

# Effect of Robot Driving Mode on Lower Limbs Rehabilitative Training

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**Abstract.** According to the combination of lower extremity rehabilitative robot(LERR) and trainer, the effects of multi-point driving form and single point driving form on muscle force and joint torque are explored. The musculoskeletal model of lower limbs was established, based on the physiological structure of human lower limbs. And considering the position of the attachment points of each muscle, the mechanical properties of muscles can be obtained under different rehabilitative training strategies by inverse dynamic analysis. Using the wire-driven rehabilitation robot as the driving device of the rehabilitation training, the robot was used to Simulate the motor function of patients' lower limbs by modifying the parameters of muscle and the parameters which can effect the resistance moment of joint ,then the effects of driving form were analysed. The results show that single point driving form was better than multi-point driving form on muscle force and joint force training.

## Introduction

Ambulation dysfunction is one of main dysfunctions in patients with stroke, and it is the main important index to evaluate the motor function of patients with stroke that the patients can resume security independent walk or not [1]. Conventional treatment is through early trunk control to strengthen the strength of lower extremity and stand balance, and then dynamic gait training will be started. However correct gait needs trunk control stably and Coordinate contraction of lower limbs muscle and other conditions. In the early walking training, the patients can get those conditions difficultly, and therapists also can not take fully consideration on the all lines of force that participate in joint movement in gait cycle, and it will result in easing the feedback of central nerve system error and forming abnormal gait [2]. Gravity balancing orthosis (GBO) was created by the college of Mechanical Engineering and the medical college in University of Delaware which was aimed at reduce or eliminate the effect of lower extremity gravity when walking. The experiment showed that 75% of the joint torque was saved when normal knee statically [3-4]. Reha Technology produced a Plantar-driven gait rehabilitative robot to help patients to practice walking which can drive patients' lower extremity moving through driving the pedals. Four kinds of patterns (flatland, steps, ramps and obstacles) and active-passive training pattern were Contained in the robot's walking patterns [5]. The lab in University of Tsukuba created gait rehabilitative robot named Gait Master that could captured patients' EMG in the training process to inform the current status of patients and switch training patterns automatically, and completely passive training pattern was overcome[6]. Another gait rehabilitative robot towed by rope, STRING-MAN, was created in German Research Center for Frances Hofer which could achieve the posture control of legs, pelvis and trunk, and meanwhile rope improved the running speed and flexibility of the system because of little Inertia and flexibility[7]. A kind of walking rehabilitation training robot was developed in Shanghai University ,and this robot was equipped a three degrees of freedom leg including hip, knee and ankle joint to help patients to complete lower extremity walking skills training and passive training basing on the theory of loss of weight training. There were two main driving forms in the cooperation of rehabilitation training robot and the trainer .One was that robot was connected to different parts of the limbs of the trainer through multiple points and did regular exercise by multi-point driving; another was that robot was connected to the extremity of limbs of the trainer and the

robot drive joints to move. The training effect of these two kinds of driving forms aiming at the same training goal had not been studied. So in the thesis multi-point driving training pattern and single point driving training pattern of the lower extremity rehabilitative robot were studied, and the advantages and disadvantages of two kinds of driving methods on the training of muscle group of thigh and hip joint and knee joint were analysed. Then it is discussed that the patients with different movement disorder should choose appropriate rehabilitation drive form.

### Musculoskeletal of Lower Extremity Modeling

Muscle modeling played a very important role in rehabilitation and medical diagnosis, and relatively complete theoretical system about muscle modeling had been established. The representative theory of muscle contraction was the theory of muscle wire sliding. In this thesis the muscle of lower limbs was modeled according to theory of Hill muscle modelling[8]. The output force of muscle was expressed as follows:

$$F = F_{CE} + F_{PE} \quad (1)$$

Wherein:  $F$ , represents the muscle force;  $F_{CE}$ , represents the characteristic values of muscle contraction;  $F_{PE}$ , represents characteristic values of muscle parallel damping;

$$F_{CE} = \alpha \cdot F_{\max} \cdot f_H(v_r) \cdot f_L(l_r) \quad (2)$$

Wherein:  $\alpha$ , represents the degree of muscle activation, value in the range of 0~1, and it can be changed according to the patient to simulate the athletic ability of patients;  $F_{\max}$ , presents maximal isometric muscle force in cross-sections of muscle,  $F_{\max} = \sigma_{\max} \cdot A$ ;  $\sigma_{\max}$ , represents the maximal isometric muscle stress;  $A$ , presents the cross-sections of muscle.

$$f_H(v_r) = \begin{cases} 0 & v_r \leq -1 \\ (1 + v_r) / (1 - v_r / CE_{sh}) & -1 < v_r \leq 0 \\ (1 + v_r CE_{ml} / CE_{shl}) / (1 + v_r CE_{ml}) & v_r > 0 \end{cases} \quad (3)$$

$$v_r = v_{curr} / v_{\max} \quad (4)$$

Wherein:  $v_{curr}$ , presents instantaneous velocity of muscle elongating,  $v_{\max}$ , presents the maximum speed of muscle contraction;  $CE_{sh}$ ,  $CE_{shl}$ , presents the coefficient of variation on force--speed curve in the process of muscle contraction and elongation;  $CE_{ml}$ , presents relative maximum force in the process of muscle elongation.

