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The Challenges of Implementing Functional Electrical Stimulation Cycling in a Patient with Hemiparesis following Stroke: A Case Report

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Abstract

Background: Strokes are the most common cause of severe disability in the United States. Functional electrical stimulation (FES) cycling may be used as an intervention to decrease disability post-stroke, though there is conflicting evidence among the existing studies exploring its use. The purpose of this case study is to describe the use of FES cycling in order to decrease residual disability post-stroke, as well as the challenges of implementing this intervention in the inpatient rehabilitation setting. **Case Description:** The patient was a 75 year-old female who presented to inpatient rehabilitation with a sub-acute ischemic right posterior cerebral artery stroke. The patient demonstrated severe left hemiparesis, left homonymous hemianopsia resulting in left neglect, as well as impairments in sensation, balance, and functional mobility. Interventions consisted of use of an FES bicycle at a low dosage, balance activities, left attention tasks, sensory reeducation, strengthening, and education. **Outcomes:** The patient's length of stay was 24 days. During this period, she demonstrated a 22-point increase in the Functional Independence Measure score from initial evaluation to discharge. The patient also demonstrated an increase in postural control as demonstrated by a five-point increase in her Postural Assessment Scale for Stroke score. **Discussion:** Though the patient made significant improvements in postural control and required much less assistance with mobility, she continued to demonstrate severe deficits at discharge that prevented her from returning home independently. Patient complexity, time constraints, scheduling difficulties, and reimbursement issues represented challenges of regular implementation of FES cycling, resulting in dosage at a level lower than is recommended. While current research is conflicting, FES cycling at an appropriate volume may be beneficial in reducing disability in sub-acute stroke survivors.

BACKGROUND

In the United States, around 795,000 people suffer a stroke each year. It remains the third leading cause of death at 140,000 deaths per year and often results in long-term disability and loss of independence in survivors.¹ According to the National Stroke Association, roughly 80% of stroke survivors experience hemiparesis post-stroke, which may severely impact quality of life.² Fortunately, rehabilitation offers stroke survivors with hemiparesis a chance to increase their functional mobility and quality of life following these life-altering events. There is a great deal of evidence that neuromuscular electrical stimulation (NMES) may be used as part of rehabilitation to promote motor relearning and recovery in these individuals.

One type of NMES, which may be used in stroke rehabilitation for those with hemiparesis, is functional electrical stimulation (FES) cycling. FES cycling incorporates synchronized electrical stimulation of multiple lower extremity muscles to allow a hemiparetic lower extremity to cycle an ergometer along with the intact lower extremity, so that both lower extremities are exerting work on the ergometer. While there are relatively few studies exploring the use of FES cycling, some research suggests it may lead to an increase in motor recovery, muscular force of hemiparetic limbs, and walking ability when compared to standard rehabilitation alone for subacute stroke.^{3,4} Another study came to similar conclusions, stating that FES cycling lead to improved walking ability, increased lower extremity strength, and improved postural control when compared to active cycling without FES.⁵ When compared to passive cycling without the FES component, yet another study showed significantly improved lower extremity function and accelerated recovery of overground ambulation.⁶ While there is some promising research on the application of FES cycling in people who have had strokes, another study found that FES cycling did not improve mobility nor lower extremity strength.⁷ Thus, current research is conflicting on whether or not FES cycling is beneficial.

Interestingly, to the author's knowledge, the current studies regarding the use of FES cycling programs in the subacute phase of stroke use this intervention 17-35 minutes per day, three to five times per week, for three to four weeks. This dosage is not always possible in the inpatient rehabilitation setting where a large percentage of sub-acute stroke survivors undergo rehabilitation. The objective of this case report is to outline the use of FES cycling at a low dosage and highlight the challenges of implementing FES cycling in the inpatient rehabilitation setting. FES cycling was used three times over the course of a 24-day stay along with conventional rehabilitation interventions in order to reduce residual disability in an individual with sub-acute stroke. In this case report, the standard rehabilitation will only be briefly outlined. An emphasis is placed on FES cycling as an intervention in order to provide the reader with information on how FES cycling was implemented in her care at a low dosage. The challenges of implementing this intervention will be examined at length in the discussion.

