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Review

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Clinical Use of Robots as a Part of Rehabilitation Medicine

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Highlights

- Robot has been developed and used variously as a part of rehabilitation medicine.
- Robot-assisted rehabilitation can be classified as therapeutic and assistive robots.
- We review the clinical use of robots in patients with stroke and Parkinson's disease.

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Clinical Use of Robots as a Part of Rehabilitation Medicine

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Conflict of Interest
The authors have no potential conflicts of interest to disclose.

ABSTRACT

During recent years, many robots have been used for rehabilitation therapy and the rehabilitation robots have also advanced considerably. These robots can eliminate the repetitive tasks of the occupational or physical therapist and provide high-intensity and high-dosage training for the patients. In general, the robots used for rehabilitation therapy are classified into therapeutic and assistive robots, and therapeutic robots can be further divided into end-effector and exoskeleton types. In the study, we reviewed the clinical use of robot-assisted therapy as a part of rehabilitation medicine, especially in patients with stroke and Parkinson's disease.

Keywords: Rehabilitation; Robotics; Stroke; Parkinson's Disease

INTRODUCTION

Recently, there has been an increase in the use of robots for rehabilitation therapies, and rehabilitation robots have also advanced considerably [1-5]. These robots can have benefits on clinical effect and neuroplasticity, and these reduce the repetitive tasks of the occupational or physical therapist and provide high-intensity and high-dosage training for the patients [1-5]. These robots are frequently used for patients with stroke, Parkinson's disease (PD), traumatic brain injury, spinal cord injury, cerebral palsy, and so on. Several studies conducted on the use of rehabilitation robots; however, there are limited reviews about the effectiveness of robot-assisted therapy in patients with stroke and PD [2,6-11]. Therefore, in the present study, we investigated assistive robots and therapeutic robots as a part of rehabilitation medicine, as a therapy by itself, or as an additional therapy combined to conventional treatments, especially in patients with stroke and PD.

ROBOT-ASSISTED REHABILITATION

Generally, robots used as a part of rehabilitation medicine can be classified as therapeutic and assistive robots [12]. Assistive and therapeutic robots are usually used to provide emotional or physical support for the elderly and repetitive motor training for the disabled, respectively [12].

Assistive robots

Assistive robots such as LEGO Mindstorms NXT® (LEGO, Billund, Denmark), Socially Assistive Pet Robot (PARO), and wheelchair robot have been developed to provide emotional or physical support for the elderly [13-15]. Yu et al. [15] found that PARO improved the mood, social interaction, and communication of the dementia patients. Pérez et al. [13] reported that LEGO Mindstorms NXT® (LEGO) improved the physical and mental activities of elderly people leading to healthy life habits along with improved quality of life. Shiomi et al. [14] developed an autonomous wheelchair robot and investigated the social acceptance for the elderly. The results of their studies indicate that the elderly considered wheelchair robots with social behaviors to be better than both caregivers and wheelchair robots without social behaviors [14]. Further developments in the field of assistive robots are needed to provide emotional or physical support, especially for the elderly people.

Therapeutic robots

Therapeutic robots are frequently used for repetitive motor rehabilitation for the disabled, and can be divided into end-effector and exoskeleton types [6]. The end-effector type robots can be easily put on and taken off and give more freedom of movements, resulting in better adaptability; however, exoskeleton type robots provide direct mechanical control to each joint, reducing the abnormal patterns of limb movement by controlling the participant's proximal joints properly [6]. These robotic are used for the training of upper limb and hand function as well as gait function in patients with stroke and PD (Fig. 1).

Robotics for stroke patients

1) Robotics for the upper limb and hand motor function of stroke patients

The examples for end-effector type robots used for upper limb and hand motor function are Arm Guide, MIT-MANUS/InMotion (Interactive Motion Technologies Inc., Cambridge, MA, USA), NeReBot (Mechatronics, Padova, Italy), and REHAROB (Zebris Medizintechnik

Fig. 1. (A) Exoskeleton robot-assisted gait rehabilitation using WALKBOT (P & S Mechanics, Seoul, Korea). (B) End-effector robot-assisted upper limb rehabilitation using MIT-MANUS/InMotion 2.0 (Interactive Motion Technologies Inc., Cambridge, MA, USA).

GmbH, Allgäu, Germany), while those for the exoskeletal-type robots are Armeo® (Hocoma, Volketswil, Switzerland), MGA Exoskeleton (Georgetown University , Washington D.C, USA), RUPERT (Arizona State University, Arizona , USA), and T-Wrex (University of California, Irvine, CA, USA), etc. (Table 1).

