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Use of exoskeleton in rehabilitation of patients with orthopedic traumas

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Abstract

Purpose: This article discusses the opportunities of using exoskeleton by patients with orthopedic traumas who are engaged in various types of activity. The article's aim is to study the effectiveness of exoskeleton in process of rehabilitation the motor functions of patients with orthopedic traumas. Methodology: Research methods - analysis and synthesis of scientific and methodological literature on the possibilities of using exoskeleton in rehabilitation practice, pedagogical testing to determine biomechanical criteria for evaluating walking disorders, pedagogical experiment and mathematical statistics methodology using Statistic V. 6.0 ("Statsoft"). Results: The article presents the study results with regards to effectiveness of exoskeleton in the process of rehabilitation of patients with orthopedic traumas. The existing classification of exoskeletons in medical practice was also studied and the features of patients with orthopedic traumas were analyzed. The results proving the effectiveness of exoskeleton application in rehabilitation practice, as well as in the process of recovery of patients with orthopedic traumas are presented and discussed. Applications: The article will be useful to doctors and rehabilitators who work with patients having orthopedic traumas, assistants who help to carry out this activity and instructors of adaptive physical education, where there is a similar specificity of activity. Novelty/Originality: the novelty of the author's study is that not much has been investigated so far in the field of patient rehabilitation with an exoskeleton, and the results of such study can serve as a basic foundation of knowledge for conducting such activities.

Keywords: exoskeleton, rehabilitation, orthopedic trauma, motor functions, biomechanical component of movement

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INTRODUCTION

As it is known, musculoskeletal system disorders are among those diseases that bring great physical suffering: they limit the ability to move and self-care, worsen the quality of life, and often lead to disability of patients. Physical rehabilitation includes the use of physical exercises and natural factors with a therapeutic and preventive purpose in the complex process of restoring the health, physical condition and working capacity of patients and people with disabilities. It is an integral part of medical rehabilitation and is used in all its periods and stages. The medical exoskeleton is created to help people with disabilities. This is a special biomechanical device for rehabilitation in case of loss or restriction of limbs mobility. The principle of its work is based on repetition of biomechanics of human movements with a proportional reduction of efforts necessary for them. The patient controls the device either independently (using a smartphone application) or under the supervision of a specialist (Avedikov & Zhmakin, 2014; Kaletina et al., 2020).

Depending on the severity of the patient's condition, exoskeletons can be used for temporary or permanent wear. They are designed for rehabilitation after a complex operation or apoplectic attack, as well as for constant wear in case of problems with the motor system, including wearing in old age. Authors such as A.A. Vorobyov et al. (2015a) note that most of the exoskeletons created are currently not for wide use in rehabilitation of patients with disabilities of the functions of upper and lower limbs due to the large mass of structure. Developers strive to make it as easy as possible to manage, but at the same time a functional and easy mechanism. This allows you to use the

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exoskeleton not only with benefit, but also with comfort. This determines the relevance of the formulated study topic.

The main condition for using exoskeletons in rehabilitation is the presence of any residual motor functions in the legs or impulses with which the apparatus can work. Experts conduct a preliminary evaluation of possibility to apply the exoskeleton using modern diagnostic methods. In each specific case, the use of this method can be effectively applied for a rather wide range of diseases:

- apoplectic attack;
- spinal cord trauma;
- multiple sclerosis;
- head injury;
- neuromuscular diseases;
- muscular dystrophy;
- neurodegenerative diseases.

According to the latest study data and broad clinical experience, most patients with traumatic spinal cord disease get a maximum effect from using exoskeletons for the back during 1-3 months. The main purpose of such rehabilitation is to increase muscle mass on the lower limbs, as well as improve walking skills. Scientific medical studies have shown the following improvements in the use of exoskeletons for lower limbs:

- reduce the need for assistive tools
- increase of walking speed;
- reduction of spasticity;
- improved sensitivity;
- increase of muscle mass on lower limbs;
- reduction of rehabilitation time;
- reactivation of affected parts of the brain;
- reduction of neuropathic pain.

