Rehabilitation Management of Friedreich Ataxia: Lower Extremity Force-Control Variability and Gait Performance

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We describe the rehabilitation management during a 12-month period of a 14-year-old female with Friedreich ataxia. Interventions included task-oriented bimanual reaching activities, functional strengthening, and gait training using a walker featuring tension-controlled wheels and a reverse-braking system. Her physical status was assessed with the Nine-Hole Peg Test, single limb stance time, manual muscle testing, self-reported falls, isometric force control testing, and 3-dimensional gait analysis in a motion-capture laboratory. Although measures of the patient's Nine-Hole Peg Test, single limb stance time, and manual muscle testing reflected minimal changes, her gait speed decreased by 69.4%. However, the force-control targeting of her dominant knee extensors showed a 43.7% increase in force variability that was concomitant with her decline in gait performance. The decrement of her initial gait speed was reduced to 42.9% on replacing the wheeled walker with the U-Step Walking Stabilizer at the end of the intervention period. Although the patient's gait remained significantly impaired, extended use of the U-Step Walking Stabilizer modestly improved her gait performance, and her rate of falls decreased from 10 to 3 per month. Our observations suggest that use of force-control testing as proxy measures of ataxia and tension-controlled gait aids show promise in the management of Friedreich ataxia and merit further investigation.

Key Words: *Friedreich ataxia—Force control—Rehabilitation.*

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Friedreich ataxia (FRDA), the most prevalent spinocerebellar ataxia, is an autosomal recessive disorder that results in significant morbidities secondary to movement dysfunction[1] The prevalence of FRDA is estimated to be 1:50,000 in Europe and the United States, with males and females affected equally.[2] The disease is caused by defects in the protein frataxin, which may be involved in mitochondrial iron homeostasis.[3] Symptoms usually begin to manifest in young children at a mean age of 6.1 years.[4]

Impairments secondary to FRDA may include scoliosis, pes cavus, and muscular atrophy.[2,5] Characteristic clinical manifestations include increased postural sway, dysdiadochokinesia, dysmetria, dysarthria, and sensory neuropathy. In addition, FRDA is often accompanied by progressive cardiomyopathy and diabetes mellitus.[2,6,7] The poor coordination and balance dysfunction associated with FRDA are significant causes of disability. The majority of people with FRDA have difficulty walking and progress to wheelchair use for mobility by their mid-20s. In addition, most people with FRDA require support of a caregiver to perform daily life activities.[8,9] Heart failure due to the cardiomyopathy is the most common cause of death. However, Klockgether and associates[10] reported a 75% survival rate for people with FRDA more than 34 years after disease onset.

There is no definitive treatment or cure for FRDA at this time. Current studies are investigating the effect of an analogue of coenzyme Q10 named idebenone.[11] Rehabilitation management is similar to other degenerative neurological conditions. The focus of treatment is compensation for loss of coordination, sensation, and aerobic endurance while minimizing secondary complications such as joint contractures and deconditioning. Adaptive equipment may be used to address balance impairments

and functional limitations caused by ataxic gait. Gait aids augment the available afferent sensory information via tactile input and enhance the base of support.[9,12] In addition, strategies such as decreasing the degrees of freedom and speed (through behavioral means or increasing limb inertia) during serial movements have been offered as accommodative strategies to help improve motor performance in people with FRDA.[13]

FRDA may be distinguished from other forms of cerebellar ataxia by its sensorimotor features. Individuals with FRDA may have involvement of the dorsal columns, spinocerebellar tracts, and peripheral nerves.[14] Damage to the cerebellum or its afferent/efferent connections may impair motor coordination by affecting predictive control and negative feedback control.[15,16] Individuals with cerebellar damage may not adequately compensate for intrinsic torque interactions during multijoint tasks,[13,17] thus limiting the ability to exhibit appropriate force control.[6] Clinical assessments of ataxia usually involve subjective nonequilibrium tests,[18] whereas quantitative measures of ataxia for research purposes often involve complex motion analysis examining trajectories of reaching or center of mass during mobility tasks.[19,20] In contrast, measurement of force control may offer an accessible, objective, proxy measure of ataxic movement. Previous studies involving force control have reported its association with dysmetria and tremor in people with cerebellar disease[21] and increased force variability in adults with cerebral palsy in comparison to control subjects.[22] Force-control activities, often involving visual targets or tracing localization tasks, require skilled motor performance that encompasses load anticipation and error correction, sufficient force generation to complete the task, and motor efficiency to avoid fatigue.[23]

This case report details the changes in lower extremity (LE) force-control variability and gait performance over a 12-month period in a child with FRDA. We also describe our rehabilitation management of this patient, which featured therapeutic exercise and use of a walker with a reverse-braking system and tension-controlled wheels.

