

# A PRELIMINARY STUDY OF FUNCTIONAL ELECTRICAL STIMULATION IN UPPER LIMB REHABILITATION AFTER STROKE: AN EVIDENCE-BASED REVIEW

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**Objective:** To review the effectiveness of functional electrical stimulation (FES) in the rehabilitation of hemiplegic upper limb after stroke.

**Methods:** A systematic review of studies published in the recent 5 years from 2003 to 2008, retrieved from MEDLINE and CINAHL, was performed.

**Results:** Outcome measures included the Jebsen-Taylor Hand Function Test and wrist range of motion. Results based on five clinical trials reviewed suggest that the use of FES together with functional practice aids the recovery of functional and motor performance in the hemiplegic upper limb.

**Conclusion:** FES may be effective as a home-based modality in the rehabilitation of the hemiplegic upper limb after stroke, and is recommended for individuals in the subacute and chronic stages, with residual voluntary wrist and finger movements.

**KEY WORDS:** Functional electrical stimulation • Functional rehabilitation • Hemiplegic upper limb • Stroke

## Introduction

Residual upper limb (UL) functional deficits are common after stroke, and are found in up to 80% of subacute and 56% of chronic stroke survivors (de Kroon, Ijzerman, Chae, Lankhorst, & Zilvold, 2005; Urton, Kohia, Davis, & Neill, 2007).

Functional electrical stimulation (FES) has been found to be useful in improving components of motor performance in the hemiplegic UL post-stroke, such as motor reaction time, isometric torque, and co-contraction of agonist and antagonist muscles (Pomeroy, King, Pollock, Baily-Hallam, & Langhorne, 2006). Recent findings suggest that FES can also be used as an adjunct to traditional neurological rehabilitation to improve UL and hand function (de Kroon, van der Lee, Ijzerman, & Lankhorst, 2002).

The concept behind FES is to provide functional restoration of the hemiplegic UL following stroke, through electrical

activation of intact lower motor neurons using electrodes on or near innervating nerve fibres (Peckham & Knutson, 2005).

There are three main types of FES. Neuromuscular electrical stimulation (NMES) produces passive repetitive muscle contraction, which the user can attempt to actively and concurrently participate in. Electromyographically-triggered electrical stimulation (EMG-stim) provides electrical stimulation that induces muscle contraction when volitionally generated EMG signals exceed a preset threshold. Positional feedback stimulation training (PFST) works in the same way as EMG-stim, using voluntary joint range of motion (ROM) as the trigger. Transcutaneous electrical nerve stimulation (TENS), commonly used for the treatment of pain, is not considered a type of FES as at low intensities, only sensory reaction is evoked without muscle contraction (de Kroon et al., 2002). FES may be delivered using surface, percutaneous or implanted systems (Peckham & Knutson, 2005). Only NMES,

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EMG-stim and surface systems are included and discussed in this review.

This review aims to determine the effectiveness of FES as a treatment modality in functional and motor rehabilitation of the hemiplegic UL after stroke.

