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A Case Study on the Current Status and Prospects of Robotic Rehabilitation

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***Abstract*— The use of robots in rehabilitation (robotic rehabilitation) is a relatively recent development and a growing field that is rapidly penetrating clinical practice. Against this background, various assistive robots reflecting the application of engineering technology have recently been developed and widely used in the field of rehabilitation in order to realize a prosperous and long-lived society that supports the independence of the elderly and disabled. This paper describes the current status of robotic rehabilitation and discusses the challenges faced in this field by presenting case reports. The purpose of the case study was to analyze the suit and body movements while wearing the robotic suit. The subjects were four healthy individuals, and the criteria for selecting the subjects were that they had not fallen in the past year, had not suffered serious pain or musculoskeletal or nervous system injuries, and were not taking medications that could impair balance. Motion analysis was performed to determine the discrepancy between the joint motions of the robotic suit and those of the human subjects when they walked normally while wearing the robotic suit. The results showed that misalignment at the knee and ankle joints was greater when the control by the robotic suit was weak. Finally, the author discusses how medical staff should approach the use of robots in clinical practice.**

***Index Terms*— robotic rehabilitation, robot suit, gait training, motion analysis.**

I. INTODUCTION

The use of robots in rehabilitation (robotic rehabilitation) is a relatively recent development and a growing area that is rapidly making inroads in clinical practice. The idea of using machines in rehabilitation dates back to 1910, when Theodor Büdingen applied for a patent on an electric motor device to assist patients with heart disease when performing the step exercise. Thus, the first robotic rehabilitation system was based on the concept of continuous passive motion [1,2]. The first exoskeleton-type powered suit for therapeutic use was introduced in the 1970s for patients with spinal cord injury [3]. Since then, robots have frequently been used in rehabilitation.

Against this backdrop, a variety of support robots that reflect the application of engineering technology have been developed and used widely in the field of rehabilitation in recent years to bring about a rich, long-lived society that supports the independence of the aged and those with disabilities.

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This article describes the current state of robotic rehabilitation and discusses the challenges the field faces as identified through interviews with robotics engineers in Japan, Europe, and the United States. Finally, the author's personal views on how medical staff in the clinical setting can approach the use of robots are discussed.

II. CHALLENGES FOR ROBOTIC REHABILITATION: FOCUS ON GAIT-ASSIST

The preceding sections reviewed the application of robots in rehabilitation to date and discussed its benefits and effectiveness. This section describes an interview that the author conducted in 2017 at the France-Japan Foundation of a prominent Paris-based robotics engineering researcher on the research topic, "A study of new technologies of personal mobility and robot suit for the elderly and persons with disabilities" [4]. This topic will be discussed with a focus on views common among robotics engineering researchers that were represented in that interview.

As an example in Japan, although devices such as canes and walkers are used and HAL and Rewalk [5] are available for use as gait-assist robots for patients with spinal cord injuries, caregivers are always needed. Moreover, compensation under the medical insurance system is available for some intractable diseases. Since 2020, an exercise therapy dimension has been added for single-joint HAL, and experience and knowledge involved in robotic therapy in fields such rehabilitation and training have also been incorporated into physical therapy. In addition, investigations of the effectiveness of this approach are being aggressively pursued. The main advantages at present of introducing robots are that they can be used for training in repetitive movements, which are difficult for patients, and as a basis for enabling medical staff (especially, hereafter referred to as "Physical Therapist: PT") to concentrate on more important training, as their motor learning effects have been described by many researchers [6-8].

As devices for assisting people in walking independently, however, they have many problems. The first problem is in the realm of the robot technology. Because the robots assist the movement of joints - primarily the hip and knee joints- along a single axis, they cannot prevent problems such as sudden falls. Consequently, they are strictly for assisting walking on level ground, they require monitoring, and their use is limited to rehabilitation programs that also use equipment to prevent falls. Robot models for assisting multi-joint, multiaxial movement of the lower extremity joints are at the research and development stage at organizations such as universities and companies. The situation is similar in Japan, Germany, and other developed countries. With regard to joint support, motors that can control smooth joint movements for normal walking have not yet been created. Moreover, rapid movements such as the protective stretch reflex seen in humans to prevent problems such as falls are required. Thus, the challenges faced are how to use robots to control movements such as the multiaxial, smooth joint movements essential for normal walking and the rapid movements needed to avoid falls and thereby assist walking. Consequently, robot suits pose technical problems, particularly how to reduce the size and weight of the motors and increase their power. Battery weight (several kilograms) is also a problem.