CASE REPORT

Case Presentation

The patient is a 14-year-old female with genetically confirmed FRDA (diagnosed at 6 years of age) with GAA repeats of 1000 and 1400. She did not have diabetes, and no scoliosis was detected on physical examination. The patient's echocardiography and electrocardiogram were consistent with left ventricular hypertrophy. Her cranial nerve exam was notable for moderate dysarthria and mild delay in swallowing without pharyngeal-phase dysphagia. Upper extremity (UE) assessment revealed full joint range of motion, mildly decreased distal perception of vibration, intact pain and temperature sense, decreased coordination with nonequilibrium testing (finger-nose-finger maneuver with more tremor noted on the right side), and decreased reflexes bilaterally (biceps 0/4, triceps 1/4, and brachioradialis 2/4). The patient demonstrated the ability to sit independently and reach moderately beyond her base of support without experiencing a loss of balance. However, external support was required for standing. Lower extremity assessment was notable for contractures in the hamstring and Achilles tendons, mildly decreased distal perception of vibration, intact pain and temperature sense, decreased coordination with nonequilibrium testing (heel-knee-shin maneuver with more tremor on the left side), absent deep tendon reflexes (quadriceps, hamstrings, and gastrocnemius 0/4), and a positive response to the Babinski test. Moderate proximal weakness and mild distal weakness of the LEs were noted with manual muscle testing (MMT), but muscle weakness did not appear to be a limiting factor for her transfers or bed mobility. The patient is independent in all activities of daily living but requires the moderate assistance of 1 person to transfer into a car and negotiate stairs. She uses both a power wheelchair and a rolling walker for mobility.

The patient receives physical therapy (PT) once per month (60 min per visit) at school and visited our department on a quarterly basis for additional PT treatment (60 min per visit) secondary to her participation in a year-long clinical trial involving idebenone.[24] In addition, she receives intermittent assistance from an aide at school for daily adaptive physical education (variable visit frequency for 20 min to 30 min per visit) in accordance with her PT guidelines. Her primary complaint was difficulty with walking. The patient and her family identified other problems including mild weakness of various hip and trunk muscles, difficulty performing UE functional tasks, and a significant fall history. However, she expressed a strong desire to continue walking with the assistance of a gait aid despite her increased frequency of falls.

Table 1. Outcome Measures

Measure	Admission	Reassessment	Change		
MMT total score (maximum score = 140)	112	109	–2.7		
PROM (right/left values, °)[a]					
Hip flexion	30/20	30/20	0		
Ankle dorsiflexion	–10/–10	–5/–5	50.0		
Single limb stance time (s)[b]	2.7	2.9	7.4		
Nine-Hole Peg Test (s)[b]	60.0	56.6	–5.7		
Gradation of force[c]					
Variability	0.245	0.352	43.7		
Accuracy	0.850	0.874	2.8		
	Admission (using RWW)	Reassessment (using RWW)	Change	Reassessment (using USWS)	Change (RWW vs. USWS at reassessment)
Gait speed (m/s)	0.49	0.15	–69.4	0.28	86.7
Double-limb support time (as a % of gait cycle)	38	66	73.7	53	–19.7
Step-length asymmetry[d]	0.87	1.27	46.0	0.88	–30.7
Step-time asymmetry[d]	1.11	1.42	27.9	1.12	–21.1

Changes in measurement values are expressed as a percentage. Interpretation of gradation of force measures is as follows: Variability improves as the value approaches 0 and accuracy improves as the value approaches 1. MMT, manual muscle test (shoulder flexion, hip flexion, hip extension, hip abduction, knee extension, knee flexion, and ankle dorsiflexion; 10-point scale); PROM, passive range of motion; RWW, Rollator wheeled walker; USWS, U-Step Walking Stabilizer.
a. Indicates primary joint motion with terminal knee extension.
b. Indicates right side values only.
c. Denotes values for the right knee extensors.
d. Represents ratio composed of right and left values.

