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BRMS:Bio-Resposive Motion System (Rehabilitation System for Stroke Patients)

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Abstract
We have developed the rehabilitation system (BRMS, Bio-Responsive Motion System) for recovery of motion ability of the lower extremities of stroke patients. This project is supported by NEDO (New Energy and Industrial technology Development Organization) from 1999 to 2003. The BRMS constitutes a total exercise machine for patients with stroke. One of the target technologies is the 'gait simulator', which allows the patients to regain gait function by the exercise of both extremities with assistance for their voluntary muscle power and coordination skill. The BRMS's concept is that spastic patients move along walking pattern based on gait analysis, and the system evaluates the gait pattern, applying assisting motion and biofeedback. As preliminary experimental results on BRMS, joint angles, joint torques, floor reaction forces, and surface integrated electromyogram on the BRMS in one normal subject, are compared to the data in the gait pattern with standing position in normal subject.

1. Introduction
In the early 21st century, Japan will become a super-elderly society in which approximately 25% of the population will be over 65 years old. It is expected that the advanced technologies such as robotics and mechatronics will be applied to the medical, rehabilitation, and healthcare areas as a means of improving the cost performance of rehabilitation.

Strokes have been one of the most serious diseases in Japan affecting 1.4 million people, the elderly making up a large proportion of this number. Recovering walking function is an important goal in the rehabilitation process in stroke patients.

For the recovery of lower extremity function to walk, the range of motion exercise (ROM-E) is usually applied as a therapeutic exercise to improve ROM and to prevent contraction of the joint [11-14]. Many therapists have noticed a decrease of spasticity by repetitive ROM-E. The exercise itself includes simple flexion/extension motion on the uniarticular muscle and straight-leg-raising (SLR) motion on the biarticular muscles to stretch the quadriceps femoris, hamstrings, gastrocnemius, and associated muscle groups.

We have commercialized the Therapeutic Exercise Machine (TEM) as a robotic exerciser for basic training of stroke patients [1-10]. But the TEM has no mechanisms that move two hip, knees, and ankles of a patient for walking exercise.

The BRMS has mechanisms that move two hips, knees, and ankles of a stroke patient according to the gait cycle.

2. BRMS Features for Rehabilitation
Figure 1 shows the target systems of the NEDO project [9-10]. Asahi Kasei Group and Osaka University develop Upper Extremity Exercise System. Daihen Tec Corporation, Oita University, and Tokyo Denki University develop Gait with stroke Training System. And Yaskawa Electric Corporation and Keio University develop Lower Exteremity Exercise System. We named the Lower Exteremity Exercise System as Bio-Responsive Motion System (BRMS). The BRMS constitutes a total exercise machine for patients with stroke.

The BRMS has three aims; the recovery of motion ability of the elderly, physically handicapped, and carebrovascular dementia persons, the decrease of therapist's burden, and the evaluation of walking function.

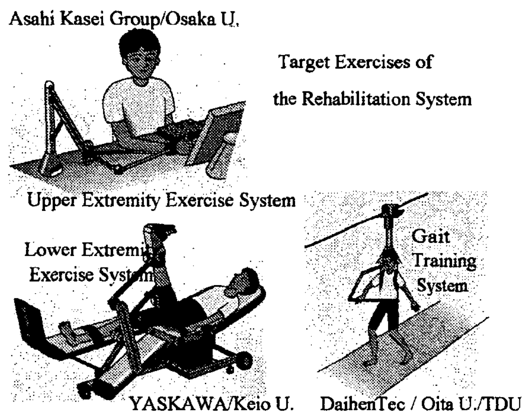


Fig.1: Rehabilitation System for Maintenance and Recovery of Motion Ability of Upper and Lower Limbs in NEDO Project

Figure 2 shows the concept of BRMS. The BRMS has four features. The first one is mechanisms that move two hips, knees, and ankles of a patient for walking exercise. The machine supports the trunk, thighs, calves, and ankles of the patient, and has wide range of motion of hip, knee, and ankle for walking exercise. Secondly, the system measures the patient's conditions in exercise. Thirdly, the machine has walking exercise of two hips, knees, and ankles for the patient. The machine has passive and active-assistive coordination exercise. Fourthly, the machine feedbacks assisting motion for the patient's conditions, and presents his/her conditions or walking exercise's timing with monitor, speaker, or vibrator. In walking exercise, these four functions run at real time.