The human body is arranged in such a way that any movement is carried out with the help of signals and impulses that the brain sends with the help of the peripheral and central nervous system. If various injuries and diseases take place the passage of these signals becomes difficult and they reach the brain in a weakened form or do not reach it at all. It makes very difficult or impossible to perform any movement at all. The effect from medical exoskeleton is aimed at ensuring that these attenuated brain signals are duly caught and amplified, as well as supporting the performance of movement. Therefore, the patient himself initiates movement, performing it with the support of the exoskeleton device. Thus, uninterrupted feedback of brain signals and movements is restored, trained and created.

Such authors as A.A. Vorobyov et al. (2015b) found that the most acceptable design for rehabilitation is the construction of a passive exoskeleton and the main groups of patients in need of exoskeletons are the ones suffering from upper and lower limbs paresis. Rehabilitation with passive exoskeleton is suitable for patients, both in the chronic period and in the acute one. Experts insist that the main and the most important condition for successful rehabilitation with exoskeleton for the disabled people is the presence of residual passage of impulses into legs which the exoskeleton device will be able to support. A wide range of Russian exoskeletons is presented on the modern market.

LITERATURE REVIEW

Physical rehabilitation should be considered as a medical, pedagogical and educational process or, to say more correctly, a learning process. The basic means of physical rehabilitation are physical exercises and sports elements and their use is always a pedagogical, learning process. Its quality depends on how much the methodologist seized pedagogical skills and knowledge (Fomina & Maslovskaya, 2019). That is why all laws and rules of general pedagogy, as well as theories and methods of physical culture, are extremely important in the activities of a rehabilitation specialist in physical rehabilitation.

The rehabilitation purpose is the most complete restoration of the lost capabilities of the body, but if this is unattainable, the task of partial restoration or compensation for impaired or lost function is set, and in any case - slowing down the progression of the disease. To achieve the abovementioned purposes a complex of therapeutic and restorative means is used and the greatest rehabilitative effect is reached from the following: physical exercises, natural factors (both natural and reformed), various types of massage, exercises on simulators, as well as orthopedic devices, occupational therapy, psychotherapy and authotraining (Zakharova, Sorokina & Udina, 2019). Even this list shows that the leading role in rehabilitation belongs to the methods of physical impact methods and the further it moves from stage to stage, the more important they are, having drawn up a branch, or a kind called “physical rehabilitation” in due course time.

The most common cause of musculoskeletal damage is the discrepancy between the load on the joints and the ability of the cartilages to resist it. As a result, there is a rapid “aging” of the articular cartilage. It loses its elasticity, articular surfaces become rough and cracks appear on them. Inflammation joins later and in response to it the bone sprawl occurs (Neverkovich et al, 2019). The main reason for dysfunction of the musculoskeletal system is the lack of motor activity - hypodynamy. It arises in connection with active replacement of the manual labor by the mechanized one, development of household appliances, vehicles, etc. It adversely affects the state of all organs and systems of the body, leads to appearance of the excess body weight, development of obesity, atherosclerosis, hypertension, coronary heart disease. The elder people, being influenced by natural age-related changes in the nervous structures and musculoskeletal system, face the decrease of volume and speed of movements, their coordination of complex and subtle movements becomes disrupted, the muscle tone weakens and some stiffness occurs as well. All this is usually manifested earlier and in a more prominent form in relation to those who lead a sedentary lifestyle (Stafeeva et al., 2020).

The lack of motor activity of the muscles surrounding the bones leads to impaired metabolism in the bone tissue and loss of their strength that leads to poor posture, narrow shoulders, falling into the chest and other consequences that adversely affect the health of internal organs.

Lack of sufficient motor activity in the day mode leads to loosening of articular cartilage and change of surfaces, articulating bones, as well as to the appearance of pain sensations, therefore, conditions for the formation of inflammatory processes in them are created.

The main types of MSDs are congenital skeletal deformities, bone tumors (primary and secondary), diseases bordering bone tumors - bone chondromatosis, exostosis, etc., aseptic necrosis, infectious polyarthritis, inflammatory bone diseases and their consequences, osteomyelitis, as well as all possible spinal injuries.

Thus, physical rehabilitation should be based on a variety of recovery and treatment methods which must necessarily include the use of modern medical devices that certainly include the use of exoskeleton which serves not only as a medical, but also as a social, emotional rehabilitation of people with musculoskeletal disorders (Ivanova et al., 2019b).