Assessment Methods

The 10-point MMT was administered as described by Kendall and colleagues,[25] and passive range of motion (PROM) was measured using universal goniometry.[26] UE dexterity was assessed using the Nine-Hole Peg Test (NHPT), as adapted from Mathiowetz and others,[27] using the patient's dominant hand. Previous studies[28,29] support the use of the NHPT as a clinical assessment tool to measure the effects of neurological impairments on dexterity in patients with cerebellar ataxia and multiple sclerosis. In addition, the NHPT has been validated for the assessment of UE dexterity in children and adolescents.[28] Balance was assessed via self-reported fall history and the single-limb stance time (SLST) of the dominant LE. This method of measuring balance impairment has test-retest reliability in children.[30,31] In addition, SLST has been used to assess balance in subjects with developmental coordination disorders and cerebral palsy.[31,32] The NHPT and SLST were performed twice in succession, and the best score was recorded.

Measures of force control were obtained using a dynamometer in the isometric testing mode (Biodex Medical Inc., Shirley, NY). Submaximal isometric force targeting with constant visual feedback was used as a proxy measure of ataxia (Figure 1). The force target was based on 50% of the maximum isometric voluntary contraction of the dominant knee extensors. Accuracy (i.e., ratio of mean force and target force) and variability (i.e., coefficient of variation) were assessed during the 30-s task. Gait assessment was performed in a motion-capture laboratory using a 6-camera Vicon 370 Motion System (Lake Forest, CA). Kinematic gait parameters obtained during the assessment visits included gait speed, double-limb support time, and ratios (right/left) of step-length asymmetry and step-time asymmetry. Step-length asymmetry and step-time asymmetry were used as indirect estimates of gait ataxia. The outcomes reported in this case report were recorded at the start of her intervention and approximately 12 months later (unless stated otherwise). The patient assessment findings are summarized in Table 1.

Intervention

Our treatment approach reflected the "enablement-disablement" process as we used accommodative and restorative strategies to minimize functional limitations.[33] There is a lack of peer-reviewed research demonstrating the efficacy of rehabilitation interventions for the ataxic move-

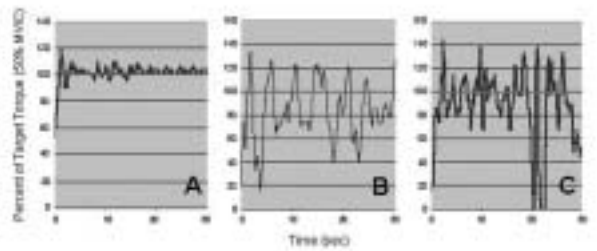

Figure 1. Gradation of force-control test of the dominant right knee extensors at 50% maximum voluntary isometric contraction. (A) Force-time curve of a subject without ataxia (coefficient of variation [CV] = 5.8%). (B) Force-time curve of our patient with Friedreich ataxia at admission (CV = 24.5%). (C) The patient's force-time curve during the reassessment at month 12 (CV = 35.2%).

ment associated with FRDA. Therefore, we addressed her ataxic UE movement with therapeutic exercise activities that were grounded in motor performance theory. Our UE activities included task-oriented reaching activities for bimanual training of the upper extremities. This form of intervention was selected since it is well established that bimanual, synchronous movements represent inherently stable, preferred patterns of coordination.[34,35] These activities featured rhythmic reaching for a ball (shoulder flexion from 80° to 170°) and object placement on a table (horizontal shoulder adduction 0° to 45° and abduction from 0° to 45° while at 80° of shoulder flexion) progressing from 2 sets for 8 repetitions to 4 sets for 12 repetitions.

LE stretching (2 to 3 sets for 60 s) of the hip extensor and ankle plantar flexor muscle groups was employed to maintain proper LE alignment during sitting in her wheelchair, improve her posture during long sitting, and augment her ankle dorsiflexion during the stance phase of gait. Functional strengthening was incorporated to address the mild weakness detected with the MMT and aid her upright mobility. Therapeutic exercise was performed for the hip (bridges while using a therapy ball for LE stabilization, wall squats while stabilizing a therapy ball against a wall, and single limb hip flexion while positioned in supine) and trunk muscle groups (seated hip flexion and extension with a neutral lumbar spine), progressing from 2 sets for 8 repetitions to 3 sets for 10 to 12 repetitions.

Gait training was performed with a Rollator wheeled walker (RWW; featuring a standard braking system; Sunrise Medical Inc., Longmont, CO) from month 1 to month 9. This intervention focused on proper weight shifting, uniform step length, maintaining the line of progression, increasing step length, control of gait speed, and proper trunk and pelvis alignment during gait (2 to 3 bouts of ambulation for 100 ft). Gait training was progressed with the U-Step Walking Stabilizer (USWS; a walker with a reverse-braking system and tension-controlled wheels; In-Step Mobility Products Corp., Skokie, IL). The USWS reverse-braking system allows the brakes to remain engaged until the user depresses the hand controls. In addition, the tension-controlled wheels provide the means to increase the resistance needed to roll the walker, thus facilitating consistent and controlled gait speed. We elected to replace her RWW and begin gait training with the USWS at month 9 of the intervention period (Figure 2). This decision was based on her continued high rate of falls (12 per month at admission and 10 per month at month 9) despite sustained behavioral modifications and therapeutic exercise and the availability of the USWS in our clinic. We determined that obtaining the proper gait aid could serve to prolong the patient's ability to ambulate, decrease her rate of falls, and minimize the secondary impairments that result from decreased standing and upright activities.

