World Journal of Biomedical Sciences
ISSN: 2960-0189
DOI: 10.61784/wjbs240141

PROGRESS IN REHABILITATION ROBOT ASSISTED GAIT RECONSTRUCTION TRAINING FOR STROKE PATIENTS

Jinwoo Jung
Yonsei University, Seoul 120-749, Korea.

Abstract: It elaborated on the high disability rate of stroke and the important position of rehabilitation robots in assisted rehabilitation training. It introduced in detail the possible mechanisms, clinical research and key technologies of different rehabilitation robots to assist stroke patients in improving hemiplegic gait, and pointed out that rehabilitation robots assist The advantages and disadvantages of gait reconstruction in stroke patients in clinical application are discussed, and it is expected that rehabilitation robots should develop towards intelligent, precise, convenient and family-oriented in the future to better assist the gait reconstruction training of stroke patients.
Keywords: Rehabilitation robot; Stroke; Gait reconstruction; Hemiplegic gait; Rehabilitation training

1 INTRODUCTION

Currently, stroke ranks first among the causes of disability in the world and is the second leading cause of death [1]. There are more than 200 new stroke patients in China every year Ten thousand people, among all diseases, stroke causes the longest disability-adjusted life years [2]. After stroke, weakness or spasm of the lower limbs and loss of proprioception will affect the patient's balance and walking ability, interfering with their normal gait [3]. Evidence-based medicine shows that the most effective way to reduce the disability rate after stroke is rehabilitation, among which exercise therapy is an effective and feasible rehabilitation strategy [4-5]. However, traditional rehabilitation methods are mainly based on one-to-one training by therapists, which are labor-intensive, high labor cost, low work efficiency and boring, making it difficult to mobilize the enthusiasm of patients for training [6]. Therefore, the use of advanced technical equipment such as rehabilitation robots to assist patients in gait training has attracted more and more attention. Rehabilitation robots integrate knowledge from multiple disciplines such as rehabilitation medicine, mechanics, robotics, artificial intelligence, and informatics. They use multidisciplinary cross-disciplinary results to assist stroke patients in rehabilitation training and improve the effectiveness of training. Lower limb rehabilitation robots were first used in clinical practice in the 1990s. They use various technologies such as virtual reality, motion control, and intention perception to improve patients' lower limb muscle strength and walking ability through various trainings such as standing, walking, and balancing, thereby improving Its hemiplegic gait [7-8]. This article mainly reviews the possible mechanisms, clinical research, and key technologies of rehabilitation robots for improving hemiplegic gait in stroke patients.

2 POSSIBLE MECHANISM OF REHABILITATION ROBOT IMPROVING HEMIPLEGIC GAIT IN STROKE PATIENTS

Normal gait is the result of the complex interaction between sensory-motor-central systems. The brain center controls different muscle groups through real-time feedback to maintain a stable walking pattern. In stroke patients, due to the destruction of neural pathways, muscle activity in certain muscle groups is activated or lost, resulting in a loss of synergy on one side of the body, resulting in abnormal gait patterns, such as foot drop [9]. Neural remodeling is the key to the recovery of lower limb motor function and gait. Although spontaneous remodeling changes occur in the damaged brain tissue of stroke patients, these changes are not enough to produce significant functional recovery [10].

The specific and rich training provided by the rehabilitation robot can improve the local blood flow of the patient's infarction, promote vascular regeneration, save the function of nerve cells around the infarction, and promote neural remodeling [11]. Li Kunbin et al. [12] used electroencephalogram measurement, cranial diffusion tensor imaging detection, three-dimensional gait analysis and other studies to confirm that lower limb rehabilitation robot-assisted training improved the activity of patients' brain cells, the symmetry of the bilateral brain and the healthy side. The compensatory effect of the cerebral hemispheres further improved his post-stroke hemiplegic gait.