Although the current focus is on joint control, humans have sensory functions that are important for controlling movement. For example, senses that are important for walking include vision, joint sensation, which enables movement of the joints to be perceived, tactile sensation of the sole of the foot, and auditory sensation. A challenge is how to incorporate these sensory functions into robots. One problem is how to add sensors that can substitute for sensory feedback and feed-forward functions with the aim of safer, more natural gait assistance. In addition, a detailed analytical examination of the gait of elderly and disabled individuals compared with that of healthy individuals will be important for determining the methods needed to make control possible. Researchers are currently collecting data by means of various experimental methods. When it comes to the above challenges, PT in the clinical setting will be deeply involved both directly and indirectly.

III. A CASE STUDY OF THE ISSUES OF ROBOT SUIT

The purpose of the research was to analyze the movement of the suit and the body when the robot suit was worn.

Ⅲ-1. Subjects

The subjects were four healthy people. The selection standards for the participants were those who had not fallen over during the previous year, those who had not suffered serious pain and musculoskeletal or neurological damage, those who were not on medication that might impair balance.

The protocol for this study was approved by the ethics committee of the University of Tokyo (No.20-210).

Ⅲ-2. The specification of the gait-assist robot

HAL exoskeleton-type gait-assist robot, developed by University of Tsukuba, was used in this study. HAL is equipped with actuators for the hip and knee joints and specialized shoes with reaction force plate sensors. The mode and assist settings for HAL are indicated below:

① Voluntary control mode: Myoelectric potentials (motor units) are sensed from electrodes for the flexor and extensor muscles of the hip and knee joint, and the center of foot pressure is sensed from specialized shoes. An assist level is then selected, and joint movement is controlled at the calculated “assist torque (Nm).”

② Impedance control mode: Weight-bearing and joint movement are smoothly controlled (synonymous with voluntary control mode without assist).

③ Assist level: The settings for the hip and knee joint actuators can each be adjusted to a level of 0 to 20.

[assist level × myoelectric potential = assist torque (maximum actuator output of 42 Nm)]

Ⅲ-3. Measurement and Analysis

The measured task was a walking task performed on a treadmill equipped with HAL. The measurement involved recording images with four digital video cameras, with one trial measured under each condition and a rest period between trials. The treadmill speed was set to 1.5 km/h, and steady-state gait was measured with Robot Suit HAL mounted over the treadmill. Table 1 showed the walking conditions with HAL. Furthermore, table indicated the definition of joint angle by use of HAL in Table 2.

The Frame-DIAS (DKH Co,.Ltd.) motion analysis system was used for the analysis. The sampling rate was 60Hz. Three-dimensional motion analysis was used to calculate joint angles (degrees) during the walking task. The joint angles and the HAL and the body joint angles were then compared under two conditions, the conditon1 (Assist 1) and the conditon2 (Assist 3). Each condition was performed five times (five gait cycles). Moreover, since the hip joint and foot of the body were surrounded by the robot suit, these joint motions could not measure, so only the knee joint and ankle joint were measured. Gait was analyzed according to the Rancho Los Amigos system, a functional classification consisting of eight phases. This system includes a major division between the stance phases, in which the heel is planted on the ground, and the swing phases, in which the foot is swung forward [9]. One gait cycle was defined as the full sequence of motion between two heel–ground contacts of the same leg. The eight-phase cycle is summarized in Figure 1.

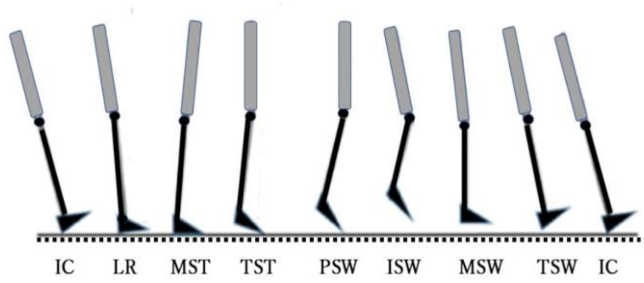

Figure 1. Gait analysis: the eight - phase gait cycle

IC: Initial Contact, LR: Loading Response, MST: Mid Stance, TST: Terminal Stance, PSW: Pre-Swing, ISW: Initial Swing, MSW: Mid Swing, TSW: Terminal Swing

Table 1. The condition setting for HAL

Condition 1：Assist 1
Left hip joint: voluntary control mode / assist level 1
Left knee joint: impedance control mode (without assist level)
Right hip and knee joints: impedance control mode (without assist level)

Condition 2：Assist 3
Left hip joint: voluntary control mode / assist level 3
Left knee joint: impedance control mode (without assist level)
Right hip and knee joints: impedance control mode (without assist level)

