REVIEW

ROBOTIC SOLUTIONS FOR POST-STROKE RECOVERY – LITERATURE REVIEW

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Abstract

Stroke stands as a widespread and severe health concern worldwide, often resulting in profound motor and cognitive impairments. Its impact is particularly pronounced in the Republic of North Macedonia, posing significant social and economic challenges. Beyond acute-phase treatments like medication and surgery, rehabilitation emerges as a pivotal component of stroke management. Robotic technology offers distinct advantages over conventional physical, occupational, and speech therapies, increasingly becoming a preferred option in post-stroke recovery. By integrating rehabilitation robots, not only does the burden on healthcare professionals decrease, but also the outlook for stroke patients improves. In this review, we provide a concise examination of the role played by therapeutic robots in the rehabilitation of individuals post-stroke. Our focus will encompass outlining the fundamental distinctions among various robotic rehabilitation devices and assessing the merits and drawbacks of employing robotic rehabilitation specifically for lower extremity rehabilitation.

ПРЕГЛЕД НА ЛИТЕРАТУРА

РОБОТСКИ РЕШЕНИЈА ЗА РЕХАБИЛИТАЦИЈА ПО МОЗОЧЕН УДАР – ПРЕГЛЕД НА ЛИТЕРАТУРАТА

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Клучни зборови: рехабилитација, мозочен удар, роботска терапија, долни екстремитети

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Печатарски права: ©2024. Марија Гоцевска, Цветанка Ѓеракароска-Савевска, Ериета Николиќ-Димитрова, Валентина Коевска, Билјана Митревска, Билјана Калчовска, Маја Манолева, Даниела Гечевска. Оваа статија е со отворен пристап дистрибуирана под условите на нелокализирана лиценца, која овозможува неограничена употреба, дистрибуција и репродукција на било кој медиум, доколку се цитираа оригиналниот(ите) автор(и) и изворот.

Конкурентски интереси: Авторот изјавува дека нема конкурентски интереси.

Извадок

Мозочниот удар претставува широко распространет и сериозен здравствен проблем ширум светот, често резултирајќи со значајни моторни и когнитивни оштетувања. Неговиот импакт е особено изразен во Република Северна Македонија, предизвикувајќи значајни социјални и економски последици. Покрај третманот во акутната фаза, кој опфаќа примена на лекови и хируршки интервенции, рехабилитацијата се издвојува како клучна компонента во менаџментот на мозочниот удар. Роботската технологија нуди посебни предности во споредба со конвенционалната физикална терапија, работна терапија и логопедски третмани, и сè повеќе станува приоритетна опција за закрепнување на пациентите по прележан мозочен удар. Со интеграција на уреди за роботска рехабилитација, не само што се намалува оптоварувањето врз здравствените работници, туку и се подобрува прогнозата за пациентите со мозочен удар. Во овој труд, даваме краток преглед за улогата на роботската рехабилитацијата кај пациентите по прележан мозочен удар. Нашиот фокус ќе биде насочен кон преглед на основните разлики помеѓу различните уреди за роботска рехабилитација и проценување на предностите и недостатоците од употребата на роботска рехабилитација, особено за рехабилитација на долните екстремитети.

Introduction

Stroke is a clinically defined syndrome of acute, focal neurological deficit attributed to vascular injury (infarction, haemorrhage) of the central nervous system. Stroke is a huge and increasing global health challenge. Worldwide, stroke is the leading cause of acquired physical disability in adults, and the second leading cause of mortality in middle- to high-income countries.

People with stroke are in need of access to efficient rehabilitation therapy. The goal of the rehabilitation in these patients is to restore the motor functional mobility, cognitive functions, to improve balance, walking ability and to return to daily activities.

Motor recovery after stroke is a complex, dynamic and multifactorial process. It includes genetic, pathophysiological, sociodemographic and therapeutic factors that determine the course of the recovery.

Parallel to the development of a large number of manual-assisted techniques, now we are in a modern technological era when technology has been largely developed and has found its place in the rehabilitation of post-stroke patients. Thus, today in the rehabilitation of patients with stroke robotics and virtual reality can be applied. The use of technology in rehabilitation of patients has been very efficient in improving the functional mobility of post-stroke patients by decreasing the costs for workforce, increasing the patients' motivation and functional monitoring of the progression of the rehabilitation process.[1] The integration of robotic rehabilitation in the conventional neurological rehabilitation has proven some level of efficacy in rehabilitation of post-stroke patients.[2]

After stroke, the most common problems that patients encounter are walking difficulty and poor balance. Hence, we have made a literature search on the use of modern technology in rehabilitation of walking ability and balance.

The aim of this review is to analyze the principal differences in the robotic devices for rehabilitation and to present the advantages and drawbacks of robotic lower limb rehabilitation.

