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PROSPECTS FOR THE USE OF H-REFLEXOMETRY IN THE STUDY OF HUMAN MOTOR FUNCTION

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SUMMARY. The article application of H-reflexometry in the study of the central mechanisms of random human movements, which is mainly carried out on healthy subjects, is demonstrated. It has been shown that the results of clinical trials performed by H-reflexometry with the participation of injured people or people with neurological disorders provide additional information about these mechanisms, reveal the causes of human motor function disorders, contribute to the improvement of methods of their study and provide opportunities for the implementation of rehabilitation measures.

The aim – to evaluate the prospects of using H-reflexometry in the study of central mechanisms of movements and means of restoring and maximizing the motor capabilities of people.

Material and Methods. The analysis was carried out using the scientific biological and medical information search system PubMed.

Results. H-reflexometry was used both for the study of motor functions of healthy people and patients with injuries and neurological disorders. The authors studied mainly H-reflexes m.soleus, m. flexor carpi radialis, m. quadriceps. The total number of publications with the results of studies performed on other muscles indicates the possibility of a wider use of H-reflexometry in the study of motor functions in humans than is generally accepted and currently implemented. It was found that H-reflexometry was used to the greatest extent in the researches of the mechanisms of motor disorders arising as a result of stroke and spinal cord injuries.

Conclusions. The results of the review indicate that H-reflexometry provides ample opportunities to study human motor function in normal and pathological conditions, and it may be especially promising at present to examine injured people using this method, to implement and monitor their rehabilitation measures.

KEY WORDS: H-reflex; H-reflexometry; muscle.

Introduction. A number of modern reviews consider H-reflexometry to be one of the most important electrophysiological methods for studying the physiology of human movements. It is known that the H-reflex is a reflex response of a muscle that occurs when it is electrically stimulated by its own low-threshold afferent nerve fibers of group Ia. It is one of the simplest reflexes that can be noninvasively recorded in humans, but it is also used to study random movements, since the central mechanisms of their control are carried out through the monosynaptic reflex arcs of the corresponding muscles.

The advantages of the H-reflexometry technique include the fact that it is standard and controlled. In particular, in each experiment, depending on the purpose of the study, the parameters of electrical stimulation of the corresponding nerve are set: intensity, frequency, pulse duration (no more than 1 ms for excitation of almost all nerves) [1]. The characteristics of the H-reflex (amplitude, latency period) are important indicators of the interpretation of this non-invasive standard test in studies of neuromuscular function and neural control of movements [1, 2].

It is known that a weak stimulus can excite several efferent motor fibers, resulting in a direct muscle response or M-response (wave) that precedes the H-reflex [3]. It is shown that the ratio between the maximum H-reflex and M-wave (N/M-ratio), which are observed when the force of electrical stimulation of the nerve increases to a certain value, is an indicator of the efficiency of transmission from Ia-afferent fibers to motoneurons, which can change with excitation and inhibition on spinal level under certain conditions.

In reviews dedicated to the physiology of movements, the importance of the H-reflexometry method in the study of sensorimotor integration and plasticity of the human CNS was demonstrated, and the effects of brain systems involved in the regulation of movements and body posture were studied [4]. The method provides an approach for elucidating a wide range of scientific problems, starting with the study of the functional organization of neural circuits and ending with the study of adaptive plasticity of spinal structures in normal and pathological conditions [5, 6]. This technique is considered as an accessible method that allows to study changes in signal transmission in the spinal neural circuits of a person when solving problems related to motor activity [2]. The main benefit of H-reflex studies is that they allow clinicians to best study conduction through the proximal segments (plexuses, nerve endings) of a peripheral nerve [1]. The H-reflex is a valuable diagnostic method for assessing nerve conduction along the entire length of afferent and efferent pathways, especially in the proximal segment of a peripheral nerve, as well as for assessing neurophysiological changes in nerve roots [7].

