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Efficacy of electrical stimulation to increase muscle strength in people with neurological conditions: a systematic review

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ABSTRACT **Background and Purpose.** *Weakness in partially paralysed muscles is a disabling impairment for people with neurological conditions. Strength training programmes are widely administered to address this impairment. There is a common belief that the effectiveness of strength training programmes can be enhanced by the addition of electrical stimulation. The purpose of this systematic review was to assess the efficacy of electrical stimulation for increasing voluntary strength in people with neurological conditions.* **Method.** *Eligible randomized trials of electrical stimulation were identified by searches of computerized databases. The search yielded 11 267 abstracts, of which 60 were retrieved. Two assessors independently reviewed full text versions of these articles.* **Results.** *Eighteen studies satisfied the inclusion criteria. These studies involved participants with spina bifida (*n *= 1), cerebral palsy (*n *= 1), peripheral nerve lesion (*n *= 1), multiple sclerosis (*n *= 1), spinal cord injury (*n *= 3) and stroke (*n *= 11). The mean (SD) PEDro score for trial quality was 4.9 (1.0) out of 10. Meta-analyses of studies involving similar patients were not done because of insufficient data or lack of homogeneity. The results of all studies were analysed individually.* **Conclusion.** *Several studies suggest a modest beneficial effect of electrical stimulation in patients with stroke. It is not clear whether patients with other types of neurological disabilities benefit from electrical stimulation in the same way. Copyright © 2007 John Wiley & Sons, Ltd.*

Key words: electrical stimulation, neurological, physiotherapy, strength

INTRODUCTION

Weakness is a common impairment and an important determinant of independence in people with neurological disabilities. Voluntary exercises utilizing the principles of progressive resistance training (ACSM, 2002) are commonly prescribed by physiotherapists to increase strength (Ada et al., 2006; Taylor et al., 2005). It is believed that the effectiveness of strengthening programmes may be further enhanced with the addition of electrical stimulation (Paillard et al., 2005). Electrical stimulation is common for the treatment of neurological weakness of all aetiologies, including cerebral palsy (Kerr et al., 2004), peripheral nerve injury (Ramos and Zell, 2000), spinal cord injury (Jacobs and Nash, 2001; Faghri and Trumbower, 2005) and stroke (Pomeroy et al., 2006).

Surface electrical stimulation is typically used in the clinical situation. It may or may not produce a muscle contraction depending on the intensity of the current. Electrical stimulation that elicits a muscle contraction can be applied to single or multiple muscle groups, during functional activities and in combination with voluntary effort. Electrical stimulation which does not elicit a muscle contraction uses low-intensity sensory stimulation, typically applied during sleep (Pape et al., 1990). Although some researchers believe that this latter form of electrical stimulation increases voluntary strength, most do not. For this reason, the present review is restricted to electrical stimulation that elicits a muscle contraction.

Three previous reviews have looked at the effect of electrical stimulation on voluntary strength. However, the three reviews were restricted to either people with stroke or children with cerebral palsy. In addition, one review was published 10 years ago (standardized mean treatment effect = 0.6; 95% confidence interval (95% CI) 0.29 to 0.98; Glanz et al., 1996) and another included non-randomized trials (Kerr et al., 2004). The most relevant of the three was a recent Cochrane systematic review. This review was primarily concerned with the use of electrical stimulation for motor re-training in people with stroke and identified only one study which had a statistically significant outcome for torque (standardized mean treatment effect for isometric torque = 1.02; 95% CI 0.46 to 1.59; Pomeroy *et al*., 2006). A number of narrative reviews, systematic reviews and meta-analyses have examined the efficacy of electrical stimulation for other purposes in people with neurological conditions. For instance, they have examined the efficacy of electrical stimulation for improving function, improving motor control, decreasing spasticity, preventing or reducing shoulder subluxation, preventing and treating shoulder pain, increasing range of motion, decreasing contractures, and assisting gait (Singer, 1987; Glanz, 1996; Price and Pandyan, 2001; Ada and Foongchomcheay, 2002; de Kroon et al., 2002; Quinn and Cramp, 2003; Bolton et al., 2004; Kottink et al., 2004; Kerr et al., 2004). However, none have clarified the effectiveness of electrical stimulation for improving strength. The purpose of this systematic review, therefore, was to examine the efficacy of surface electrical stimulation for increasing the voluntary strength of partially paralysed muscles in neurological populations.

METHOD

Search strategy

Computerized databases were searched from 1966 to March 2006 and included Medline (March 1966 to Week 4, 2006), Cinahl (1982 to March 2006) and Embase

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(1980 to Week 13, 2006). All databases were searched using the Cochrane Musculoskeletal Injuries Group optimal trial search strategy for identifying randomized controlled trials (Clarke and Oxman, 2001) combined with the MeSH terms, 'electric stimulation therapy', 'electric stimulation' and key words for electrical stimulation. The Physiotherapy Evidence-based Database (PEDro) was searched using 'neurology' in the 'Subdiscipline' field and 'clinical trial' in the 'Method' field. In addition, reference lists of the randomized controlled trials and relevant systematic reviews were hand searched.

Inclusion of studies

All randomized and quasi-randomized trials investigating surface electrical stimulation for the treatment of neurological weakness of all aetiologies were included. 'Neurological weakness' referred to weakness secondary to upper or lower motor neuron lesions. 'Surface electrical stimulation' referred to stimulation of sufficient frequency and intensity to result in a muscle contraction, and included electrical stimulation of single and multiple muscle groups, functional electrical stimulation, positional feedback stimulation treatment and electromyographic (EMG) triggered electrical stimulation. Only studies which directly measured voluntary strength were included (for example, any voluntary measure of active movement, force, torque, power, endurance, weight or functional strength). Studies which rated voluntary strength on ordinal scales, such as the manual muscle test, were also included.

Studies were included where electrical stimulation (with or without superimposed voluntary strength training) was compared with a control, conventional treatment, sham treatment or a voluntary strength training treatment. Studies were also included if the co-intervention was the same for both the treatment and control groups. Studies containing three or more treatment groups were included if they compared voluntary strength training with any of the above-mentioned interventions. If a crossover design was used, only the first arm of the study was considered.