The school PT focused on LE stretching (hip extensor and ankle plantar flexor muscle groups), gait training (with walker or manual assistance), upright balance activities (weight shifting), and strengthening of the hip and trunk groups (isodynamic exercise using elastic bands and mat activities) as our plans of care were coordinated between months 3 and 12. The interventions were reviewed in our clinic and issued as a home exercise program (performed 5 times per week) in coordination with the primary school PT.

Patient Outcomes

The patient's right UE physical performance was reflected by her score of 60.0 s on the NHPT during the initial assessment and 56.6 s during her reassessment 12 months later. We observed a mild decrease in the patient's strength as her total MMT score declined from 112 to 109 (out of a maximum score of 140 for 7 bilateral muscle groups). Although PROM for hip flexion with terminal knee extension remained unchanged at 30° on the right and 20° on the left, her bilateral ankle dorsiflexion improved from –10° to –5°.

Her initial SLST was 2.7 s and increased to 2.9 s at the end of the 12-month period. She reported 12 falls per month at the time of her admission and 10 falls per month at month 9 of the intervention

Figure 2. Gait aids. (A) Use of the Rollator wheeled walker during gait analysis in the motion-capture laboratory. (B) U-Step Walking Stabilizer (i.e., a walker with tension-controlled wheels and a reverse-braking system).

period. Additionally, her fall rate declined to 3 falls per month following gait training with the USWS during months 9 through 12. Her gait speed decreased from 0.49 m/s to 0.15 m/s, and her double support time increased from 38% of the gait cycle to 66% while using the RWW. However, her gait speed and double support time improved to 0.28 m/s and 53%, respectively, during ambulation with the USWS at the end of the intervention period. Ratios of step-length asymmetry and step-time asymmetry rose from 0.87 and 1.11 to 1.27 and 1.42, respectively. These values nearly reverted to the initial assessment levels with use of the USWS as step-length asymmetry was 0.88 and step-time asymmetry was 1.12 during the gait aid comparison at the final assessment. Finally, the patient's force-control accuracy of her right knee extensors was 0.850 at the initial assessment and 0.874 following the intervention, whereas the variability of force increased from 0.245 to 0.352 during this period.

DISCUSSION

Our patient's UE motor performance was assessed with the NHPT, as it is a frequently used outcome measure for patients with neurological dysfunction. The patient's NHPT score improved by 3.4 s following the intervention period, but the standard error of measurement (a measure of response stability based on the estimated standard error in a group of repeated scores)[36] for NHPT performance by children with FRDA in our clinic is 9.0 s, indicating that there was no significant difference between the patient's 2 scores. However, stability in the NHPT times may not be a negative finding given the chronic, progressive nature of FRDA. The PT sessions at our clinic featured practice of synchronous, bimanual functional tasks (e.g., rhythmic reaching for a ball and object placement on a table) using guided movement with progressively less assistance. There is some evidence that repetitive

bilateral UE training may transfer to unilateral performance improvement in patients with chronic neurological dysfunction.[37] Although the patient was observed to have smoother trajectories of motion during the guided bilateral movement, little functional carryover was seen during independent bilateral or unilateral movement. This may be related to the limited sessions using this technique, thus restricting the amount of practice.[38] The recent work of Lang and Bastian[39] suggested that cerebellar dysfunction precludes the acquisition of movement automaticity and that diverted attention can adversely affect task performance despite formalized practice. Moreover, controversy exists regarding guided movement, as it may model movement patterns for task acquisition but also impede learning by interfering with error correction.[40] Given these factors, we are uncertain if her lack of UE dexterity and coordination improvement was affected by inadequate practice time or poor efficacy of the intervention.