It should be noted that a significant part of the research in which the H-reflexometry method is used is devoted to the study of movement disorders that arise as a result of neurological disorders such as stroke, brain injury, cerebral palsy, multiple sclerosis and other diseases. Studying the causes of these disorders, improving the methods of their research and eliminating the consequences is an important and urgent problem of scientists and clinicians all over the world. In addition, the study of processes and mechanisms that occur in locomotion disorders can be a productive approach to expanding scientific knowledge in the field of human motor neurobiology, as well as understanding normal motor control processes [8].

Along with data on the high value of H-reflexometry in the study of the physiology of movements, according to [1], this method is not used enough in clinical practice due to the perception that only the H-reflex of the soleus muscle can be reliably registered. However, the author of the publication emphasizes that H-reflexes can be registered from almost all muscles that have muscle spindles. At the same time, it should be taken into account that the absence of the H-reflex is not always a deviation from the norm, for example, the H-reflex may be absent in healthy people older than 60 years [7].

In the research [9], the authors showed that due to the fact that H-reflexometry is used "to assess the functions of the human spinal cord system in vivo", this method "has both methodological advantages and potential limitations."

In a review [2], which is devoted to the use of H-reflexometry in the study of human motor control, it is shown that although "this is a relatively simple electromyographic research method, subtleties are hidden behind such simplicity that require strict experimental protocols and careful interpretation of data» [2]. The complex interaction of the H-reflex with the other neural components requires considering all factors that affect the reflex response for an objective assessment of the obtained research results [1].

Taking into account some contradictory views on the possibilities of using H-reflexometry in studies of normal and pathological movement physiology, we formulated the purpose of the present work.

The aim of the study – to evaluate the prospects of using H-reflexometry in the study of central mechanisms of movements and means of restoring and maximizing the motor capabilities of people by systematizing modern scientific data.

Material and Methods. The review includes publications from 01.01.2018 to 01.07.2023 (the last five and a half years), which are published in the PubMed database. Search keyword: H-reflex. Criteria for excluding publications from the presented review: 1. the muscle from which the H-reflex was registered is not specified; 2. there is no access to the full text or to the abstract.

Results and Discussion. In the electronic database of biological and medical publications PubMed, 475 works are placed for the specified time period under the key word "H-reflex". These include review articles (34), meta-analyses (8), randomized controlled trials (33), results of clinical trials (43), thematic articles (357). According to the above exclusion criteria, we did not analyze 103 papers: 52 studies in which healthy people participated, as well as 49 papers in which the authors investigated various neurological diseases, 2 studies realized on animals. Thus, our review included 209 publications that reflected the results of research on healthy people, 117 works involving neurological patients and injured persons, and 46 works in which animals were the object of research (Fig. 1).

In many works involving healthy and sick people, the authors recorded the H-reflex of the soleus mus-

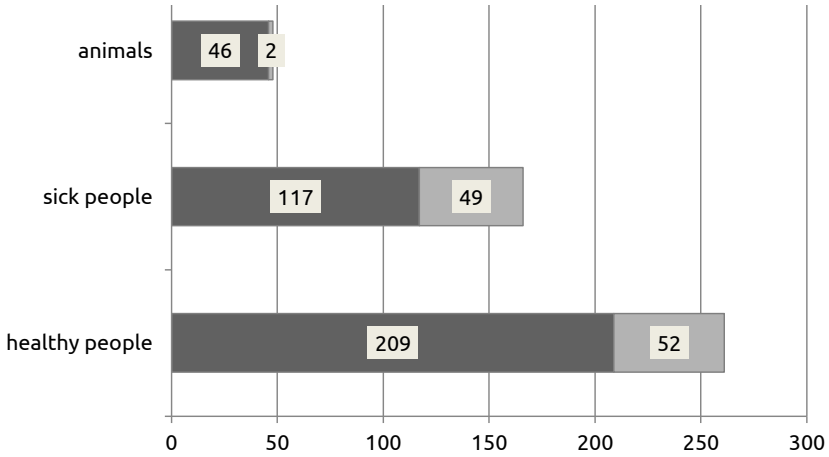

Fig. 1. The total number of scientific publications over the past 5.5 years with application of H-reflexometry. Works included in our review are marked in dark grey, works excluded from the review are in light grey.

cle. Out of 326 publications, 224 refer to the study of the H-reflex of m.soleus (in its pure form, that is, only this muscle), which is almost 69 % of the total number of works (Fig. 2). H-reflexometry of only the wrist flexor m. Flexor carpi radialis was used as a research method in 12 % of all presented publications. In 14 presented works (4.3 % of the total number), the H-reflex of the quadriceps muscle of the thigh m. quadriceps was recorded. Studies of H-reflexes of other muscles together accounted for about 15 % of all works. Such data may be a confirmation of the opinion [1] that H-reflexes can be registered from various muscles of the human body, and not exclusively from the soleus muscle.