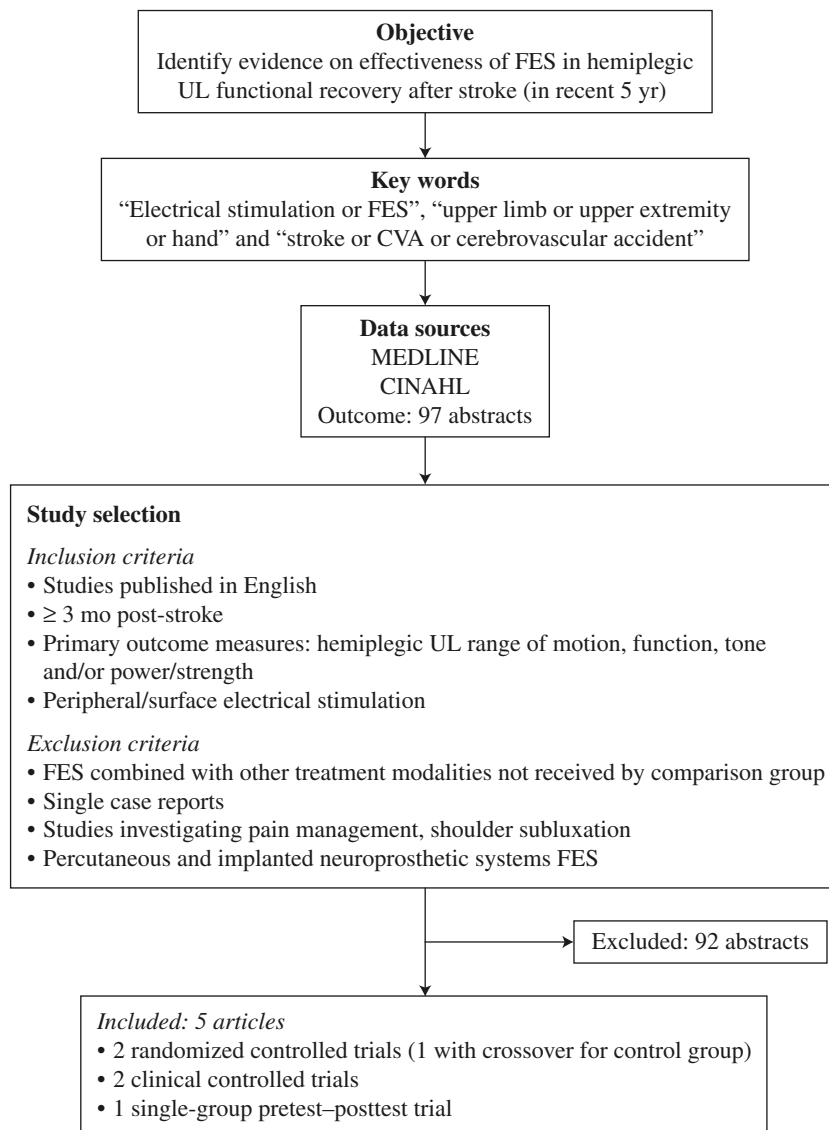
## Methods

The Figure summarizes the literature search and recruitment process. A systematic literature search for articles published in the recent 5 years, from January 2003 to February 2008, was performed in MEDLINE and the Cumulative Index to Nursing and Allied Health Literature (CINAHL), in order to identify studies in which electrical stimulation was applied with the

intention to improve post-stroke hemiplegic UL function and motor performance. MEDLINE and CINAHL were chosen as they are among the most authoritative and comprehensive databases indexing the professional literature of rehabilitation medicine, occupational therapy and physical therapy.

The following key words were used: “electrical stimulation or FES”, “upper limb or upper extremity or hand” and “stroke or CVA or cerebrovascular accident”.

Inclusion criteria were: studies published in English; studies involving participants who were at least 3 months post-stroke, to exclude the effects of spontaneous recovery in the acute post-stroke stage; hemiplegic UL function, ROM, tone and/or power/strength as primary outcome measures; and the use of peripheral/surface electrical stimulation.



**Figure.** Flowchart of literature search and recruitment process. FES=functional electrical stimulation; UL=upper limb.

Studies where the experimental group received electrical stimulation combined with other treatment modalities not received by the control group were excluded. Single case reports, studies investigating pain management, shoulder subluxation and the effects of percutaneous and implanted neuroprosthetic systems for the hemiplegic UL were also excluded.

The literature search of the two databases yielded 97 articles in total (MEDLINE—55; CINAHL—42); five publications fulfilled all selection criteria.

## Results

Details of the included studies are reported in the Table.

### *Characteristics of the Studies*

Among the five studies selected for this review, there was one single-group pretest–posttest study; two clinical controlled trials (CCTs); and two randomized controlled trials (RCTs), of which one investigated the effects of crossover to FES treatment for the control group after post-test. Four of the studies implemented FES in a home-based setting.

