

# Development of Training Instrument for Upper Limb Muscle Rehabilitation

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## Abstract

This equipment can work in multiple degrees. By the single joint and composite motion, it imitates human upper limb movement. Composite motion can be multiple degrees of freedom, so that the equipment can fit with the physiological structure of human body well. Upper limb strength can be recovered efficiently and the muscle contraction can also be well preserved as expected. Obtaining vibration module, it enhances the effect of recovering. Wireless transceiver module makes the wireless monitoring and data wireless transmission be a feasible way. It is connected with the computer, and the recover information of patients could be gathered, analyzed and recorded in computer as well. Data can also be transmitted by the internet, so as to offer the recover information to medical institution.

**Keywords:** multiple degrees, efficiently, recovering, muscle contraction, training instrument

## 1. Introduction

With the rapid development of economy, people's living standards have improved significantly since the 21st century. So modern people pay more attention to the improvement of life quality. High incidence of diseases such as apoplectic hemiplegia is seriously threatening the health of human body. How to deal with those ills has become a problem to be solved.

The symptoms of apoplectic hemiplegia mainly embodies in the patient's physical activity, which is that the limbs can't be controlled by the brain. Due to the severity of the disease, the symptoms will show in a variety of sides. The limbs of the most serious cases are completely unable to motion. Some patients only show that physical activity becomes awkward and action becomes inconvenient. The physical activity of others performances worse and worse and due to the untimely recovery treatment, the illness becomes more serious. The clinical manifestations of this kind of patients are

paralysis or half paralyzed. The symptoms are that upper limbs are not controlled by the brain, upper limb activity was blocked, and even lost independent living skills. It can cause muscle belly shortening in a short time, then will harden the soft tissues which are near the muscles and joints and make the joint contracture, over time can lead to loss of muscle contraction function and muscle atrophy. It was called disuse atrophy. It will produce adverse effect on the digestive system and cardiovascular system and worsen the condition. From what has been mentioned above, we can come to the conclusion that it is important to develop the equipment that it can help patients with muscle rehabilitation <sup>1</sup>.

Rehabilitation training not only can effectively alleviate the exacerbation of illness. Insisting for a long time to arm rehabilitation exercise, the patients also can obtain good effect, such as make muscle cross-sectional area increase, the enlargement of muscle fibers. Then can enhance the shoulder muscle strength and muscular endurance and prevent muscle contracture around

shoulder joint<sup>2</sup>. Muscles exercise can speed up the upper limb blood flow, and indirectly enhances the cardiovascular function, meanwhile, patients can get some relief in psychological and spiritual aspects. Rehabilitation exercise can be divided into the passive motion, the massage movement, the help active movement, the active movement, the resistance movement and so on. The research shows that the guidance of proper upper limb movements and auxiliary recovery can restore upper limb movement, strengthen the upper body strength, repair the damaged motor function and prevent malformation, paralysis and atrophy of upper limbs. Thus, it can play a positive recovery effect.

Upper limb rehabilitation equipment is a kind of modern device which can help paralyzed patients to avoid to lose function of upper limbs and help upper limbs muscle rehabilitation. But this kind of auxiliary recovery equipment research is still in its infancy. There aren't finished products on sale on the market. And most of instrument developed by the researchers at home and abroad has its limitations. There is a lot of difficulty which hasn't been overcome in technical and functional aspects<sup>3-4</sup>. Problems are mainly manifested in the following aspects:

(1) Safety performance. Safety is the primary premise. Safety should be considered firstly in the rehabilitation process. It includes that the limitation of human upper limb movement should be considered. For example, in order to avoid the harmless to human body health, it should be taken into account when rehabilitation equipment is in action group.

(2) The man-machine comfort. For complete relax in the recovery process can help enhance recovery effect, it requires equipment should have good comfort and can't make the patient produces psychological resistance.

(3) Portability. Because the existing recovery area of some hospital is too large, mobility is not convenient, and restricted by regional recovery process, Patients need spend too much time and energy on treatment. Those require that the recovery equipment should be in small shape, easy to move, recover at home and save time and effort.

(4) Working time. Because the recovery equipment need motor to drive the human upper limb and cost more power, the arm recovery equipment need have

long life battery and ensure the recovery time meet the requirements.

## 2. Research of the field

Many experts from elite schools domestic and overseas have done a lot of researches about the upper limb rehabilitation equipment<sup>5</sup>. Such as the six degree of freedom robot ROBOTHERAPIST designed by Takehito Kiuchi team from Osaka University. The whole robot use external traction structure, through measuring the hand position of patients, it couple back training information, patients can also have access to movement information through screen with the virtual reality technology. This robot can make patients recover preferably, and add more interest into recover training. But the cost of manufacture is too high to popularize to public, it's more suitable to deploy in professional places such as hospital.