In this regard, we considered it appropriate to present some new data obtained in studies using H-reflexometry on muscles, which are relatively rarely studied by the authors, but the conclusions of these studies are of obvious relevance and scientific value (Table 1).

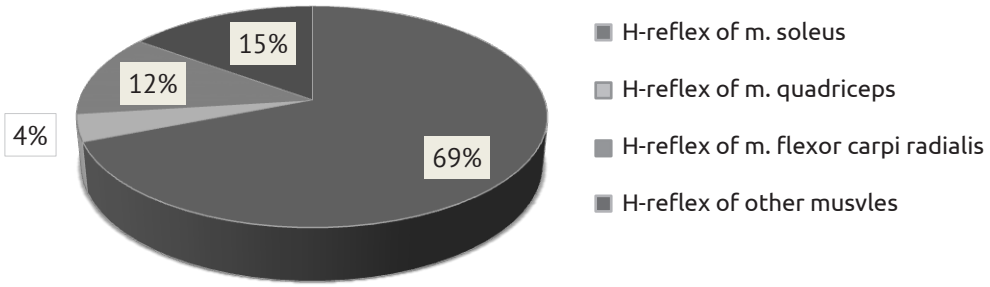

Fig. 2. Relative numbers of studies of H-reflexes of different muscles.

Table 1. Results of H-reflexometry of some human muscles

The muscle which were used to record the H-reflex	Research publications and their main conclusions
m. lateral gastrocnemius	The works [10–12] studied peripheral neuropathy, which occurs in almost 20 % of people older than 60 years. Studies have shown that to assess adaptation to this disease, it is necessary to determine the functions of the peripheral nervous system and their modulation by the central nervous system. It was shown that the characteristics of the H-reflex of the *lateral calf muscle* were more reliable compared to the characteristics of the *soleus muscle*.
m. medial gastrocnemius	[13] showed that performing exercises for functional stretching of the muscle can significantly affect the nervous and mechanical properties of the spastic *medial calf muscle* in patients with chronic stroke.
m. abductor hallucis	[14] studied the difference between the H-reflex *m. abductor halluces* healthy people and those with flat feet in different body positions (lying or standing on two or one leg). Modulation of the H-reflex depended on the posture. The authors concluded that with an increase in postural requirements, muscle activity increases, as evidenced by an increase in the amplitude of the H-reflex in the position of standing on one leg.
m. tibialis anterior	[15] studied the modulation of H-reflexes *m. tibialis anterior* with increased postural requirements when changing the position of the human body from a sitting position to a standing position. The obtained data indicate the sensitivity of the H-reflex to the position of the body. The authors suggested that a possible mechanism of modulation is presynaptic regulation of afferent transmission of group Ia nerve fibers.
m. trapezius muscle	[16] observed in subjects who had chronic shoulder pain, a decrease in the Hmax/Mmax ratio, as well as an increase in the latent period of the H-reflex *m. trapezius*. It is recommended during the rehabilitation of such people to control the H-reflex of the studied muscle as an indicator of its success.
m. extensor digitorum communis	[7] evaluated the relationship between the normal value of the latent period of the H-reflex *m. extensor digitorum communis*, length of the upper limb and age of healthy participants. We obtained results indicating a reliable correlation between the latent period and the length of the limb. With age, this correlation became insufficient. Active extension and passive flexion of the wrist led to relief of the H-reflex of the *extensor digitorum communis*. The results of the study are recommended to be used in the diagnosis of radiculopathy.
m. temporal, m. masseter	[17] Heteronymous H-reflex *m. temporal* is much more common in patients with amyotrophic lateral sclerosis than in healthy people. The reflex does not disappear with increased intensity of stimulation. The publication suggests to use this test to detect upper motor neuron lesions.

