A Case Study: Functional Electrical Stimulation (FES) for the effective management of foot drop in a paediatric post-stroke patient.

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ABSTRACT

Introduction: The paediatric evidence base for Functional Electrical Stimulation (FES) is limited; particularly considering FES as a treatment for foot drop in post-stroke children. This case study aims to show the instant benefits and long-term efficacy of FES for a paediatric patient with right-sided hemiplegia secondary to stroke.

Case Study: A 13-year-old girl with post-stroke right-sided hemiplegia was fitted with a FES Drop Foot Stimulator (DFS). Observational gait analysis showed instant improvements in dorsiflexion throughout swing-phase, allowing for full foot clearance and a reduction in hip circumduction and hitching. Dorsiflexion was maintained until initial contact allowing heel strike whereby a gradual reduction in FES stimulation allowed for increased ankle control and stability at loading response. Improvements in functional gait parameters included increased stride length and speed. At follow up, the patient reports an ability to walk without support for longer distances when FES is worn, a marked decrease in tripping and improvement in confidence. Positive patient and parental satisfaction has been reported throughout the pathway of care, with the patient expressing preference to FES over her previous orthotic.

Discussion: This case study found FES to be an effective treatment in managing drop foot when worn whilst ambulatory in a paediatric post-stroke patient.

The patient tolerated FES at therapeutic settings and adhered to a sustained treatment protocol for over 18 months; indicating the long-term feasibility of FES in a paediatric patient. It is the authors' opinion that all children who present with foot-drop secondary to stroke should be considered for suitability for FES including long term follow up with standardised outcome measures. This will allow for increased knowledge to be gained regarding the use of this adjunct in post-stroke paediatric recovery and to develop treatment protocols for this patient group.

Introduction

Use of Functional Electrical Stimulation (FES) is widely used in neurological rehabilitation with clinical benefits including the facilitation of movement, muscle strengthening and improved joint ranges. Literature in the adult stroke population has established the use of FES as an effective and feasible treatment to support mobility (Nascimento et al 2020).

The paediatric evidence base for FES is emerging although sparse (Garzon et al 2018) and predominantly considers cerebral palsy. A literature review identified two original research papers published thus far considering FES for treatment of foot drop in post-stroke children. Karunakaran et al (2019) investigated the use of FES in 7 children with foot drop secondary to either cerebral palsy (n=4) or post-stroke (n=3). They reported increased dorsiflexion during swing-phase in children with hemiplegia. Thibaut et al (2017) considered a case report on one chronic stroke adolescent patient who received implanted peroneal nerve electrical stimulation; following positive results with an external FES stimulator. Other papers considered FES in children following differing pathologies, or for upper limb stroke rehabilitation (Kapadia et al, 2014). The literature is limited regarding optimal timing for FES treatment post-stroke, with most evidence considering use in the chronic phase in adults (van Bloemendaal et al 2016). In practice, FES can start acutely provided the patient is medically stable with a stroke diagnosis.

The Royal College of Paediatrics and Child Health (RCPCH) have published clinical guidelines on management of stroke in childhood (2017). It details recommendations on accounting for all aspects of the International Classification of Functioning, Disability and Health (ICF) (WHO, 2001) including the family and child's priorities, preferences and goals when planning rehabilitation interventions. It is also recommended that motor interventions should be focused on functional goals and time since stroke should not be a barrier for the consideration of intensive training.

The NICE guidelines on FES for drop foot of central neurological origin (National Institute for Health and Care Excellence 2009) have stated a need for further publication considering the efficacy of FES specifically including patient reported outcomes (PROs). These guidelines specifically considered the adult population; further supporting the need to establish a paediatric evidence base.

This case study aims to share a successful example of a child with post-stroke hemiplegia who has demonstrated immediate improvement in walking and reduction in trips when set up with a FES device in walking mode. Additionally, this case study details PROs taken at 18 months which supports the long-term efficacy of FES management and considers the patient perspective.

Case Study

Patient history:
A 13-year-old girl was referred to the FES service with a right hemiplegia; secondary to a stroke occurring 2 years previously, caused by an arterio-venous malformation.

She had a past medical history consisting of sensorineural deafness and communicates with British Sign Language (BSL). On examination, she presented with a right foot drop and absent heel strike. She had no active dorsiflexion but was able to briefly extend her toes when seated. There was a mild reduction of sensation in her right lower limb following the stroke. The family reported the patient frequently tripped and fell, requiring supervision and intermittent hand-held support when walking. The patient used a drop foot splint at the point of referral. The patient fatigued due to muscle weakness in her hemiplegic side; stopping to rest in-between walking distances of up to 100m (whilst wearing her drop foot splint).