Helparm rehabilitation equipment produced by Kinsman company<sup>6</sup>, use pulley winded by wire rope to motive patient upper limb to achieve rehabilitation training. With simple structure, each side of patients can be trained partly, it has strong controllability, which make it easy to achieve rehabilitation training at home or in community. The defect is it's hard to control and can only provide several movements, which can't make a full recovery.

## 3. Design of mechanical structure

Upper limb auxiliary recovery equipment should have sufficient strength, and can withstand the pressure of human arm and pulling force. In the aspect of material selection, use the high strength aluminum plate, and use organic glass in upper limbs fixed place. Organic glass plate is bent into a radian. The radian which accords with human body upper limb physiological radian makes patients without the feeling of discomfort after tighten the arm. Recovery device based on a chair. It gives patients a more comfortable experience. In order to make patients in rehabilitation has the best effect, mechanical structure was designed into the shape of human upper limb exoskeleton to making it easier for upper limb when fixed.

The designed machinery structure considered the actual situation of different patients. In order to meet the different needs, can adjust the length of the forearm and

the big arm with more holes on the fittings. There also design the adjustable artifacts, which can slightly adjust in the design of the shoulder. A rough adjustment is controlled by a set of three cross slide guide rail. Stepper motor provides power supply, which by remote control can automatically adjust. The design meets the different patients demand, making it to have a wider range of use.

The hardware structure of the mechanical structure parts takes the design of the stationary. For small land occupation, the whole hardware of device fixed on the seat. On the design of some adjustable parts innovate boldly, by adjust the spacing and density of drilling hole to achieve the adjustment of dimension. 3 d figure of the overall and local figure as shown in figure 2-1, 2-2 and 2-3. Material selection is 6 mm thick aluminum plate. The density of aluminum plate  $\rho = 2700 \text{ (kg/m}^3\text{)}$ . Take the person of weight 75 kg, height 75 cm as an example by check data. The weight of Human upper limb a single arm materials is about 3.5 kg<sup>7</sup>. Through the data calculation and finite element analysis, 6 mm thick aluminum plate can support the weight of the human upper limb and meet the required strength requirements. Three-dimensional structure are shown in Fig 1.

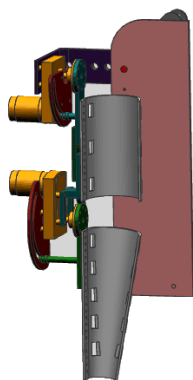


Fig 1. Three-dimensional structure

## 4. Research on human upper limb rehabilitation equipment

### 4.1. Review of circuit system

In the aspect of software: Synthetically analyzing the strength needed by the human upper limbs and calculating the steering engine power and torque need output pulse signal to control steering gear rotation.

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Need low speed large torque in the rehabilitation process .Large torque servo provide tangential force to do twist motion, generate bigger torque in a smaller space and provide convenience for shoulder structure design .The large steering engine is used to complete the training of rehabilitation.

### 4.2. Construction of circuit system

In the aspect of electric system's control: Master control chip is Freescale 32-bit Kinetis (ARM Cortex - the M4) micro controller .It has the advantages of high performance, low cost and low power consumption .The steering gear control panel is used on the control and execution of the action. The steering gear control panel can provide more accurate rotation Angle. Realize the communication between the servo control board and the stm32 chip. In the servo control board keep several sets of action in advance. When the steering gear control panel and stm32 chip make communication each other, draw on the inner recovery process according to the demand of the patients. There have set a few buttons on the back of arm recovery equipment. Family members of patients or doctors can choose different rehabilitation movement patterns according to the needs. The function of control system as shown in Fig 2.

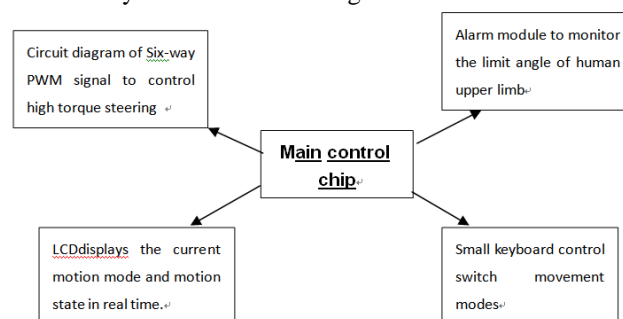


Fig 2. The function of control system

### 4.3. Limit size of upper limb

The upper limb rehabilitation equipment is designed to help patients recover in a safe and comfortable way, as a result, the extreme dimension is necessary while designing in case injury may happen during training. Through consulting data the author found: In the human body, the limit of the physiological structure of the upper limb of is 80°~90°.When the degree is based on the upright standing human body with arm dropping, the angle of lifting arm upward is 170°and extending arm