The task-oriented repetitive motion training of rehabilitation robots can inhibit the patient's neuronal apoptosis, prune the dendrites around the infarction focus, regulate neuroplasticity [13], and promote the cortex around the infarction focus and the distal cortex to replace the original function of the infarction focus. Allowing the reorganizing cortex to learn and store correct movement patterns [14]. Liu Chang et al. [15] guided patients to use lower limb rehabilitation robots to provide timely and appropriate load stimulation and sensory input, thereby promoting the activation of neural mechanisms, and at the same time conducting a large number of high-precision training close to physiological gaits. The results confirmed that the lower limb rehabilitation robots are improving The patient's hip flexion strength, 6-min walking distance and 10-m walking time were significantly improved. Calabrδ et al. [16] also confirmed that the repetitive and rich movement training provided by the lower limb rehabilitation robot can promote neural remodeling, enhance the muscle memory of the patient's hemiplegic side, thereby improving his hemiplegic gait.

3 CLINICAL STUDY ON THE IMPROVEMENT OF HEMIPLEGIC GAIT OF STROKE PATIENTS USING REHABILITATION ROBOTS

The main manifestations of hemiplegic gait in stroke patients include decreased muscle strength of the affected lower limbs, increased muscle tension, knee hyperextension, foot drop, foot inversion, insufficient knee and hip flexion angle or straight knees, etc., which are dragged or circled when walking. status[17]. Motion analysis and surface electromyography are important methods for evaluating gait changes. Among them, the motion analysis method is a scientific method to observe and explore the time and space changes of lower limb movement [18]. In clinical research, three-dimensional gait analyzers are commonly used for time-space measurement. The specific parameters include step width, step speed, stride length, and step length. Length, cadence, phase of stance, and swing are equal. Surface electromyography detection technology can collect electrical signals of muscle activity in various motion states through electrode pads and conduct quantitative and qualitative analysis, which is of great significance for the assessment and guidance of gait rehabilitation and training guidance for hemiplegic patients with stroke [19]. Based on the current clinical research status of different rehabilitation robots, the significance and value of assisting gait reconstruction in stroke patients are analyzed.

3.1 A3 Type Rehabilitation Robot

The training principle of the A3 rehabilitation robot is weight loss walking. By adjusting parameters such as guidance force, weight loss support, walking speed, hip and knee joint range of motion, and gait deviation, different training intensities and training methods (such as (shown in Figure 1) [20]. Redebaugh et al. [21] randomly divided 80 stroke and hemiplegic patients into 2 groups: the A3 rehabilitation robot group (hereinafter referred to as "A3 group") and the control group. The control group received relevant physiotherapy, hydrotherapy, daily activity training and gait correction training. The A3 group cooperated with the A3 type rehabilitation robot to assist lower limb training on the basis of the control group. Both the above two groups completed 8 weeks of rehabilitation training. Before and after the start of training, After completion, a three-dimensional gait analysis system was used for gait evaluation. The results showed that compared with the control group, the walking speed and cadence of the patients in the A3 group were significantly faster, the step length was longer, the step width was smaller, and other gait parameters were also significantly improved. Cheng Xue et al. [22] also used the A3 rehabilitation robot to conduct gait training research, and selected 12 stroke patients for 6 weeks of gait rehabilitation. Gait Watch three-dimensional gait analyzer was used to measure and analyze gait parameters before and after training. , the daily living ability and walking ability of 12 patients were significantly improved compared with before training, but the improvement in gait symmetry was less significant. The above two studies show that although the A3 type rehabilitation robot is used to assist stroke patients in gait training, due to the differences in the population extracted, the degree of disease progression, the robot's setting parameters, and the evaluation of three-dimensional gait analysis equipment Differences in parameters will affect the evaluation of training results, and further research and demonstration are still needed.