This paper expresses the measurement results in one normal subject. The BRMS has the following four primary features:

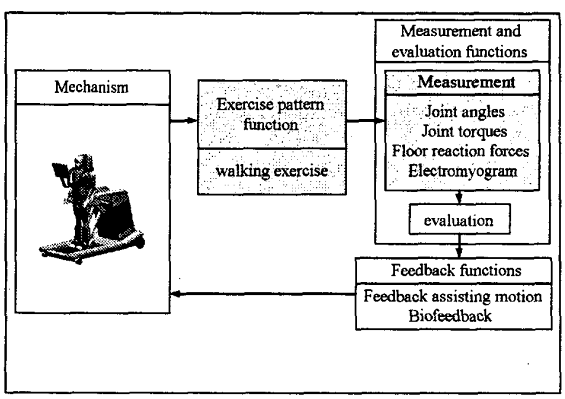


Fig.2: The concept of BRMS

2.1 Mechanism

The BRMS is a novel exerciser for two hip, knee, and ankle joints of spastic patients. Figure 3 shows the apparatus of the BRMS. The machine is composed of a link mechanism, bed for the patient to lie on, an operating/monitoring panel, a patient's monitoring panel, and control unit. One pair of two mechanical arms of the BRMS move the targeted lower extremity. The link mechanism comprises one pair of actuated arm mechanisms and splints. One of the mechanisms supports the thigh of the patient, giving two-degrees-of-freedom rotating/linear motion. The another drives the lower leg, giving three-degrees-of-freedom rotating/linear motion. The other drives the ankle joint. Hip, knee, and ankle have a wide range of motion (ROM) with the BRMS. Table 1 shows the available range of motion realized by the BRMS. The arm mechanism can follow the three-degrees-of-freedom motion of the lower extremity in the sagittal plane. The ROM of each joint is wide enough for the repetition of passive walking exercise.

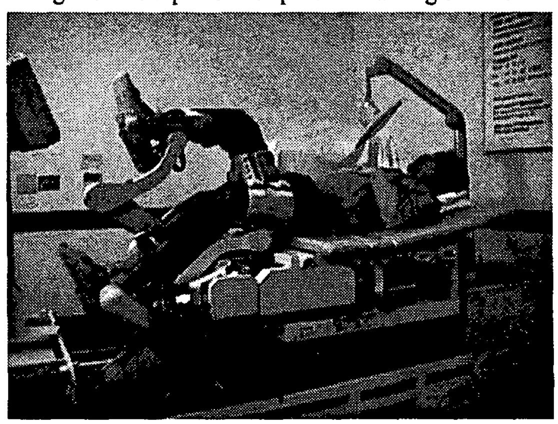


Fig.3: BRMS Apparatus

Table 1: Available ROM in Walking Exercise

Knee	0 – 120 [deg.]	
Hip	0 – 90 [deg.]	In SLR with knee extended.
	-10 – 60 [deg.]	In walking pattern
Ankle	-40 – 20 [deg.]	

2.2 Measurement and Evaluation functions

The BRMS measures the angle and the torque of the hip and knee, and records the signals of six channels of floor reaction forces and eight channels of a surface integrated-electromyogram (I-EMG). The joint angles are measured using potentiometers on the splints determining the postures of these splints in relation to the base of BRMS.

The load torque of the joints is estimated using kinematics and inverse kinematics of the patient's leg together with information describing the angle of the link mechanisms and load sensor information. And gait performance is evaluated in spastic patients with stroke.

2.3 Exercise pattern function

The BRMS follows and memorized walking pattern, and the system replays the pattern precisely. The BRMS can execute not only passive gait cycle of two legs, but also active-assistive walking exercise of one leg and passive walking exercise of the other leg, and active-assistive exercise of two legs. Passive coordination exercise is repetitive training along the walking motion pattern. The BRMS's active-assistive exercise function helps patients who have insufficient muscle strength by restoring their capacity to move their legs independently. The patients can continue to move their legs smoothly along the pattern.

