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Design of an Upper Limb Rehabilitation Robot Based on Medical Theory

Xiangli CHENG[a], Yiqi ZHOU[a,]*, Cuipeng ZUO[a], Xiaohua FAN[b]

[a]*School of Mechanical Engineering, Shandong University, Jinan, China*
[b]*Center of Rehabilitation Medicine, Shandong Provincial Hospital, Jinan, China*

Abstract

Robot-assisted upper limb rehabilitation training was proposed instead of the traditional rehabilitation training in this paper. The basic principle of motor function recovery is the medical theoretical basis of robot-assisted rehabilitation training, and contains two aspects, one is that the central nervous system has a high degree of plasticity after the brain injury, and the other is that motor function recovery can be achieved through motor relearning programme. Based on the analysis of the human upper limb, the design of the upper limb rehabilitation robot with an exoskeleton structure and three degrees of freedom (DOFs) that resembles the human upper limb was completed. According to the medical theory, robot-in-charge and patient-in-charge training models were developed for exercise therapy.

Keywords: Upper Limb; Motor Relearning Programme; Rehabilitation Robot; Training Model

1. Introduction

1.1. Clinical background

According to the statistics, stroke and other cerebral vascular diseases is one of the three diseases with the highest mortality rate in China, more than 2,500,000 new patients each year, and the total number of

* Corresponding author. Tel.: +86-531-88396551.
E-mail address: yqzhou@sdu.edu.cn.

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the patients exceeds 10,000,000. With the development of the brain surgery, the mortality rate of stroke is decreasing, however, the disability rate is still high, about 80% [1], and the relapse rate is as high as 40% within five years. Besides, there are always sequelaes after stroke, and the most common result is paralysis of limbs that seriously affects the living of the patient and brings a tremendous burden to both the patient family and the society. In addition, with the accelerated of aging, the incidence of the cerebral vascular diseases will continue to rise, and there will be more and more stroke patients. Therefore, it is essential to receive systematic rehabilitation therapy with the aim to improve the life quality and rebuild the confidence of life for the patients.

1.2. Robot-assisted upper limb rehabilitation training

Exercise therapy is an effective rehabilitation treatment, and the goal is to promote the motor function recovery, to improve the motor coordination, and to prevent secondary complications, such as muscle atrophy and muscle spasticity.

At present, the upper limb rehabilitation training method is the therapist one-to-one manually assisted motor training in China, which has several limitations. Firstly, due to the shortage of therapists, neither training duration nor training intensity can be guaranteed, so it is unable to gain an optimal therapeutic effect. Secondly, because one therapist only can implement rehabilitation treatment on one patient at the same time, the therapist has low efficiency and great work intensity. Finally, it is impossible to measure the physiological information of the patient when training, so it is difficult to quantitatively evaluate the process of rehabilitation. Therefore, there is a need to find a new and effective rehabilitation treatment instead of the traditional rehabilitation training.

Under this background, some research institutes proposed robot-assisted upper limb rehabilitation training that can overcome the shortcomings of one-to-one manually assisted motor training. At first, both the duration and the intensity of training can be guaranteed without increasing the number of the therapists. In addition, one therapist can implement rehabilitation training on two or more patients at the same time, so the working efficiency can be improved greatly. Furthermore, it provides quantitatively measure, allowing the observation and evaluation of the process of rehabilitation.

Because of the advantages of robot-assisted upper limb rehabilitation training, there is increasing interest in developing upper limb rehabilitation robots for stroke patients. Peter S. Lum *et al*. developed a hand-object-hand system [2] and a bimanual lifting rehabilitator [3]; however, no clinical results have been presented. The MIT-MANUS robot [4] designed by H. I. Krebs *et al*. could only provide two-dimensional movements in the horizontal plane. Based on an industrial manipulator, Charles G. Burgar *et al*. developed a mirror image motion enabler called MIME [5] [6], but the robot had no back drivability. David J. Reinkensmeyer *et al*. designed the ARM Guide [7] to diagnose and treat arm movement impairment following stroke and other brain injuries, and the robot can provide a means to implement and evaluate active assist therapy for the arm. Tobias Nef *et al*. developed an exoskeleton robot called ARMin [8] [9] with four active and two passive DOFs. Thomas G. Sugar *et al*. developed a device called RUPERT [10] for robotic upper extremity repetitive therapy that had four DOFs driven by pneumatic muscles on the shoulder, elbow and wrist.

Although the existing upper limb rehabilitation robots could provide a varying degree of assistance for the patients, from no assistance to full assistance, the design of the robots is not under the guidance of the medical theory, and not all the movements can conform to the motion of the human upper limb, which made the patients uncomfortable. In this paper, we firstly analyzed the basic principles of motor function recovery after stroke. Then, the design of the upper limb rehabilitation robot that resembles the human upper limb was completed based on the analysis of the human upper limb. At last, robot-in-charge and patient-in-charge training models were developed for exercise therapy based on the medical theory.

2. The Medical Theoretical Basis of Rehabilitation Training

2.1. The plasticity of the central nervous system

In the field of neurological rehabilitation, many researchers have committed themselves to the research on the mechanism of motor function recovery following the brain injury. And the most important research result is that the central nervous system has a high degree of plasticity, which provides a theoretical basis for the motor function recovery after the central nervous system injury in medicine.

