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Rehabilitation exoskeleton - the perspective of improving the quality of life for people with disabilities

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Abstract: The objective of the rehabilitation is to restore the patient's lost physical fitness, undertake activities preventing this loss and accelerate the creation of substitute compensatory mechanisms in the event of permanent morphological damage. The effectiveness of rehabilitation of disabled people can be increased through the use of manipulators and rehabilitation robots. Manipulators and rehabilitation robots are used for wheelchairs, for direct patient support and for therapeutic exercises. The exoskeleton offers vast possibilities of use in rehabilitation and patient care, both by medical personnel (in support mode) and by patients themselves (in rehabilitation mode).

Keywords: rehabilitation robotics, disability, exoskeleton

Introduction

An exoskeleton (Greek: exoskeleton - external) is a mechanical-electrical structure which put on its user similarly to a suit, and attached to individual parts of the body in order to support the movements by effectors (e.g. actuators) [1]. The powered exoskeleton is a computer-controlled robot (armour, suit), the design of which corresponds to the user's external anatomy. Other names used for the powered exoskeleton are power suit, wearable robot, powered armour, exoframe or exosuit [2]. The exoskeleton in rehabilitation is to help perform the daily activities in the most autonomous and natural way. Exoskeletons are intended for patients with damaged nervous system. They actively support the re-education of correct gait patterns by appropriate shifts of the centre of gravity. People with disabilities experience chronic health problems caused by immobilisation in a sitting position. These include loss of bone density, poor blood circulation, bedsores, muscle spasms, and recurrent bladder infections. Some of these problems require systematic medication. The forced sitting position puts pressure on the spine and muscles and causes chronic pain. The exoskeleton gives a chance to reduce the physiological and social effects of using a wheelchair.

Types of rehabilitation exoskeletons

The most popular exoskeletons used in the rehabilitation include: REX, EKSO, HAL, and ReWalk [2].

The Rex Bionics Robotic Exoskeleton (New Zealand) - is a device for people who are able to take it off by themselves and operate the joystick. RehabRex is a version used in hospitals, rehabilitation centres and other facilities of similar profile, which can be adapted to the different dimensions of the patient's body, and is used under the supervision of a physiotherapist. The prototype of the device was created by Richard Little and Robert Irving in 2007. The objective was to create a functional, robotic exoskeleton which would allow people with disabilities to be more mobile, thereby improving the quality of their everyday

life. The REX moves slowly but has plenty of manoeuvrability in a variety of directions including forward, backward and side to side. It is self-stabilising so its users do not need to have external support, leaving the upper body relatively free for other functions. Currently, the device does not allow climbing and descending stairs. The device was made of carbon fibre, lithium-ion battery with an adjustable balancing system. It is controlled by a panel placed on the device at hand height and a joystick. The REX is powered by a reusable battery which allows for two hours of operation when fully charged. The frame weighs 38 kg, the maximum walking speed is 3 m/min (180 m/h). The permissible patient weight cannot exceed 100 kg. The permissible height is in the range from 1.46 m to 1.95 m. It can be used for patients with spinal cord injuries and multiple sclerosis, it supports recovery after strokes or traumatic brain injury. Before the purchase, the consent of the attending doctor and physiotherapist to use the exoskeleton is required [3, 4].

Fig. 1. Rex Bionics exoskeleton [5].

ReWalk™ is the first exoskeleton approved by the FDA (Food and Drug Administration) for therapeutic purposes for use at home or at a rehabilitation centre with a physiotherapist. The exoskeleton has motors in each hip and knee joint, a battery, a closed-loop computer controller, and sensors for measuring the tilt angle of the upper part. It has activity modes: standing, sitting or walking, which can be selected by the user. The device allows to cover a distance of 50-100 meters without stopping in 5-10 minutes with an average speed of 0.25 m/s. The system detects the forward tilt of the torso which initiates the first step. Repeated body movements generate a sequence of steps that mimics the functional natural gait. The device may be used by people weighing less than 100 kg and with a height between 160 and 190 cm [6.7].

Fig. 2. ReWalk exoskeleton [7].

The EKSO exoskeleton, also known as eLEGS, Exoskeleton Lower Extremity Gait System (Berkeley Bionics, California, USA) is a device for people with paraplegia who are able to move themselves independently from a wheelchair to a chair. The indications include: spinal cord injury (SCI) - regardless of the level of damage, multiple sclerosis (MS), Parkinson's disease. The device allows you to restore independent gait with the use of crutches. Clinical tests have confirmed that gait training with the use of the Ekso exoskeleton helps

patients to re-learn the correct step pattern and enables them to perform more steps at a faster pace compared to traditional rehabilitation [8].

Fig. 3. Ekso exoskeleton [8].