backward is  $40^\circ$ . The range of swing arms left and right is  $70^\circ$  to  $60^\circ$ . In order to prevent accident that do harm to the patient during the recovery process, we must set aside scope of safety margin during compile program of rehabilitation action. Setting the security range (should not exceed the limit angle) is as follows: the range of lifting arm upward is  $0^\circ \sim 130^\circ$  and extending arm backward is  $0^\circ \sim 10^\circ$  and the range of swing arms left and right is  $0^\circ \sim 30^\circ$ . It must fit with the physiological characteristics of human body at the same time, and refer to the dimension of human upper limb and range of motion of the body.

#### 4.4. Realize alarm function

Upper limb rehabilitation auxiliary equipment also has the function of ultralimit alarming. When the duty cycle adjusts the output, it may be result steering rotational angle is too large from adjusting the duty cycle is too large. Thus, it will lead to accidents if it is beyond the scope of the human upper limb. According to the human upper limb medical data, we pre-configured angular range of human upper limb movement in the mechanical design and program. In the recovery process, if the equipment will exceed the limited data, the angle monitor will detect the change. As the same time, it will send the feedback to the main control chip, and then trigger the alarm to prevent the action. It makes the equipment keep in a safe range and prevent damage to patients. In a word, the mode of automatic alarm and reset has a protective effect on patients and enhances safety performance. The main function as shown in Fig 3.

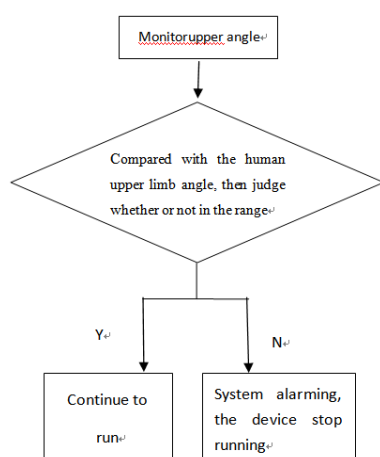


Fig 3. The main function

#### 4.5. Current and voltage

At the same time, Aiming at different voltage requirements of chip and motor in the system, adopt the power supply method of different lines with different voltage. In the aspect of power supply, high-power, multi-voltage output switching power supply as the power supply equipment, chip with 5V voltage of power supply, motor power supply with 12V voltage. those not only meet the requirements of the voltage of the motor, make the motor has enough energy to drive the upper limb movement, but also can satisfy the requirement of the chip safe voltage<sup>[8]</sup>. Equipment as shown in Fig 4.

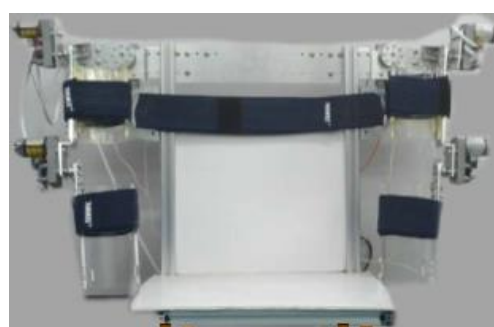


Fig 4. Equipment

#### 4.6. LCD and data transmission

Upper limb rehabilitation system is equipped with liquid crystal display, which not only can display the current patterns, exercise and other information, but also show that the rehabilitation training time and rehabilitation action group. The design so as to patients and their family members can better understand the current state of motion and reasonably arrange rehabilitation exercise group, training time and intensity of training. LCD shown in Fig 5.



Fig 5. LCD shown

The equipment is different from the traditional device. It is equipped with vibration module, in the recovery process, the vibrating plate is attached to the patient's arm by the control unit to control it. It can stimulate the patient's muscles, blood circulation and peripheral nerve, at the same time, combined with the recovery design of professional doctors. Then you can achieve better and faster recovery of upper limb motor function.

The wireless transceiver module, which is introduced in the device, can realize wireless monitoring and wireless transmission of motion data. By the module, the doctor can monitor remotely the patient's motion state, and change the program in real time. The computer terminal equipment can summarize and analyze the recovery information of patients, and can record the recovery of patients, which helps medical workers to analyze and improve the action group. It provides the basis for the record of the rehabilitation data and provides the basis for the future data processing, by the Internet, it can provide rehabilitation data for medical institutions.