Fig. 1 A3 type rehabilitation robot[20]

3.2 Gait Exercise Assist Robot (GEAR)

GEAR is mainly composed of wearable knee-ankle-foot orthotics, flat treadmills, safety suspension devices, weight support devices, monitors and control panels. It has many advantages, such as the ability to adjust training difficulty and assistance according to individual needs. level, the training volume and mode can be adjusted through visual and auditory feedback (as shown in Figure 2) [23-24]. Wang et al. [25] divided subacute stroke patients into 2 groups. The control group received conventional physical therapy and occupational therapy, and the GEAR group received GEAR gait training on the basis of the control group. The results showed that the independent walking function score, Stroke Injury Rating Scale lower limb motor function total score, and cadence of the patients in the GEAR group at discharge were significantly improved compared with those before training, and the knee hyperextension, insufficient knee flexion, and hip joint of the affected limb were significantly improved. External rotation and other improvements were obvious. However, no significant changes were observed in the control group at the corresponding evaluation time points, which shows that GEAR is better than conventional rehabilitation training alone in improving the gait of patients with subacute stroke. Ogino et al. [24] proved that GEAR-assisted gait training can improve hip abduction in patients with chronic stroke, and in the follow-up evaluations 1 month and 3 months after training, the patient's walking speed and step length increased. This shows that the gait and walking ability of subacute and chronic stroke patients have improved with the assistance of GEAR, and the optimized gait and walking ability can be maintained for a long time. The difference is that Katoh et al. [26] believe that although auxiliary training using GEAR can reduce patients' abnormal gait, compared with traditional gait training, there is no significant change in walking speed, stride length and step length. At present, many studies are based on conventional gait training combined with rehabilitation robot training. Although the results are better than conventional training alone, the effectiveness of using rehabilitation robots alone to improve gait function is still insufficient.

Fig. 2 GEAR[24]

3.3 Lokomat Robot

The Lokomat robot is mainly composed of three parts: a treadmill, a weight reduction system and two exoskeleton mechanical legs. It has two training modes: active and passive. The patient can choose the appropriate mode according to his or her own situation (as shown in Figure 3) [27]. In addition, technologies such as autonomous control and impedance control make patients' active walking training more intelligent, and their biofeedback, training reward and other systems can mobilize patients' enthusiasm for participating in training [28]. There are many positive reports at home and abroad about Lokomat robot-assisted gait training for stroke patients [29-31]. In order to understand the impact of the Lokomat robot on patients' limb muscle activities in terms of body weight support and walking speed, so as to optimize the exercise guidance program, Van Kammen et al. [32] gave 10 healthy subjects different levels of guidance and weight loss. Support and pace training, and use surface electromyography to record the information of the gluteus medius, vastus lateralis, biceps femoris, gastrocnemius medialis and tibialis anterior muscle. Average muscle activity levels are compared. The results showed that in subjects with guidance ability, the activity range of muscles related to stability and propulsion, such as erector spinae, gluteus medius, biceps femoris and gastrocnemius medialis, was reduced, and abnormal activity information appeared normal. ation, and the size of the guiding force depends on the pace and body mass support. Low speed and high body mass support will lead to a reduction in the patient's own activity. Therefore, although the Lokomat robot can effectively induce normal muscle activity patterns and optimize hemiplegic gait, it also requires specifically set motion parameters. Another study by the same team [33] selected 10 stroke patients and performed different levels of guidance, weight loss support, and pace training, and recorded their bilateral gluteus medius, biceps femoris, and vastus lateralis muscles. , surface electromyography of the gastrocnemius medialis and tibialis anterior muscles, but the results were different from those of healthy subjects. Different guiding force and body mass support have little effect on muscle activity in stroke patients, but increasing the walking speed will cause the activity of the biceps femoris, gastrocnemius medialis, tibialis anterior and all muscles of the unaffected leg. increases, and the space-time symmetry is not affected by parameter settings. Therefore, the Lokomat robot training parameters are ineffective in shaping short-term muscle activity and gait symmetry in stroke hemiplegic patients, and gait speed is the only parameter that significantly affects the amplitude of muscle changes. It can be seen that there are differences in exercise training between healthy subjects and stroke patients. It is beneficial for early stroke patients to increase the training speed as early as possible for gait recovery. As their own gait improves, the rehabilitation robot should be appropriately adjusted. training parameters.