Many randomized controlled trials have been conducted with end-effector type robots, to compare the effects of the robot-assisted treatments with conventional treatments on improving the upper limb motor function and activities of daily living (ADL) [2,3,16-21]. Among these, several studies asserted that robot-assisted therapy achieved better results than conventional treatments for ADL as well as for upper limb function [2,3,18,19]. However, the other studies concluded that robot-assisted rehabilitation showed results that are similar to conventional treatments [16,17,20,21]. Moreover, robot-assisted treatments for stroke patients who were in a chronic condition demonstrated no additional effects on ADL compared to conventional treatments [19]. Recently, Veerbeek et al. [2] conducted a systematic review and meta-analysis (38 trials, total 1,206 participants), and these concluded that shoulder/elbow robot-assisted treatments significantly improved motor control and muscle strength and elbow/wrist robot-assisted treatments significantly improved only motor control, however, they asserted that these effects for the paretic upper limb were small. However, with regard to hand motor function, some reports revealed that robot therapy had better or similar effects compared to conventional treatments [22-24]. However, all these studies recruited relatively small numbers of patients without randomization, at a single-center; therefore, further studies are needed to evaluate the effect of end-effector type robot-assisted therapy on the upper limb and hand motor function.

Randomized controlled studies regarding upper limb with exoskeleton type robots were conducted only in chronic stroke participants [25-28]. Among these, one study reported a significantly superior result for the upper limb spasticity in the group that underwent robot-assisted treatment, in comparison with the group that underwent conventional treatment; however, the other studies demonstrated no significant differences between the 2 kinds of treatments [25-28]. Regarding the hand motor function, one randomized controlled trial which

Table 1. Robots for upper limb and hand motor function

Robot type	Company
End-effector robot	
Amadeo	Tyromotion
Arm Guide	University of California
Bi-Manu Track	Reha-Stim
Biodex System 4 Dynamometer	Biodex Medical System
CON_TRES	CMV AG
HUMAN NORM	Computer Sports Medicine Inc.
MIT-MANUS/InMotion	Interactive Motion Technologies Inc.
NeReBot	Mechatronics
Neuro-X system	Apsun Inc.
REHAROB	Zebris Medizintechnik GmbH
Exoskeleton robot	
Armeo®	Hocoma
Hand of Hope	Rehab-Robotics
mPower arm brace	Myomo Inc.
MGA Exoskeleton	Georgetown University
RUPERT	Arizona State University
Rapael Smart Glove	Neofect
T-Wrex	University of California

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included subacute stroke participants showed similar results between the exoskeleton type robot with conventional treatments, and the other randomized controlled trial which included chronic stroke participants showed superior results with the exoskeleton type robot than conventional treatments; however, these studies did not evaluate the ADL function of the participants [29,30]. Therefore, we assumed that exoskeleton type robot-assisted training may show similar or superior effectiveness for hand function compared to conventional treatments in subacute to chronic stroke patients. Moreover, Mehrholz et al. [7] conducted a Cochrane review, which included 34 trials (total 1,160 participants), and they concluded that electromechanical-assisted arm training improved the ADL (standardized mean difference [SMD], 0.37; 95% confidence interval [CI], 0.11–0.64; $p = 0.005$), arm function (SMD, 0.35; 95% CI, 0.18–0.51; $p < 0.001$), and arm muscle strength (SMD, 0.36; 95% CI, 0.01–0.70; $p = 0.040$) after stroke; however, the quality of the evidence of their studies was rated low to very low.

2) Robotics for the gait function in stroke patients

The rehabilitation robots for the gait function also can be divided into end-effector and exoskeleton types (Table 2). The examples for the end-effector type robots for gait function include Gait Master 5 (Mulholland Positioning Systems Inc., Burley, ID, USA), Gait Trainer (Rifton Equipment, Rifton, NY, USA), Gait Trainer GT1 (Reha-Stim, Berlin, Germany), G-EO system (Reha Technology, Blue Bell, PA, USA), and Morning Walk (Hyundai Heavy Industry, Seoul, Korea), which are subtypes of the foot-plate-based gait trainers. The examples for exoskeleton type robots for gait function include LokoHelp (LokoHelp Group, Weil am Rhein, Germany), Lokomat® (Hocoma), and ReoAmbulator™ (Motorika Medical Ltd., Mount Laurel, NJ, USA), which are subtypes of the Treadmill Gait Trainers (Biodex Medical System, Shirley, NY, USA), and Hybrid Assistive Limb® (HAL®; CYBERDYNE Inc., Ibaraki, Japan), KineAssist® (HDT Global Inc., Solon, OH, USA), and ReWalk (Argo Medical Technologies Ltd., Yokneam Illit, Israel), which are subtypes of the overground gait trainers.