Technological advancement of robotic rehabilitation devices

Robotic devices are technological revolution in the rehabilitation medicine. As representatives of the technology they assist, improve and accelerate the recovery, enhance the quality of life and independence of the patient.[3] Robotic-assisted gait training (RAGT) has been in use since 1980 for assisted gait in patients with walking difficulty caused by neurological disorders.[4] This treatment is based on the principle of body-weight supported treadmill (BWSTT) and by successive repetition of different gait phases, the functional motor learning is achieved.[5] Repeating the same movement enables the nervous system to create a better communication between the central and peripheral nervous system.[6] After stroke, the brain can be influenced by intensive sensorimotor training through neuroplasticity that has impact across the subacute and chronic phases of the post-stroke recov-

ery. Rehabilitation of patients after stroke based on the BWSTT principle includes one or two physical therapists that facilitate the desired movement while the patient is on a treadmill, where the robot provides partial or full body weight support to the patient's lower limbs.[7] BWSTT, in comparison with the conventional mode of rehabilitation, has proven to be better since patients increase walking distance as well as the number of steps performed, resulting in more repetitions of the gait cycle.[8]

Rehabilitation robots are programmed, multifunctional electromechanical devices, divided into robotic exoskeleton and endoskeleton.[9] Exoskeleton robotic device is attached parallel to the patient's lower limbs and allows movements of all joints of the lower limbs. Robotic endoskeletons are attached to the distal segment of the limbs and they help in movements of only those segments; they are the so-called end-effectors.[10,11] The end-effector is a series robot mechanism, which has larger movement space and provides more freedom of the patient's movements.[12] Unlike the end-effectors types, robotic exoskeletons are installed outside the patient's body. The joints of the robot have a direct correspondence with those of the human body, that is, with the limbs. This portability of the exoskeleton makes it a good choice for rehabilitation of patients who have sustained a stroke. Although there are problems in adjustment with the anatomical axis of the human body, robotic exoskeletons are widely used in robotic rehabilitation and have reached a significant development in recent years. Exoskeletons are increasingly becoming a major option in clinical treatment compared to end-effectors.

Rehabilitation robots can also be classified to upper and lower limb robotic rehabilitation devices depending on the affected area.[13]

Virtual reality is a rehabilitation platform that enables creation of a virtual world for the patient during the process of robotic rehabilitation treatment. In the virtual world, the patient performs tasks that are a constituent part of the rehabilitation process. Virtual reality can be an individual choice of rehabilitation or additional assistance during robotic rehabilitation. Therefore, the third division of robotic devices is made according to the level of interaction between the patient and virtual environment. Consequently, they are divided into traditional and robots using virtual reality.[14]

Review of robotic rehabilitation devices for lower limbs

In recent years, various types of robotic devices have been developed for the rehabilitation of patients with impaired motor function, including those with paralyzed limbs or individuals who have had a stroke.

The existing robots designed for physical therapy are most commonly included in the neuromotor training of patients suffering from neurological diseases.[15] Verticalization of a patient and maximum independence are priorities of the rehabilitation process. The major problem in the lower limb rehabilitation is that patients are not able to maintain balance and to walk independently.[16] Robotic systems provide stability to patients.[17] In addition, these systems

participate actively in the patient's lower limb motion by an integrated software system that is coordinated with sensors, thus imitating the work of the therapist. These robotic systems are usually exoskeleton type devices.

In 2001, the Swiss Federal Institute of Technology developed the exoskeleton rehabilitation robot Lokomat. It was produced by Hocoma, and is an advanced type of a robot developed to recover the function of the lower limbs in adults and children with partial or total loss of the lower limb function. The device consists of an integrated running treadmill with dynamic (body-weight) support system, a computerized gait orthosis, and a hardware control system.[18] In an entertaining and interactive way, by using video games, Lokomat stimulates the patient to make certain motions several times that leads to faster patient's recovery. Locomat moves the patient's legs in a repeated cyclical gait motion in the sagittal plane.[19] Additional motivation for the patient is the biofeedback, that is, the precise measure through sensors located on the knees and hips. Thus, a clear insight into the patient's functionality and course of the recovery can be obtained.