2.4 Feedback functions

Gait performance is evaluated in spastic patients with stroke, feedback assisting motion, and biofeedback. For example, the patient's panel or auditory biobeedback sound device presents his/her condition (joint angles, joint torques, floor reaction force, electromyogram etc.) or walking exercise's timing (swing phase etc.). And the patient recognizes his/her conditions or walking exercise's timing, and exercises. We think that the BRMS's walking exercise is more effective.

3.Preliminary Experimental Results on BRMS

We measured two hip, knee, and ankle angles in one normal subject, two hip and knee torques, floor reaction forces of two heels, outside of metatarsophalangeal joints, and toes, and surface integrated electromyogram of two quadriceps, hamstrings, tibial anterior, and gastrocnemius, with supine position. One gait cycle is 20[sec.]. We measured them five times a trial. One normal subject's motion was passive for a trial. But for stance phase, he moved actively from dorsiflexion to plantar flexion. BRMS's ankle joint was moved from 10[deg.] of dorsiflexion to 20[deg.] of plantar flexion. One gait cycle of left leg was taught by direct teaching. The first half of one gait cyclic data of left leg were turned into the latter half of one gait cyclic data of right leg, and the latter half of one gait cyclic data of left leg were turned into the first half of one gait cyclic data of right leg.

Figure 4 shows the history of one gait cycle in one normal subject. About two hip, knee, and ankle angles, their range of motion (ROM) of left leg were hip: -8 — 43[deg.], knee: 0 — 47[deg.], and ankle:-10 — 20[deg.]. And their ROM of right leg were hip:-13 — 48[deg.], knee:0 — 53[deg.], and ankle:-10 — 20[deg.]. One gait cycles of left leg and right leg were moved in the same pattern. The gait cycle of right leg was later for a half cycle than the gait cycle of left leg.

About two hip and knee torques, the maximum hip torque of left leg was nearly equal to 76[Nm], the maximum knee torque was nearly equal to 29[Nm]. And the maximum hip torque of right leg was nearly equal to 68[Nm], the maximum knee torque was nearly equal to 25[Nm]. These maximum torques approximated to gait analysis data with standing position in normal subject. They were generated from heel off to toe off.

About floor reaction forces of two heels, outside of metatarsophalangeal joints, and toes, they were generated in order of heel, outside of metatarsophalangeal joint, and toe, from heel contact to toe off.

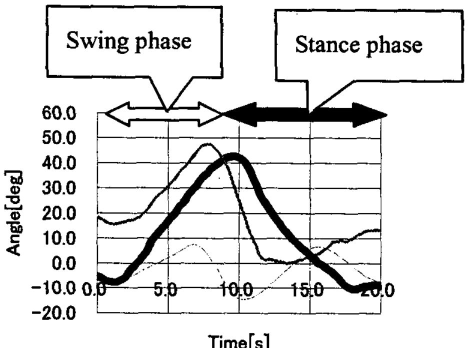
About surface integrated-electromyogram of two quadriceps, hamstrings, tibial anteriors, and gastrocnemius, quadriceps contracted from the latter half of swing phase to the first half of stance phase, hamstrings contracted for stance phase. Tibial anteriors contracted from the latter half of swing phase to the first half of stance phase, and from the latter half of stance phase to the first half of swing. And gastrocnemius contracted for the first half and the latter half of stance phase. Surface integrated electromyogram approximated to gait analysis data with standing position in normal subjects.

Therefore, BRMS's motion looks like the 'gait simulator'. Hereafter, we will measure and evaluate two hip, knee, and ankle angles in one normal subject, two hip and knee torques, floor reaction forces of two heels, outside of metatarsophalangeal joints, and toes, and surface integrated electromyogram of two quadriceps, hamstrings, tibial anteriors, and gastrocnemius, with standing position in normal subject. And gait performance will be evaluated in normal subjects and spastic patients with stroke, feedback BRMS's motion, and biofeedback.