CASE DESCRIPTION

Patient History

A 75-year-old female presented to the emergency room with complaints of a posterior orbital headache and left-sided weakness. An MRI revealed that the patient had sustained an acute ischemic CVA involving the right occipital and temporal lobes, as well as small remote infarcts within the bilateral cerebellum. A head CT scan four days later confirmed involvement of the majority of the right occipital lobe, posteromedial right temporal lobe, and "likely" a percentage of the right thalamus. An optometry consult revealed left homonymous hemianopsia and gross left neglect with right gaze preference, however, the patient was able to attend to her left visual field with verbal cues or visual stimulation. The patient remained in acute care for one week after she initially presented in the ER. At this time, she was transferred to an inpatient rehabilitation facility.

Examination

The patient was alert and oriented at the time of physical therapy examination eight days after sustaining her stroke. It was noted that the patient preferred to maintain right cervical rotation at rest, which was considered a sign of left neglect. Formal assessment of upper extremity function was

deferred to occupational therapy due to time constraints, but it was noted that the patient demonstrated severe left upper extremity hemiparesis. Passive range of motion of bilateral lower extremities was within normal limits. Manual muscle testing of the patient's right lower extremity was within normal limits, and left lower extremity measurements are listed in Table 1.

Muscle tone was decreased overall in the patient's left upper and lower extremities, and coordination was unable to be tested due to lack of active range of motion. Light touch sensation was absent in the left upper and lower extremities upon evaluation. The patient required total assistance for all bed mobility and demonstrated a severe left lateral lean in standing with total assist to maintain upright posture. The patient was able to propel her wheelchair 20 feet using her right upper and lower extremities, but she demonstrated poor attention to the task and poor steering ability with frequent PT assist to maintain a straight path. It was noted that the patient displayed very poor static sitting balance.

Table 1. MMT grading of left lower extremity.

Manual Muscle Testing	
Hip flexion	1/5
Knee extension	2/5
Knee flexion	2/5
Ankle plantar flexion	0/5
Ankle dorsiflexion	0/5
Hip abduction	1/5
Hip adduction	1/5

Clinical Impression

The patient's stated goal for inpatient rehab was to return home at her prior level of function. Thus, she would need to regain the ability to ambulate independently. The author was optimistic the patient would ambulate independently or with an assistive device and return home after rehabilitation given activity in the proximal musculature of her hemiparetic lower extremity. Since this patient was initially unable to ambulate, however, it was decided that FES cycling would provide a safe and comfortable alternative to ambulation. While best practice guidelines in rehabilitation recommend the use of task-specific interventions⁸, cycling is similar to ambulation in that it requires cyclical, repetitive, alternating activation of agonists and antagonists. Thus, it is thought that a training program of FES cycling may lead to an improvement in ambulation.^{3,4,5,6}

This patient was chosen for this case study because of her severe left-sided hemiparesis that limited her functional mobility, making her an ideal candidate for an FES cycling program. Importantly, electrical stimulation was able to elicit palpable contractions of the target muscles for changes to occur, and she was screened for contraindications to NMES to ensure her safety.

Interventions

Physical therapy was performed in conjunction with occupational therapy and speech therapy for a total of three hours of combined therapies per day for five days per week. The patient received a minimum of one hour of physical therapy per day—which could be delivered in one-hour sessions or 30-minute sessions. The patient's total length of stay was 24 days, including weekends. The patient received a total of 21 physical therapy treatment sessions during this time period. The first day arriving to inpatient rehabilitation, initial evaluation, weekends, and the final day of inpatient rehabilitation are not included in the treatment session count as she did not receive actual treatment on these dates. Thus, of the 24 days, only 16 days included physical therapy treatment. Of the 21 physical therapy treatment sessions delivered over 16 days, 14 sessions were 60 minutes in length and seven sessions were 30 minutes in length. The patient received a grand total of 17.5 hours of physical therapy. The patient's episode of care will be organized by week following admission.

Week One

Physical therapy intervention during the first week focused on seated balance, postural strength, transfer training, and visual scanning activities for left-sided attention due to her severe functional

limitations. The patient was able to complete limited standing activities, as she was able to stand with maximal assist of one person for very short periods of time.