In some publications, in accordance with the purpose of the study, the results of registration of H-reflexes of several muscles are displayed. For example, in 8 publications that we analyzed, the authors studied H-reflexes of the soleus muscle and radial flexor carpi [18–20].

It should be noted that the majority of the studies included in the review were realized with the participation of healthy people as subjects. The authors studied the modulation of muscle H-reflexes under various conditions, revealing age-specific features [21–28], gender differences [5, 29]; the influence of various sports [30–33] on spinal reflexes.

The subject of the research was also the effects of the corresponding muscles of the human posture on the H-reflexes (standing, sitting, lying) [34], the position of the body in a sitting position (straight, hunched over), types of movements (walking, running, jumping [35, 36], removing a person from a position of equilibrium [37, 38].

In the works [38, 39] authors used H-reflexometry to study the central mechanisms that allow you to compensate the disturbances in balance quickly and to maintain the vertical position of the body when people are standing and moving, that is, in conditions in which human motility is quite unstable nature. Afferent feedback mechanisms have been demonstrated to provide postural stability by rapidly triggering muscle responses in different parts of the body after balance is lost [38]. The results of the study of the excitability of the soleus muscle by the method of H-reflexometry during forward and backward tilt of the body [38] showed that the amplitude of the H-reflex changed according to the direction of the tilt (increased and decreased, respectively), which may indicate different mechanisms for establishing balance in relation to these movements.

In the research [34], the H-reflex of the soleus muscle was studied in three body positions: sitting, standing, and lying down. The results showed that the effectiveness of the primary afferent spindle synapse on motoneurons of the soleus muscle can be presynaptically influenced by the tonic activity of proprioceptors. This conclusion was made because in the supine position the amplitude of the H-reflex significantly increased compared to other body positions, although the background level of electrical activity of the soleus muscle did not change in different body positions.

The study [36] characterized the modulation of the H-reflex of the soleus muscle in flight during a jump and at the moment of landing on both legs, i.e. during dynamic tasks. It was shown that approximately 30ms before contact with the ground, the H-reflex of the soleus muscle decreased. Such modulation of the reflex response could support a neural strategy to prevent mediated muscle activation, which in turn would contribute to corresponding musculotendinous joint stiffness [36].

A number of scientific works performed with the help of H-reflexometry are devoted to the assessment of the impact of the aging of the human body on the mechanisms of implementation and control of movements [22, 25, 28, 39, 40]. Most of these publications present the results of studying balance control in elderly people and means of improving it. The work [22] shows that every voluntary movement is preceded by a physiological preparatory state - postural adaptation, which is one of the strategies used by the central nervous system to prevent loss of balance. As a result of the aging of the body, violations of balance control occur, which can lead to falls, injuries, and loss of independence of the elderly [39]. Research [41] showed that postural adaptation decreases with age. [22] observed a relief of the H-reflex of the soleus muscle in elderly people when quickly bending the arm and raising it to a horizontal position. On the contrary, suppression of the amplitude of the H-reflex was observed in young people (in the corresponding experiment). The obtained data indicate age-related disorders of inhibitory control of voluntary movements. In the study, it was assumed that the facilitation of the reflex response during translational adjustments in the elderly is associated with supraspinal influences on the spinal reflex arcs [22].

During the review period, the H-reflexometry method was widely used by researchers not only to find out the mechanisms of motor functions of healthy people. It has also been widely used for the diagnosis and monitoring of neurological disorders such as stroke, spinal cord injury, multiple sclerosis, cerebral palsy, and other neurological diseases (Parkinson's disease, neuropathy, idiopathic walking in children, restless legs syndrome), in studies of the mechanisms of motor disorders that occurred as a result of changes in spinal reflexes relative to their manifestations in healthy people (Fig. 3).

