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Case Study

Application of a tri-axial accelerometry-based portable motion recorder for the quantitative assessment of hippotherapy in children and adolescents with cerebral palsy

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Abstract. [Purpose] This case series aims to evaluate the effects of hippotherapy on gait and balance ability of children and adolescents with cerebral palsy using quantitative parameters for physical activity. [Subjects and Methods] Three patients with gait disability as a sequela of cerebral palsy (one female and two males; age 5, 12, and 25 years old) were recruited. Participants received hippotherapy for 30 min once a week for 2 years. Gait parameters (step rate, step length, gait speed, mean acceleration, and horizontal/vertical displacement ratio) were measured using a portable motion recorder equipped with a tri-axial accelerometer attached to the waist before and after a 10-m walking test. [Results] There was a significant increase in step length between before and after a single hippotherapy session. Over the course of 2 year intervention, there was a significant increase in step rate, gait speed, step length, and mean acceleration and a significant improvement in horizontal/vertical displacement ratio. [Conclusion] The data suggest that quantitative parameters derived from a portable motion recorder can track both immediate and long-term changes in the walking ability of children and adolescents with cerebral palsy undergoing hippotherapy.

Key words: Cerebral palsy, Hippotherapy, Gait analysis

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INTRODUCTION

Cerebral palsy (CP) is a permanent motor disorder caused by a nonprogressive lesion that occurs in the immature brain[1)]. Various movement and postural impairments can occur and can limit physical activity and daily life of children and adolescents with CP[2)].

Hippotherapy is thought to be a useful method for improving trunk balance and gait ability in children with CP. It is believed that improvements in balance and sensory integration are mediated by improvements in muscle tone and control of movement patterns caused by sitting on a horse[3, 4)]. In recent years, the potential for hippotherapy to promote gross motor

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function in children with CP of various functional levels has been demonstrated in randomized controlled trials[5–8]. However, the scoring systems used in these trials can provide only a rough quantitative estimate of motor function[9, 10], and thus in-depth analysis regarding the nature of the improvements in movement is highly desired.

More recently, a novel portable motion recorder equipped with a tri-axial accelerometer has been developed and used for objective gait and balance analyses in patients with Parkinson's disease[11–13]. The device is capable of recording long-term changes in gait and balance parameters as well as immediate dynamic changes, and thus may allow quantification of gait patterns and reflect the motor skills of subjects undergoing hippotherapy. In this case series, we present our initial experience with using the portable motion recorder to evaluate the effects of hippotherapy on gait and balance ability of children and adolescents with CP using quantitative parameters for physical activity.

SUBJECTS AND METHODS

Potential participants were included if they had 1) the ability to walk independently for more than 10 m with a walking aid, 2) a diagnosis of bilateral spasticity, 3) a Gross Motor Function Classification System (GMFCS) level of I to IV, 4) no orthopedic problems that would obstruct the performance of a training program, and 5) the ability to train for more than 30 min. The exclusion criteria were as follows: 1) moderate-to-severe intellectual disability, 2) uncontrolled seizure, 3) poor visual or hearing acuity, and 4) previous participation in horseback riding therapy. A full explanation of the procedures was provided in accordance with the ethical standards of the Declaration of Helsinki, and informed consent was obtained from the participant's parents or caregivers.

Hippotherapy was performed at the Holistic Betterment and Wellness Through Riding PIROUETTE riding center located in Utsunomiya, Japan. The sessions were conducted by a therapeutic riding instructor accredited by the Riding for the Disabled Association Japan, and the horse was led by a trained assistant. Three staff members, including one who led the horse at a walk and two who walked at the horse's side, ensured that the protocol was followed and that it was safe, but they did not provide postural support to the participant at any time. The horse was led at a walk around an arena (27 m × 12 m) in clockwise and counterclockwise directions, including a winding ride and slalom. The participant was placed on a saddle wearing a helmet and was asked to actively adjust their posture. The total horse riding time was 30 min per session.

The gait and balance ability of each participant were evaluated during a 10-m walk test (average values of gait parameters from a 5-m one-way trip) using a portable motion recorder (MG-M1110-HW, LSI Medience, Tokyo, Japan; this product is discontinued but a similar replacement model [MVP-RF8-GC, MicroStone, Nagano, Japan] is available) that measures tri-axial (vertical, anteroposterior, and mediolateral) accelerations by detecting limb and trunk movements, and measures step-in and kick-off motion generated during gait, as reported previously[14, 15]. The device (75 mm × 50 mm × 20 mm, 120 g) was fixed to a belt at the level of the L3 spinous process, and it recorded the above motion signals at a sampling rate of 100 Hz. The data were stored on a Windows PC (MG-M1110-PC, LSI Medience, Tokyo, Japan) and used to quantify step rate, step length, gait speed, mean acceleration, and horizontal/vertical displacement ratio.