Table 2. Robots for gait function

Robot type	Company
Treadmil gait trainers	
Active Leg Exoskeleton (ALEX)	Columbia Engineering's Robotics and Rehabilitation Laboratory
Automated Locomotion Training using Actuated Compliant Robotic Orthosis	Free University of Brussels
LokoHelp	LokoHelp Group
Lokomat®	Hocoma
Lower-extremity Powered Exoskeleton	Kennispark Twente
ReoAmbulator™	Motorika Medical Ltd.
Robotic Gait Rehabilitation Trainer	Northeastern University
String-Man	Fraunhofer Institute
WALKBOT	P & S Mechanics
Foot-plate-based gait trainers	
Gait Master 5	Mulholland Positioning Systems Inc.
Gait trainer	Rifton Equipment
Gait trainer GT1	Reha-Stim
G-EO system	Reha Technology
Hapticwalker	FraunhoferIPK
Morning Walk	Hyundai Heavy Industry
Overgound gait trainers	
Hybrid Assistive Limb® (HAL®)	CYBERDYNE Inc.
Kine assist	Kinea Design LLC
ReWalk	ARGO Medical Technologies Ltd.
Walk trainer	Swortec SA
Stationary gait trainers	
Motion maker	Swortec SA
Lambda	Lamdba health system

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Some randomized controlled studies compared the treatment using end-effector-type robots with conventional treatments for the gait function [31-37]. Among these, 2 studies, which were conducted in chronic stroke patients, revealed similar effectiveness between the 2 kinds of treatments [31,34]. However, the other reports, which were conducted in subacute stroke patients, demonstrated that end-effector type robot-assisted treatments combined with physiotherapy were more effective for gait function than conventional physical therapy alone [32,33,35-37]. Therefore, these studies indicate that the additional end-effector-type robot-assisted therapy with conventional physical therapy can be used in subacute stroke participants.

Several randomized controlled studies with exoskeleton type robots were conducted for the gait function [38-43]. Among these, 2 studies demonstrated that conventional physical treatment was more effective than exoskeleton type robot-assisted treatment for gait function [39,40]. On the other hand, 2 other reports showed superior results for exoskeleton type robot-assisted treatment, compared to conventional treatments; however, these studies included relatively small numbers of participants [41,42]. In addition, 2 other studies reported better or similar effectiveness for robot-assisted treatment combined with physical therapy, compared to physical therapy alone in subacute stroke patients [38,43]. Therefore, the authors assumed that exoskeleton type robot treatments could not substitute conventional physical therapy for improving the gait function; however, a combination of these 2 kinds of treatments were recommend, especially in subacute stroke patients. In 2013, Mehrholz et al. [8] conducted a systematic review, which included 23 trials (total 999 participants), and they concluded that electromechanical-assisted gait training combined with physiotherapy showed better independent walking than gait training without these devices in stroke patients (odds ratio, 2.39; 95% CI, 1.67–3.43; $p < 0.001$) [8]. In addition, they described the difference of effect from 2 types of robot (end-effector or exoskeleton type), and no difference was found in terms of ability to walk except for walking velocity [8].

Robotics in patients with PD

PD is a chronic progressive neurodegenerative disease, and the management of PD patients is based on a goal-directed approach. Recently, robot-assisted therapy was applied in patients with PD to enhance their functional ability; however, there were only a limited number of studies performed.

Only one randomized study was performed to evaluate the effect of robot-assisted therapy for improving the upper limb and hand motor function in patients with PD [44]. Ten patients with PD (Hoehn & Yahr stage, 2.5–3.0) performed 10 treatment sessions (5 days a week, total 2 weeks) of 45-minutes each, using the Bi-Manu-Track (Reha-Stim), which provides bilateral wrist flexion/extension and forearm pronation/supination training [44]. In that study, the robot-assisted therapy showed significant improvement in the patients, with regard to the 9-hole peg test, upper limb Fugl-Meyer assessment, and 9-hole peg test [44].

In terms of the gait function, one study compared the robot-assisted therapy with the treadmill therapy in mild to moderate PD patients [45]. After treatments, the primary outcomes between the 2 groups showed no significant difference, and they asserted that the robot-assisted gait training did not show better effectiveness than the treadmill treatment in improving the gait function in participants with mild to moderate PD [45]. However, 2 other randomized controlled studies showed superior results in patients who underwent robot-assisted training [46,47]. Picelli et al. [46] treated 41 patients with PD using either the Gait

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Trainer or physiotherapy, and the robot-assisted gait-training group showed better walking ability compared to the physiotherapy group. Sale et al. [47] compared robot-assisted gait treatment with treadmill treatment in mild PD patients, and the patients who underwent robot-assisted gait-training showed significant improvement in the gait index than the patients who underwent treadmill training.

Regarding the improvement of balance in patients with PD, one study concluded that robot-assisted gait training may enhance the postural stability in PD patients (Hoehn & Yahr stage, 3–4); however, the other study showed no significant difference between robot-assisted gait training and conventional physiotherapy including balance training [48,49]. Therefore, further studies are needed to obtain conclusive evidence for the efficacy of robot-assisted treatment in patients with PD, with respect to the upper extremities, gait function, and balance.

CONCLUSION

Here, we reviewed the clinical use of robots as a part of rehabilitation medicine, especially in patients with stroke and PD. Several studies on the use of robots for rehabilitation have been conducted; however, there are limited well-designed reviews about the effectiveness of robot-assisted therapy [2,6-11]. Further studies with large numbers of patients are needed for considering the efficacy and economic aspects of robot-assisted training as a part of rehabilitation. In addition, complementary studies on robots, which are controlled by brain-computer interface or artificial intelligence, are warranted.

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