METHODOLOGICAL FRAMEWORK

The use of robots, including computer-controlled robots, has become one of the main areas of neurorehabilitation in recent years. Training walk was developed by robotic orthoses and it has been demonstrated that robotic walking on a treadmill made it possible to more effectively maintain the patient's movement, while imitating the gait close to normal, and patients having CC could reach an increase in walking speed and in the strength of knee extensor muscles (Bystritskaya et al., 2020).

A recent study showed an improvement of walking as an extension of distance, but this change was recorded at short distances. At the same time, there was an improvement of balance that the authors associated with enhancing the knee extensor muscles. An important aspect was the improvement of the patients' mental state.

The authors fixed the continuation of the course results for 3 months and linked them to the duration of the classes (12 classes for 6 weeks, 2 classes per week). These and other similar studies used different robotic systems, involved patients with varying degrees of neurological deficits on the EDSS scale. The effectiveness of this neurorehabilitation approach is shown and the relevance of further research in this direction is emphasized.

Currently an ExoAtlet exoskeleton is being introduced into rehabilitation practice in the Russian Federation; it is intended for social adaptation and medical rehabilitation of patients with motor disorders of the lower limbs due to disorders of musculoskeletal system and nervous system. The domestic approach is that use of exoskeleton is one of the most effective methods of medical rehabilitation of patients with consequences of the cerebrospinal injury (Ivanova et al., 2019a).

ExoAtlet exoskeleton is a robotic device that provides support for vertical pose and walking during a neurorehabilitation procedure. Pilot studies have been conducted to assess the effectiveness of using ExoAtlet by patients after spinal injuries, spinal surgeries and apoplectic attack.

The purpose of the present study is to analyze the effectiveness and safety of using the exoskeleton in rehabilitation work on restoration of motor functions of patients with musculoskeletal system disorders.

The following tests were used in this work to determine biomechanical criteria for evaluation of walking disturbance:

The main walking parameters:

1. Walking speed;

- the most common spatial-temporal characteristic of the gait expressed in meters per second.

$$\mathrm{WS} = \mathrm{SL}\ (\text{step length}) * \mathrm{SF}\ (\text{step frequency})$$

2. Pace (step frequency);

Step frequency is the ability of a person to perform movements at a maximum pace per time unit.

$$SF = \frac{1\ \mathrm{min}}{0{,}5\ \mathrm{W}C}$$

3. Length of the patient's double pitch (DP);

This is the distance measured in the sagittal plane between the eponymous points of right and left foot. Step length at arbitrary rate of healthy person of average height is 70-72 cm.

4. Duration of walking cycle (WC).

The walking cycle is usually measured in seconds. Using such a test allows to compare the duration of motor actions correctly.

The study involved 12 patients with various musculoskeletal injuries.

A prerequisite for inclusion of patients in the study was the presence of motor paralysis of the lower limbs with a change in muscle tone to 3 points on the modified Ashworth scale (1964) for clinical evaluation of muscle tone.

According to the “patient’s refusal to cooperate” criterion, 3 patients were excluded during the study. Thus, the follow-up group was 9 patients (5 men and 4 women) aged 28-59 years, all of them having partial injuries and spinal injuries. Everyone had lower complete paraplegia. 5 patients had paralysis caused by trauma of the thoracic spine, 4 patients - the one caused by breast-elbow trauma. The age of the disease ranged from 2 to 7 years. Muscle tone of 6 patients is rated as high, the one of the remaining 3 patients – as reduced.

100% of patients have motor disorders and this dictates the organization of restoring the movement functions. At the same time, restoring walking by such patients is a difficult task. In addition to drug support, a whole range of additional procedures is needed, including the use of exoskeleton.

The exoskeleton classes were held for 30-40 minutes once a day daily during 14 days of hospital stay. The study procedure included analyzing of walking development criteria after applying the exoskeleton technique. To study the biomechanical structure of patients’ walking before and after the exoskeleton training course the Tekscan (USA) flexible force sensors- F-Scan force sensing sock linings were used. Sensors were located inside the patients’ shoes, between the foot and sole of the shoes. This measuring technology has previously been used to study walking biomechanics of patients having orthopedic and neurological diseases.