Data collection and analysis

Two pairs of reviewers (JG and PV or JG and LH) used a predetermined inclusion criterion to independently screen titles and abstracts identified by the computerized searches. Full-length copies were obtained for studies which potentially met the inclusion criteria. All studies identified in this way were then independently reviewed by two physiotherapists experienced in the management of people with neurological conditions (JG and LH). A third person was used to resolve disagreements between reviewers.

Data were independently extracted from the included studies by both reviewers (JG and LH). The following details were extracted where possible: study design, participant characteristics, intervention details, number of participants and initial strength. Strength data were extracted in the form of both pre- and post-test means or between-group means with corresponding standard deviations (SDs) or 95% CIs (extracted from tables, raw data and graphs). If SDs were not available they were calculated from standard errors (SEs), 95% CIs, interquartile ranges and p values (Fleiss, 1993; Herbert, 2000). Studies of like subjects using similar outcome measures were considered for pooling. Cochrane Collaboration review software (RevMan 4.2) was used for analyses.

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Both reviewers (JG and LH) assessed methodological quality of the included studies using the 10-point PEDro scale (Moseley et al., 2002). The scale, based on the Delphi list developed by Verhagen et al. (1998), assesses specification of eligibility criteria, random allocation to groups, concealed allocation, groups similar at baseline, blinding of subjects, therapists and assessors, outcome measures obtained from >85% of subjects, between-group statistical comparisons, reporting of point measures and measures of variability. Authors were only contacted to clarify randomization but not to obtain missing data. Studies with low PEDro scores were included to better reflect the status of current research.

RESULTS

The search of computerized databases yielded 11 267 abstracts, of which 60 full-paper copies were retrieved. Eighteen of these studies met the inclusion criteria. Characteristics of the included studies are outlined in Table 1. Forty-two studies investigating the use of electrical stimulation in neurological populations were excluded. Reasons for exclusion are detailed in Table 2.

The 18 included studies had participants with spina bifida (n = 1), cerebral palsy (n = 1), peripheral nerve lesion (n = 1), multiple sclerosis (n = 1), spinal cord injury (n = 3) and stroke (n = 11). Sixteen of the studies had adult and two had paediatric participants. Studies in each population were analysed separately.

No study interpreted their results with respect to a clinically worthwhile treatment effect. It is acknowledged that it is difficult to nominate a clinically worthwhile increase in strength because this depends on many factors, including initial strength. However, results of strength studies cannot be readily interpreted without some indication of a clinically worthwhile treatment effect. We therefore nominated, post-hoc, a 20% increase from initial strength as worthwhile. This decision was based on consensus from the reviewers as well as the results of studies in people without neurological weakness.

Spina bifida

One study included children with spina bifida (Karmel-Ross et al., 1992). It was of moderate methodological quality (PEDro score 5/10) but had few participants (n = 5). A within-subjects design was used to compare functional electrical stimulation of the quadriceps muscles of one leg during standing or gait, with a control leg. The mean difference (95% CI) calculated from graphical representation of peak torque raw data was 4.2 Nm (95% CI 0.5 to 7.9; Figure 1 (a)). This reflected a 24% increase from initial strength, suggesting a worthwhile treatment effect. However, there is uncertainty around this estimate as reflected by the 95% CI. The result of this study should be interpreted with caution because of the trial's susceptibility to bias and low number of subjects.

Cerebral palsy

One study was retrieved in the cerebral palsy population (Van der Linden et al., 2003). The methodological quality of this study was moderate (PEDro score 6/10). A parallel-groups design compared the application of electrical stimulation to the gluteus maximus of one leg with a control leg. The mean difference (95% CI) in hip extension strength between groups was −0.5 N/kg (−3.0 to 2.0; Figure 1 (b)). The lower end of the 95% CI suggests no treatment effect while the upper end of the 95% CI suggests a convincing treatment effect (100% increase

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TABLE 1: Details of included studies

Study	Quality (PEDro score)	Study design	Pathology	n	Intervention dose			Electrical stimulation details			Outcome		Initial strength
					Min per treatment	No. per week	No. of weeks	Hz	Pulse width	Itensity (mA)	Muscle group	Measure	
Yan et al. (2005)	7/10	Parallel-group ES + CT vs sham + CT vs CT	Stroke	46	30	5	3	30	0.3 ms	20–30	Tibialis anterior, gastrocnemius, quadriceps and hamstrings stimultaneously	Isometric ankle dorsiflexion	2.2 Nm
Powell et al. (1999)	6/10	Parallel-group ES + CT vs CT	Stroke	60	30	21	8	20	300 (μs)	Full extension	Wrist and finger extensors	Isometric wrist extension	0.2 Nm
Kimberley et al. (2004)	6/10	Crossover ETES + ES vs sham (first arm only)	Stroke	16	180–360	3–4	3	50	200 (μs)	Finger movement	Finger extensor	Isometric finger extension	8.1 N
Peurala et al. (2005)	6/10	Parallel-group ES + GT vs GT vs CT (over ground walking)	Stroke	45	20	5	3	25	0.3 (ms)	40	Two weakest lower limb muscles	Manual muscle test (six-point scale)	n/a
Newsam and Baker (2004)	5/10	Parallel-group ES (during standing or gait) + CT vs CT	Stroke	20	n/a	5	3	35	220 (μs)	Comfort/ optimal contraction during stance	Quadriceps	Isometric knee extension	19.7 Nm converted from ft/lb