The patient experienced a 2.7% decline in strength, a 5° increase in ankle dorsiflexion PROM, and no change of hip flexion PROM following the intervention period. Although she experienced a mild progression of muscle weakness over the course of the year, it is difficult to know if her exercise program limited the rate of her decline. The rehabilitation team was concerned that her hip extensor weakness (an MMT score of 7/10 bilaterally) was a significant factor in the patient's gait impairments. However, the gait analysis in the motion-capture laboratory revealed that her gait dysfunction was inconsistent with hip extensor weakness. She prolonged her knee extension throughout the stance phase of gait and anteriorly tilted her pelvis with her trunk flexed forward, resulting in an increased demand on the hip extensors. Therefore, her trunk orientation along with her prolonged knee extension likely serves as an accommodative strategy to limit the degrees of freedom, obtain greater stability, and minimize the complexity of a multijoint motor task. In contrast, the patient's poor SLST scores were consistent with her diminished walking performance. Balance deficits have been found to have a stronger relationship with cerebellar gait ataxia than leg placement deficits.[12] Nevertheless, the stability of the SLST over 12 months (from 2.7 s to 2.9 s) was not reflective of the significant decline in the patient's gait performance over the same period of time.

Although many of the patient's rehabilitation outcomes such as the NHPT, MMT, PROM, and SLST exhibited minimal or absent decline, force-control variability of the LE became considerably worse in concert with the diminished gait performance. The submaximal force control exhibited by her dominant knee extensors became more impaired as force variability increased 43.7% over the 12-month period. Interestingly, the force-accuracy values were relatively unchanged as this measure increased by 2.8% over the course of 12 months. However, it should be noted that the mean force attained during the force-targeting task is incorporated into the accuracy ratio, so it is possible for a patient to demonstrate increased variability without altering accuracy during continuous tasks.

The increase in LE force-control variability paralleled the patient's 69.4% decrease in gait speed and a 73.7% increase in double-limb support time while using the RWW. In addition, her step-length asymmetry and step-time asymmetry increased by 46.0% and 27.9%, respectively. Many of the aberrant features of the patient's gait such as prolonged stance or double-limb support times have been previously associated with cerebellar gait ataxia.[41]

Her final gait assessment in the motion-capture laboratory featured gait analysis trials with both the conventional RWW and the USWS. Gait speed increased by 86.7% (which equates to 42.9% of the initial value) and double-limb support time decreased by 19.7% on replacing the RWW with the USWS. Use of the USWS was also associated with a decrease of step-length asymmetry and step-time asymmetry of 30.7% and 21.1%, respectively. The patient's rate of falling declined from 10 falls per month to 3 falls per month with use of the USWS during the final 3 months of the intervention period. Nonetheless, it is important to note that her walking ability remained greatly impaired despite her improved gait characteristics.

The patient may have had more difficulty walking because of the progression of her disease. However, in comparison to the RWW, the USWS resulted in modest improvements in gait performance during the final assessment session. The USWS may have been central to her decrease in falls given the stability of her SLST scores and previous use of the RWW. Paradoxically, the patient nearly doubled her gait speed in comparison to the month 12 values using the RWW, despite the moderate tension settings of the walker wheels (high tension settings were not well tolerated by the patient). Her discontinuous gait pattern and increase in double-limb support time while using the RWW may have reflected her effort to maintain the line of progression while limiting potentially excessive gait speed. The benefits of USWS may have been derived from the modicum of control offered by the tension-controlled wheels and the margin of safety pro-

vided by the reverse-braking system. It has been noted that slower movements are associated with decreased ataxic symptoms during reaching tasks[13,42] and that weighted movements reduce gait instability in patients with ataxia.[43,44] This may occur because increased limb inertia via added weight promotes slower movements and enhances proprioceptive feedback. Despite these benefits to motor performance, increased inertia typically diminishes force control (e.g., absolute measures of force variability) and results in greater energy expenditure demands.[13,43,44] However, we have observed that behavioral strategies for decreased movement speed without mechanical constraints are often met with limited success in children with FRDA. Therefore, the facilitation of controlled movement provided by the tension-controlled wheels and reverse-braking system of the USWS may outweigh the negative consequences of increased inertia.

CONCLUSIONS

We observed the progressive decline of gait performance associated with FRDA. Although general inferences cannot be drawn from a case report, the USWS appeared to be useful in reducing the patient's frequency of falls. The tension-controlled wheels and reverse-braking system of the USWS may have facilitated the increased movement control that resulted in improved gait speed and step-length symmetry. Force-control testing was an objective proxy assessment of ataxia that was the only outcome measure that paralleled the decline in the patient's gait performance. The assessment of force-control variability was a valuable adjunct to our clinical management of a patient with FRDA. Additional study will be needed to understand how the characteristics of the force-time integral obtained during force-control tests may be used to aid the scientific investigation of FRDA and other movement disorders.[22]

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