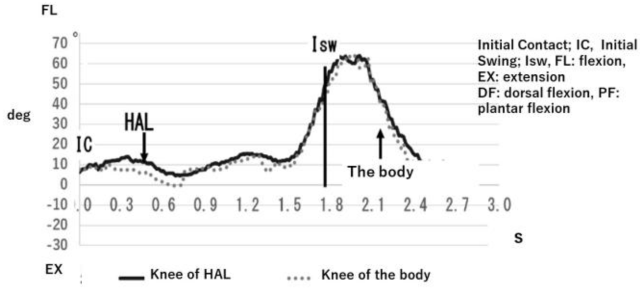

Fig 3. Angle change in a single gait cycle of knee joint of the body and HAL in the condition of Assist 3 of an assist level.

Table 2. The definition of angles for the hip, knee, and ankle joints of HAL and the body

HAL hip joint angle: Z axis — HAL hip joint — HAL knee joint
HAL knee joint angle: HAL hip joint — HAL knee joint — HAL ankle joint
Body knee joint angle: HAL hip joint — body lateral aspect of knee — body lateral malleolus
HAL ankle joint angle: HAL knee joint — HAL ankle joint — HAL 5th metatarsal head
Body ankle joint angle: body lateral aspect of knee — body lateral malleolus — HAL 5th metatarsal head

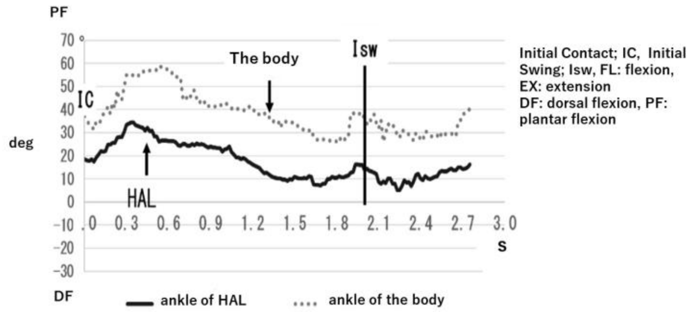

Fig 4. Angle change in a single gait cycle of ankle joint of the body and HAL in the condition of Assist 1 of an assist level.

Ⅲ-4. Results

As a result, 4 subjects showed the same tendency. Therefore, these figures showed the data of one representative example.

According to the comparison of HAL and the body joint angles in Fig. 2–5 and Table 3, the misalignment may arise between the assist robot and the body during the period of swing phase of one gait cycle walking as a characteristic of exoskeleton-type gait-assist robots (Table 3). The value (mm) of the knee joint of misalignment between HAL and body of Assist 1 was significantly greater than that of Assist 3. In addition, especially, the direction of ankle joint movement during the swing phase was plantar flexion for HAL, while the direction of joint movement for the body was dorsiflexion.

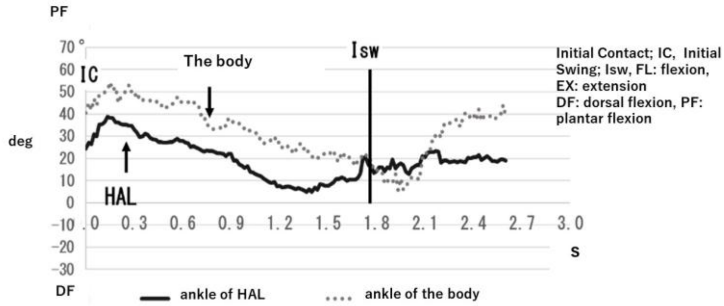

Fig 5. Angle change in a single gait cycle of ankle joint of the body and HAL in the condition of Assist 3 of an assist level.

Table 3. The misalignment between the assist robot (Robot Suit HAL) and the body during the period of swing phase of walking (a single gait cycle).

	Condition 1（Assist 1)	Condition 2(Asist 3)	
The value (mm) of misalignment of the knee joint of between hal and body	12.4 ±4.7	6.25 ±3.2	*
The value (mm) of misalignment of the ankle joint between hal and body	6.0 ±3.6	3.2 ±2.6	

＊：*P<0.05*

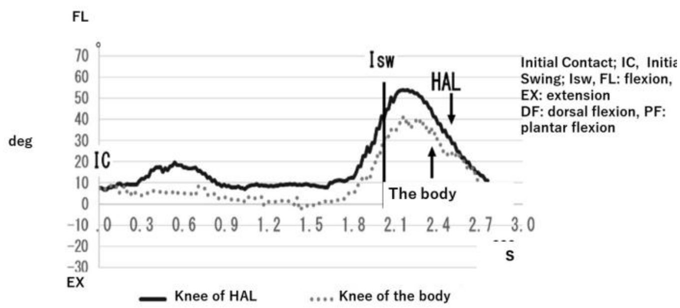

Fig 2. Angle change in a single gait cycle of knee joint of the body and HAL in the condition of Assist 1 of an assist level.