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TABLE 1: *continued*

Study	*Quality (PEDro score)*	*Study design*	*Pathology*	*n*	*Intervention dose*			*Electrical stimulation details*			*Outcome*		*Initial strength*
					Min per treatment	*No. per week*	*No. of weeks*	*Hz*	*Pulse width*	*Itensity (mA)*	*Muscle group*	*Measure*	
Winchester et al. (1983)	5/10	Parallel-group ES + PFST + CT vs CT	Stroke	40	ES, 120; PFST, 30	7	5	30	220 (µs)	Maximal comfortable contraction	Quadriceps	Isometric knee extension	9.6 Nm
Heckmann et al. (1997)	5/10	Parallel-group ETES + CT vs CT	Stroke	28	45	5	4	80	0.3 (ms)	20–60	Forearm hand extensors, knee flexors, ankle extensors	Manual muscle test (six-point scale)	hand ext = 1.2 pts, ankle ext = 1.7 pts
Popovic et al. (2004)	5/10	Crossover ES + FT + CT vs FT + CT (first arm only)	Stroke	41	30	7	3	50	200 (µs)	10–45	Finger, thumb, thenar	Active ROM of thumb, finger and wrist	n/a
Merletti et al. (1978)	4/10	Parallel-group ES (seated or during gait) + CT vs CT	Stroke	49	20	6	4	30	0.3 (ms)	Optimal contraction	Tibialis anterior and peroneals	Isometric dorsiflexion	6.6 Nm
Gabr et al. (2005)	4/10	Crossover ETES vs home-based exercise (first arm only)	Stroke	12	35	14	8	n/a	100–400 (µs)	n/a	Wrist extensors	Active ROM of wrist	13.9°

TABLE 1: *continued*

Study	*Quality (PEDro score)*	*Study design*	*Pathology*	*n*	*Intervention dose*			*Electrical stimulation details*			*Outcome*		*Initial strength*
					Min per treatment	*No. per week*	*No. of weeks*	*Hz*	*Pulse width*	*Itensity (mA)*	*Muscle group*	*Measure*	
Bowman et al. (1979)	3/10	Parallel-group PFST + CT vs CT	Stroke	30	30	10	4	35	200 (µs)	30–45	Wrist extensors	Isometric wrist extensors	1.5 Nm
Karmel-Ross et al. (1992)	5/10	Parallel-group ES vs control	Spina bifida	5	30	6	8	35	347 (µs)	50	Quadriceps	Isometric knee extension	17.7 Nm
Van der Linden et al. (2003)	6/10	Parallel-group ES vs control	Cerebral palsy	22	60	6	8	10–30	75–100 (µs)	Comfort	Gluteus maximus	Isometric hip extension	2 N/kg
Livesley (1992)	5/10	Parallel-group ES vs sham	Multiple sclerosis	40	12	5	6	3, 10, 35	200 (ms)	n/a	Quadriceps, hamstring	Isometric knee flexion and extension	Knee flex = 3.8; knee ext = 4.3
Boonstra et al. (1987)	4/10	Parallel-group ES (four groups) vs control	Peripheral nerve lesions	73	30, 60	5,7	35	n/a	70–200 (ms)	n/a	Abductor digit, abductor pollicis brevis, tibialis anterior	Manual muscle test (six-point scale)	n/a

TABLE 1: *continued*

Study	*Quality (PEDro score)*	*Study design*	*Pathology*	*n*	*Intervention dose*			*Electrical stimulation details*			*Outcome*		*Initial strength*
					Min per treatment	*No. per week*	*No. of weeks*	*Hz*	*Pulse width*	*Itensity (mA)*	*Muscle group*	*Measure*	
Klose et al. (1990)	4/10	Crossover ES vs BF vs CT (first arm only)	Spinal cord injury	43	n/a	3	8	50	300 (µs)	0–150	Biceps, triceps, wrist extensors, wrist flexors (simultaneously)	Manual muscle test (11-point scale)	n/a
Needam-Shropshire et al. (1996)	4/10	Parallel-group ES + AE vs AE + ES then AE	Spinal cord injury	43	10	3	8	50	250 (mµ)	Optimal contraction	Triceps	Manual muscle test	n/a
Kohlmeyer et al. (1996)	4/10	Parallel-group ES vs CT vs BF vs ES + BF	Spinal cord injury	60	20	5	5–6	20	0.3 (ms)	Therapist decision/ comfort	Wrist extensors	Manual muscle test (nine-point scale)	n/a

AE = arm ergometry; BF = biofeedback; CT = conventional therapy; ES = electrical stimulation; ETES = electromographicy (EMG)-triggered electrical stimulation; FT = functional training; GT = gait training; n/a = not available; Nm = Newton meters; PFST = positional feedback stimulation treatment; ROM = range of motion.

TABLE 2: Excluded studies, listed by primary reason for exclusion

Study population	*Non-randomized*	*Not motor electrical stimulation*	*No outcome measure of voluntary strength*	*Not comparison of interest*
Neuromuscular disease	Milner-Brown and Miller (1988)			
Cerebral palsy		Steinbok et al. (1997) Sommerfelt et al. (2001) Dali et al. (2002)	Chan et al. (2004)	
Peripheral nerve lesion	Targen et al. (2000)			
Spinal muscular atrophy		Fehlings et al. (2002)		
Traumatic brain injury			Peri et al. (2001)	
Spinal cord injury	Seeger et al. (1989) Belanger et al. (2000) Hartkopp et al. (2003) Skol et al. (2002)	Beekhuizen and Field-Fote (2005)	Baldi et al. (1998)	Postans et al. (2004)
Stroke	Kraft et al. (1992) Kobayashi et al. (1999) Peurala et al. (2002) Ring and Rosenthal (2005)		Faghri et al. (1994) Macdonell et al. (1994) Bogataj et al. (1995) Hesse et al. (1995) Burridge et al. (1997) Faghri and Rodgers (1997) Chae et al. (1998) Francisco et al. (1998) Hesse et al. (1998) Chantraine et al. (1999) Linn et al. (1999) Cauraugh et al. (2000) Wang et al. (2000) Cauraugh and Kim (2003a) Cauraugh and Kim (2003b) Popvic et al. (2003) Cauraugh et al. (2005) Mann et al. (2005) Cozean et al. (1988)	Johnson et al. (2002) Cauraugh and Kim (2002) de Kroon et al. (2004) Hesse et al. (2005) Popovic et al. (2005)

from initial strength). This study does not provide good evidence about the effectiveness of electrical stimulation in people with cerebral palsy.

