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THE USE OF AN EXOSKELETON IN THE REHABILITATION OF PATIENTS WITH IMPAIRED FUNCTIONS OF THE MUSCULOSKELETAL SYSTEM

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ABSTRACT

Exoskeletons are one of the promising technologies used in rehabilitation medicine aimed at restoring lost motor functions in patients with musculoskeletal disorders. The article discusses the design features of active and passive exoskeletons, the principles of their operation, as well as the scope of application in medical practice, industry and the military. Special attention is paid to modern models of exoskeletons developed by both foreign companies (ReWalk, HAL, eLEGS, Titan Arm, WREX, etc.) and domestic manufacturers, in particular, MBionics (Kazakhstan).

The Kazakhstan exoskeleton was tested based on the «Department of Rehabilitation and Sports Medicine» of Astana Medical University. The study noted such effects as an increase in the psychoemotional state of patients, motivation to study, but there is no significant decrease in the severity of paresis. The safety of the device has been confirmed: no cases of injury, complications or deterioration have been recorded.

The authors emphasize the need to develop rehabilitation exoskeletons tailored to the needs of patients with disabilities in order to enhance their functional and social independence.

KEYWORDS: *Exoskeleton Device, Rehabilitation, Motor Activity, Disabled Persons, Mobility Limitation, Neurorehabilitation, Musculoskeletal System, Human Engineering*

INTRODUCTION

At the present stage, a new type of mechanotherapy is used to restore motor function and improve the mobility of the joints of the lower extremities: robots or exoskeletons. Robotic exoskeletons were invented in the middle of the last millennium and now these devices are at a new stage of development, opening up more and more opportunities for patients. The use of an exoskeleton for the purpose of neurorehabilitation is especially important, firstly, because the number of elderly people in the world is growing, and secondly, the number of injuries has increased, including injuries to the spine and lower extremities [1].

The computerized control system of most devices ensures the autonomous use of the simulator. The design of the exoskeleton is created in such a way that the entire load falls on the simulator structure itself, despite the impressive weight of the equipment. Special software of the simulator allows monitoring and timely adjustment of the rehabilitation process. Thanks to the use of the simulator, patients can return to normal life much faster [2].

The peculiarity of using an exoskeleton is to improve the emotional state of patients, reduce blood pressure, increase the respiratory capacity of the lungs, prevent degeneration of muscle and bone tissue, and increase mobility in the joints. An exoskeleton is a smart electronic system, which is essentially the patient's brain. The desire to take a step, in the form of a nerve impulse, is formed in the brain and transmitted through the spinal cord along the nerves to the leg muscles. This impulse is captured by the exoskeleton, which helps the patient make the first movement. And as a result, neuromuscular facilitation improves, new strong nerve connections are formed [3].

Modern exoskeletons are used in many areas, from medical rehabilitation to industrial production. This market is growing rapidly: in 2023, its global volume in terms of revenue was estimated at $0.7 billion. According to a report published on the Marketsand Markets portal, the exoskeleton market will increase by 38.6% by 2028. Currently, developments are underway regarding practical skills for working with exoskeletons. They can be grouped into the following areas: research into the biomechanical properties of new devices and the creation of schemes for their use on this basis [4].

PURPOSE OF THE STUDY

To analyze the operation of modern models of exoskeletons, their use in medical rehabilitation, safety and impact on the functional capabilities of patients.

Data from Russian researchers have shown that the use of an exoskeleton in the rehabilitation process is safe and effective. Training in exoskeletons is the main trend in the rehabilitation of patients with locomotor disorders worldwide. It was found that as a result of training using an exoskeleton, motor function, spasticity, blood pressure, and gastrointestinal and genitourinary system dysfunction were restored in a short time. [5].

Special attention should be paid to passive exoskeletons, which have found their main application for military purposes. The weight of such an exoskeleton is from 2 kg, ergonomics, unpretentiousness in maintenance make it an indispensable assistant in long expeditions, military forced marches, in areas with emergency situations. The developers of this system also note the possibility of its use in patients with impaired function of the lower extremities [6].

Russian scientists have created a working model of a passive exoskeleton for soldiers and rescuers of the Ministry of Emergency Situations, which allows the human operator to carry large loads of up to 100 kg, and also to relieve the load on soldiers when carrying an assault shield [7].

They also formulated a clinical and anatomical criterion for exoskeletons, especially for people with impaired upper limb function. The exoskeleton has a range of motion close to that of a healthy person, which allows for the habilitation and rehabilitation of disabled people, as well as their social adaptation. When using exoskeletons, metabolic costs that occur during walking are reduced, which is why these devices are successfully used in teaching walking and restoring lost functions in post-stroke patients and patients undergoing rehabilitation after spinal cord injury [8].