## 5. Medical foundation of upper limb rehabilitation

The movement of the human body shoulder joint is accomplished by movement of the arm movement. To design a reasonable shoulder joint rehabilitation training plan, need to analyze the mode of Human arm motion. According to the theory of the human anatomy, when the body vertically stands on the ground, call the axis which is perpendicular to the ground and through the body vertical axis, call the axis which through the body of the front and rear and is perpendicular to vertical axis sagittal axis, call the axis which through the body and is perpendicular to the above two axes coronal axis. The human body is divided into three planes by the human anatomy. They are defined as:

- Horizontal plane (cross section): It parallels to the ground and through the sagittal axial and coronal axis. The plane divides the human body into Upper and lower two parts.
- Coronal plane (frontal plane): It is perpendicular to the sagittal axis and through the coronary axis and vertical axis. The plane divides the human body into front and back two parts.
- Sagittal plane (longitudinal section): It is perpendicular to coronal axis and through the

sagittal axis and vertical axis. The plane divides the human body into left and right two parts.

The shoulder joint motion is defined into three kinds: flexion and extension movement, outreach and adduction movement and extorsion and intorsion movement by Human anatomy<sup>9</sup>.

(1) Flexion and extension movement: Arms move around the coronary axis in the sagittal plane. Forward is flexion. Backward is extension.

(2) Outreach and adduction movement: Arms move around sagittal axis in the coronal plane. Away from the trunk is outreach. Near the trunk is adduction.

(3) Extorsion and intorsion movement: Arms move around the vertical axis movement in the horizontal plane. Away from the trunk is extorsion. Near the trunk is intorsion.

Upper limb movement is divided into two categories in accordance with degree of freedom of the movement.

### (1) Single joint movement

Single joint movement is only a single joint training, such as the elbow bend and stretch. It is a training methods which is adopted in the early stages of the rehabilitation training, or to improve the strength of a particular muscle group. The way of movement is simple. The purpose is clearer. It can strengthen the impression of the nervous system to specific actions and promote the rapid recovery of neural function.

### (2) Compound movement

Compound movement is the most popular way in rehabilitation exercise. Patients' muscle groups must be achieved through multiple joints movement, and multi-joint muscle in the majority in the joints and muscles. So the compound training must be conducted: compound movement can exercise the coordination of muscle, and the control of multiple muscle groups. Compound movement mainly adopt the way of a specific task to achieve, such as take water glass to drink. This series of composite action, must pass through joint movement to achieve. At the same time, treat patients from the psychological and improve the rehabilitation confidence of patients. It must be very careful when composite motion do, avoid muscle damage.

For normal human upper limb movement, the brain controls the upper limb different muscle contraction in order to realize the upper limb movement, then complete a series of actions. Upper auxiliary

rehabilitation equipment according to the human upper limbs motion common action to drive the upper limb muscle contraction and expansion. Action group is divided into different movement patterns: the horizontal motion model, the vertical movement patterns and stretching model. Different patterns train different muscle tissue. This can get better effect.

## 6. Conclusion

Upper secondary recovery equipment is a kind of for upper limb movement disorder patients recovery equipment. The recovery equipment based on the analysis of the human body of medical knowledge, mechanical structure design, and the construction of the circuit system, combined with the test data and so on comes out the conclusion. Through mode selection for designed recovery actions in advance group then moves to restore, restored information real-time display on the LCD screen.

The innovation points of this paper is to design the adjustable mechanical structure and recovery of real-time display. This device can replace physical therapy for patients with rehabilitation massage in some degree, achieve the effect of upper limb rehabilitation. At the same time, consider the characteristics of less occupied area, easy to move and portable. Therefore the rehabilitation equipment made into the shape of a chair. In order to reduce the cost of production, adopt standard parts as far as possible in the meantime. with 24V safe voltage, make it safe and reliable to use.

Synthetically consider arm recovery equipment simplicity, aesthetics, and security of human body recovery and comfort of the design. Ultimately determines the design of upper limbs restoration equipment:

(1) From a security perspective come out the extreme dimension of human upper limb. With alarm device to monitor the data.

(2) From the point to achieve the best recovery effect, design different action group to implement the recovery of upper limb different muscles.

(3) From the humanistic perspective, the display screen shows the currently executing movement patterns and can be adjusted and chosen according to need.

In this paper, the design of upper limbs restoration equipment adopted a large number of aluminum and its standard fittings in structural design. Under the premise

of meeting the structure and strength requirement, greatly reduced the quality of ontology and control the manufacturing cost. Equipment test result and the effect of human movement experiment of upper limbs to restore movement basically corresponds. It shows that the design of the upper limbs restoration equipment structure design is reasonable. In the design of the upper limbs restoration movement groups, can achieve the effect of upper limbs to restore, feel safe and comfortable and provide certain help for upper limb disorders.

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