Fig. 3 Lokomat robot[27]

3.4 Other Rehabilitation Robots

Swank et al. [34] conducted relevant research on gait recovery in chronic stroke patients. Their team compared the immediate changes in kinematics and muscle activity of patients before and after Ekso robot treatment, and observed changes in ankle joint mobility after a single training session. , and the abnormal muscle activity of the affected limb is reduced when swinging, and the patient's coordination of limb movements when standing and swinging is also improved. Therefore, a single Ekso robot training appears to immediately change the gait of chronic stroke patients, but these changes are not sufficient to promote rapid changes in parameters such as gait speed, cadence, step length, etc. For patients with subacute stroke, Park et al. [35] showed that after using a rehabilitation robot to assist with gait training, the improvement in lower limb motor function and gait continued until the 4-week follow-up, proving that the rehabilitation robot can improve gait. However, it also clearly states that during the patient training process, the auxiliary control of the rehabilitation robot should be gradually reduced according to the degree of recovery to avoid patients becoming dependent on it. A case study by Krishnan et al. [36] showed that for patients who can walk, traditional rehabilitation training is better than rehabilitation robots, and the auxiliary training of rehabilitation robots will reduce the patients' enthusiasm for autonomous movement. However, the sample sizes of the above studies are small, and many of them are preliminary studies. Large-scale, randomized multi-center studies are still needed to verify the scientific nature of these data.

4 KEY TECHNOLOGIES FOR REHABILITATION ROBOTS TO IMPROVE HEMIPLEGIC GAIT OF STROKE PATIENTS

4.1 Virtual Reality Technology

Virtual reality technology has three basic characteristics: immersion, imagination, and interaction. It allows patients to integrate into the virtual environment and communicate and interact with virtual objects. It has high safety, strong fun, diverse feedback forms, and good repeatability. Features[37]. Rich practice tasks, realistic training scenarios, adjustable pace, and simulated realistic walking conditions increase the variability of walking and the possibility of gait reconstruction. Park [38] asked patients to use virtual reality and auditory stimulation robots for balance and gait ability training. The results showed that the patients' Berg balance scale score, Fugl-Meyer lower limb motor function scale score, stand-up and walk test score and 10 m walking ability All gait movement-related indicators such as gait and other parameters have been significantly improved, indicating that virtual reality and auditory stimulation robot-assisted gait training can help improve patients' balance and walking ability. Research by Lu Fang et al. [39] also confirmed that the use of Lokomat robot combined with virtual reality technology can effectively improve the balance ability, motor function and walking ability of stroke patients. Ballester et al [40] used navigation brain stimulation program measurements to confirm that virtual reality technology can not only improve the lower limb motor function of stroke patients, but also increase the excitability of the corticospinal tract and induce cerebral cortex reorganization. Rehabilitation robots use virtual reality technology to provide patients with a simulated real-life environment, which increases the interest of gait training, improves patients' enthusiasm for active participation, and makes large-scale and repeated training possible.

4.2 Motion Control Technology

Motion control technology plans the movement trajectory of the exoskeleton based on the normal movement trajectory of the human body. Under the guidance of the exoskeleton, the affected limb can perform gait training along the pre-planned trajectory, which is suitable for the early rehabilitation of patients. Zhang Zheng et al. [41] used the traditional proportional integral differential (PID) control method to design bangbangPD trajectory, and under the control of the exoskeleton, the knee and hip joint activities can fit the predetermined reference curve, which reduces the tracking error and shortens the adjustment time, but it is difficult to solve the problem of variable gait curve. Wu Qinghong et al[42] A fuzzy PID control method is proposed, and simulation experiments prove that the fuzzy PID control method can track the normal human gait curve more accurately and quickly than the traditional PID control method. Huang Jintao et al. [43] proposed an active disturbance-rejection control strategy, which can achieve decoupling between systems, has little dependence on the precise mathematical model of the system, and has strong anti-interference ability. In simulation experiments, it is the same as PID control method and Compared with the calculated torque control method, the active disturbance rejection control strategy can not only ensure the effect of gait tracking, but also significantly reduce external interference. The constantly updated and iterative motion control technology can provide standardized motion curves and postures for patients' gait training, which is beneficial to improving the quality of gait training.