FES intervention:
The FES Service is based in The West Midlands Rehabilitation Centre (WMRC), a tertiary centre providing specialist outpatient rehabilitation. Established in 2002, The FES Service has continued to expand and first appointed a Specialist Paediatric Physiotherapist in 2015.

Following the patient's initial assessment at the FES clinic, she was fitted with a Microstim device (Odstock Medical Ltd) to be used in exercise mode (when seated) to stimulate right dorsiflexors. Electrodes were applied in standard positions with the active electrode over the common peroneal nerve, below the head of the fibula and the in-active electrode placed over the belly of tibialis anterior to the outside border of the tibia. Aims of treatment of fitting the Microstim device were to increase tolerance to the sensation of stimulation, to prevent deterioration of muscle physiology and facilitate neurological activity. Advice was given on parameters (Table 1). The frequency was set by the therapist and advice was given achieving a gradual progression of increased output towards a target window of stimulation that induces active dorsiflexion.

Table 1: Table showing FES Microstim machine parameters

Microstim Parameters	
Output level:	35 - 40mA
Frequency:	40Hz
Mode: 6	alternating stimulation (14 seconds on including ramps) with rest periods (14 seconds off) rather than continuous stimulation
Polarity:	Normal

The pathway of care at The FES service following initial assessment and fitting, is to review at 6 weeks, 3 months, 6 months and consequently yearly once the family and child are confident with the application of FES and have established optimal parameters and routine of use.

At the patient's 3 months review, the patient had established a routine whereby she used the Microstim device twice daily, for up to 30 minutes per session and tolerated the FES sensation at an output that induced an active movement into dorsiflexion with neutral foot alignment. The patient's own goals were based on increased independence in walking, when out with her family and also in school. At this review, she reported that she was due to be a bridesmaid next year and therefore had a goal of walking up the aisle independently with good balance.

The patient was consequently assessed for and fitted with a PACE V2 machine (Odstock Medical Ltd) Drop Foot Stimulator (DFS). The small digital device stimulates the dorsiflexors to help lift the foot whilst walking and is timed to synchronise with the gait cycle by a small footswitch placed in an insole in the shoe. The footswitch is activated when the foot is lifted from the ground and pressure is removed. Electrodes were fitted in standard positions for right dorsiflexors and the DFS was worn in a pouch at hip level.

Parameters were precisely adjusted for optimal stimulation and timing (Table 2). The rising ramp (the time taken for the pulse width to go from zero to set pulse width), extension (period of stimulation added after heel strike) and falling ramp (time taken for stimulation pulse width to fall to 0%) were adjusted to correspond with the patient's gait cycle. Patients can alter the pulse width and are supported by their therapist's guidance on how to achieve an optimal setting. The PACE machine is worn when ambulatory and can be paused by the patient when FES stimulation is not required.

Table 2: Table showing FES PACE machine parameters

PACE Parameters	
Pulse Width	40 - 50 %
Current	50mA
Frequency	40Hz
Rising Ramp	50ms
Extension	100ms
Falling Ramp	50ms
Timeout	2500ms
Switch activation	Heel rise
Polarity	Normal
Waveform	Asymmetrical

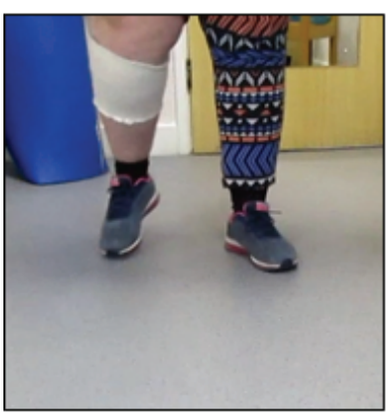
Visual Gait analysis pre-FES fitting:
The patient was observed walking bare foot. The patient had an inability to selectively control the ankle dorsiflexors of her hemiplegic side. She had flat foot strike and pronated right foot, with occasional episodes of initial contact at her toe. There was reduced foot clearance during swing phase. She compensated for this by circumduction and hitching her hip. There was poor hip control, with intermittent episodes of excessive abduction and adduction. The patient appeared hesitant; gait was slow and inefficient, with a short stride length. She walked with poor fluidity of movement. A lack of strength reduced the stability of her stance leg. She sought support from furniture or an adult to correct her balance. With shoes and her orthotic worn, the patient was steadier, but continued to lack active dorsiflexion and hip control. Foot strike remained flat, and the patient continued with circumduction of her hip.