On treatment day five of the patient's first week of inpatient rehabilitation, lower extremity FES cycling using the RT300-SL FES bicycle was added to her treatment. The patient was positioned in her wheelchair in front of the ergometer, and her bilateral lower extremities were strapped into the ergometer to allow cycling. The wheelchair was fastened to the FES bicycle via u-hooks attached to dual straps with winching mechanisms in order to tension the straps to prevent tipping of the wheelchair. Two surface electrodes were applied over the muscle belly of the following muscles or muscle groups: quadriceps, hamstrings, tibialis anterior, and gastrocnemius, for a total of eight electrodes. The facility generally included the gluteus maximus in electrode application, but the final supply of electrodes was used for application to the previously mentioned sites. Therefore, gluteus maximus did not receive electrical stimulation on this date, but electrodes were applied to gluteus maximus on future dates after a new shipment was received. Gluteus maximus was chosen to be excluded over other muscles or muscle groups due to research generating successful effects without the stimulation of gluteus maximus.⁴ Proper electrode application and positioning in front of the ergometer took approximately 10 minutes per session.

Several parameters can be controlled when setting up FES cycling, including speed, resistance, frequency, pulse width, and intensity. A target speed of 35 rpm was selected which ensured the program would continue to run if the patient fatigued and was unable to exert the effort required to pedal at 35 rpm. In this event, continued cycling induced entirely by electrical stimulation would occur without volitional effort by the patient. A resistance of 0.5 Nm was selected based on patient preference for an intense but comfortable workload. A frequency of 40 Hz and a pulse width of 250 μ s were used based on established parameters for neuromuscular re-education using NMES in current literature. The intensity of electrical stimulation is displayed in Table 2 below, as is the intensity delivered during subsequent treatments for ease of comparison. These intensities were set to the maximum amount tolerated by the patient for a strong but comfortable muscle contraction. A one-minute warm up of FES cycling—consisting entirely of passive movement via electrical stimulation—was completed prior to instructions to pedal volitionally at a self-selected speed. With this first use of FES cycling, the patient fatigued after 17 minutes of cycling, but the electrical stimulation program continued to run for a total duration of 30 minutes.

Table 2. Intensity of electrical stimulation.

Intensity (mA)			
Location	Week 1	Week 2	Week 3
Quadriceps	60	64	55
Gastrocnemius	60	50	46
Hamstrings	60	61	55
Tibialis Anterior	40	50	56
Gluteus Maximus	N/A	25	21

Week Two

By week two, more challenging dynamic balance activities were incorporated into treatment, and a mechanical standing frame was integrated to increase standing tolerance and improve muscle activation in this position. Visual scanning tasks were continued as left-sided awareness continued to be a major deficit, and sensory and proprioceptive tasks were included in the patient's care. Supine strengthening exercises were included as the patient regained strength in her left lower extremity.

The patient participated in one session of FES cycling this week. The electrodes were applied to the same target muscles at approximately the same locations, and gluteus maximus was also targeted this session for a total of five muscle groups targeted with 10 electrodes. The target speed was again set for 35 rpm, the frequency of stimulation at 40 Hz, and the pulse width at 250 μ s for neuromuscular

re-education parameters. The resistance was initially set for 0.5 Nm and was adjusted mid-session to 0.64 Nm to increase workload as tolerated. The patient was able to actively participate in the treatment for 28 of the 30-minute cycling session, an increase of 11 minutes.

Week Three

Additional standing balance and tolerance training was performed this week. In addition to more functional standing strengthening, isolated strengthening activities were again performed this week. The patient was also able to attend a 30-minute stroke education class as part of her rehabilitation in order to decrease her risk of stroke in the future. For the first time since sustaining her stroke, the patient was able to ambulate with maximal assistance decreasing to moderate assistance for short bouts with a railing as an assistive device at her right upper extremity. In order to improve the patient's independence in her discharge environment, wheelchair mobility was also practiced to a greater extent this week.

The patient completed one additional bout of FES cycling this week. Electrodes were again applied to approximately the same locations of the muscles previously identified, including gluteus maximus. The target speed was again set for 35 rpm, the frequency at 40 Hz, and the pulse width to 250 μ s. The resistance was increased to 0.91 Nm for increased workload. The patient increased her total active ride time to 30 minutes total without fatiguing. After 24 days in inpatient rehabilitation, the patient was discharged to a skilled nursing facility for continued rehabilitation.