Statistical analyses were performed using IBM SPSS Statistics for Windows (IBM, Armonk, NY, USA). A p-value of less than 0.05 was considered statistically significant. A paired t-test was used to examine the change in each parameter between before and after a single hippotherapy session. For evaluating the long-term outcome, serial changes in the aforementioned gait parameters (values before each session) were employed. A one-way repeated-measures analysis of variance was used to evaluate the change in each parameter over the course of intervention.

RESULTS

Characteristics of the participants are described in Table 1. In all participants, there was an improvement in GMFCS level after the 2-year intervention. There was a significant increase in step length between before and after a single hippotherapy session (Table 2). An improvement in horizontal and vertical displacement was recognized qualitatively by the symmetric reproducibility of the acceleration curve, with an increase in the amplitude of displacement after a single hippotherapy session (Fig. 1).

Over the course of the 2-year intervention, there was a gradual but significant increase in step rate, gait speed, step length, and mean acceleration ($p<0.05$). Step rate significantly increased from baseline to the 18-month time point, and this may have been related to an increase in gait speed and/or mean acceleration (Table 3). The horizontal/vertical displacement ratio gradually improved to close to the normal level (approximately 1.5 during normal gait)[16, 17], with a significant decrease from the baseline value detected at 2 years.

DISCUSSION

Hippotherapy is a form of physical, occupational, and speech therapy in which a therapist uses the characteristic movements of a horse to provide passive motor and sensory input to the patient in order to obtain functional improvements. Studies have shown improvements in motor function and sensory processing following hippotherapy in patients with a variety of neuromuscular disabilities, developmental disorders, and skeletal impairments[18]. This is the first case series to describe the

Table 1. General characteristics of the subjects

	Age (years)	Gender	Diagnosis	GMFCS level		
				Before hip-potherapy	After 1 year of hip-potherapy	After 2 years of hip-potherapy
Participant 1	5	Male	Spastic CP	III	II	II
Participant 2	12	Female	Spastic CP	III	III	II
Participant 3	25	Male	Spastic CP with cognitive impairment	IV	III	II

CP: cerebral palsy; GMFCS: Gross Motor Function Classification System

Table 2. Comparison of gait and balance measurements before and after a hippotherapy session

	Before	After
Step rate (step/min)	117 ± 17	119 ± 19
Step length (cm)	39 ± 11	42 ± 10*
Gait speed (m/min)	45.9 ± 11.7	48.6 ± 12.2
Mean acceleration (G)	0.41 ± 0.08	0.44 ± 0.11
Horizontal/ vertical displacement ratio	2.6 ± 0.8	2.4 ± 0.8

Values are expressed as the mean ± SD and were measured at 6-month intervals until 24 months
*Significant difference from the value before hippotherapy ($p<0.05$).