A total of 168 participants are included in the review. One study recruited participants in the subacute stage of stroke (3–6 months post-stroke), while four studies recruited those in the chronic stage (at least 6 months post-stroke). This was to exclude the effects of spontaneous recovery in the acute stroke stage. All studies recruited participants with some voluntary finger movement in the hemiplegic hand. One study (Ring & Rosenthal, 2005), in addition, included participants with no finger movements. Participants were mostly stroke survivors who had completed formal rehabilitation, and were recruited through rehabilitation centres, support groups and advertisements.

Treatment regimes lasted from 2 to 12 weeks, and the total duration of treatment ranged from 6 to 168 hours. Participants had at least two sessions per week, with three studies having daily sessions. The total duration of treatment received each day were all fairly long, lasting from 60 minutes to 6 hours.

Two studies employed the Automove stimulator (Danmeter A/S, Odense C, Denmark) (Cauraugh & Kim, 2003; Kimberly et al., 2004), which delivered EMG-stim. The other three studies used the commercially available NESS Handmaster™ (Neuromuscular Electrical Stimulation Systems Ltd. [now Bioness Neuromodulation Ltd.], Ra'anana Israel) (Alon & Ring, 2003; Alon, Sunnerhagen, Geurts, & Ohry, 2003; Ring & Rosenthal, 2005), which delivered NMES-type FES. In all three studies using the NESS Handmaster™, treatment was self-administered in the home. Studies using the same device employed similar stimulation parameters. However, between the two groups, stimulation parameters such as frequency (50 Hz vs. 36 Hz),

current type (direct vs. alternating) and rest intervals (25 s vs. 5 s) varied.

The two studies using the Automove stimulator stimulated the wrist and finger extensors, whereas the NESS Handmaster™ studies stimulated the wrist and finger flexors and extensors, as well as the thenar muscles.

The outcome measures for hand function were evaluated using the Box and Blocks (BB) Test, Jebsen-Taylor Hand Function (JT) Test, 9-Hole Peg Test and Motor Activity Log (MAL). Outcome measures for motor performance were: joint ROM; strength (isometric finger extension, sustained muscle contraction); motor reaction time; and tone.

### *Effect of FES on Hand Function*

All five studies reported a significant increase in the number of blocks moved in the BB Test. Apart from the Cauraugh & Kim (2003) study which did not use the JT Test, all the other four studies (Alon & Ring, 2003; Alon et al., 2003; Kimberly et al., 2004; Ring & Rosenthal, 2005) reported a significant reduction in the time required to complete the subcomponents of the JT Test, in comparison with the control groups. In particular, reduction in time required to move a large heavy object in the JT Test was recorded in all four studies.

The MAL measures participants' subjective view of change in amount of use (AOU) and quality of movement (QOM) of the paretic UL. Kimberly et al. (2004) reported an increase in MAL-AOU and MAL-QOM scores in the FES group, as well as in the control group *after* crossover. No significant differences in MAL-AOU and MAL-QOM scores were found in the control group prior to crossover.

### *Effect of FES on Motor Performance*

Only one study, conducted by Ring and Rosenthal (2005), investigated joint ROM as an outcome measure. The authors found that there was a significant increase in wrist and finger extension in the FES group with partial finger/wrist movement. The control groups and the other FES group which did not have residual voluntary finger/wrist movement in the hemiplegic UL did not show significant improvements in joint ROM.

Cauraugh and Kim (2003) reported improvement in motor reaction time, as well as improved sustained muscle contraction only in the FES groups.

One study (Kimberly et al., 2004) measured strength, using index finger isometric contraction. Significant improvement in strength was found in both the FES group and the control group. This was the only incidence within all the studies in which the control group had significant improvement in results comparable to the FES treatment groups.