4.3 Movement Intention Sensing Technology

Movement intention sensing technology is of great significance to patients' active rehabilitation. Currently, it mainly senses patients' action intentions through bioelectric signals, and then converts intention information into movement decisions. This can improve human-computer interaction capabilities and mobilize patients' enthusiasm for active rehabilitation [44]. Bioelectrical signals that are currently receiving widespread attention include electromyographic signals, electroencephalographic signals, etc. [45]. Myoelectric signals can reflect the functional status of muscles and can be used to analyze human muscle movements, perceive the human body's action status, and make predictive analysis of future actions [46]. Ma Xunju [47] used myoelectric signals for exoskeleton robot control, confirming that it can predict the movement intentions of the human lower limbs in advance, and achieved gait switching and active voluntary control of lower limb exoskeletons based on myoelectric signals, thus facilitating patients' active rehabilitation. Training improves the intelligence level and human-machine collaboration performance of exoskeleton robots. EEG signals are electrical activities formed when the brain is stimulated by the outside world, produces motor consciousness, or engages in thinking activities [48]. It is often used in brain-computer interfaces (brain-computer interfaces). computer interface (BCI) information collection. BCI can judge and interpret people's control intentions through real-time analysis of EEG signals, and convert them into robot output commands to guide patients to complete corresponding rehabilitation tasks [49]. Hung et al. [50] used BCI based on EEG signals Combined with functional electrical stimulation to treat stroke patients, the results showed that the patients' standing and walking timing, stride length and step width were significantly improved, proving that BCI based on brain electrical signals can effectively improve the walking function and balance function of stroke patients. It can be seen from this that by extracting bioelectric signals under different movement states of the human body, the wearer's movement intention can be sensed, which can replace the rehabilitation physician to a certain extent, speed up the issuance of rehabilitation training instructions, and achieve ideal training effects [51].

5 CONCLUSION

Due to brain tissue lesions and blockage of neural pathways, stroke patients are prone to develop changes in muscle strength, muscle tone, and uncoordinated limb activities due to the loss of control of high-level centers over low-level centers, and then develop hemiplegic gait [52], which seriously affects patients. quality of life. Although traditional gait training methods such as transfer training, walking training, balance function training and occupational therapy can achieve certain results, they also have certain limitations. Rehabilitation robots integrate a variety of advanced technologies based on clinical practice, such as virtual reality technology, motion control technology, motion intention perception technology, etc., to provide patients with high-intensity, repeatable, and precise training. Wang Rongli et al[53] Research has proven that sufficient rehabilitation training may cause plastic changes in patients' neural structures and remodeling of neural networks, increase the excitability of the cerebral cortex, and promote the recovery of their motor functions. Therefore, rehabilitation robots have broad development prospects in assisting gait training for stroke patients.

Although rehabilitation robot-assisted gait training for stroke patients has achieved many positive results in terms of clinical efficacy and research, there are still the following problems that need to be solved: (1) Most of the existing clinical trials have small sample sizes and require large-scale, randomized, multiThe center will conduct research to improve relevant data and continue to explore the mechanism of rehabilitation robots in promoting neurological rehabilitation. (2) Most rehabilitation robots lack rehabilitation assessment and post-healing evaluation mechanisms , and research and development of related technologies should be strengthened. (3) Excessive rehabilitation robot-assisted training may affect patients' enthusiasm for independent movement, and relevant human-computer interaction technology needs to continue to be improved. (4) At present, rehabilitation robot equipment is bulky and expensive, making it difficult to popularize and promote it. (5) It is necessary to continue to improve the relevant parameter information of rehabilitation robots at different stages of gait training to guide the training time and intensity of different groups of people.

With the development of related technologies, rehabilitation robots will inevitably be updated and develop in the direction of intelligence, precision, convenience, and familyization. In particular, the maturity of new technologies and the application of cost-effective materials will greatly reduce the manufacturing cost of rehabilitation robots, accelerate their promotion and application, and benefit more stroke and hemiplegic patients.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

REFERENCES

[1] CHUMNEY D, NOLLINGER K, SHESKO K. Ability of functional independence measure to accurately predict functional outcome of stroke-specific population: systematic re-view. J Rehabil Res Dev, 2010, 47(1): 17-29.