$f_L(l_r)$ , presents the force-length relationship function of elongation of the muscle  $l_r$ , as follows:

$$f_L(l_r) = e^{-((l_r - 1) / s_K)^2} \quad (5)$$

$$l_r = l_{curr} / l_{ref} \quad (6)$$

Wherein:  $l_{curr}$ , presents the instantaneous length of muscle;  $s_K$ , presents coefficient of variation on force--speed curve;  $l_{ref}$ , presents the optimal referenced length when muscle can produce force in the most efficient way.

$$F_{PE} = \sigma \cdot A \quad (7)$$

Wherein:  $\sigma$ , presents the muscle stress. Its expression is:

$$\sigma = (k \cdot \varepsilon)(1 - \varepsilon / \text{asym}) \quad (8)$$

Wherein:  $k$ , presents the rigidity of muscle;  $\varepsilon$ , presents contraction percentage;  $\text{asym}$ , presents coefficient of tension.

In the rehabilitative training of lower limbs, the force response of muscle in different rehabilitative training patterns and the motion of different muscular abilities were analysed. Then the basis for the development of recovery strategies was provided.

Kinematics model, as shown in Fig.1, of animal mechanics was established according to physiological structure of bone and joint of lower limbs [9-11]. And mechanical properties of muscle in different rehabilitative training strategies were obtained by considering the position of the attachment points of each muscle connecting and analysing its inverse kinematics. Although the muscle group of lower limbs is a redundant system, and the relationship between the muscles were complex. But various movements were still driven by the major muscle groups. The muscle groups of Lower limbs (like) were considered when the model was established that based on motor function of lower limbs. It was shown as Fig.2.

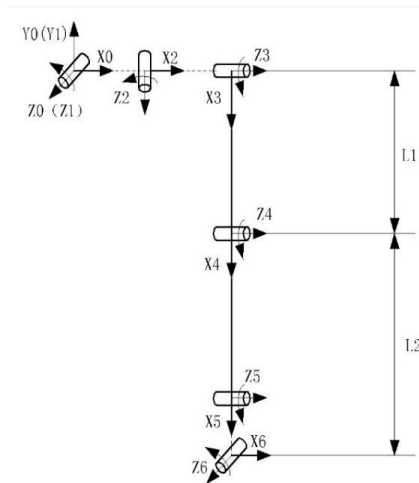


Fig. 1. D-H model of Lower limbs.

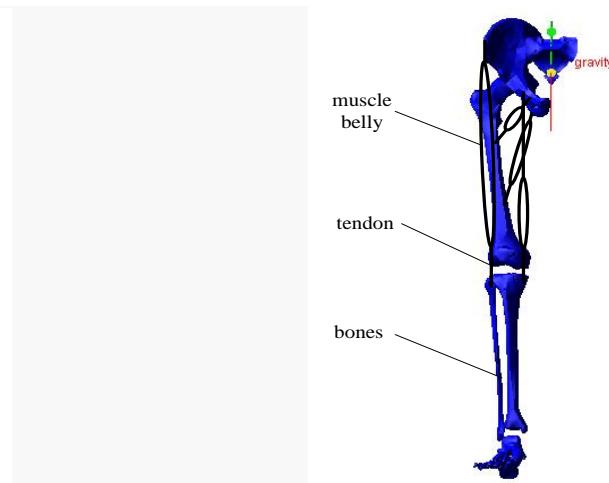


Fig. 2. Model of musculoskeletal.

### Analysis of Training Program and Training Pattern

External skeletal driving form was driving the connecting rod tied to a leg that can drive the lower limbs swing. Because there were many ties connecting lags and rod, the driving pattern was multi-point driving pattern. The abduction and adduction movements training robot analysed in the thesis was a typical robot driven by rope. The rope driven by electric motor drove the moving platform flexible connected with crus to help lower limbs to complete training, and this driving pattern was single point driving pattern. The effective training method was obtained by analysing the advantages and disadvantages of the two driving forms aiming at the training of thigh muscles and hip and knee joints. Then some small balls flexible connected with lower limbs were used as signalized points to simulate the drive point that drive the rope and exoskeleton. Those balls were No.1(RFEMW), No.2(RFEMC), No.3(RTIBW), No.4(RLATM), No.5(RHEEL), No.6(RGAIT). It was shown as Fig.3.

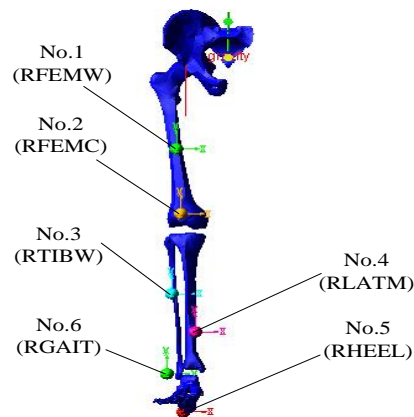


Figure 3. Location of driving points.

