

ENERGY CONSUMPTION AND PHYSIOLOGICAL REACTIONS OF TREADMILL WALKING WITH FUNCTIONAL ELECTRICAL STIMULATION USING ORIGINAL PRIMEWALK AND MODIFIED PRIMEWALK IN PARAPLEGIA

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ABSTRACT

The Primewalk is a slide type of medial single hip joint originally designed by Saitoh, and later modified to add hip internal rotation devices. The purpose of this study is to evaluate the influence on the cardiopulmonary system of paraplegic walking by means of FES while using the original Primewalk and the modified Primewalk. The subject was a 22-year-old male with T12 complete paraplegia who walked on a treadmill using FES with both Primewalks. The walking speed was 1 km/h (equivalent to a comfortable walking speed) and the walking time was 4 minutes. During the walking trial, oxidative energy consumption, step cadence, physiological cost index and blood pressure were measured. There were no significant differences found between the original Primewalk and the modified Primewalk when comparing all parameters. The modified Primewalk was useful for restoring paraplegic walking without any serious cardiopulmonary.

INTRODUCTION

To restore walking performance in complete paraplegic patients, functional electrical stimulation (FES) combined with orthotic devices (hybrid FES) was used effectively. The Walkabout [1] is a medial single hip joint (MSH) that is attached to the knee ankle-foot orthosis (MSH-KAFO). Because the hip joint axis of the MSH is lower than that of a human physiological hip joint, Saitoh and colleagues developed the Primewalk (slide-MSH) to resolve the problem [2] (Fig. 1). Later, they modified the Primewalk with a new hip internal rotation device (modified slide-MSH) to rotate 5 degrees (Fig. 2), allowing paraplegic patients the possibility of more natural physiological walking than provided by any other orthotic device.

We have previously compared the Walkabout and Primewalk on individual gait movements and the energy consumptions for paraplegic walking using



Fig 1: Primewalk, a slide type of medial single hip joint.

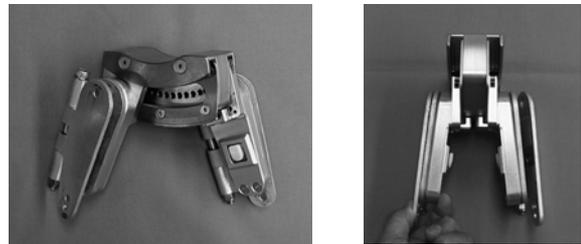


Fig 2: modified Primewalk, a slide type of medial single hip joint added to hip internal rotation devices.

the FES [3 - 7]. In this study, we compared oxidative energy consumption and physiological conditions during paraplegic walking using the original Primewalk and the modified Primewalk with FES.

SUBJECT and METHOD

The subject was a 22-year-old male with T12 complete paraplegia who was injured 3.5 years ago in a traffic accident. He was treated with FES using 10 percutaneous intramuscular electrodes (SES114, Nippon Seisen Co., Ltd., Japan), implanted in both femoral and sciatic nerves, for 3 years. Five months after the accident his walking was reconstructed with FES using an Akita Stimulator I (BIOTEC Ltd., Japan) and MSH-KAFO. He has used the Walkabout, for 2 years and the original Primewalk for over 1.5 years. His capability of walking reached the level of



Fig 3: The subject walked using FES with the original Primewalk and the modified Primewalk on a Treadmill.

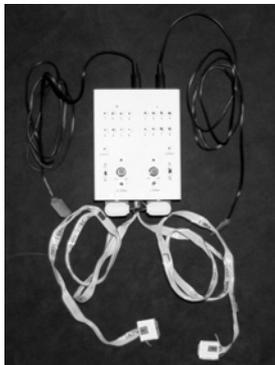


Fig 4: Akita stimulator I has 16 channels and two hand switches.

double crutch gait, but his gait velocity has not been constant during walking trial using MSH-KAFO with FES.

The subject was asked to reciprocally ambulate on a treadmill using FES with the original Primewalk and the modified Primewalk (Fig. 3). A motor-driven treadmill (MINATO, Japan) was utilized in order to maintain constant walking speed. The subject used the treadmill frame and supported his body with his bilateral upper extremities.

Akita Stimulator I has 16 channels and two hand switches (Fig. 4). Switches were attached bilaterally to his hands. When one side of the hand switch is on the peroneal nerve is stimulated, which causes the withdrawal reflex to swing the leg by a contraction of the iliopsoas muscle. The alternate operation of the switch allows reciprocal walking.

The walking speed was 1 km/h (his self-selected comfortable walking speed using an L-walker over flat surfaces). The walking time was 4 minutes so as to raise cardiopulmonary activity to a 'steady state'. Measurements were randomized and repeated twice a day. During the walking trial, oxidative energy consumption (EC; kcal/min/kg) and heart rate data