LokoHelp is a gait-training robot that was produced and developed by a German company. It consists of three components: a device to which the feet or limbs are tied, a running treadmill, and a body-weight support system. This robot can provide basic gait rehabilitation. It has a modular design that is easily assembled, dismantled and adjusted for allowing vertical up and down motion of the patients. Clinical and experimental studies about LokoHelp have shown that the influence of rehabilitation of this robotic system is almost identical to the conventional method of gait rehabilitation training, but it significantly reduces the human resources and provides physical relief to the therapists.[20]

Andago robot provides stability and a sense of safety while enabling safe walking, ensuring quality body posture that results in the elimination of patients' fear of free walking.[21] Andago is the safest robotic device.[22] It affords control of the functional rehabilitation that allows patients to walk without fear of falling. This gait-training device automatically presents the graphic functional recovery that can be stored in the patient's digital memory card.[23]

C-Mill and virtual reality (VR) is a robotic device that combines virtual technology with a running treadmill developed for training and assessment of the patient's gait and balance for safe daily walking. There are three types: C-Mill, C-Mill VR and C-Mill VR +. Although C-Mill VR and C-Mill VR + types use elements of virtual technology for stimulating patients, their final goal is different. Robotic C-Mill VR device is used in training of automated movements whereas C-Mill VR + is a thorough/detailed solution for rehabilitation with body-weight support on gait and balance.[24]

ALEX (Active Leg Exoskeleton)robotic system consists of a treadmill, exoskeleton orthoses for lower limbs and a control system. It has four degrees of freedom assisting free movements, two degrees of freedom assisting the hip movements, one degree of freedom for the knee and

one for the ankle. It uses a balancing mechanism for human body's gravity, and hence, it can help patients achieve balance.[25] However, it has a major drawback – it puts a great deal of physical labor to both therapists and patients, and one or two therapists are needed to assist the patient by manually guiding limb movements and providing trunk stability. Manual help during the training process varies from one therapist to another and thus it is difficult to be consistent in each training session.[26]

Walkbot G is a robotic rehabilitation system for gait training assisted by double robotic orthoses compatible for adults and children. It uses a mode for dynamic body-weight support in real time with distant remote control.

Ekso GT is a robotic exoskeleton constructed by Ekso Bionics and approved to be used for hemiplegic patients after stroke. Ekso is a wearable robot powered by batteries, made of 30 carbon fibers that uses a hydraulic system for charging. This exoskeleton is bilaterally attached to the lower limbs and has electrically movable joints for the hips and the knees, and passive ankle articulation.[27] Built-in sensors are placed around the patient's body and respond to the patient's muscle performances. Ekso robot works in several modes depending on the necessary degree of assistance required by the patient, and it also assists in training motions such as standing up from a chair, walking and sitting down, and vice versa.[28]

Advantages and drawbacks in the application of robotic rehabilitation

Robotic rehabilitation as a new technology has its own advantages, but also its limitations. Advantages include patients' greater motivation, program dynamics and shorter duration of the entire rehabilitation process, greater objectivity and possibility to modify a larger number of parameters. The advantage of robotic rehabilitation is the option to quantify and monitor the patient's motor improvement. It provides precision in the therapeutic engagement and precise measurement of the achieved results. It improves the coordination and helps in reaching the desired scheme of motions.[29] During robotic-aided training, the patient's body weight is supported by a belt system thus eliminating the need of therapeutic assistance. Robotic exoskeletons have proven to be an attractive tool not only in the gait rehabilitation, but also improving the level of patients' physical activity after motor deficits.[30] Robotic hardware enables control of the treadmill, control of the belt and harness system so that different techniques can be applied adjusted to the need of the patient. The software enables programming of the devices for movement control. It regulates the precision and intensity of the movements as well as the mode of interaction of the patient by monitor's virtual reality. Software applications allow collecting, interpretation and sending information regarding the progress of the patient in a real time.[28] This allows doctors and therapists to (continually) monitor and analyze the patient's performance and to individualize

the training session. Many of the rehabilitation robotic devices include software (video) games that make the rehabilitation sessions more interesting and fun for the patient. Patients are additionally motivated and the outcome rehabilitation results are improved.

Along with advantages, there are disadvantages when using rehabilitation robots. Newer technologies have not yet been thoroughly investigated in clinical trials; then, the price of the devices is very high; they occupy more space; require a specific education of physical therapists. End-effectors robots have been associated with more technical drawbacks.[31,32]

Over the last ten years, there has been a dramatic advancement in the field of robotic rehabilitation, and when reviewing the literature, every year there is more research on this topic.