### Analysis and Discussion

There were some of the most common features like lower limb muscle weakness, myotonia, muscle atrophy and joint stiffness when it comes to patients with lower limb motor dysfunction. In this thesis the musculoskeletal of lower extremity of patients was modeled by changing some of muscle parameters and resisting moment that can effect joint movement in LIFEMOD software according to Hill's theory about contraction of muscles. The main difference in muscle between patients and normal people was low muscle activity that will make decrease and presenting increase from the formula(2) of muscle force. Based on the above analysis, musculoskeletal model of lower limb was established using LIFEMOD in ADAMS environment. The parameters of the musculoskeletal model contained that joint damping was 1.3 (normal 1), coefficient of muscle activity was 0.3 (normal 1), preload was 0.52 (normal 0.4448 ).

The initial position of those balls (towing points) in the coordinate system of D-H model of lower limbs was given in ADAMS environment. The initial position was shown as Tab.1.

Table 1. Position of drive points.

"MARKER"	Position in the world coordinate system	name of local coordinate system	the position in local coordinate system
RFEMW	(-20,-220,22)	X3Y3Z3	(220,-22,-20)
RFEMC	(-10,-390,60)	X3Y3Z3	(390,-60,-10)
RTIBW	(-30,-600,10)	X4Y4Z4	(180,-10,-30)
RLATM	(20,-700,20)	X4Y4Z4	(280,-20,20)
RHEEL	(-5,-910,-80)	X6Y6Z6	(-5,-100,-80)
RGAIT	(-40,-810,0)	X6Y6Z6	(-40,0,0)

Basing on the kinematic model established by using MATLAB, the trajectory was obtained, and law of motion of towing points along the X axis, Y axis and Z axis were obtained which was recorded in ADAMS in the form of spline curves.

The force condition of Multi-point driving pattern and single point driving pattern were analysed in the abduction and adduction training, and then the effect of the robot to rehabilitative training was evaluated. The changes in the muscle force of mesogluteus, rectus femoris, medial vastus muscle and musculus vastus lateralis was obtained by simulation. The results were shown as Fig.4.

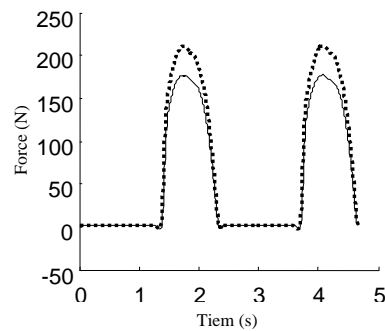


Fig.4(a). Mesogluteus.

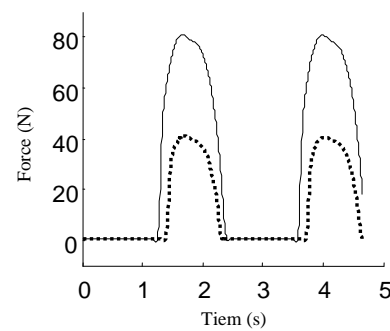


Fig. 4(b). Rectus femoris.

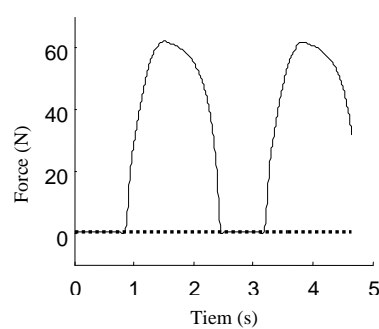


Fig. 4(c). Medial vastus muscle.

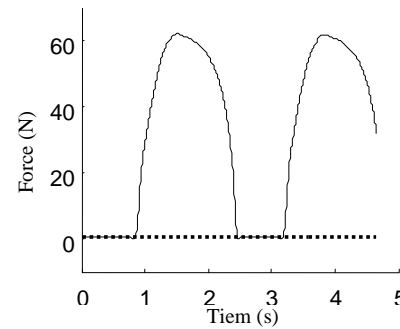


Fig. 4(d). Musculus vastus lateralis

— single point driving      ..... multi-point driving

As shown in Fig.4, the multi-point driving pattern were better than the single point driving pattern on the train of mesogluteus. It was because that the multi-point driving pattern can drive the points more accurately. However the single point driving pattern was better on the train on rectus femoris, medial vastus muscle and musculus vastus lateralis. Considering the structure, the robot driven in single point form was more simple and cheaper than the one driven in multi-point form. When came to simulate training effect, the single point pattern had better effect on muscle training than the multi-point pattern, and the large degree of unnecessary injury to the lower extremity of the patient was reduce. So, the single point driving pattern was superior.

## Summary

Through simulating that patients with lower extremity motor functional disorder did abduction and adduction passive training in single point driven pattern and multi-point driven pattern, and changes of muscle force and joint torque of the main muscles of the lower limbs were analysed .Then the conclusion was draw that the single point driven pattern is more benefit for the patients to recover their muscle strength.

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