[2] WU S,WU B.LIU M. Stroke in China: advances and challenges in epidemiology, prevention, and management. Lancet Neurol, 2019, 18(4): 394-405.

[3] AN B, WOO Y, PARK K. Effects of insole on the less affected side during execution of treadmill walking training on gait ability in chronic stroke patients: a preliminary study. Restor Neurol Neuros, 2020, 38(5): 375-384.

[4] CHEN K, ZHENG YH, WEI J A. Exercise training improves motorskill learning via selective activation of mTOR. Sci Adv, 2019, 5(7): eaaw1888.

[5] Zhang Tong, Zhao Jun, Bai Yulong. Chinese Clinical Management Guidelines for Cerebrovascular Disease (Extracted Version) Stroke Rehabilitation Management. Chinese Journal of Stroke, 2019, 14(8): 823-831.

[6] KWAKKEL G, KOLLEN B, KREBS H I. Effects of robot assisted therapy on upper limb recovery after stroke: a systematic review. Neurorehabil Neural Repair, 2008, 22(2): 111-121.

[7] SWINNEN E, BECKW鲔E D, MEEUSEN R. Does robotassisted gait rehabilitation improve balance in stroke patients ? A systematic review. Top Stroke Rehabil, 2014, 21(2): 87100.

[8] MASIERO S, POLI P, ROSATI G. The value of robotic systems in stroke rehabilitation. Expert Rev Med Devic , 2014, 11(2): 187-198.

[9] GASSERT R, DIETZ V. Rehabilitation robots for the treatment of sensorimotor deficits: a neurophysiological perspective. J Neuroeng Rehabil, 2018, 15(1): 46.

[10] TENNANT KA, TAYLOR SL, WHITE E R. Optogenetic rewiring of thalamocortical circuits to restore function in the stroke injured brain. Nat Commun, 2017, 8: 15879.