OUTCOMES

The patient spent 24 days at this inpatient rehabilitation facility. The Functional Independence Measure (FIM) score was obtained weekly at this facility by a variety of disciplines including nursing, physical therapy, occupational therapy, and speech therapy. The FIM is a widely used outcome measure in inpatient rehabilitation and was developed to assess level of disability in order to determine burden of care.⁹ More recently a large study was done which revealed the FIM at admission, along with age, are the strongest predictors of outcome at discharge.¹⁰ Due to the widespread use of the FIM, there has been a great deal of research done to determine its usefulness. It has been determined to be "the rehabilitation industry's most reliable, valid, and responsive functional assessment tool".^{9,11} The intraclass correlation coefficient (ICC) for total FIM score is 0.98 for elderly adults, and the minimal clinically important difference (MCID) is 22 points for total FIM score.¹²

The FIM is composed of 13 motor tasks and five cognitive tasks rated on a 7-point scale from a score of 1, which is total assistance, to 7, which is complete independence. A score of 0 may be given on admission only for certain tasks when they are not performed. The total score at discharge will range from 18 to 126. The physical therapist was responsible for collecting information pertaining to three of the thirteen motor tasks: bed to and from wheelchair transfers, walk/wheelchair mobility, and stairs. The patient scored a total of 35 points at admission, which improved to 53 points at discharge for a total change of 18 points. Thus, the patient did obtain a clinically important difference with her total FIM change of 18 points. For physical therapy tasks, the patient scored 2 points at admission and 9 points at discharge. Specific FIM scores related to physical therapy tasks may be viewed in Table 3. She received a score of 3 for bed to and from wheelchair transfers because she required moderate assistance with sliding board transfers. She required supervision only for wheelchair mobility, which corresponded with a score of 5. Lastly, she was unable to complete stairs at discharge due to safety concerns, so she received a score of 1, which corresponds to total assistance.

Table 3. FIM Scoring throughout rehabilitation stay.

FIM Scores				
	Admission	9 days post-admission	16 days post-admission	Discharge
Bed to/from chair transfers	1	2	2	3
Wheelchair mobility	1	2	2	5
Stairs	0	0	0	1

The patient also completed the Postural Assessment Scale for Stroke (PASS) at admission and again at discharge to assess improvements in postural control. The PASS has excellent reliability (ICC 0.84) and validity and is especially sensitive to change in the first three months following stroke, which is consistent with the described patient's presentation.¹³ The patient initially scored 15 points out of a possible total of 36 points, which improved to a score of 20 points at discharge for a change of five points, which exceeds the minimal detectable change of 2.22.¹³ The areas of improvement were sitting without support, standing with support, supine to sitting, sitting to supine, and sitting to standing, which each increased by 1 point (Table 4).

Table 4. PASS Scores from admission to discharge.

PASS Scores			
	Maintaining a posture	Changing posture	Total
Admission	4	11	15/36
Discharge	6	14	20/36

DISCUSSION

The patient improved a total of 22 points on the FIM and 5 points on the PASS outcome measures—which reflect significant improvement in level of assist and postural control. However, these scores are ultimately still low and do not reflect a capacity for safe, efficient, and independent mobility. At the end of her inpatient rehabilitation course of treatment, she continued to demonstrate significant balance impairments in standing and was unable to ambulate functionally and independently. Thus, she was unable to return home independently from a physical therapy perspective, which was her goal.

It is possible that the patient in this case study would have benefited from a greater volume of FES cycling, as she received a 30-minute session only once per week. The research supporting the use of FES cycling is done in much larger volume—17-35 minutes per day, three to five times per week, for three to four weeks^{3,4,5,6}—than was completed in this case report. The manufacturer of the RT300-SL FES cycle recommends a minimum of three hours of use weekly in order to make improvements in muscle mass.¹⁴ Unfortunately, it can be very challenging to incorporate the recommended amount of FES cycling in the inpatient rehabilitation setting.

Patient complexity is a factor in determining whether or not it is possible to perform FES cycling at the recommended dosage. This patient experienced many deficits post-stroke, which required intervention from physical, occupational, as well as speech therapies. This often limited the physical therapy this patient was able to receive to one hour per day, as she received three hours of these combined therapies daily. It may be easier to incorporate FES cycling as an intervention for a patient

who has sustained a stroke affecting purely motor abilities, as he or she may not require intervention by speech therapy, thus allotting a greater amount of the three hours of combined therapies to physical therapy tasks. Due to this patient's severe deficits, it was also necessary to implement a variety of supplementary interventions to address all impairments in a task-specific manner, such as balance and wheelchair mobility. While necessary, these supplementary interventions required a significant amount of scheduled physical therapy time.