There are models of mixed type exoskeletons - active and passive exoskeletons. For the active model to work, external devices are used as a source of energy, while the mechanics of passive exoskeletons are based on the use of kinetic energy and human strength. Active exoskeletons have also found wide application in military purposes, as a specialized suit for servicemen in field conditions. For people with mobility difficulties, exoskeletons such as eLEGS (Ekso Bionics, USA) are also used. This is a special hydraulic exoskeleton designed for patients with partially paralyzed lower limbs. The basis of the work is an interface-hardware-software complex that uses natural human movement to safely translate it into the action of the exoskeleton using a microcomputer [9].

Scientists from the University of Pennsylvania have developed an active upper limb exoskeleton - a fragment of the Titan Arm exoskeleton. Its design is cheaper, and the components are cheaper to produce, since some elements of the exoskeleton are printed on a 3D printer. The exoskeleton system is powered by batteries that are attached to the back, and is set in motion using special wires[10].

In foreign literature we came across the following descriptions of passive exoskeletons.
A representative of a passive exoskeleton is a soft pneumatic robot created by a group of researchers from Harvard University, the University of Southern California, the Massachusetts Institute of Technology and the developer of wearable sensors BioScience. The passive exoskeleton is lightweight sensory sensors and controlled software. The device is made of a soft elastic polymer. At present, it can only be worn on the shin, the biological structure of which is painstakingly reproduced in the device. In the new device, three cylindrical artificial muscles correspond to the muscles of the front of the shin and one to the back. Artificial tendons (steel cables) are stretched from the ends of these muscles down to the foot and serve to move the ankle. Feedback is provided by hyperelastic strain gauges located on the upper and lateral part of the ankle [11].

The exoskeleton's mobility is provided by flexible materials, but such a device is much more difficult to control than an exoskeleton made of conventional rigid materials. Studies have shown that the device is able to move the ankles in a 27-degree range of motion, which is enough for normal walking. Currently, scientists are trying to improve the design of the exoskeleton so that patients with real mobility problems can wear the device more comfortably [12-15].

As for the upper limb exoskeleton, US scientists have developed a robot that, thanks to drives controlled by neural signals coming from the patient, allows the limb to move in all planes. The basis of such an exoskeleton is the desire of a person to move his arm (shoulder, hand) somewhere. The machine detects this desire thanks to non-invasive surface electromyography, i.e. by a set of sensors that record biocurrents going to the muscles. The computer uses the natural, imperceptible to the eye, delay between the appearance of the first myoelectric signals and the actual start of movement of a particular muscle to have time to calculate the expected movement of the arm. As a result, the sensors of the robot suit operate absolutely synchronously with muscle contractions and "press" in the direction in which the wearer of the device wants to bend his arm, i.e. a control system called a bioport is formed. But the system for ensuring the conduction of impulses is still imperfect, self-care skills become impossible, which forces patients to be completely dependent on outside help [16].

The most popular is the development of researchers led by Tariq Rahman from the University of Delaware. This design is called WREX - Wilmington Robotic Exoskeleton. It is designed for children with upper limb weakness. WREX is a mobile system of supporting joints, which is usually attached to a wheelchair. The limb movements are carried out with little effort. The design allows for limited amplitude movements in three projections [17].

Our domestic Kazakhstan company "MBionics" has developed an exoskeleton, which was tested at the Department of Rehabilitation and Sports Medicine of the Astana Medical University

The testing of the Exoskeleton showed that all patients (100%) experienced a feeling of fear of falling during the first two sessions, especially when getting up from a chair. In one case (16.7%), this was a reason for refusing further testing. Also, during the first two sessions, patients noted pain in the abdomen and hips at the points where the device was fixed. However, starting from the third session, all five patients who continued the study showed a significant improvement in their psychoemotional state, a decrease in the feeling of fear, satisfactory well-being, and motivation for further training [18].

The testing of the exoskeleton showed complete safety of its use, risks of injury to soft tissues of the trunk and lower limbs, joints of the lower limbs and the spine were not identified. The degree of severity of the tone of the lower limbs and the severity of lower paraparesis in patients remained unchanged. The studies showed the lack of effectiveness of the presented exoskeleton in reducing the severity of paresis / plegia of the lower limbs and independent movement of the patient, at the same time, this device makes it possible for the patient to move with the help of the exoskeleton, which significantly expands the patient's ability to self-care.

CONCLUSIONS

Summarizing the above, we can draw the following conclusions: firstly, exoskeletons with an active operating principle allow for a greater range of motion, but they are dependent on external power sources. Secondly, their high cost and massive design limit their wide application, including for medical purposes. Passive exoskeletons do not have these disadvantages. They do not depend on external power sources, therefore, the weight of the structure is less, and its reliability is much higher. The cost of passive devices and their maintenance is much lower than that of their active counterparts. Thirdly, most of the known designs are aimed at the military industry, and development materials are poorly presented in the public domain, and are often simply classified. At the same time, such models are intended for healthy people (military personnel). At the moment, an important task is to develop exoskeletons with an expansion of their capabilities for the rehabilitation of disabled people in everyday life by restoring lost functions.

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