[11] SUN H, LI A, HOU T T. Neurogenesis promoted by the CD200/CD200R signaling pathway following treadmill exercise enhances post-stroke functional recovery in rats. Brain Behav Immun, 2019, 82: 354-371.
[12] Li Kunbin, Wu Zhiyuan, Wu Yanzhi. Preliminary observation of the impact of lower limb rehabilitation robot training on brain function reconstruction in patients with ischemic stroke. Journal of Stroke and Neurological Diseases, 2019, 36(5): 420-424.
[13] XIE QF, CHENG JY, PAN G Y. Treadmill exercise ameliorates focal cerebral ischemia/reperfusion-induced neurological deficit by promoting dendritic modification and sy-naptic plasticity via upregulating caveolin-1/VEGF signaling pathways. Exp Neurol, 2019, 313: 60-78.
[14] Lu Liping, Sander Chun, Ji Shufeng. Effect of lower limb rehabilitation robot training on motor ability and daily living activities of patients with hemiplegia after stroke. Chinese Rehabilitation Theory and Practice, 2016, 22(10): 1 200-1 203.
[15] Liu Chang, Qie Shuyan, Wang Hanming. Effect of lower limb rehabilitation robot on lower limb motor function and walking ability in stroke and hemiplegic patients. Chinese Rehabilitation Theory and Practice, 2017, 23(6): 696-700.
[16] CALABRO RS, NARO A, RUSSO M. Shaping neuroplasticity by using powered exoskeletons inpatients with stroke: a randomized clinical trial. J Neuroeng Rehabil, 2018, 15(1):35.
[17] Chen Peishun, Li Taotao, Guan Hongli. Effect of foot drop walking aid combined with movable platform training on foot drop gait after stroke. Nerve Injury and Functional Reconstruction, 2020, 15(11): 670-672.
[18] Li Jianan, Meng Dianhuai. Clinical applications of gait analysis. Chinese Journal of Physical Medicine and Rehabilitation, 2006, 28(7): 500-503.
[19] Lu Wen, Zhang Jinming, Lu Zheng. Application of surface electromyography in the analysis of lower limb muscle dynamics in patients with hemiplegia. Medical Review, 2020, 26(24): 4 8834 886, 4 891.
[20] Lin Haidan, Zhang Tao, Chen Qing. Rehabilitation robot-assisted walking training is endless Effects on walking ability of patients with total spinal cord injury. Journal of Automation, 2016, 42(12): 1 832-1 838.
[21] Redebaugh, Wu Xiaolin, Zhu Rui. The impact of lower limb robot training on the test results of the three-dimensional gait analysis system in stroke and hemiplegic patients. Journal of Clinical and Experimental Medicine, 2019, 18(12): 1 323-1 327.
[22] Cheng Xue, Zhang Tao, Bai Dingqun. A preliminary study on the rehabilitation effect of A3 lower limb rehabilitation robot on assisted gait training for chronic stroke. West China Medicine, 2020, 35(5): 579-584.
[23] TOMIDA K, SONODA S, HIRANO S. Randomized Controlled trial of gait training using gait exercise assist robot (GEAR) in stroke patients with hemiplegia. J Stroke Cerebrovasc, 2019, 28(9): 2 421-2 428.
[24] OGINOT, KANATA Y, UEGAKI R. Improving abnormal gait patterns by using a Gait Exercise Assist Robot(GEAR) in chronic stroke subjects: a randomized, controlled, pilot trial. Gait Posture, 2020, 82: 45-51.
[25] WANG YJ, MUKAINO M, HIRANO S. Persistent effect of gait exercise assist robot training on gait ability and lower limb function of patients with subacute stroke: a matched case-control study with three-dimensional gait analysis. Front Neurorobotics, 2020, 14: 42.
[26] KATOH D, TANIKAWA H, HIRANO S. The effect of using Gait Exercise Assist Robot(GEAR)on gait pattern in stroke patients: a cross-sectional pilot study. Top Stroke Rehabil, 2020, 27(2): 103-109.
[27] Zheng Huanchi, Wang Junhua, Wang Chengling. A review of walking rehabilitation robots. Massage and Rehabilitation Medicine, 2019, 10(20): 1-5.
[28] Dai Jun. Effect of LOKOMAT lower limb rehabilitation robot combined with cognitive rehabilitation on the walking ability of stroke patients. Wuhan: Wuhan Institute of Physical Education, 2018.
[29] Chen Fei, Xu Jing, Guo Cuiying. Observation on the efficacy of scalp acupuncture combined with Lokomat lower limb robot in the treatment of lower limb motor dysfunction in patients with cerebral infarction. Clinical Journal of Traditional Chinese Medicine, 2021, 33(2): 326-330.
[30] U AR DE, PAKER N, BU GDAYCI D. Lokomat: a therapeutic chance for patients with chronic hemiplegia. Neuro Rehabilitation, 2014, 34(3): 447-453.
[31] VANNUNENM PM, GERRITS KHL, KONIJNENBELT M. Recovery of walking ability using a robotic device in subacute stroke patients: a randomized controlled study. Disabil Rehabil Assist Technol, 2015, 10(2): 141-148.
[32] VAN KAMMEN K, BOONSTRA A M, VAN DER WOUDE L H V. The combined effects of guidance force, bodyweight support and gait speed on muscle activity during able-bodied walking in the Lokomat. Clin Biomech(Bristol, Avon), 2016, 36: 65-73.
[33] VAN KAMMEN K, BOONSTRA A M, VAN DER WOUDE L H V. Lokomat guided gait in hemiparetic stroke pa tients: the effects of training parameters on muscle activity and temporal symmetry. Disabil Rehabil, 2020, 42(21): 2 9772 985.
[34] SWANK C, ALMUTAIRI S, WANG-PRICE S. Immediate kinematic and muscle activity changes after a single robotic exoskeleton walking session post-stroke. Top Stroke Rehabil, 2020, 27(7): 503-515.
[35] PARK I J, PARK J H, SEONG H Y. Comparative effects of different assistance force during robot-assisted gait training on locomotor functions in patients with subacute stroke: an assessor-blind, randomized controlled trial. Am J Phys Med Rehabil, 2019, 98(1): 58-64.
[36] KRISHNAN C, KOTSPOUIKIS D, DHAHER Y Y. Re-ducing robotic guidance during robot-assisted gait training improves gait function: a case report on a stroke survivor. Arch Phys Med Rehabil, 2013, 94(6): 1 202-1 206.
[37] Hu Jingran, Chen Xiaofei. Research on the impact of virtual reality technology combined with lower limb rehabilitation robot training on lower limb function and balance ability in patients with ischemic stroke. Chinese Rehabilitation, 2020, 35(12): 633-636.