RESULTS

A full course of restorative treatment including the training with use of the ExoAtlet exoskeleton was completed by all 9 patients.

In the course of classes with exoskeleton a good tolerability of patients to the loads within 30-40 minutes can be noted. Patients coped quite well with the proposed tasks and their well-being during classes and after them did not deteriorate. All patients showed a positive attitude to following-up with exoskeleton.

Rehabilitation classes were conducted according to the standard methodology. They were carried out by a team of specialists, including a neurologist who performed the function of controlling the exoskeleton using a pad and a physical therapy (PT) methodologist.

The training technique consists in the fact that the exoskeleton performs and maintains the movement of patient himself by recording and amplifying the minimum impulses in the muscles of his legs, which are not enough to perform the movements on their own. Special motors in the device perform limbs movement. They are located in the area of knee and hip joints. In other words, the patient himself initiates movement, performing it with the support of exoskeleton device. Thus, the uninterrupted feedback of brain signals and movements is restored, trained and created.

At the beginning of the experiment the conservation capabilities of the main walking parameters of all 9 patients were determined.

The exoskeleton classes were held for 30-40 minutes once a day daily during 14 days of hospital stay.

At the end of the experiment, the parameters of patients’ walking (walking speed, pace, length of the patient’s double pitch, duration of walking cycle) were re-studied.

By comparing the results of the group of examined patients before and after work with the ExoAtlet exoskeleton positive shifts in walking characteristics should be noted. Positive dynamics is demonstrated in figures 1, 2, 3.

According to the «Length of the patient’s double pitch» indicator (in meters) in the group of patients before and after the work carried out, the following results were obtained, shown in **Fig. 1**.

Using the Student’s test, the difference between before and after results was examined. The obtained test value t = 8,23 is significant - it means that the differences reach statistical significance.

According to the «Duration of walking cycle» criterion (s) in the group of patients before and after the work carried out, the following results were obtained, shown in **Fig. 2**.

Using the Student’s test, the difference between before and after results was examined. The obtained test value t= 1,79 is not significant - it means that the differences do not reach statistical significance.

According to the «Walking speed» criterion (m/s) in the group of patients before and after the work carried out, the following results were obtained, shown in **Fig. 3**.

The difference between before and after results was examined using the Student’s t test as well. The obtained test value t = 2,33 is significant - it means that the differences reach statistical significance.

Finally, according to the «Pace (step frequency)» (step/min) criterion, in the group of patients before and after the work carried out, the following results were obtained, shown in **Fig. 4**.

The difference between before and after results was examined using the Student’s t test as well. The obtained test value t = 2,47 is significant - it means that the differences reach statistical significance.