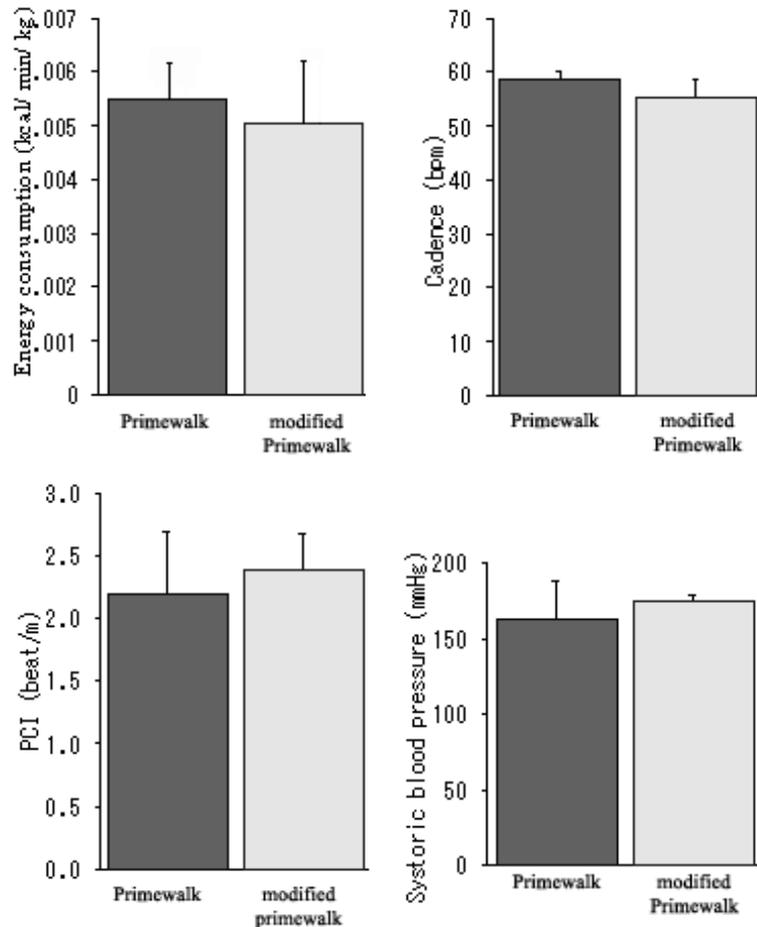


Fig 5: There were no significant differences found between the original Primewalk and the modified Primewalk when comparing energy consumption, step cadence, PCI and systolic blood pressure.

were collected using a portable telemetric system, the K4b2 (COSMED Ltd., Italy) via breath-by-breath methods. Physiological cost index (PCI; beat/m) was calculated as (HRW – HRR) divided by gait velocity, where HRW = heart rate at the end point of each walking trial; HRR = heart rate resting, both in beats per minute and velocity in m/min. We evaluated step cadence (SC; beat/min), PCI, blood pressure, and EC.

Students t-test was used to compare the two MSH devices. A 0.05 significant level of probability was required.

RESULTS

The subject experienced no failed trial of walking, but we observed that the step cadence gradually increased from the start to the end of walking at each trial. The rate of perceived exertion at the end of walking was 5 (heavy) on each trial.

In the original Primewalk, EC was 0.054 ± 0.007 kcal/min/kg, SC was 58.9 ± 1.5 beats/min, PCI was 2.2 ± 0.5 beats/m, and systolic blood pressure (SBP) was 163 ± 42 mmHg. In the modified Primewalk, EC was 0.051 ± 0.011 kcal/min/kg, SC was 55.5 ± 3.1 beats/min, PCI was 2.4 ± 0.3 beats/m, and SBP was

174 ± 4.0 mmHg (Fig. 5). There were no significant differences found between the original Primewalk and the modified Primewalk when comparing EC, SC, PCI, and SBP.

DISCUSSION

Although vertical ground reaction force, which measured on a treadmill or on an overground, are different during free-body walking [8], there is no significant difference in oxygen consumption in normal subjects [9]. Disabled subjects with moderate or severe gait impairments may have difficulty or be unable to adapt to treadmill walking or adjust to a speed other than their customary walking speed [10]. In paraplegic patients, treadmill walking required 30% less energy than open-field ambulation prior to training, but the treadmill training improved RGO/ARGO walking capability, and perhaps both the walking efficiency (short term adaptation) and physical fitness (long term adaptation) [11]. In this study, the subject did not experience treadmill training, and changes in walking efficiency are not clear.

To compensate high-energy consumption and instability on paraplegics walking, we have used several types of hybrid FES. If the modified Primewalk caused more instability in walking, patients need to increase upper extremity support to compensate for this lack of stability, increasing energy consumption. However, this study did not reveal significant differences in expenditure or other physical conditions between either Primewalk. Corresponding studies on gait motion performed by other members of our research team raised two interesting points: first, the modified Primewalk absorbs orthosis twist when internal rotation occurs in a single supported leg. This action assists the swing leg due to muscle strength caused by FES. Secondly, the modified Primewalk allows a reduced lateral displacement of the center of gravity to patient's body during walking. This phenomenon supplies a smooth weight shift, decreasing muscular effort in walking [10]. It is conceivable that these points may have affected energy consumption during walking. The modified Primewalk is able to closer resemble human physiological walking by means of a hip internal rotation device. In addition, the modified Primewalk had no serious recognizable problems in energy consumption.

CONCLUSION

This study shows that the modified Primewalk is useful for restoring paraplegic gait by means of FES, without unnecessary energy consumption or serious physical problems.

ACKNOWLEDGMENT

The authors thank Prof. E. Saitoh who inverted the modified Primewalk for providing it for us.

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