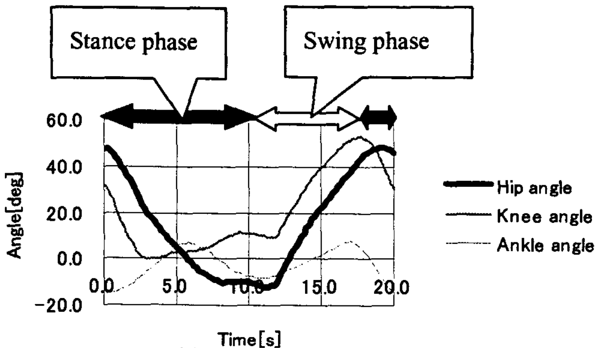
4. Conclusions and Future Topics

The new rehabilitation machine, BRMS for the therapeutic exercise of stroke patients was presented. As preliminary experimental results on BRMS, with supine position, range of motion of two hip, knee, and ankle angles in one normal subject, two hip and knee torques, floor reaction forces of two heels, outside of metatarsophalangeal joints, and toes, and surface integrated electromyogram of two quadriceps, hamstrings, tibial anteriors, and gastrocnemius, approximated to gait analysis data with standing position in normal subjects. Hereafter, we will measure stroke patient's conditions, and compare them with the gait pattern.

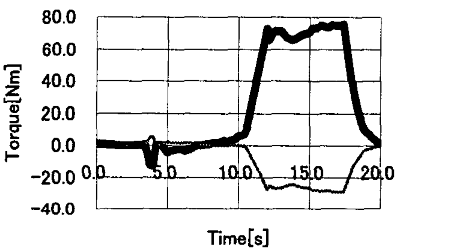
Also we have a plan to extend the measurement of stroke patient's conditions with standing position by the next machine of BRMS.



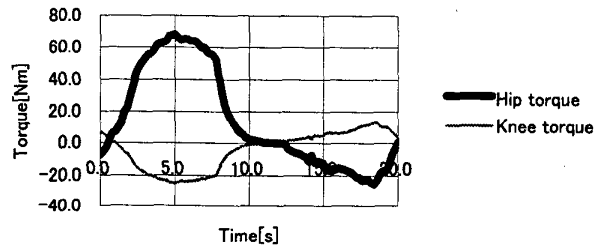
(a)Hip, knee, and ankle angle of left leg



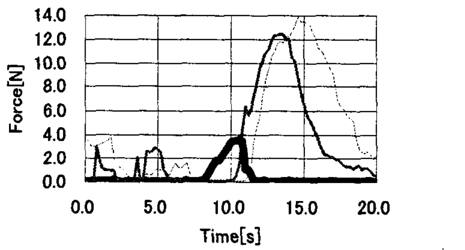
(e)Hip, knee, and ankle angle of right leg



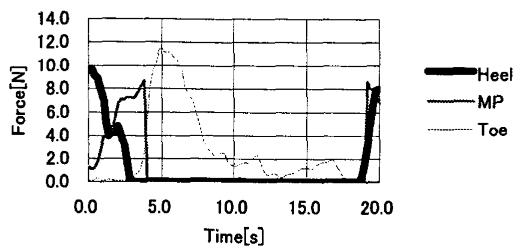
(b)Hip and knee torque of left leg



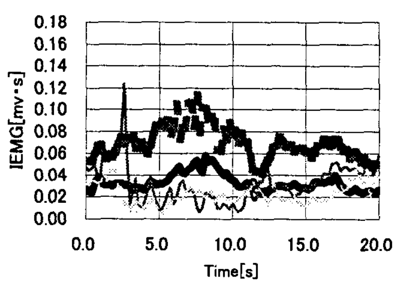
(f)Hip and knee torque of right leg



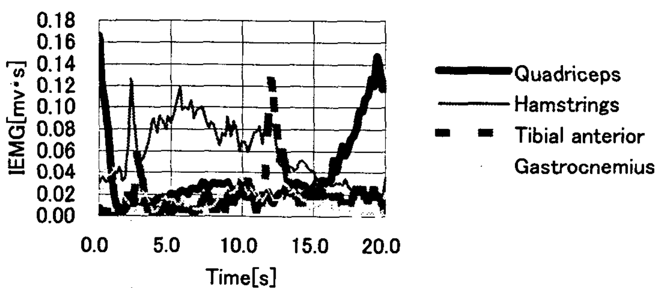
(c) Floor reaction forces of heel, MP, and toe of left leg



(g) Floor reaction forces of heel, MP, and toe of right leg



(d)Surface integrated electromyogram of quadricep, hamstrings, tibial anterior, gastrocnemius of left leg



(h)Surface integrated electromyogram of quadricep, hamstring, tibial anterior, and gastrocnemius of right leg

Fig.4: The history of one gait cycle in one normal subject

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