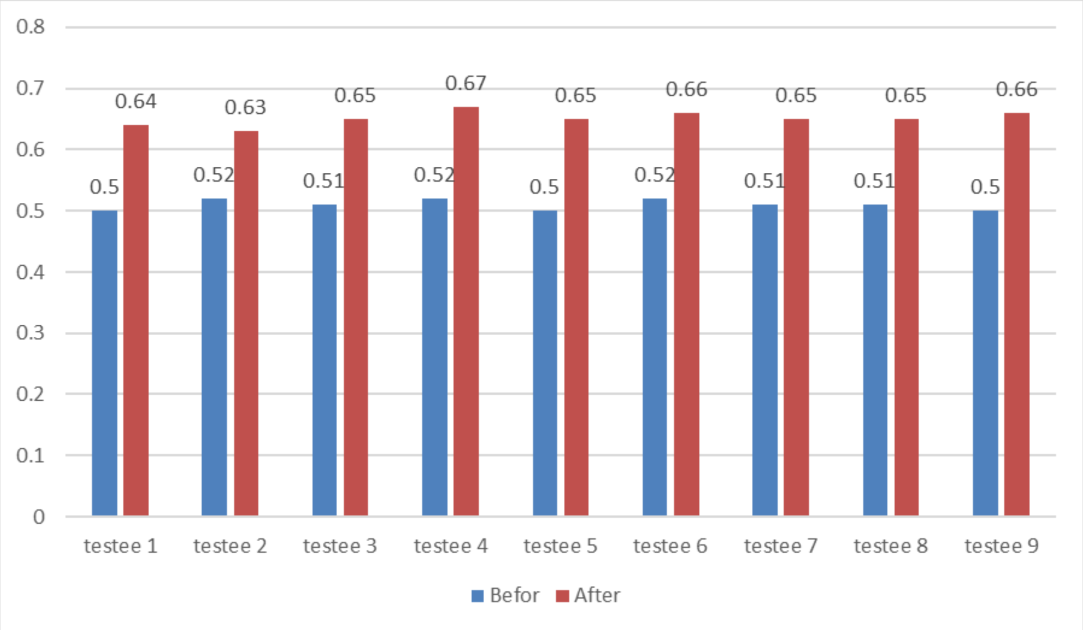

Fig. 1. Length of the patient's double pitch before and after training with the ExoAtlet exoskeleton

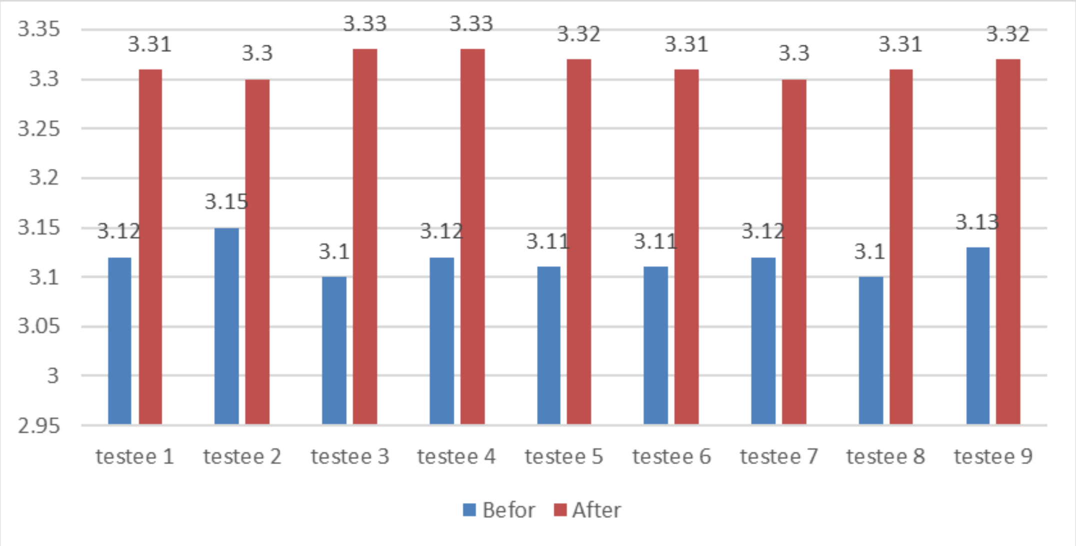

Fig. 2. Duration of the patients' walking cycle before and after training with the ExoAtlet exoskeleton