In these works the method of H-reflexometry was used to study the causes of neurological disorders, improve the methods of their research and eliminate the consequences, which are important and urgent problems of scientists and clinicians all over the world. It has been demonstrated that these disorders negatively change the influence of the brain on the spinal cord, resulting in abnormal spinal reflexes that impair motor control. This, in turn, can limit the mobility of patients, due to the occurrence of, for example, muscle spasticity. In addition, the state of synovial reflexes was affected by the negative consequences of neurological diseases, such as sleep disturbances, the appearance of pain and fatigue [42]. It

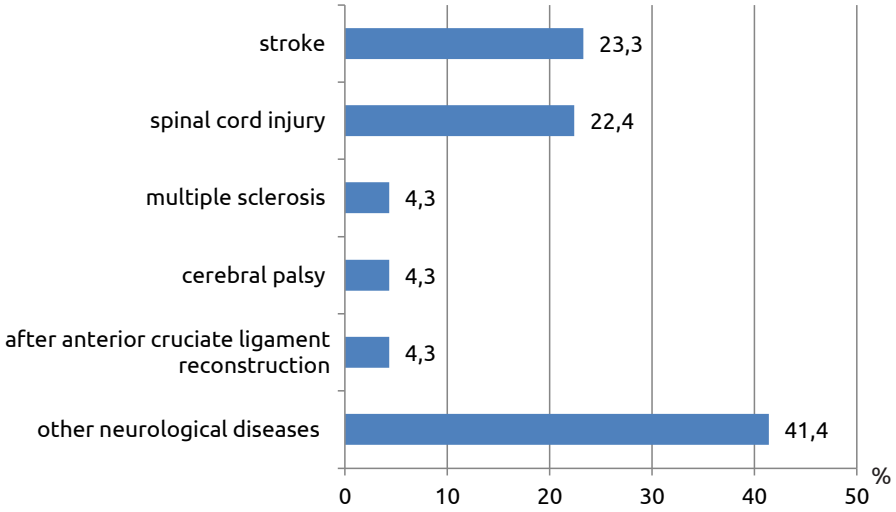

Fig. 3. Relative numbers of studies of H-reflexes of muscles in various neurological diseases of people.

should be noted that studying the processes and mechanisms that occur in locomotion disorders also provides valuable information for understanding of normal motor control processes in humans [8].

Researches [20] focus on the development of rehabilitation paradigms to improve walking after spinal cord injury. By recording the H-reflexes of several muscles, the authors showed that neural networks of the cervical and lumbar regions of the spinal cord are actively connected during human movement, which is necessary for coordination of the activities of arms and legs. In these studies, people with incomplete spinal cord injury, who performed bicycle training during the experiment, took part. The results showed that "active use of the arms regulated the excitability of lumbar neural networks" better than exercises that focused only on training the legs.

In the research [18] using H-reflexometry, it was demonstrated that transcutaneous electrical stimulation of the spinal cord in the cervical and lumbar regions improved sensorimotor rehabilitation due to non-invasive modulation of spinal cord circuits. It was shown that external electrical stimulation, unlike epidural, is a safe approach for modulating the excitability of neural networks of the spinal cord, as it is well tolerated with minimal skin irritation and adverse changes in blood pressure, heart rate, etc. The authors of the article provided recommendations on the correct selection of stimulation parameters (current strength, modulation depth, frequency) depending on the purpose of use, as well as to ensure patient safety.

Another work [19] compared changes in the excitability of H-reflexes in spastic and intact upper and lower limbs of the patients with acute and chronic stroke. The results of the study made it possible to determine a neurophysiological indicator for the assessment of clinical and neurophysiological spasticity, which can be used as a comprehensive approach to the assessment of post-stroke spasticity and its monitoring.

A number of works have demonstrated that spinal reflexes, particularly H-reflexes, can be therapeutic targets. Previously, scientists considered the spinal cord as a programmed system that responds stereotypically to incoming signals. In modern studies, including those which applied H-reflexometry, a large amount of data has been obtained on the ability of the spinal cord to store information and change its effector capabilities, demonstrating plasticity that depends on different types of activity [4], for example, from various forms of physical activity [13, 35, 43], from exogenous influences [18, 40, 44, 45], from mental modeling of action [46–49]. The results of studies where various means of operant conditioning were studied, which had a positive and beneficial effect on the plasticity of reflex pathways, make it possible to use these means as a supplement to standard methods of treatment.