Visual Gait analysis with FES:
An immediate effect was noted when the PACE stimulator was worn when walking. The FES stimulation of contraction in tibialis anterior following heel rise facilitated dorsiflexion (approx. 10^{o}) through swing-phase and allowed for heel strike (see Figure 1). There was no foot slap (due to adequate stimulation in extension and falling ramp). An improvement in speed and stride length was also observed. A reduction in compensatory gait mechanisms observed (hip circumduction and hitching) allowed for more efficient and less effortful gait. Gait was more symmetrical with increased stability in midstance on her hemiplegic right limb.

Figure1: Stills taken from video gait analysis, at heel strike

a.) 6 months post treatment: Without FES

b.) 6 months post treatment: With FES



c.) 18 months post treatment: Without FES

d.) 18 months post treatment: With FES

A Timed 10 Metre Walk Test was recorded at the point of the first PACE fitting. She was filmed walking ten metres with and without the PACE machine switched on. This was repeated 3 times allowing for averages to be calculated (Table 3). The time taken to complete the 10m walking test reduced notably by an average of 6 seconds, from 32s to 24s. Stride length increased as the average number of steps taken to clear the distance reduced by 3 steps (from 20 to 17) with FES.

Table3. Table showing Timed 10M Walk Test Findings

10 Metre Walk		**Time Taken (s)**	**No. of Steps**
(No FES)	1.)	35	22
	2.)	31	19
	3.)	29	18
	Mean	**32**	**20**
(With FES)	1.)	25	16
	2.)	26	19
	3.)	20	15
	Mean	**24**	**17**

Pathway of care:
The patient was reviewed at 3, 6, 12 and 18 months following the PACE (walking mode) fitting. Strong positive parental and patient satisfaction has been reported throughout this pathway, with a wish to continue with FES treatment reported at each review interval. Following fitting of the PACE machine, the patient no longer uses any form of orthotics or foot splint and expressed her preference for FES in management of her drop foot. 3 months post initial fitting, the family had demonstrated confidence and accuracy in replicating electrode positioning. The patient had gradually increased her tolerance to the sensation, increasing from a pulse width of 40% to 50%. The patient had established independence with operating the play/pause button when required throughout her day. She expressed a desire to be able to use FES at school. The family were consequently supported with advice and leaflets on how to start to introduce FES into her school day and this was successfully implemented.

Patient Reported Outcomes:
The FES department at the West Midlands Rehabilitation Centre has developed an assessment tool to collate Paediatric Patient Reported Outcomes using a VAS type scale (FES-COMB: Functional Electrical Stimulation – Children's Outcome Measure Birmingham). Point A of the FES-COMB considers self-reported tripping frequency (Figure 5). At the patient's 18 month review, she specified her usual walk is now of 5 minutes duration and reported that if she does not wear her FES she usually trips over (Score 4 on Point A of FES-COMB) and when she wears her FES she never trips over (Score 1 on Point A of FES-COMB).

Figure 5: Point A of FES-COMB scale of frequency of trips (See Appendix*)

During your usual walk, how often do you trip over?
1– Never trip over
2– Don't usually trip over
3– Sometimes trip over
4– Usually trip over
5– Always trip over

The patient was presented with a VAS scale of 1-10 to represent confidence in walking, with 10 representing maximum confidence and 0 representing no confidence. The patient scored her confidence at point 3 at baseline (prior to using FES) and at point 7, one year post commencing treatment (whilst wearing FES).

Parents have emphasised the positive impact of FES treatment in improving the patient's mobility, safety and independence as she no longer trips over her hemiplegic foot and is able to walk longer distances when FES is worn. The patient reports experiencing less fatigue when walking whilst wearing FES.

In this case study, there were no reports of adverse effects, skin reactions or irritation whilst using FES. Standard non-hypoallergenic electrodes were used. No equipment faults have occurred during this treatment journey, with consumables replaced regularly as per recommendations.