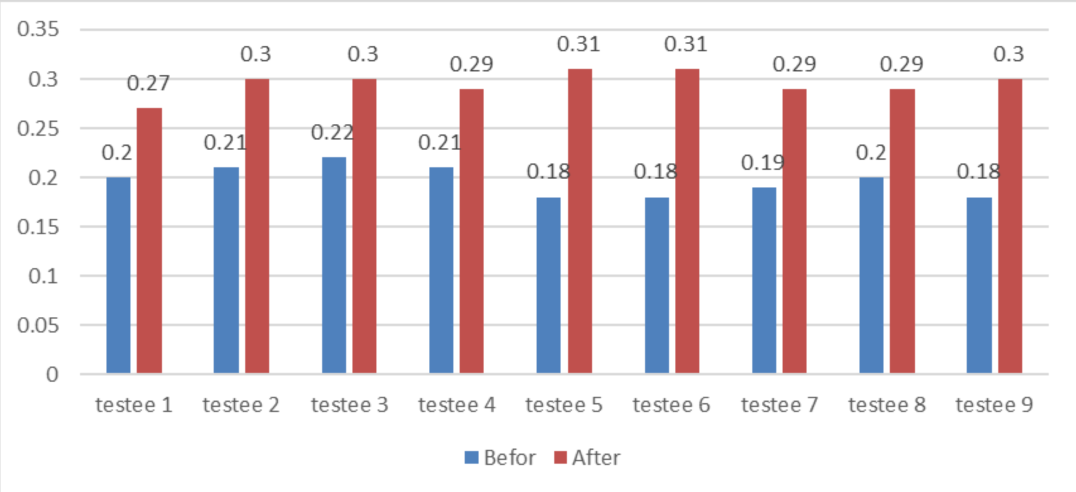

Fig. 3. Speed of the patients' walking before and after training with the ExoAtlet exoskeleton

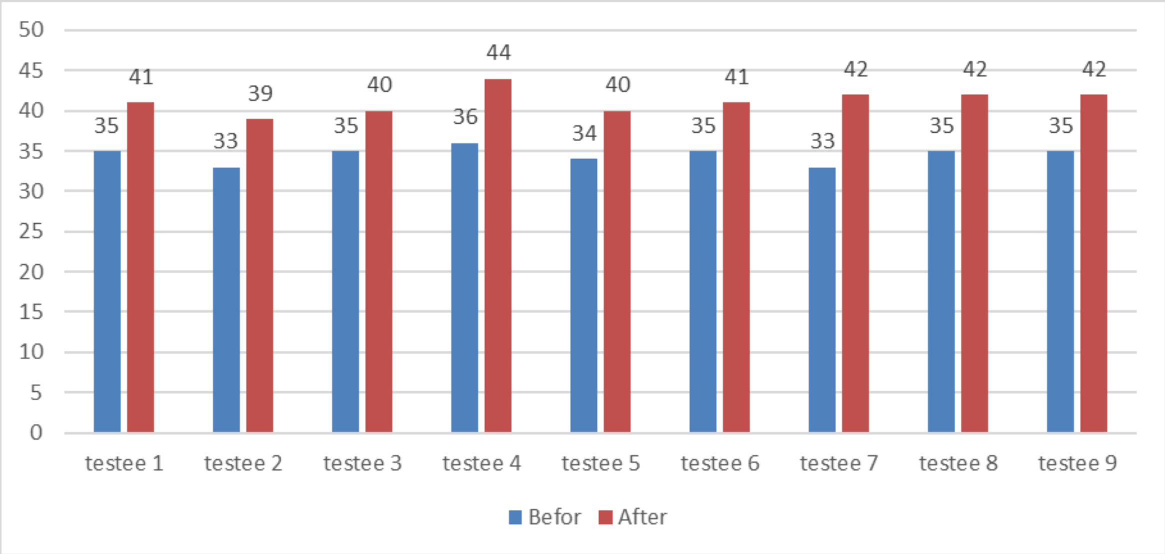

Fig. 4. Frequency of the patients' before and after training with the ExoAtlet exoskeleton

DISCUSSIONS AND CONCLUSION

The findings confirm the effectiveness of exoskeleton use to improve the above walking characteristics of patients with MSDs.

As a result of a relatively short course of restorative treatment, patients clinically showed an improvement in the state in the form of an increase in muscle strength.

Thus, as a result of studying the effectiveness of the ExoAtlet exoskeleton in rehabilitation of patients with MSDs as a robotic device for promoting walking and maintaining posture, positive results are obtained. All patients showed good tolerability to the proposed loads, no adverse events were recorded during follow-up.

The presented results of the study demonstrated the perspective of further research into the possibilities of robotic assistance in walking and supporting vertical posture with use of the ExoAtlet exoskeleton in order to restore motor abilities of patients with MSDs.

Currently exoskeletons are used to improve the quality of life of patients with a rather wide range of diseases, for example, MSDs (orthopedic traumas). The field of medical exoskeletons today is the most diverse and colorful in the entire robotics industry.

The use of medical exoskeletons in orthopedics is divided into two groups:

Rehabilitation exoskeletons are used to restore the locomotor system of a person and the result of using them favorably affects the patient's entire rehabilitation period.

Augmentative exoskeletons are intended for use by a person for the rest of his life and they allow him to abandon the wheelchair and bed, as well as live a conditionally full life.