**Table.** Summary of studies investigating use of functional electrical stimulation (FES) in hemiplegic upper limb (UL) rehabilitation after stroke

Reference	Study design (N)	Comparison gps	Time post-stroke (mean ± SD)	Treatment regime (wk × sessions/wk × duration/d)	Device applied; target muscles	Outcome measures	Results (only significant results reported)	Remarks
Cauraugh & Kim, 2003	RCT (N = 34)	1. EMG-triggered NMES (blocked practice) 2. EMG-triggered FES (random practice) 3. Control	> 1 yr (3.2 yr)	2 wk × 2 sessions/wk × 90 min NMES gp: movement + stimulation Control gp: passive range + voluntary movement	Treatment gp: Automove EMG facilitator stimulator Control gp: nil EDC, ECU, triceps brachii, anterior & middle deltoid	<i>Hand function</i> BB <i>Motor performance</i> Motor reaction time; sustained muscle contraction	Increased no. of blocks moved in BB; improvement in motor reaction time; reduced fluctuation in sustained muscle contraction for EMG-triggered blocked & random practice gps	No mention if treatment was clinic- or home-based
Kimberly et al., 2004	Double-blind RCT with crossover for control gp after posttest (N = 16)	1. EMG-triggered NMES 2. Control with sham stimulation	> 6 mo (3.0 ± 2.1 yr)	60 hr in 3 wk (3 wk × daily or alternate days × 3–6 hr) Both gps: 50% active effort to trigger response, 50% automatic stimulation	Treatment gp: Automove AM706 Stimulator Control gp: Automove 700S Wrist & finger extensors stimulated	<i>Hand function</i> BB; JT page-turning/small obj/stacking/feeding/light obj/heavy obj; MAL; finger movement tracking <i>Motor performance</i> Isometric index finger extension	<ul style="list-style-type: none"> <li>Improved isometric IF extension; BB; JT small obj/stacking/heavy obj; MAL for treatment gp posttest</li> <li>Improved isometric IF extension for sham gp posttest</li> <li>Improved isometric IF extension; BB; JT page-turning/feeding; MAL for sham gp post-crossover</li> </ul>	<ul style="list-style-type: none"> <li>No instructions were given to encourage increased hand use or to modify behaviour</li> <li>Both active (EMG-triggered) &amp; passive stimulation employed</li> <li>Intensive home-based FES</li> </ul>
Ring & Rosenthal, 2005	CCT (N = 22)	1. NESS + Rehab (☑ hand) 2. NESS + Rehab (☒ hand) 3. Rehab (☑ hand) 4. Rehab (☒ hand)	3–6 mo	NESS = 6 wk × 7 d × 3 sessions × 50 min Rehab = 6 wk × 3 d × 3 hr	NESS Handmaster ED, EPB, FDS, FPL, thenar muscles	<i>Hand function</i> BB; JT feeding/light obj/heavy obj <i>Motor performance</i> Shoulder flex/abd; elbow flex/ext; wrist flex/ext; finger flex/ext; tone (MAS)	<ul style="list-style-type: none"> <li>Improved hand function (BB &amp; JT light obj/heavy obj) &amp; wrist flex/ext in NESS gp with partial wrist/hand movement</li> <li>Reduced spasticity in both NESS gps</li> </ul>	<ul style="list-style-type: none"> <li>Both gps concurrently received functional ADL training &amp; NDT</li> <li>Home-based use of NESS</li> <li>Only study that recruited subjects with no visible wrist &amp; finger movements</li> </ul>

(Contd)

Table. (Continued)