Time constraints may also pose challenges to FES cycle use. For example, the time required to transport the patient to and from the rehabilitation gym was included in the total scheduled time for each physical therapy session. So, a one-hour session was not entirely useful therapy time in which specific interventions could be completed, especially if the patient required transferring out of bed at the beginning of a session or into bed at the end of a session. If the patient required toileting or administration of medications during a physical therapy session, this was also deducted from useful therapy time. This particular patient experienced frequent bouts of diarrhea and abdominal pain, which often required lengthy toileting time or resulted in patient refusal to participate in FES cycling. Every effort was made to incorporate useful tasks—like transferring or wheelchair mobility—into time spent toileting or transporting to or from the rehabilitation gym, however, it was impossible to incorporate certain tasks, such as FES cycling into this time. Additionally, despite education on the potential benefits of FES cycling, the patient described in this case study did not particularly enjoy use of the FES cycle. Specifically, she found it uninteresting and tedious. Therefore, it was challenging to encourage its regular use.

Further, scheduling difficulties such as 30-minute sessions and treatment received from multiple physical therapists made it difficult to perform FES cycling more frequently. Taking into consideration transportation time and time required to set up for an FES cycling session, 30-minute sessions simply did not afford enough time to perform this intervention for the recommended amount of time. Thirty-minute sessions comprised 3.5 hours of the total 17.5 hours the patient received physical therapy (20%) of this patient's total care, which represents a significant portion of time that could not be used to perform FES cycling. It may be more feasible to perform the recommended dosage of FES cycling in an inpatient rehabilitation facility that schedules treatment sessions at least one hour in length only, as this eliminates the possibility of shorter sessions that do not allow enough time for setup. Furthermore, while the author performed the majority of this patient's care, the patient did receive treatment by other physical therapists that were either not trained in the use of the FES bicycle or that prioritized other interventions over FES cycling, as well. While this is not faulty care by any means, it can introduce further difficulty in completing FES cycling a certain number of times per week.

Issues with reimbursement and insurance coverage may also impact the feasibility of performing FES cycling at the recommended dosage in the inpatient rehabilitation setting. The majority of current research utilized at least four weeks of FES cycling to achieve positive outcomes. This may not always be a possibility based on individual insurance coverage. Our patient received only 24 days in inpatient rehabilitation, which translated to 16 days of therapy. Thus, her length of stay did not reach the four-week mark that current research employs in FES cycling programs. Of importance, the manufacturer of the FES cycle used in this report does state that cycling may be continued in the home setting or in a community-based wellness program, where it is likely easier to perform a larger volume of FES cycling. However, it may be more difficult to acquire an FES cycle in these locations.

Clearly, there are many factors that influence the feasibility of FES cycling use in the inpatient rehabilitation setting. However, FES cycling is a relatively easy intervention that may be beneficial in promoting motor recovery, increasing ambulatory capabilities, and increasing lower extremity strength in those with hemiparesis. For this reason, the author chose to persist with weekly FES cycling treatments despite the challenges to implementation. The research discovered in the literature review was compelling enough to persevere in the effort to attain a therapeutic dosage. However, it is worth mentioning that participants of two research studies, which reported positive effects of FES cycling, were asked to cycle passively without contributing volitional effort.^{3,6} In regards to neuroplasticity, active and purposeful movement is more effective than passive movement in generating neural adaptations

leading to improved outcomes as pointed out by Bauer, et al.^{5,15,16} One might make the conclusion that encouraging study participants to contribute to as much of the cycling motion as possible would be more beneficial given current understanding of neuroplasticity. This serves as just one example of some of the disagreement in the current literature that future researchers in this area should be aware of.

The patient described in this case report demonstrated significant improvements in the FIM and the PASS outcome measures following use of FES cycling at a low dosage combined with standard rehabilitation. However, she continued to experience limitations in functional mobility that limited her ability to return home independently. While performed at a low dosage, FES cycling may have contributed to the improvements accomplished by this patient. Limitations of this case study include small sample size—a single case cannot test the effectiveness of a treatment. Though this case attempts to highlight the outcomes of FES cycling performed at a low dosage, the difficulties of performing FES cycling at the recommended dosages were also discussed at length. Patient complexity, time constraints, scheduling difficulties, and reimbursement issues represent challenges to regular implementation of FES cycling. There are likely many more barriers to performance not included in this discussion. The amount of present research is limited, findings are conflicting, and not all studies are of high quality. In order to determine if FES cycling treatment is worth the significant investment of time required for therapeutic dosage, future research of higher quality performed with larger sample sizes is needed for more conclusive information on its potential benefits.

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