Today many foreign companies are engaged in the development of exoskeletons.

Under the influence of a course of comprehensive rehabilitation, including walking in an exoskeleton in combination with physical therapy (PT), a significant improvement in dynamic parameters of walking is noted.

Positive changes are favorable criteria and can be used to identify rehabilitation potential and subsequently – to make rehabilitation prognosis and reach an early recovery of the patient's health.

Thus, we can conclude that the goal set above is safely realized - the effectiveness of using exoskeleton in rehabilitation work to restore motor functions of patients with MSDs has been duly studied. This objective has been achieved through the following tasks:

1. The concept and essence of exoskeleton, possibilities and contraindications to its use have been described.
2. Existing classifications of exoskeletons in medical practice have been studied.
3. Peculiarities of patients with MSDs were duly analyzed.
4. Analysis of using exoskeleton in medical practice was carried out.
5. Conclusions on the research carried out have been formulated.

Therefore, the first assumption that use of the ExoAtlet exoskeleton in the process of rehabilitation of patients with MSDs will contribute to restoration of their lost motor functions is safely confirmed.

REFERENCES

Avedikov GE, Zhmakin SI (2014) Exoskeleton: design, control. In the collection: XII All-Russian meeting on control problems of VSPU-2014. Institute for Management Problems V.A. Trapeznikov RAS: 84-90.

Bystritskaya EV, Skitnevskiy VL, Grigoryeva EL, Krasilnikova YS, Sedov IA, Balashova VF, Germanov GN (2020) Physical training teacher certification as a basis of the professional standard requirements for teachers. Journal of Environmental Treatment Techniques, 2: 674-678.

Dmitriev SV, Zagrevskaya AI (2018) Semantic planning of motor task solutions in the context of ontodidactics. Tomsk state university journal, 427: 184-190.

Fomina MV, Maslovskaya SV (2019) Practices for the development of communicative skills of professional communication of medical university students. Vestnik of Minin University, 7(4): 1-21.

Ivanova SS, Bystritskaya EV, Burkhanova IY, Stafeeva AV, Vorobyov NB, Dreiko NY, Bobyleva LA (2019a) The role of rhizome model in future physical education teachers self-realization. EurAsian Journal of BioSciences, 2:1581-1588.

Ivanova SS, Bystritskaya EV, Burkhanova IY, Stafeeva AV, Vorobyov NB, Dreiko NY, Bobyleva LA (2019b). Rhizome model of formation of the need for the self-realization of a future physical education teacher. International Journal of Applied Exercise Physiology, 8(2), 1581-1588.

Kaletina LA, Ibraeva GR, Martynenko EV, Sukhodolova EP, Grinev VA, Magomedova AA, Zhdanov SP (2020) Access to information resource: problem of openness and privacy in internet space. Eurasia Journal of Bioscience, 14: 4305-4309.

Neverkovich SD, Bystritskaya EV, Burkhanova IY, Ivanova SS, Ignatyeva EV (2019) Principles and technologies of improving the educational autonomy of students in the conditions of two-level education. Humanities and Social Sciences Reviews, 4: 1180-1188.

Stafeeva AV, Ivanova SS, Burkhanova IY, Vorobyov NB, Reutova OV, Komercheskaya SP (2020) Forming self-development competences in engineering students during physical culture lessons. International Journal of Applied Exercise Physiology, 9(4): 111-116.

Vorobyov AA, Petrukhin AV, Zasypkina OA, Krivonozhkina PS, Pozdnyakov AM (2015a) Exoskeleton as a new tool in the habilitation and rehabilitation of disabled people (review). Modern technologies in medicine, 7(2): 185-197.

Vorobyov AA, Zasypkina OA, Krivonozhkina PS, Petrukhin AV, Pozdnyakov AM (2015b) Exoskeleton - the state of the problem and prospects for implementation into the system of habilitation and rehabilitation of disabled people (analytical review). Bulletin of the Volgograd State Medical University, 2(54): 9-18.

Zakharova EA, Sorokina TM, Udina EA (2019) Research activity in the structure of the future doctor’s psychological readiness to the profession. Vestnik of Minin University, 7(3): 1-18.