Development of prototype FES-rowing Power Rehabilitation equipment

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Abstract

Most types of resistance training equipment for exercise are designed for healthy people with higher fitness levels, but the equipment used in Power Rehabilitation is designed exclusively for rehabilitating the elderly, and even disabled individuals. The purpose of this study was to develop power rehabilitation equipment for wheel-chair users or elderly people with limited mobility. We devised the prototypical FES-rowing machine device incorporating a controller of lower limbs and a trunk stabilizer. We used an able-bodied individual to test the new equipment. A measurement system included the experimental rowing machine with six force-sensing resistors, a 2-channel electrical muscle stimulator using surface electrodes, and a three-dimensional motion analyser. The electrical stimulator activated the quadriceps femoris muscles in drive phases of the rowing cycle. A four -link model was used to calculate the joint moment. The knee extension moment from the end of the pull phase to the flexed ready position was approximately 2 times that at the stroke start. Comparing general rowing and FES-rowing, no significant difference was observed in joint moment and range of movement. Our results suggest that safe, effective training is possible for seniors and paraplegics if postural stability is improved during FES-rowing.

1. INTRODUCTION

Generally the number of muscle fiber loss begins in your 30's, and continues to decrease until at 80 you will have less than half of what you had in your 20's. Muscle weakness due to aging is particularly evident in the lower limbs, and many senior citizens begin using a wheelchair early to prevent bone fracture caused by falling. Quadriplegic or paraplegic individuals also use a wheelchair for life, which often causes *disuse syndrome*. To prevent disuse syndrome, all patients using a wheelchair are encouraged to stand up and do exercises such as walking, if possible. However, specialized equipment and staff are necessary for walking exercise, and there is the inconvenience of going to a rehabilitation facility. Recently, power rehabilitation is attracting attention in geriatric rehabilitation. The purpose of this rehabilitation is to prevent being bedridden by restoring activity level. One of the characteristic features of Power Rehabilitation is to utilize resistance training machines in individual or group sessions twice a week for three months. Also, functional electrical stimulation tends to be effective for paralyzed involuntary muscles. Andrews and colleagues [1][2] demonstrated that FES-rowing for persons with spinal cord injury was safe and could play a role in decreasing risk factors for cardiovascular disease. In this study, based on a new concept to effectively restrengthen fast twitch muscles and enable whole body exercise in seniors or paraplegics, we developed hybrid power rehabilitation equipment which included FES technology. The purpose of this study was to develop a rowing machine that seniors and paraplegics could use for safe and effective rehabilitation exercise.

2. METHODS

2.1. The concept of prototype

Development of the equipment is based on the concept of using FES: using lower limbs of seniors and paraplegics as with FES. Therefore we limited lower limb movement and a device to maintain the stability of the upper body was devised.

2.2 Prototype FES-rowing machine

The prototype adopted a flywheel which has magnetic brakes with 9 levels of resistance adjustment. The prototype was based on a commercial rowing machine (R610, TUNTURI co., Finland), and with a senior or paralyzed user in mind, a backrest was installed on the seat. In addition, one belt was put on to prevent falling to the side (figure 1), and another was installed to restrain the lower limbs in sagittal plane (figure 2). We installed a switch on the handle bar so the subject could manually control the electrical stimulation timing (figure 3).

2.3. FES equipment

A 2-channel electrical stimulator (MINATO, Japan), which provides carrier median frequency pulses, was used to activate the quadriceps femoris muscle for knee extension using surface electrodes (figure 4).

2.4. Timing of electrical stimulation during exercise

The sequence is initiated from the starting position (maximally flexed ready position) by pressing the hand switch, which remains pressed until final extension and throughout the upper-extremity pull phase so that the lower extremities are maintained in an extended position. On completion of the upper-extremity pull, the hand switch is released, and the participant pushes the upper extremities forward. This initiates a return to the starting position (fully flexed position) and the beginning of the rowing stroke.