Reference	Study design (N)	Comparison gps	Time post-stroke (mean ± SD)	Treatment regime (wk × sessions/wk × duration/d)	Device applied; target muscles	Outcome measures	Results (only significant results reported)	Remarks
Alon & Ring, 2003	CCT (N=19)	1. Stimulated gp 2. Control gp	> 6 mo (4.1 ± 2.9 yr)	12 wk × daily × 2 sessions × 60 min Stimulated gp: self-administered FES with functional tasks Control gp: functional training & self-exercise	NESS Handmaster & circumferential device with 4 electrodes (for arm) ED, EPB, FDS, FPL, thenar muscles, elbow flexors, triceps brachii	Hand function BB; JT feeding/light obj/heavy obj	Greater improvements in BB & JT feeding/light obj/heavy obj in stimulated gp	Home-based, self-administered
Alon, Sunnerhagen, Geurts, & Ohry, 2003	Single-group, pretest-posttest (N=77)	N/A	> 6 mo (3.3 ± 1.9 yr)	5 wk × 7 sessions/wk × 2-3 sessions/d × 10-55 min (daily duration increased gradually)	NESS Handmaster ED, EPB, FDS, FPL, thenar muscles	Hand function BB; JT feeding/light obj/heavy obj; 9-Hole Peg Test Motor performance Tone (Ashworth scale)	<ul style="list-style-type: none"> <li>Increased no. of blocks moved in BB (26.3%).</li> <li>Improvements in JT timing in feeding (34.8%); light obj (44.9%); heavy obj (40.9%)</li> <li>Improved 9-hole peg time (58.7%)</li> <li>Reduction in spasticity in elbow (-0.87 pts) &amp; wrist (-0.78 pts)</li> </ul>	Home-based

**Study design:** CCT = clinical controlled trial; RCT = randomized controlled trial; **Comparison gps:** ☑ hand = partial wrists/finger movement present; ☒ hand = no finger/wrist movement present; **Muscles stimulated:** ED = extensor digitorum; EPB = extensor pollicis brevis; FDS = flexor digitorum superficialis; FPL = flexor pollicis longus; **Outcome measures:** BB = Blocks and Box Test; JT = Jebsen-Taylor Hand Function Test; MAL (AS/HW) = Motor Activity Log (amount of use/how well); MAS = Modified Ashworth Scale.

Two studies (Alon et al., 2003; Ring & Rosenthal, 2005) investigated the effect of FES on muscle tone and found that spasticity was reduced in the groups who received FES.

None of the studies reported greater improvements in outcome measures in the control groups over the stimulation groups. Of greater note, however, was the finding of improvements in strength and hand function in the control group of the Kimberly et al. (2004) study *after* crossover to receive FES. This strengthens the unanimous results of all five studies, i.e. that the use of FES improves functional and motor outcomes of the hand.

## Discussion

### *Mechanism of Action*

Cauraugh and Kim (2003) proposed that FES decreased the processing time required for stimulus identification and response initiation. Muscular activation patterns improved as a result, leading to improved voluntary initiation of movements in the impaired limb.

FES may help to activate neurons that can orchestrate synergistic control of multiple muscular forces for functional hand movements (Alon & Ring, 2003; Alon et al., 2003; Kimberly et al., 2004; Ring & Rosenthal, 2005). Specifically, activation of both flexors and extensors of the wrist and fingers in a synchronized way resulted in the ability to open and close the hand.

### *Functional Training*

In the two RCTs and two CCTs, all the control groups received functional UL movement training. The treatment groups received similar functional training, in conjunction with FES.

Results of the studies suggest that active stimulation in conjunction with functional practice aids the recovery of function (Cauraugh & Kim, 2003). In one case, study participants using FES were even able to learn new functional tasks (Alon & Ring, 2003).

In contrast, individuals performing functional tasks alone, without FES or with sham stimulation, showed no significant improvement in all functional outcome measures. In the study by Kimberly et al. (2004), the control group which performed voluntary functional movement patterns without FES showed improvements in index finger isometric contraction, but did not improve in functional measures post-treatment. Improvement in strength was attributed to repeated extension of the finger. However, this same control group was found to have improvements in function *after* crossover to receive FES. This strengthens the conclusion that FES combined with functional training improves function.

Therapists should note that specificity of training (Alon & Ring, 2003) yields more effective and efficient outcomes than training provided in isolation and out of context of functional performance. Thus, FES training provided should be related to the functional task that is being retrained.

### *Type of Patients Suitable for FES*

From the five studies reviewed, FES is suitable for individuals in the subacute and chronic phases of stroke, with mild to moderate severity of hemiplegic UL dysfunction. Individuals should also have at least some visible residual voluntary wrist and finger movements (Alon et al., 2003; Ring & Rosenthal, 2005).