Ⅲ-5. Discussion

The misalignment (mm) may arise between an assist robot and the body during the period of swing phase of walking. The value of the knee joint of misalignment between HAL and body of Assist 1 was significantly greater than that of Assis 3. Because the assist level of Assist 1 is weaker than Assist 3, so the control of the joint movement of the body may be small in the condition of Assist 1. Especially, a comparison of HAL and the body indicated that large misalignment occurred when differences were seen in plantar flexion and dorsiflexion, based on the shape of the graph for a single gait cycle. Under the Assist 3 condition, the ankle joint showed differences in movement direction for HAL and the body from the terminal stance to the Initial swing (hereinafter referred to as Isw in Figure1) of the body, accompanied by the elimination of plantar flexion of the body ankle joint. The misalignment between HAL and the body with movement of the body ankle joint may have resulted from changes in hip and knee joint movement caused by differences in the hip joint assist torque.

In conclusions, this study obtained measurement data for small subjects. In near future, it will therefore be necessary to increase the amount of data by, for example, increasing the numbers of participants and trials and conducting statistical analyses. The results showed that there was a possibility of the quantified values of misalignment between the robot suit and the body in relation to versatile assist levels of a robot suit. Although the suit and the body should be fitted ideally, the potential for a misalignment during use of a robot suit should be understand carefully. Since robot suits are mainly used by the elderly and disabled, and because they have declined muscle strength and joint movement, so medical professionals should fully understand and prescript that they cannot control suit use by themselves.

IV. ADDRESSING THE USE OF THE ROBOTIC REHABILITAION

It goes without saying that in using robots, PT must naturally first be adequately prepared with knowledge of the field of physical therapy. Similarly, with robotic rehab, there is a need to analyze carefully whether what the PT is implementing is rehabilitation that enables the patient to walk normally and achieve independence in daily activities by using the device. This is much the same as examining the effectiveness of a prescribed prosthesis. Examining the effectiveness of robot use by no means involves a special analysis. The aim is to approach rehabilitation by adequately examining risk management for the patient, monitoring the patient, avoiding undue distress for the patient, and enabling the patient to use a device under comfortable conditions. Careful thought should be given to whether a robot should be used in view of these considerations.

The typical hospital is not adequately equipped with expensive motion analysis systems, force plates, or sensors. Under these circumstances, analyzing the effectiveness of robot use involves motion observation, primarily by kinematic analysis. This is in no way different from rehabilitation as it routinely implemented and is not a special case. Tolerating motion or abnormal movements or placing a heavy burden on the patient simply because a robot is being used is fundamentally impermissible. The PT should consistently analyze whether the use of a robot is pleasant or uncomfortable for the patient. In this regard, it should be used after adequate consideration is given to risk management and how effective its use can be for the patient within a limited amount of time. Cost vs. benefit, risk, and national health insurance points must also be taken into account.

Before a robot is used for patients, a thorough explanation of the skills needed to operate it should be provided by the manufacturer, and PTs should attain proficiency in its use. However, not only how it is used, but also the specifications of the robot should be understood to some extent. The characteristics of robots differ depending on whether they are the exoskeleton or end-effector type [10]. Drive methods include electric motors, air-pressure actuators, hydraulic actuators, shape memory alloy actuators, and metal hydride (hydrogen storage alloy) actuators. For use in rehabilitation, it should first be determined whether the actuator has ideal characteristics such as low rigidity (does not produce excessive reaction forces), small size and high output (can operate in limited space), and quietness (not noisy or fear-inducing). In considering the use of a robot for a patient, if the strength of the drive motor changes automatically based on muscle activity, it is important to first understand in more quantitative terms, if possible, how much power will be applied with a given level of muscle activity.

Moreover, the manufacturer must make an effort to inform the clinician of the basic principles of the device carefully. It is dangerous to use a robot without understanding the technology. The latest robots are easy to operate, and the risks associated with their use are well managed. However, it is important for the PT to understand the device's specifications, and the manufacturer should therefore carefully explain them. When using a robot, the PT needs to understand thoroughly aspects such as the many fine-tuning modes related to its operation and troubleshooting methods. However, the latest robots provide a rich user interface and good user experience that complement operation by the PT. A useful reference is the 2019 report from the Japanese Ministry of Economy, Trade and Industry titled, "New International Standard for Safety Requirements of Medical Robots for Rehabilitation Issued" [11].