2.5. Motion analysis

Experimental conditions were as follows;

1) General rowing: without FES, seat rail incline set at 14 degrees
2) FES-rowing: with FES, seat rail incline set at 14 degrees

An able-bodied subject (22-year old male height 175cm, weight 55kg) participated in this examination. In FES-rowing we assumed the paraplegia, and had him start the pull phase after the kick phase had ended (after the knee joint extension ends), and to relax his lower extremity during the recovery phase. In this study, the rowing movement was measured kinematically using the VICON140 system and analyzed by a model calculation.

2.6. Calculation of joint moment using a link model

Modeling of the human body was performed and the joint moment was calculated using a link model. The dynamic model consisted of 2 dimensions of a 4-link model (foot, shank, thigh, and body) (figure 5). Some assumptions were predetermined for simplification. Considering gravity and acceleration of each link, dynamic joint moment on the ankle, knee, and hip were calculated from balancing horizontal and vertical forces and moments at

Figure 1. Seat

Figure 2. Belt for restaining the lower limbs

Figure 3. Control switch

each joint.

2. RESULTS

3.1. Joint motion

It was observed that arm and lower limb movement started simultaneously, and continued until the handle bar and the seat return to the flexed ready position. That indicated the necessary muscle strength of lower limbs in the recovery phase (knee joint flexion period) and enough braking force for the inclined seat rail. Compared to general rowing, the noticeable difference was the time difference from the start of rowing to the end of the pull phase. Also the motion lacked braking force for the inclined seat rail in recovery phase. As a result, the return speed of the seat increased. This resulted in a collision of the seat and machine at the stopping point, which caused excessive rolling on the upper body in the recovery phase.

3.2. Joint moment

The knee extension moment from the end of the pull phase to the flexed ready position was approximately 2 times that at the stroke start (figure 6). Comparing general rowing and FES-rowing, no significant difference was observed in joint moment and range of movement.

DISCUSSION AND CONCLUSIONS

We developed rehabilitation equipment that seniors and paraplegics can use for safe and effective exercise. We did research on the characteristic of the rowing movement. Our results suggest that safe, effective training is possible for seniors and paraplegics if postural stability is improved during FES-rowing. In order to be put to practical use, further development is necessary.

References

[1] Wheeler GD, Andrews B, Lederer R, *et al.*, Functional electric stimulation-assisted rowing: increasing cardiovascular fitness through functional electric stimulation rowing training in persons with spinal cord injury. *Arch Phys Med Rehabil* **83**: 1093–1099. 2002.

[2] Davoodi R, Andrews BJ, Wheeler GD, *et al.*, Development of an indoor rowing machine with manual FES controller for total body exercise in paraplegia. *IEEE Trans Neural Syst Rehabil Eng.* **10**: 197-203, 2002.

Figure 4. Stimulator

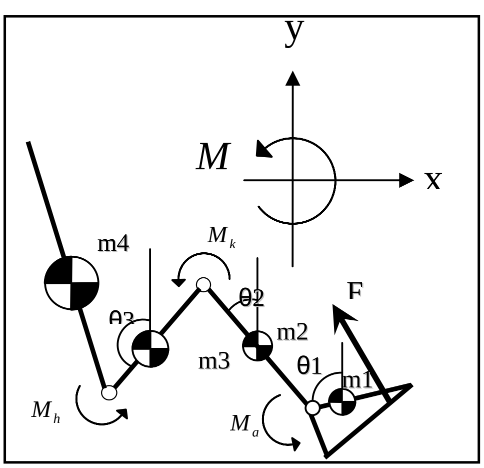

Figure 5. Four-link model

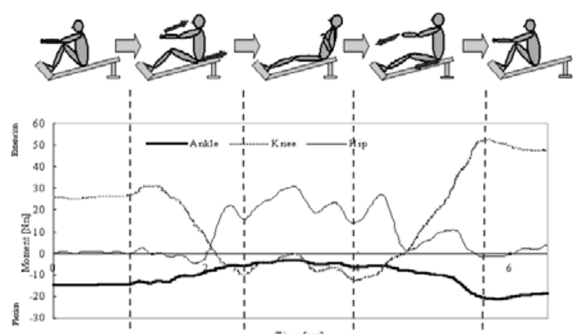

Figure 6. Joint moment