The use of FES is not recommended in subjects with pacemakers, uncontrolled seizure disorders, structural impairment in the hemiparetic UL, severe neglect, severe aphasia and skin problems (Ring & Rosenthal, 2005).

### *Effect of Treatment Regime Factors*

Based on the study by Cauraugh and Kim (2003), there appears to be no difference between blocked (same movement repetitively attempted in successive trials) and random (different movements attempted in successive trials) practice. Therefore, therapists need not be overly concerned with the practice schedule for UL movements.

In two of the studies (Alon & Ring, 2003; Cauraugh & Kim, 2003), FES combined with bilateral movements in the unimpaired limb resulted in additional functional motor recovery improvements. There appears to be an advantage in simultaneously initiating the same movement in both limbs.

A previous review by de Kroon et al. (2005) stated that triggered electrical stimulation may be more effective than non-triggered electrical stimulation in facilitating UL recovery. In this review, two studies employed the use of triggered EMG-stim (Cauraugh & Kim, 2003; Kimberly et al., 2004), whereas three studies used non-triggered NMES (Alon & Ring, 2003; Alon et al., 2003; Ring & Rosenthal, 2005). The unanimous outcomes of these five studies, however, suggest that non-triggered FES may be as effective as triggered FES, provided that non-triggered-FES users attempt to concurrently and actively follow through with the movement induced by the passive stimulation, as was done in the studies.

Though the stimulation parameters used in the studies were different, outcomes were all positive. This echoes the proposition by de Kroon et al. (2005) that stimulation parameters may not be crucial in determining motor outcomes.

### *Use of FES in the Home Setting*

The two devices employed in the studies, Automove EMG facilitator stimulator and NESS Handmaster™, were simple,



accurate and comfortable to use (Alon & Ring, 2003; Alon et al., 2003).

Despite the high intensity and long duration of use, high compliance with the FES equipment was recorded (Alon & Ring, 2003; Ring & Rosenthal, 2005).

These factors contributed to the success of self-administered home use, which has benefits over clinic-based treatment. Home-based use of FES allows for long duration (60 minutes to 6 hours) of daily use.

However, the high cost of the NESS Handmaster™ may pose a barrier to more widespread use of this treatment modality.

### Adverse Effects

Apart from minor, transient skin irritation mentioned in the study by Alon and Ring (2003), there were no reports of increased limb pain, spasticity or other adverse reactions from the use of FES (Alon & Ring; Ring & Rosenthal, 2005).

### Study Strengths and Limitations

The strengths of the five studies include good study design with clear study protocols. All five studies had at least 10 study participants, with one study having a sample size of 77. Even though three studies had fewer than 30 participants, the unanimous outcomes and low drop-out rates add strength to the conclusions drawn.

Two limitations were identified. The long-term sustainability of using FES in the treatment of hemiplegic UL dysfunction post-stroke was not studied. Secondly, there was insufficient evidence on the incorporation of bimanual tasks with FES training to make definite conclusions.

### Limitations of Review

The conclusions of this review can only be generalized to individuals in the subacute and chronic stages of stroke, as there were no articles relating to acute stroke included in this review. A more thorough literature search, using additional databases and hand-searching of articles will yield a greater number of studies with good study design, to add more strength to the discussion and conclusions made.

### Conclusion

FES is effective as a treatment modality in functional and motor rehabilitation of the hemiplegic UL following stroke,

and is recommended as a home-based treatment modality by occupational therapists for individuals in the subacute and chronic stages of stroke, with at least some visible residual voluntary wrist and finger movements.

Training in the use of FES as a treatment modality in undergraduate occupational therapy programmes is also recommended, to introduce to students an effective and innovative modality which has not been commonly used before, as studies have found that the choice of treatment selected by therapists appears to be determined by the treatment approach that is prevalent during training (Pomeroy et al., 2006).

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