[38] PARK J, CHUNG Y J. The effects of robot-assisted gait training using virtual reality and auditory stimulation on balance and gait abilities in persons with stroke. NeuroRehabilitation, 2018, 43(2): 227-235.
[39] Lu Fang, Zhu Lin, Song Weiqun. Effect of lower limb rehabilitation robot combined with virtual reality technology on lower limb function in stroke patients. Chinese Journal of Rehabilitation Medicine, 2018, 33(11): 1 301-1 306.
[40] BALLESTER BR, NIRME J, CAMACHO L. Domicliary VR -based therapy for functional recovery and cortical reorganization:randomized controlled trial in participants at the chronic stage post stroke. JMIR Serious Games, 2017, 5(3):e15.
[41] Zhang Zheng, Zhao Liping, Liang Yiwei. Research on the trajectory tracking control method of lower limb exoskeleton based on differential gear train. Coal Technology, 2015, 34(4): 305-307.
[42] Wu Qinghong, Li Jian, Liu Huan. Control technology of lower limb exoskeleton robot based on fuzzy PID. Journal of Guangxi University of Science and Technology, 2020, 31(4): 104-111.
[43] Huang Jintao, Li Ying, Zeng Jianping. Gait trajectory tracking control of lower limb exoskeleton robot in passive mode. Journal of Xiamen University (Natural Science Edition), 2020, 59 (1): 108-115.
[44] Zhang Xiaodong, Chen Jiangcheng, Yin Gui. Myoelectric sensing and human-computer interaction control method for lower limb rehabilitation robots. Vibration, Testing and Diagnosis, 2018, 38(4): 649-657,866.
[45] NAMY, KOO B, CICHOCKI A. GOM-face: GKP, EOG, and EMG-based multimodal interface with application to humanoid robot control. IEEE Trans Biomed Eng, 2014, 61 (2): 453-462.
[46] Zhang Bi, Yao Jie, Zhao Xingang. An adaptive human-computer interaction control method based on electromyographic signals. Control Theory and Applications, 2020, 37(12): 2 5602 570.
[47] Ma Xunju. Research on gait switching control method of lower limb rehabilitation exoskeleton robot based on surface myoelectric signals. Zhengzhou: North China University of Water Resources and Hydropower, 2019.
[48] Zheng Changkun, Wang Haixian, Gu Lingyun. Lower limb movement intention recognition method based on EEG and EMG signals. Chinese Medical Equipment, 2021, 36(5): 61-66.
[49] Wang Fei, Yang Guangda, Zhang Dan. Current research status of brain-computer interface applications in robot control. Robotics Technology and Applications, 2012 (6): 12-15.
[50] HUNG E, PARK SI, JANG Y Y. Effects of brain-computer interface-based functional electrical stimulation on balance and gait function in patients with stroke: preliminary results. JPhys Ther Sci, 2015, 27(2): 513-516.
[51] Li Longfei, Zhu Lingyun, Gou Xiangfeng. Research status and development trends of wearable lower limb exoskeleton rehabilitation robots. Medical and Health Equipment, 2019, 40(12): 89-97.
[52] Chen Yi, Shi Haitao, Mao Ling. Surface electromyography characteristics of lower limb muscles in each phase of the gait cycle in stroke patients. Chinese Rehabilitation Theory and Practice, 2019, 25 (8): 956-961.
[53] Wang Rongli, Wang Ninghua. Application principles of the motor relearning theoretical system in the field of neurological rehabilitation. West China Medicine, 2020, 35(5): 519-526.