It should be noted that during the review period, several articles were devoted to improving the technique of recording the H-reflex, especially in terms of reducing the discomfort of research participants (or patients), which is caused by the action of electrical stimuli [50, 51], and as well as determining the optimal position of the stimulating electrodes for the stimulation of the corresponding nerves [52].

A number of publications are devoted to the researches that were realized on animals (46), the vast majority of them – on rats, namely 43 works. Studies of H-reflexes were also tested on dogs [53], rabbits [54], cats [55]. Functional recovery of motility after spinal cord injuries [56, 57], means of diagnosis and overcoming spasticity that occurred after strokes [58] or spinal cord injuries [57, 59, 60].

Conclusions. The results of a review of publications published in PubMed using the keyword "H-reflex" over the past 5.5 years have shown that the H-reflex method is a promising means of studying motor functions in humans in normal and pathological conditions. This is indicated by a fairly large number of studies performed using the method, which has the advantage of being non-invasive and standardized, and can be performed on different muscles (both separately and on several simultaneously) under well-controlled experimental conditions.

The systematization of data about the use of H-reflexometry in modern research has shown that the method provides wide opportunities in three main areas: for the study of the central mechanisms of movements of healthy people of various ages, in the case of injuries and neurological disorders of motor function caused by various diseases, as well as during the implementation of rehabilitation methods restoration of motor activity of a person to control their efficiency. In addition, electrical stimulation used in H-reflexometry can be a therapeutic factor in rehabilitation, and spinal reflexes are its targets that require correction due to their impairment in pathology. Additional opportunities for study of the neurophysiology of movements by the H-reflectometry method are provided by experiments that can be tested on animals.

Prospects for further research. In today's modern conditions, the areas of examination with the help of H-reflexometry of the motor functions of injured people, as well as the implementation and control of rehabilitation measures in them, can be particularly promising.

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ПЕРСПЕКТИВИ ВИКОРИСТАННЯ Н-РЕФЛЕКСОМЕТРІЇ ПРИ ДОСЛІДЖЕННІ РУХОВОЇ ФУНКЦІЇ ЛЮДИНИ

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РЕЗЮМЕ. У статті продемонстровано застосування Н-рефлексометрії у вивченні центральних механізмів довільних рухів людини, яке переважно проводиться на здорових суб'єктах. Показано, що результати клінічних випробувань Н-рефлексометрії за участю постраждалих або людей з неврологічними розладами дають додаткову інформацію про ці механізми, виявляють причини порушення рухової функції людини, сприяють удосконаленню методів їх лікування, вивченню та забезпеченню можливостей реалізації реабілітаційних заходів.

Мета – оцінити перспективність використання Н-рефлексометрії у вивченні центральних механізмів рухів і засобів відновлення та максимізації рухових можливостей людини.

Матеріал і методи. Аналіз проводився за допомогою системи пошуку наукової біологічної та медичної інформації PubMed.

Результати. Н-рефлексометрію використовували для дослідження рухових функцій як здорових людей, так і хворих із травмами та неврологічними розладами. Автори вивчали переважно Н-рефлекси m. soleus, m. flexor carpi radialis, m. квадрицепс. Загальна кількість публікацій з результатами досліджень, проведених на інших м'язах, свідчить про можливість ширшого використання Н-рефлексометрії у вивченні рухових функцій людини, ніж це загальноприйнято і реалізовано в даний час. Установлено, що Н-рефлексометрія найбільшою мірою застосовувалася при дослідженні механізмів рухових розладів, які виникають унаслідок інсульту та травм спинного мозку.

Висновки. Результати огляду свідчать про те, що Н-рефлексометрія надає широкі можливості для вивчення рухової функції людини в нормі та при патології, і особливо перспективним на даний час може бути обстеження постраждалих цим методом, проведення та контроль їх реабілітаційних заходів.

КЛЮЧОВІ СЛОВА: Н-рефлекс; Н-рефлексометрія; м'яз.

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