Discussion

This case study demonstrates FES is effective in the management of foot drop in a paediatric stroke patient with hemiplegia. This supports the findings of Karunakaran et al (2019) who described the orthotic effect of a DFS in children with hemiplegia. Immediate improvements in gait were observed with the patient able to achieve heel strike on her hemiplegic side when FES is worn. An instant improvement in active range of movement into dorsiflexion was seen with eliminated drag and full foot clearance through swing phase. Improvements in functional gait parameters include increase in speed and stride length. Benefits of increased stride length include dynamic hip flexor and gastrocsoleus stretch of the stance leg, supporting maintenance of muscle length. Although it is not necessarily the case that improvements in speed correspond with enhanced quality of movement, in our patient there was a parallel. Gait was observed to be more symmetrical and efficient, and the patient described feeling less tired when walking with FES. Reduction of inefficient gait preserves energy. Perhaps most significantly for our patient, with her DFS she is able to walk further independently without adult assistance or support. When she initially presented to the FES Service, she walked distances of up to 100m and now walks for 5 minutes with her DFS (across her external school environment). PROs included reduction in trips and improved confidence.

The patient tolerated FES at therapeutic settings and adhered to a sustained treatment protocol for over 18months, demonstrating the long-term feasibility of FES in a paediatric patient. She has had a successful treatment journey and continues to report the benefits of using FES and a wish to continue with FES treatment. When considering paediatric FES application, the child's ability to tolerate the sensation is key. A gradual, individualised approach is essential in preparation for a sustained positive relationship with FES. The slight reduction of sensation in our patient's hemiplegic limb may have supported her ability to tolerate and establish an optimal FES programme.

FES treatment requires commitment on the part of the family supporting the child. In addition to daily FES application, families must attend regular clinical reviews. The family in this case study have found it feasible to support setting up and removing FES equipment (electrodes and wires). Despite a potential barrier to communication (hearing impairment) our patient understands FES application supported by translation (BSL). This demonstrates a level of accessibility of FES; provided potential candidates have adequate cognition. The patient continues with her established routine of wearing her PACE machine daily and additional 2 x 30 minutes exercise FES sessions with her Microstim device.

Our patient no longer uses her drop foot splint as she prefers to use FES. The reduction in reliance on orthotics demonstrates an additional advantage of FES; although she still has access to her splint and the option to resume orthotic support should her needs or preferences change. As FES produces an active muscle contraction and therefore an increase in muscle strength and size with regular use, there are potential carry-over benefits to be seen in increase of active dorsiflexion and maintenance of flexibility of the opposing muscle group (calf complex). For suitable candidates, this therapeutic effect may have benefits over more passive splinting options for drop-foot, although this comparison requires further research (Prenton et al, 2016). An increase in independent active dorsiflexion has not yet been observed in this case study; however, there may have been a prevention of deterioration that is not possible to measure. Further research is required to determine if, in addition to an orthotic effect of FES (whilst worn), there is a therapeutic effect of increased active dorsiflexion. We will continue to record independent active dorsiflexion in our patient to determine any changes over a longer period, whilst she continues to access the FES Service.

In addition to the immediate effect of wearing FES in walking mode, this case study demonstrates continued satisfaction and concordance with FES treatment for the scope of over one year. Recognising the role for FES in paediatric populations is growing, particularly as a means of supporting ambulation in hemiplegic patients with drop foot. Clinical practice has shown that FES is effective in managing drop foot in suitable paediatric patients. It is the authors' opinion that all children who present with foot-drop secondary to stroke should be considered for suitability for FES. Increased accessibility will allow more children to benefit from a greater choice of treatment adjuncts for post-stroke footdrop and consequently more bespoke pathways of care. This supports recommendations to consider the ICF when managing paediatric post-stroke rehabilitation. With increased research and knowledge gained on FES outcomes, we will be able to develop and progress our treatment protocols for FES in this patient group.

Key Points

- FES in walking mode can be an effective aide to walking for the paediatric patient with drop foot secondary to stroke
- This case study has demonstrated the feasibility of FES as a long term treatment (over 18months duration) in a paediatric stroke patient
- Patient Reported Outcomes play a key role in evaluating therapeutic interventions

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Consent

Written parental consent was obtained for the publication of this case study.

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Appendix

The FES-COMB was developed by the main author with the support of the FES Clinicians at the WMRC. The purpose of developing this tool was to facilitate the process of collating Patient Reported Outcomes relating to FES, in a way that is accessible to families and patients. In addition to the score sheet (attached appendix) we have produced separate A4 reference sheets for each aspect of the outcome measure. These sheets provide an easy observational VAS type scale, with large font and colour gradient, for the child and/or family to select their answer. The FES-COMB has been through stages of internal validation and guidance has been produced on the delivery and recording of this outcome measure to facilitate standardisation. For more information or feedback, please contact the main author at neba.alhashim2@nhs.net