Peripheral nerve lesion

One study was retrieved with participants who had sustained a peripheral nerve lesion (Boonstra et al., 1987). The methodological quality of this study was low (PEDro score 4/10). The comparison of interest in this study was electrical stimulation compared to control in lesions of the brachial plexus, median, ulnar or peroneal nerves. The outcome measures were hand grip dynamometry and the Medical Research Council (MRC) six-point scale. Insufficient data

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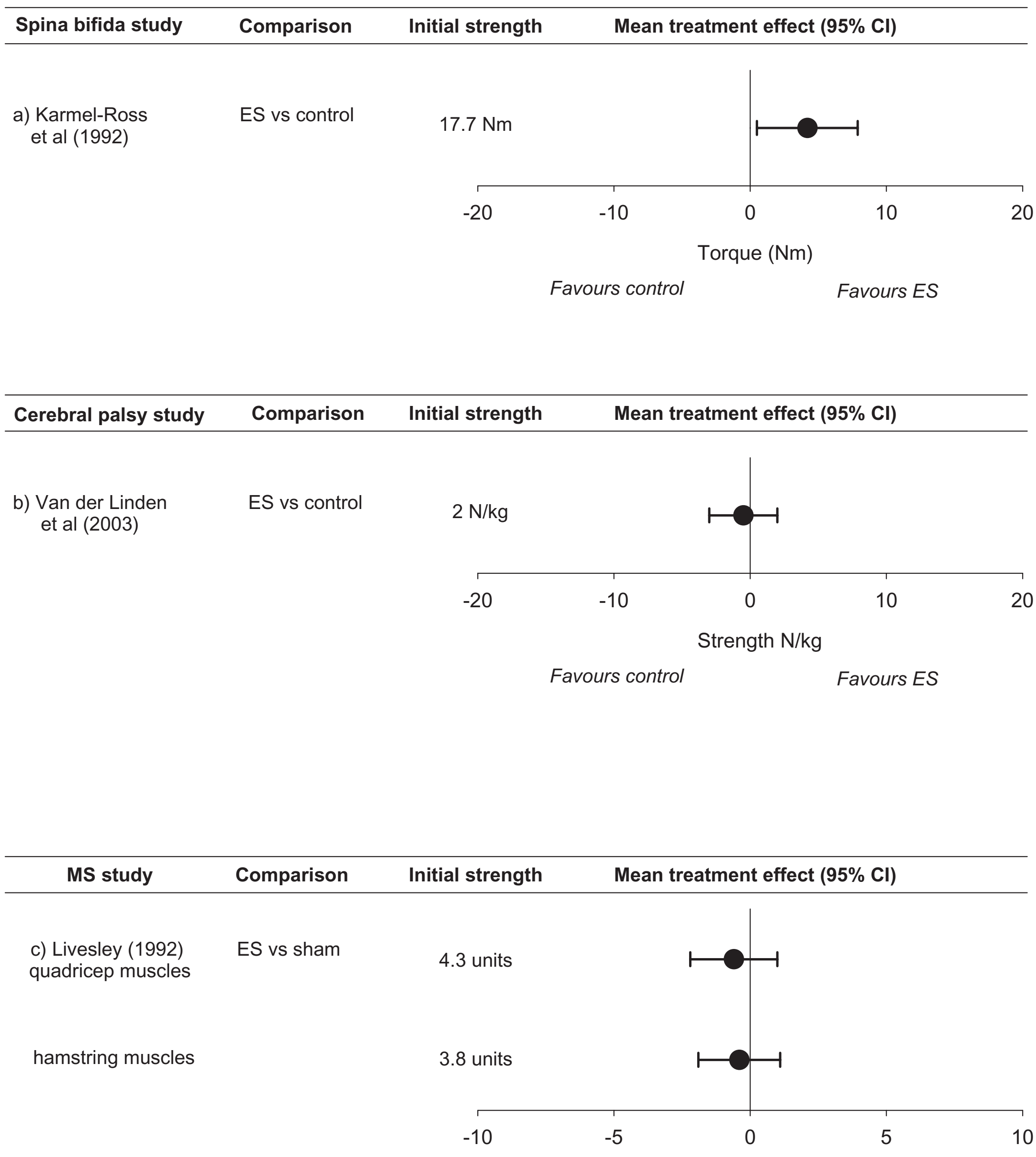

FIGURE 1: Effects of electrical stimulation on strength in individual studies of people with: (a) spina bifida; (b) cerebral palsy; and (c) multiple sclerosis. Effects are between-group differences with 95% confidence intervals (CIs). ES = electrical stimulation.

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were provided to calculate the mean difference or corresponding 95% CI.

Multiple sclerosis

One study was retrieved with participants who predominantly had multiple sclerosis (Livesley, 1992). The methodological quality of this study was moderate (PEDro score 5/10). Treatment was divided into three consecutive phases. The first two phases compared electrical stimulation of the quadricep and hamstring muscles with a sham stimulation treatment. The third phase added active assisted anti-gravity movement to both comparisons. The mean differences (95% CI) were −0.6 (95% CI −2.2 to 1.0; Figure 1 (c)) for the hamstring muscles and −0.4 (95% CI −1.9 to 1.1; Figure 1 (c)) for the quadriceps muscles (units not provided). In both of these studies the lower end of the 95% CI suggests no treatment effect while the upper end of the 95% CIs suggests a small treatment effect (26% increase from initial strength). This study does not provide convincing evidence about the effectiveness or otherwise of electrical stimulation in people with multiple sclerosis.

Spinal cord injury

Three studies were retrieved with participants who had sustained a spinal cord injury (Klose et al., 1990; Kohlmeyer et al., 1996; Needham-Shropshire et al., 1996). All three studies had a PEDro score of 4/10. Many comparisons were made in these studies; however, only those that fitted the inclusion criteria were considered. One study compared electrical stimulation and voluntary training with conventional treatment (including voluntary strength training) of the wrist extensor muscles (Kohlmeyer et al., 1996). The second study compared electrical stimulation of upper limb muscles with a control (Klose et al., 1990). The third study compared electrical stimulation of the triceps during arm ergometry with arm ergometry alone (Needham-Shropshire et al., 1996). All three studies used the manual muscle test as a primary outcome measure. Insufficient data were provided to make decisions about treatment effectiveness.