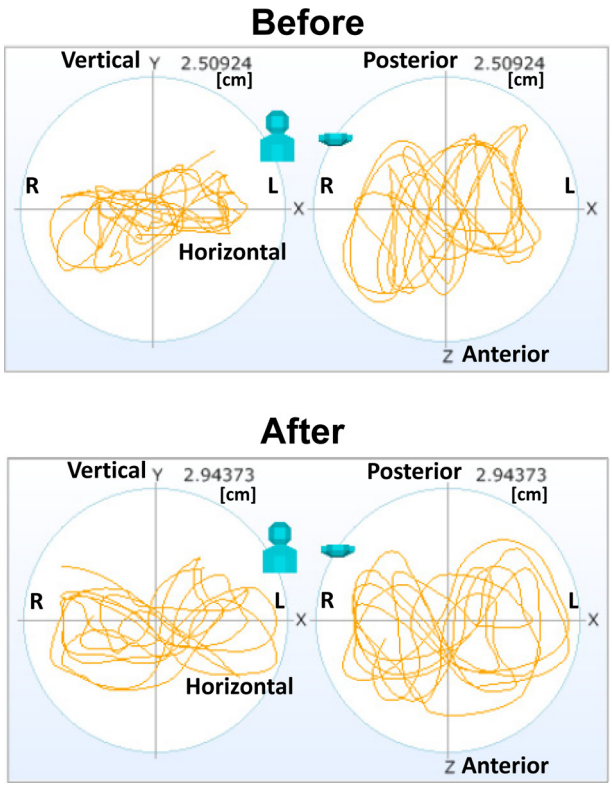

Fig. 1. Representative data showing improvements in horizontal and vertical displacement after a hippotherapy session
Data are from participant 2 and were obtained 18 months after the start of the hippotherapy intervention. The left and right panels indicate vertical (Y-axis, vertical plane; X-axis, horizontal plane) and horizontal (Z-axis, anterior-posterior direction; X-axis, mediolateral direction) trunk displacement, respectively. Note the irregular trunk movement before the hippotherapy session (upper panels), and the improvements in symmetry, with reproducible figures-of-eight visible in the traces, after the hippotherapy session (lower panels).

clinical importance of quantitative assessment of gait and balance ability in tracking immediate and long-term effects related to hippotherapy in patients with CP.

Patients with CP have poorer balance ability than healthy subjects and thus have a higher risk of falls. Mobility declines with increasing age[19]. A shorter step length and slower step rate in these patients can cause instability (e.g., reduced mean acceleration) and falls. By using the portable gait monitoring device, we have successfully recorded an increase in step length, indicating an improvement in balance control (Table 2 and Fig. 1). This means that, as the center of gravity moves during gait and causes instability, balance can be recovered from larger angles[20]. An increase in gait speed can be regarded

Table 3. Serial changes in motor function

	Baseline	6 months	12 months	18 months	24 months
Step rate (steps/min)	99 ± 23	117 ± 11	118 ± 17	121 ± 15*	123 ± 11*
Step length (cm)	35 ± 6	37 ± 9	36 ± 11	44 ± 14	45 ± 13
Gait speed (m/min)	34.7 ± 10.7	44.0 ± 5.3	41.3 ± 10.0	44.0 ± 11.8	53.0 ± 14.4*
Mean acceleration (G)	0.30 ± 0.07	0.39 ± 0.03	0.36 ± 0.04	0.41 ± 0.06	0.45 ± 0.03*
Horizontal/ vertical displacement ratio	3.5 ± 1.3	2.6 ± 1.3	2.4 ± 0.8	2.2 ± 0.6	1.9 ± 1.0*

Values are expressed as the mean ± SD and were measured at the start of a hippotherapy session.
*Significant difference from the baseline value ($p<0.05$)

as a response to control balance. Therefore, increases in step length and gait speed increase the ability to cope with the risk of falls when balance has been lost. We clearly demonstrated increased step length and balance control immediately after a single hippotherapy session, and a gradual improvement in all functional parameters over the course of the 2 years of hippotherapy. Beneficial effects of hippotherapy on gait parameters (except for balance indicators) have also been reported using a walkway-type gait analysis system (GAITRite, CIR Systems, Franklin, NJ, USA) in elderly patients with stroke[21]. However, no other data is available with respect to clinical application of accelerometry-based handy motion detectors for quantitative gait assessment following hippotherapy[22, 23].

In children with CP, the most rapid improvements in gross motor function occur during the first 4 years of life, with children reaching a plateau between 5 and 6 years, depending on the severity of their disability[24]. In the present study, we observed significant improvements in GMFCS level after 1–2 years of hippotherapy (30 min, once a week) in three participants with a wide age range (2 to 25 years), supporting the beneficial effects of hippotherapy on gross motor function. Our results are consistent with a recent systematic review, suggesting that hippotherapy sessions of 30-min duration, once or twice a week for 8–10 weeks were correlated with positive effects on gross motor function in patients with CP aged 4 to 10 years[6, 7, 9, 10, 25]. Although the device used to evaluate gait in the current study is simple to use and user-friendly, it cannot give in-depth quantitative details concerning how muscles activate[4] or how acceleration converts into weight loads[14, 26, 27], but it can provide sufficient data to compare functional outcomes across time.

A limitation of this study is the small number of participants, which means that the results cannot be extrapolated to all types and severity levels of CP. In addition, the length of time over which the improvements in balance and gait abilities can be maintained after 2 years of hippotherapy is uncertain. These issues need to be examined in future studies with a larger sample size.

In conclusion, the quantitative evaluation of gait and balance parameters using the portable motion recorder can detect both immediate and long-term changes in the walking ability of individuals undergoing hippotherapy, and the results of the present study support the therapeutic benefits of hippotherapy in children and adolescents with CP.

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