The EksoUE exoskeleton, an exoskeleton for the rehabilitation of the upper limbs, helps physiotherapists and doctors in the clinical rehabilitation of patients with weakness or paralysis of the upper body. It can be used in muscular dystrophy, brachial plexus injuries, upper limb paralysis. Spring powered operation allows continuous use without recharging as there is no battery. It enables the patient to perform an active range of motion with assistance in all planes. It can be used while sitting, standing and moving around. Thanks to EksoUE, patients can perform rehabilitation sessions with a higher dose, more intensive therapy and a wider active range of motion [8].

Fig. 4. EksoUE exoskeleton [8].

HAL- (Hybrid Assistive Limb) can be used by people with incomplete spinal cord injuries, after strokes and craniocerebral injuries, by patients suffering from multiple sclerosis, neurodegenerative diseases (Parkinson's disease). The therapy is intended for patients with gait dysfunctions who have a minimal function of the lower limbs (paresis of the lower limbs), because the robot is controlled by the nerve impulses. The exoskeleton is controlled by sensors placed on the user's skin which read the electrical impulses generated by the muscles. The drive unit is monitored on the basis of the collected signals. This allows the joints of the exoskeleton to move in line with the work of the user's muscles. In the absence of the above-mentioned signals, the exoskeleton is equipped with a "robotic autonomous control system" enabling it to perform human-like movements. It can also be used by children, after cerebral palsy for instance, but they must be at least 140 cm tall. For patients with spinal cord injury, the use of the HAL system improves the gait function and at the same time improves the excitability of the cortex, which induces plasticity of the brain. The advantage of

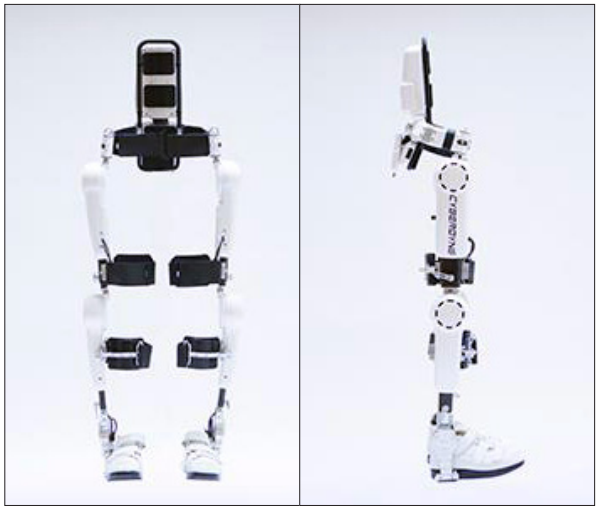

Fig. 5. HAL-(Hybrid Assistive Limb) [11].

the device is dividing the trained movements into sequences and such control of the movement that for each joint it is performed according to a separate, dedicated trajectory [9, 10].

Indego exoskeleton - the device acts as an external skeleton. It fits tightly around the torso and rigid supports are attached to the legs extending from the hip to the knee and from the knee to the foot. The hip and knee joints are operated by the computer-controlled electric motors powered by advanced batteries. Patients use powered equipment with walking frames or crutches to maintain balance. The Indego is another exoskeleton, apart from ReWalk, to be FDA-certified for use at home or in a rehabilitation facility. The approval of the Indego exoskeleton for general use was preceded by the completion of many years of clinical trials in the United States. During more than 1,200 individual sessions, study participants were able to use the Indego testing the device both indoors and on various outdoor surfaces. One requirement was to allow the user to put on and remove the exoskeleton while sitting in a wheelchair. No serious adverse events were reported. As a result, the Indego is much lighter and less cumbersome than other external skeletons. The device incorporates proven rehabilitation technology called functional electrical stimulation. The FES applies small electrical impulses to paralysed muscles, causing them to contract and relax. FES can improve leg strength for people with incomplete paraplegia. In the event of complete paralysis, FES can improve circulation, change bone density, and reduce muscle atrophy.

Fig. 6. Indego exoskeleton [12].

Conclusions

Robotics is an opportunity to significantly improve the quality of life of people with disabilities and reduce the physiological and social effects of disability. Devices such as exoskeletons considerably support rehabilitation by shortening its time and increasing its effectiveness. Numerous studies among people with disabilities in the field of partial and complete damage to the spinal cord with the use of rehabilitation robots show a high level of acceptance of this form of rehabilitation, the effectiveness in overcoming barriers, patients' safety and satisfaction. Exoskeletons give people with spinal cord injury the opportunity to engage in physical activity and exercise, thus contributing to increasing cardiovascular and respiratory efficiency, muscle strength, and positively influencing spasticity and mood.

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