Although there are many engineering articles on robot specifications, it can take considerable effort for a PT to read them. Consequently, it is considered appropriate initially to refer to articles from the fields of rehabilitation engineering and welfare engineering. Because PTs study kinesiology, it is important to at least learn mechanics by studying engineering articles in greater detail in order to gain a better understanding of robot specifications and operation. For handling robots, it is also important to confer with engineers, and to minimize the risk to patients and provide better rehabilitation, it is important to learn basic literacy common to engineering researchers and engineers. Rather than simply using a robot as indicated in the engineering guide, PTs should apply kinematic analysis and logically articulate their own views to avoid unnecessary risk to the patient and produce better results. Otherwise, their role may be little more than that of a part of the equipment. On this point, it would seem that it is indispensable to be adequately prepared before arriving at the point where robots are introduced in practice.

V. CONCLUSIONS

In Europe and the United States, a robot is considered something that should be subordinate, while Japan appears to have a greater ability to adapt to robots. In this regard, Ifukube [12] asserted that robots are viewed differently in Japan and the West: "In Europe and the United States, the view of Isaac Asimov of robots as being strictly servants and nothing more than tools has persisted. In Japan, robots are not considered subordinate objects, but rather members of the family. This sensibility has led to Japan being the world's leading robot producer." This may be because Japanese people have a greater sense of familiarity with robots and respect for the robot technology humans have produced, and therefore, patients do not typically reject communication robots, but rather, view them favorably. However, as was mentioned in the previous sections, robots should be introduced to health-care fields with greater sensitivity because they are used for patients who tend to be vulnerable.

It is likely that the robots and related techniques introduced to healthcare fields will evolve rapidly in the next 10 to 20 years. For example, multiaxial joint movement will become a possibility with the emergence of small actuators. Amid these changes, it will be necessary for PT to advance the evolution of physical therapy itself. The question in the case of multiaxial joint movement is how to validate quickly the effectiveness of these changes with kinematic analysis and utilize them in patient treatment; however, we should carefully consider the risks become greater with multiple axes. This too will demand skill on the part of the PT. Patient-centered physical therapy that utilizes the advantages of various types of robots can be implemented by integrating knowledge and skills at the vanguard and constantly innovating. This will first require a refinement of the abilities of PTs and their knowledge, experience, skills, and creativity to understand other fields.

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REFERENCES

[1] D Khalili, M Zomlefer. An Intelligent robotic system for rehabilitation of joints and estimation of body segment petameters. IEEE Trans Biomed Eng. 35(2):138–146, 1988.
[2] P.S. Lum, D.J. Reinkensmeyer, S.L. Lehman, "Robotic assist devices for bimanual physical therapy: Preliminary experiments", IEEE Transactions on Rehabilitation Engineering. 1(3):185-191, 1993.
[3] M. Vukobratovic, D. Hristic & Z. Stojiljkovic. Development of active anthropomorphic exoskeletons. Med. Biol. ENG. 12(1):66–80, 1974.
[4] Toshiaki Tanaka, A study of new technologies of personal mobility and robot suit for the elderly and persons with disabilities. Fondation France-Japon de l'EHESS. #18-06:pp1-6,2018.
[5] ReWalk Robotics. https://www.rewalk.com/, (12/2020)
[6] A Duschau-Wicke, J V Zitzewitz, A Caprez, L Lunenburger, R Riener. Path control: a method for patient-cooperative robot-aided gait rehabilitation. IEEE Trans Neural Syst Rehabil Eng.18(1): 38-48. 2010.
[7] Cai LL. Fong AJ. Otoshi CK., et al.: Implications of assist -as-needed robotic step training after a complete spinal cord injury on intrinsic strategies of motor learning. J Neurosci 26:10564-10568. 2006.
[8] Weiss A. Suzuki T. Bean J. et al: High intensity strength training improves strength and functional performance after stroke. Am J Phys Med Rehabil. 79 : 369- 376. 2000.
[9] J Perry and J M. Burnfield. Gait Analysis: Normal and Pathological Function. Second edition. Slack Inc., 2010.
[10] Roger Gassert and Volker Dietz. Rehabilitation robots for the treatment of sensorimotor deficits: a neurophysiological perspective. J NeuroEng and Rehabil.15:46. 2018.
[11] METI : New International Standard for Safety Requirements of Medical Robots for Rehabilitation Issued. https://www.meti.go.jp/english/press/2019/0723_001.html.
[12] Tohru IFUKUBE. Basics of Assistive Engineering (in Japanese). Corona Publishing Co., Ltd. 2016.

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