forecasting the course of the disease, and selecting an effective treatment method.

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КОМП'ЮТЕРНЕ МОДЕЛЮВАННЯ РОЗПОДІЛІВ ТЕМПЕРАТУРИ В СЕРЦІ ЛЮДИНИ ПРИ КРІОАБЛЯЦІЇ

У роботі наведено результати використання термоелектричних тепломірів у локомоторній терапії при реабілітації пацієнтів з травмами попереково-крижового відділу хребта. Проведені клінічні дослідження дають можливість діагностувати запальні процеси, зокрема при неврологічних проявах остеохондрозу хребта, та відслідковувати ефективність проведеного консервативного лікування при дегенеративно-дистрофічних захворюваннях попереково-крижового відділу хребта. Підтверджено ефективність застосування термоелектричних тепломірів у медичній діагностиці. Бібл. 45, рис. 4, табл. 2.

Ключові слова: термоелектричний тепломір, густина теплового потоку, температура, теплометричні показники, остеохондроз хребта, локомоторна терапія.

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