Rehabilitation robotics in lower limb function

In recent years, there has been significant development in lower-limb rehabilitation robotics, which have become indispensable in assisting stroke patients by improving motor function in paralyzed limbs. These robotic systems enable structured and efficient training to enhance motor skills in affected limbs.[33]

Most randomized controlled trials have utilized exoskeleton robots, either alone or with combined endeffector devices (end – effector).[34,35] Additionally, there have been studies involving gait robots based on the end-effector principle, where a vest supports the patient's weight, and their feet are fastened to the system using two platforms to simulate gait movements.[36,37] Most robots developed to enhance patients' walking or stair-climbing capabilities in the lower limbs typically provide three degrees of freedom. This allows independent rotation at the hip joint, knee joint, and ankle joint within the sagittal plane. Some robotic systems integrate harnesses to aid patients in supporting a portion of their body weight while walking with the device. In the study by van Dellen F et al. the participants had stroke stages ranging from acute to sub-acute and chronic phases. The experimental group used a robot, either alone or in combination with traditional rehabilitation techniques, while the subjects in the control group applied only traditional rehabilitation methods. The result of the study showed that robot-assisted gait training with body weight support effectively improved the walking ability of stroke patients.The result of the study indicates that robot-assisted gait training with body weight support effectively improved the gait of stroke patients.[39]

Lower-limb rehabilitation robots do not appear to beeffective in improving the spasticity status of the lowerlimbs. The Modified Ashworth Scale (MAS) is commonly usedto assess lower-limb spasticity in stroke patients. Li et al. discovered that patients who underwent robot-assisted gait training with exoskeletons for 4 weeks did not experience greater improvements in MASthan thosewho received traditional training.[26]

The study by Hesse S. et al indicatedthatrobot-assisted practice of gait and stair climbing did notprovide any

benefits in reducing lower extremity (LE)muscle tone in stroke patients[37] However,Park et al. suggested that utilizing an inventivehumanoid robot capable of coordinating interlimb movementbetween the ankle, knee, and hip joints, can significantlyincrease active and resistive forces in these jointscompared with physical therapy. They observed that resistivestiffness in the hip extension, knee extension, ankledorsiflexion, and ankle plantarflexion muscles had a moderatecorrelation with spasticity, suggesting that RAGT (Robotic assisted gait training) mighthelp reduce spasticity, stiffness, and abnormal synergistic(extensor) gait patterns in thelower limbs[39]. In summary,further research is necessary to confirm the efficiency of thelower limb rehabilitation robots for lower limb spasticity.

Only a small number of randomized controlled trials (RCTs) have explored the impact of lower limb rehabilitation robots on muscle strength. Lin et al.were the only ones to observe notable improvements within the Robot-Assisted Gait Training (RAGT) intervention group. However, no significant disparity in manual muscle test (MMT) scores was detected between the intervention group and the control group undergoing conventional rehabilitation[40].

In general, therapeutic robots designed for lower limb rehabilitation have generated mixed evidence regarding their effectiveness in improving active functional movement of the lower limbs. The Fugl-Meyer Assessment of Lower Extremity (FMA-LE) serves as a widely accepted standard for evaluating motor function post-stroke[42]. Results regarding the effectiveness of RAGT compared with the conventional rehabilitation, as measured by FMA-LE, have varied. While some studies have reported significant improvements in the RAGT group[43,41]others have not observed significant differences between the two groups[41,42,43]. When itcomes to assessing walking ability, the Functional Ambulation Classification (FAC) of stroke patients in the acute orsub-acute phase showed improvements following RAGT, but no significant difference was observed betweenexperimental and control groups.

Furthermore, Mayr et al. concluded that an early treatment protocol involving conventional physical therapy in addition to RAGT is not superior to that of adding conventional gait training intervention for improving locomotion in stroke patients, as measured by the modified Emory Functional Ambulation Profile. In summary, the effectiveness of lower-limb rehabilitation robots in improving lower limb motor function remains uncertain.

Regarding lower limb coordination and balance among stroke patients, Kim et al. observed a notable improvement in coordination function within the Robot-Assisted Gait Training (RAGT) group compared to the conventional training group.[35] However, research on the efficacy of rehabilitation robots for improving balance function in lower limb rehabilitation has not consistently produced positive outcomes. Concerning balance in the standing position, rehabilitation robotic therapy exhibited improvement only within the group, with no significant distinction between groups compared

to conventional therapy.[43]

Summary and future perspectives

This review article has given insight into the application of robotic-assisted rehabilitation, its advantages and drawbacks and its efficacy in rehabilitation post-stroke. In summary, robotic technology holds significant promise in aiding the motor recovery of individuals post-stroke. Robotic rehabilitation allows patient's active participation in walking while overcoming interesting challenges and biofeedback as well as providing a safe support. By utilizing rehabilitation robots, healthcare professionals can alleviate the demands of intensive training tasks. With their precision and reliability, these robots present an efficient avenue to improve outcomes for stroke patients.

Although some results point to the superiority of robotic rehabilitation over manual one, i.e., one-on-one rehabilitation, the effect of the therapy is best when combining both methods of rehabilitation.

Literature search has shown the necessity of new, more detailed research in order to define the right time when to start with robotic-assisted rehabilitation after stroke and to determine the dynamics of its application.

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