Stroke

Eleven studies were retrieved with participants who had sustained a stroke. The mean (SD) PEDro score was 5.0/10 (1.1). The following comparisons were made in the 11 studies.

Electrical stimulation compared with conventional physiotherapy

One study compared EMG-triggered electrical stimulation with a home-based exercise programme in a crossover trial (Gabr et al., 2005). Only the first arm of the crossover was considered. The mean difference between groups of active wrist extension was 23°, favouring the EMG-triggered electrical stimulation group. However, insufficient data were provided to determine the corresponding 95% CI.

Electrical stimulation (and conventional physiotherapy) compared with control (and conventional physiotherapy)

Seven studies were retrieved which compared electrical stimulation and conventional therapy with conventional therapy alone (Merletti et al., 1978; Bowman et al., 1979; Winchester et al., 1983; Heckmann et al., 1997; Powell et al., 1999; Newsam and Baker, 2004; Yan et al., 2005). Strength outcome was expressed in terms of torque

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for six studies and on a six-point scale for one study (Heckmann et al., 1997). The methodological quality was moderate, with a mean (SD) PEDro score of 5.0/10 (1.2).

There were many similarities between studies, including the characteristics of subjects and dosage of electrical stimulation. A meta-analysis was therefore considered but not done because of heterogeneity between trials (χ^2 test = 13.7; $p < 0.010$). The heterogeneity is probably explained by the inclusion of different muscles of varying strength and size.

Two studies each applied electrical stimulation to the wrist extensor, ankle dorsiflexor and knee extensor muscles. Both studies of the wrist extensor muscles had similar results. The mean differences (95% CI) were 0.9 Nm (95% CI 0.1 to 1.6; Figure 2; Bowman et al., 1979) and 0.5 Nm (95% CI 0.2 to 0.8; Figure 2; Powell et al., 1999; average of isometric strength at 0°, 15° and 30°). This represented a 60% increase from initial strength in one study (Bowman et al., 1979) and a >250% increase in the other (Powell et al., 1999). The narrow 95% CI indicates certainty around these estimates. These studies provide good evidence for the efficacy of electrical stimulation of the wrist extensor muscles following stroke.

Two studies applied electrical stimulation to the ankle dorsiflexor muscles. The results of the two studies differed. In the first study (Yan et al., 2005) the mean difference (95% CI) was 4.9 Nm (95% CI 1.1 to 8.7; Figure 2). This represents a more than 220% increase from initial strength. The 95% CI indicates certainty around this estimate. In the second study (Merletti et al., 1978) the mean difference (95% CI) was 1.8 Nm (0.3 to 3.3 Nm; Figure 2). This represents a 27% increase from initial strength but there is uncertainty around this estimate as reflected by the 95% CI.

Two studies applied electrical stimulation to the quadriceps muscles. The mean difference (95% CI) in knee extension strength was 19.1 Nm (95% CI 3.2 to 35; Figure 2; Winchester et al., 1983) and 7.5 Nm (95% CI −21.3 to 36.2; Figure 2; Newsam and Baker, 2004). Both studies have a large treatment effect (approximately 200% of initial strength in the first and 38% of initial strength in the latter), however, the wide 95% CI in both studies indicates considerable uncertainty in the estimate of this effect. These studies do not provide convincing evidence about the effectiveness or otherwise of electrical stimulation of the quadriceps in people with stroke.

One study expressed strength on a six-point scale (Heckmann et al., 1997). The mean difference (95% CI) was 0.8 points (95% CI −0.2 to 1.8; Figure 3 (d)) for the hand extensors and 1.1 points (95% CI 0.2 to 2.0; Figure 3 (d)) for the ankle extensors. This represents a 66% increase from initial strength in the hand extensors and a 64% increase from initial strength in the ankle extensors. There is uncertainty around these results as the lower end of 95% CI suggests no treatment effect while the upper end of the 95% CIs suggests a moderate treatment effect.

Electrical stimulation compared with a sham electrical stimulation

Two studies compared electrical stimulation with a sham electrical stimulation treatment (Kimberley et al., 2004; Yan et al., 2005). One study compared the combination of electrical stimulation and conventional physiotherapy with sham electrical stimulation and conventional therapy (Yan et al., 2005). The outcome of interest was dorsiflexor and plantarflexor torque. The mean difference (95% CI) calculated from pre- and post-test

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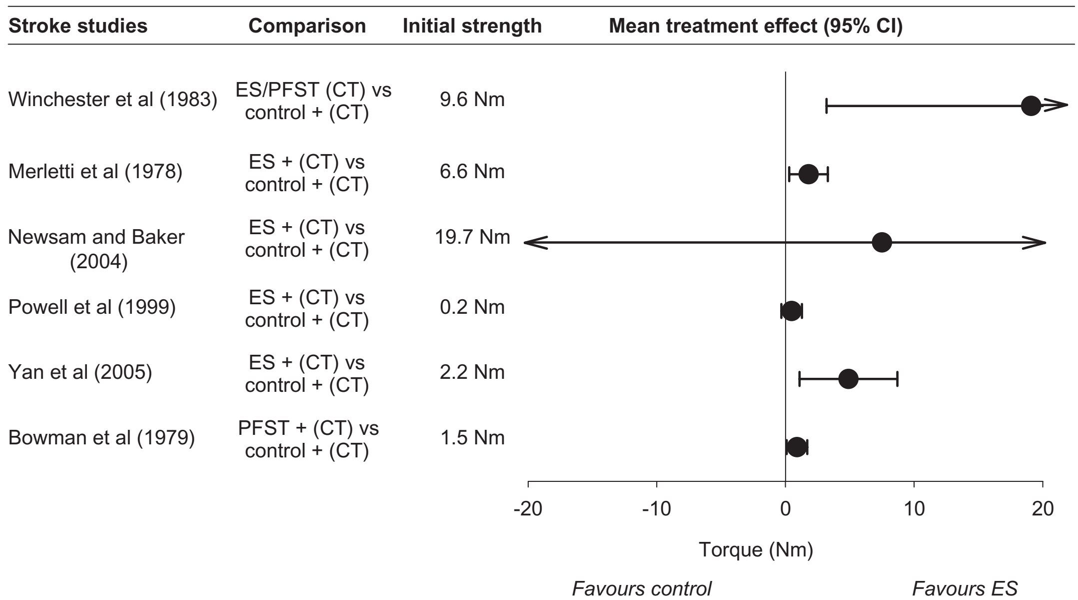