2.2. Motor relearning programme

The theory and the clinical practice of rehabilitation medicine have proved that the repetitive and active movements can promote the functional compensation and functional reorganization of the central nervous system, thus the plasticity of the central nervous system can be strengthened and consolidated through continuous motor relearning programme. The rehabilitation training is considered to be a process of motor relearning. In the process of training, the patient should complete several tasks at different levels, and the method emphasizes the importance of active participation.

3. The Analysis of the Human Upper Limb

3.1. The structure

The human upper limb is mainly composed of skeletons and skeletal muscles, and can be divided into shoulder joint, upper arm, elbow joint, forearm, wrist joint and hand. The upper arm is connected to the torso through the shoulder joint; the forearm is attached to the upper arm through the elbow joint, and the wrist joint connects the forearm and the hand.

According to the human anatomy and mechanisms, the human upper limb can be simplified as a spatial linkage mechanism that is composed several rigid links connected through revolute pairs. The skeletons are links, and the revolute pairs represent the joints. On the basis, the wearable exoskeleton structure that resembles the human upper limb was adopted in the upper limb rehabilitation robot.

3.2. The motion

Because the movements of the human hand are very complicated, they will not be considered. In this case, there are only seven independent DOFs in the human upper limb, and they are the shoulder flexion and extension movement, the shoulder abduction and adduction movement, the shoulder medial and lateral rotation movement, the elbow flexion and extension movement, the forearm pronation and supination movement, the wrist flexion and extension movement, the wrist abduction and adduction. And the kinematical model of the human upper limb is shown in Fig. 1.

To get best treatment effect, the hand, the elbow and the shoulder are fixed on the robot arm through bandage, this moment the patient is being in the anti-spasticity. In this requirement, it is necessary to ignore several DOFs, and there are only three DOFs in the upper limb rehabilitation robot, and they are the shoulder abduction and adduction movement, the shoulder flexion and extension movement, the elbow flexion and extension movement.

As the robot is wearable, the range of motion (ROM) of the robot must conform to the ROM of the human upper limb. Considering the actual situation of patients, the ROM of the robot is smaller than the normal and can be adjustable.

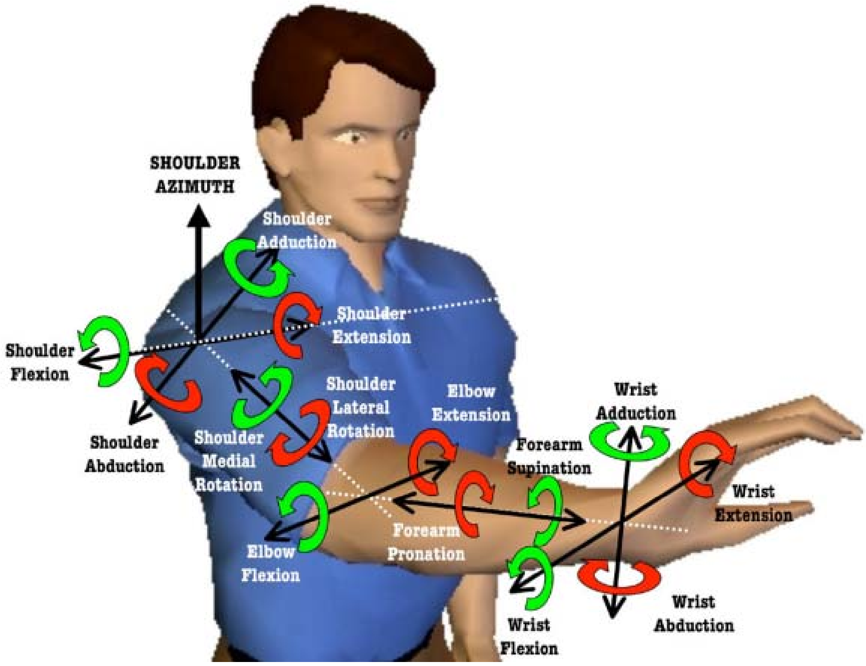

Fig. 1. The Kinematical Model of the Human Upper Limb [11]

4. Training Modes

According to the mechanism of rehabilitation therapy, the process of rehabilitation can be divided into three stages, which are flaccid paralysis, spasm stage and recovery stage. During the flaccid paralysis and spasm stage, the patient receives rehabilitation training in a passive state to improve muscle tension and restrain abnormal movement. In the recovery stage, the movement pattern and velocity can be chosen by the patient voluntarily, and the positive of training can be improved greatly. Therefore, robot-in-charge and patient-in-charge training modes were developed in this paper.

4.1. Robot-in-charge

When working in robot-in-charge training mode, the movements of the human upper limb is passive completely. The normal trajectory is generated by the control system, and the robot drives the human upper limb according to the pre-defined trajectory and velocity.

4.2. Patient-in-charge

With the depth of the rehabilitation process, the strength of the upper limb is increasing and the motor function is resuming gradually, which require that the patient shoulder take the initiative to participate in the rehabilitation training. Therefore, the active movement desire is introduced into the control system, and the robot provides assistance or resistance for the patient based on the actual situation. In this paper, the surface electromyography (sEMG) collected from the upper limb muscle groups is considered to be the active movement desire.

5. Conclusion

In conclusion, the upper limb rehabilitation robot with the exoskeleton structure and three DOFs could replace the traditional rehabilitation, and robot-in-charge and patient-in-charge training models meet the medical clinical requirements.

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