FIGURE 2: The effects of electrical stimulation on strength in people with stroke; all studies are comparing electrical stimulation combined with conventional therapy with conventional therapy; effects are between-group differences with 95% confidence intervals (95% CIs); outcome is measured in Newton meters (Nm). CT = conventional therapy; ES = electrical stimulation; PFST = positional feedback stimulation treatment.

data for dorsiflexor torque was 4.6 Nm (95% CI 1.8 to 7.4; Figure 3 (a)). This represents a 210% increase from initial strength but there is uncertainty around the size of this estimate as reflected by the 95% CI. This study provides some evidence for the efficacy of electrical stimulation of the ankle dorsiflexors following stroke. Insufficient data were provided to extract the mean difference (95% CI) for the ankle plantarflexor muscles.

The second study compared EMG-triggered electrical stimulation with sham electrical stimulation (Kimberley, 2004). This was a crossover study, but only the first arm of the crossover was considered. The outcome measure of interest was strength of the index finger. The mean difference (95% CI) calculated from pre- and post-test data were 1.9 N (95% CI –3.9 to 7.6; Figure 3 (b)). This represents a 23% change of initial strength, however, there is uncertainty around these results as the lower end of 95% CI suggests a negative treatment effect whilst the upper end of the 95% CIs suggests a moderate treatment effect. These data indicate that there is no evidence that EMG-triggered electrical stimulation is superior to sham electrical stimulation treatment.

Electrical stimulation (and a functional task) compared with a functional task

Two studies investigated whether electrical stimulation administered during functional training enhanced strength outcomes. In these studies electrical stimulation was applied to multiple muscle groups with the aim of facilitating functional movement. Many studies apply electrical stimulation during functional tasks, however, these studies are unique because the amount of

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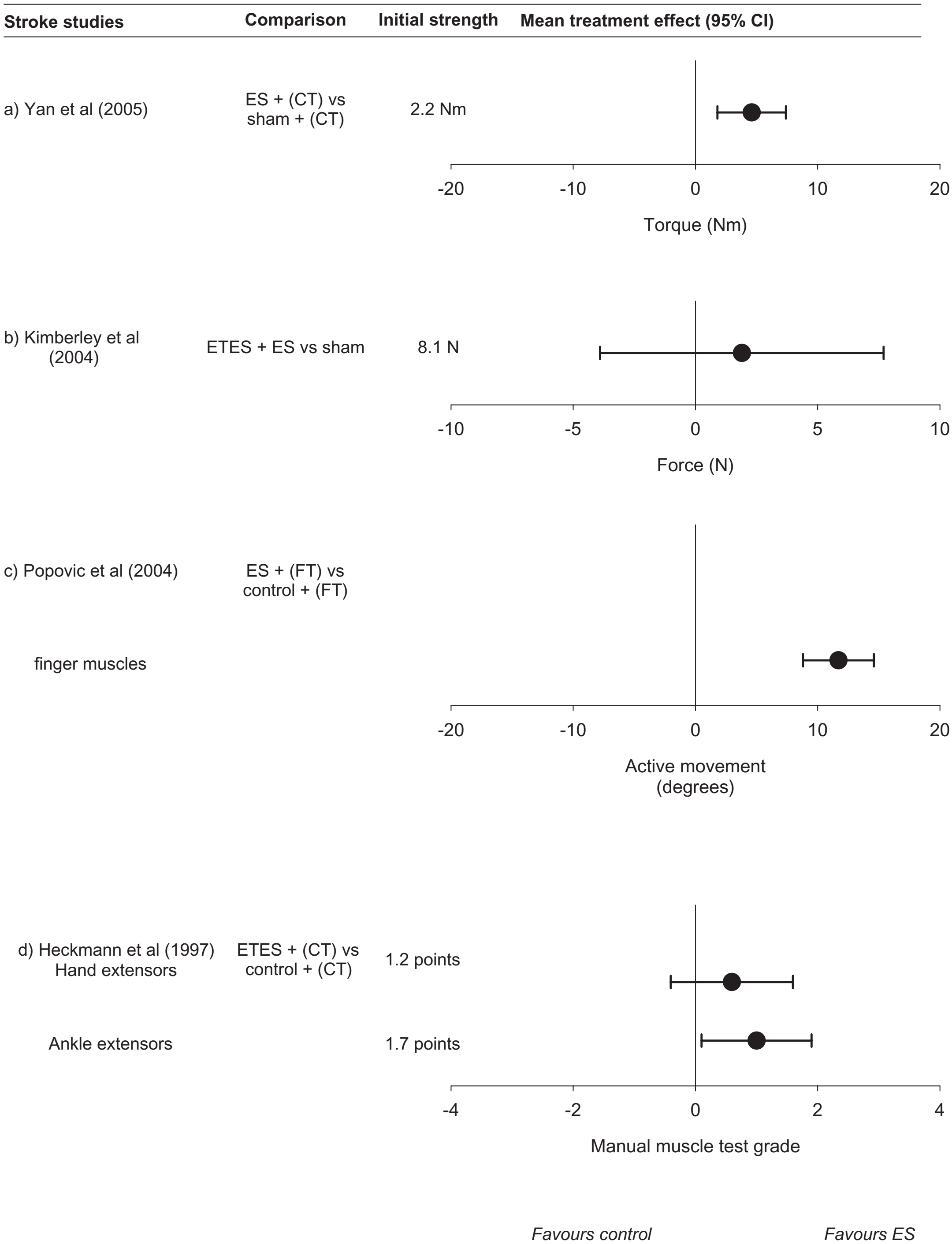

FIGURE 3: The effects of electrical stimulation on strength in individual studies of people with stroke; effects are between-group differences with 95% confidence intervals (95% CIs); outcomes are measured in: (a) Newton meters (Nm); (b) Newton (N); and (c) degrees. CT = conventional therapy; ES = electrical stimulation; FT = functional task; ETES = EMG triggered electrical stimulation.

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functional training in both groups is the same. Thus, it is the electrical stimulation not the amount of practice of the task that differentiates the groups. One trial compared electrically stimulated grasping with grasping alone (Popovic et al., 2004). A second study compared the combination of functional electrical stimulation and a gait trainer with a gait trainer alone (Peurala et al., 2005). Only one trial provided sufficient data to calculate the mean difference (95% CI) (Popovic et al., 2004). Active range of motion (ROM) was used to reflect strength. The average mean difference (95% CI) calculated for the finger and thumb joints (the finger extensors, finger flexors, thumb extensor and thenar muscles were stimulated) measured six months later was 12° (95% CI 9 to 15; Figure 3 (c)). Initial mean active ROM was not provided, but presumably a treatment effect possibly as low as 9° is worthwhile. The data for the finger and thumb joints from one clinical trial (Popovic et al., 2004) suggest a beneficial effect of electrical stimulation.

DISCUSSION

The aim of the present review was to determine if surface electrical stimulation increased voluntary muscle strength in people with neurological weakness. The results were considered by aetiology. No evidence exists to support or refute the use of electrical stimulation for increasing voluntary muscle strength in people with spina bifida, peripheral nerve lesion, multiple sclerosis, spinal cord injury or cerebral palsy. However, electrical stimulation may increase strength in people after stroke.

It is difficult to make conclusions about the effectiveness of electrical stimulation in people with spina bifida, peripheral nerve lesion, multiple sclerosis, spinal cord injury or cerebral palsy because of the small number of studies with low methodological quality. It is also difficult because of the large variability in the response of these people to electrical stimulation (reflected by the wide 95% CI). This result is surprising considering the widespread use of electrical stimulation in patients with these aetiologies. The results pose difficulties for clinicians who need to make evidence-based decisions about the merits of providing electrical stimulation. Either, clinicians must rely on lower level evidence and draw conclusions from single studies, or they must draw clinical implications from population groups such as stroke where reasonable quality evidence is available.

The present review indicates that electrical stimulation may increase strength in people after stroke. The studies in people with stroke made various comparisons; however, the best investigated comparison was between conventional therapy and conventional therapy combined with electrical stimulation. In this comparison the only difference between the experimental and control groups was the addition of electrical stimulation. This comparison was investigated in two moderate-quality studies which provided evidence for the use of electrical stimulation (Powell et al., 1999; Yan et al., 2005). However, there were an additional four studies investigating this comparison that were inconclusive (Merletti et al., 1978; Winchester et al., 1983; Heckmann et al., 1997; Newsam and Baker, 2004). The results indicate that electrical stimulation is better than no intervention for increasing voluntary strength in people with stroke when patients continue to receive routine care. The clinical usefulness of a treatment effect, possibly as low as 0.2 Nm (Powell et al., 1999), depends on many factors, including subjects' initial strength and the size of the muscle group. For weaker subjects or smaller muscle

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groups, such increases would be worthwhile, whereas for stronger subjects or larger muscle groups it may not.

Several studies in people with stroke reported substantial increases in strength not commonly seen with any type of strength training (from 50% up to 250% of initial strength) (Bowman et al., 1979; Winchester et al., 1983; Powell et al., 1999; Newsam and Baker, 2004; Yan et al., 2005). Only two of these studies had moderate PEDro scores (Powell et al., 1999; Yan et al., 2005). These results may reflect the inherent problems associated with expressing treatment effects as a percentage of mean initial strength or they may reflect bias introduced by methodological weaknesses. Furthermore, these large treatment effects may be related to the dosage and settings used in these studies (outlined in Table 1), however, there are not enough studies to definitively link treatment effectiveness with dosage and settings.

Although it appears that electrical stimulation is superior to no intervention for increasing muscle strength after stroke, it is not clear whether it is as effective as progressive resistance training (ACSM, 2002). Nor is it clear whether electrical stimulation superimposed on voluntary strength training confers any additional benefit. This latter question is arguably the most important. Electrical stimulation is a time-consuming and costly intervention. Its widespread use in conjunction with voluntary strength training is only justified if it is clearly superior to voluntary strength training alone.

This systematic review is not without limitations. Too few homogeneous trials were identified to carry out a meta-analysis in any of the populations. It is recognized that the mechanisms underlying loss of strength and the effect of electrical stimulation will differ according to aetiology. The broad grouping of aetiologies in the present paper was intended to provide a clinically relevant overview of electrical stimulation across the spectrum of neurological weakness that physiotherapists treat in the clinic.

This systematic review indicates that electrical stimulation may be effective for increasing voluntary muscle strength in people with stroke. The efficacy of electrical stimulation for people with spina bifida, cerebral palsy, peripheral nerve lesion, multiple sclerosis or spinal cord injury is not clear. Furthermore, it is not known whether electrical stimulation with or without superimposed voluntary strength training is superior to voluntary strength training alone in any neurological populations.

IMPLICATIONS

Electrical stimulation appears to enhance muscle strength when applied to weak muscles after stroke. However, it is not clear whether electrical stimulation is as effective as progressive resistance training. Nor is it clear whether it confers any additional benefits when used in conjunction with progressive resistance training. Until further research is undertaken, we recommend combining electrical stimulation with progressive resistance training in all patients with neurologically induced weakness.

REFERENCES

Ada L, Foongchomcheay A. Efficacy of electrical stimulation in preventing or reducing subluxation of the shoulder after stroke: a meta analysis. Australian Journal of Physiotherapy 2002; 48: 257–267.

Ada L, Dorsch S, Canning CE. Australian Journal of Physiotherapy 2006; 52: 241–248.

Baldi JC, Jackson RD, Moraille R, Mysiw J. Muscle atrophy is prevented in patients with acute spinal

DOI: 10.1002/pri

cord injury using functional electrical stimulation. Spinal Cord 1998; 36: 463–469.

Beekhuizen K, Field-Fote E. Massed practice versus massed practice with stimulation: Effects on upper extremity function and cortical plasticity in individuals with incomplete spinal cord injury. Neurorehabilitation and Neural Repair 2005; 19: 33–45.

Belanger M, Stein RB, Wheeler GD, Gordon T, Leduc B. Electrical stimulation: can it increase muscle strength and reverse osteopenia in spinal cord injured individuals? Archives of Physical Medicine and Rehabilitation 2000; 81: 1090–1098. DOI: 10.1053/apmr.2000.7170.

Bogataj U, Gros N, Kljajic M, Acimovic R, Malezic M. The rehabilitation of gait in patients with hemiplegia: a comparison between conventional therapy and multichannel electrical stimulation therapy. Physical Therapy 1995; 75: 490–502.

Bolton DA, Cauraugh J, Hausenblas H. Electromyogram-triggered neuromuscular stimulation and stroke motor recovery of arm/hand functions: a meta-analysis. Journal of Neurological Sciences 2004; 223: 121–127. DOI: 10.1016/j.jns2004.05.005.

Boonstra AM, van Weerden TW, Eisma WH, Pahlplatz VB, Oosterhuis HJ. The effect of low-frequency electrical stimulation on denervation atrophy in man. Scandinavian Journal of Rehabilitation Medicine 1987; 19: 127–134.

Bowman BR, Baker LL, Waters RL. Positional feedback and electrical stimulation: an automated treatment for the hemiplegic wrist. Archives of Physical Medicine and Rehabilitation 1979; 60: 497–502.

Burridge JH, Taylor PN, Hagan SA, Wood DE, Swain ID. The effects of common peroneal stimulation on the effort and speed of walking: a randomized controlled trial with chronic hemiplegic patients. Clinical Rehabilitation 1997; 11: 201–210.

Cauraugh J, Light K, Kim S, Thigpen M, Behrman A. Chronic motor dysfunction after stroke: recovering wrist and finger extension by electromyography-triggered neuromuscular stimulation. Stroke 2000; 31: 1360–1364.

Cauraugh JH, Kim BK. Chronic stroke motor recovery: duration of active neuromuscular stimulation. Journal of Neurological Sciences 2003a; 215: 13–19. DOI: 10.1016/S0022-510X(03)00169-2.

Cauraugh JH, Kim BK. Stroke motor recovery: active neuromuscular stimulation and repetitive practice schedules. Journal of Neurology, Neurosurgery and Psychiatry 2003b; 74: 1562–1566.

Cauraugh JH, Kim S. Two coupled motor recovery protocols are better than one: electromyogram-triggered neuromuscular stimulation and bilateral movements. Stroke 2002; 33: 1589–1594. DOI: 10.1161/01.STR.0000016926.77114.A6.

Cauraugh JH, Kim SB, Duley A. Coupled bilateral movements and active neuromuscular stimulation: intralimb transfer evidence during bimanual aiming. Neuroscience Letters 2005; 382: 39–44. DOI: 10.1016/j.neulet.2005.02.060.

Chae J, Bethoux F, Bohine T, Dobos L, Davis T, Friedl A. Neuromuscular stimulation for upper extremity motor and functional recovery in acute hemiplegia. Stroke 1998; 29: 975–979.

Chan NN, Smith AW, Lo SK. Efficacy of neuromuscular electrical stimulation in improving ankle kinetics during walking in children with cerebral palsy. Hong Kong Physiotherapy Journal 2004; 22: 50–56.

Chantraine A, Baribeault A, Uebelhart D, Gremion G. Shoulder pain and dysfunction in hemiplegia: effects of functional electrical stimulation. Archives of Physical Medicine and Rehabilitation 1999; 80: 328–331.

Clarke M, Oxman AD (eds). Optimal Search Strategy for RCTs. Cochrane Reviewers Handbook 4.1.4 (Updated October 2001) Appendix 5c. In: The Cochrane Library (database on disk and CD-ROM). The Cochrane Collaboration. Oxford: Update Software; 2001 Issue 4, Updated quarterly.

Cozean CD, Pease WS, Hubbell SL. Biofeedback and functional electrical stimulation in stroke rehabilitation 1988; 69: 401–405.

Dali C, Hansen FJ, Pederson SA, Skov L, Hilden J, Bjornskov I et al. Threshold electrical stimulation (TES) in ambulant children with CP: a randomized double-blind placebo-controlled clinical trial. Developmental Medicine and Child Neurology 2002; 44: 364–369.

Faghri PD, Rodgers MM. The effects of neuromuscular stimulation-augmented physical therapy program in the functional recovery of hemiplegic arm in stroke patients. Clinical Kinesiology 1997; 51: 9–15.

Faghri PD, Rodgers MM, Glaser RM, Bors JG, Ho C, Akuthota P. The effects of functional electrical stimulation on shoulder subluxation, arm function recovery, and shoulder pain in hemiplegic stroke patients. Archives of Physical Medicine and Rehabilitation 1994; 75: 73–79.

Faghri PD, Trumbower RD. Clinical applications of electrical stimulation for individuals with spinal

DOI: 10.1002/pri

cord injury. Clinical Kinesiology 2005; 59: 48–62.
Fehlings DL, Kirsch S, Mc Comas A, Chipman M, Campbell K. Evaluation of therapeutic electrical stimulation to improve muscle strength and function in children with types II/III spinal muscular atrophy. Developmental Medicine and Child Neurology 2002; 44: 741–744.
Fleiss, JL. The statistical basis of meta analysis. Statistical Methods in Medical Research 1993; 2: 121–145.
Francisco F, Chae J, Chawala H, Kirshblum S, Zorowitz R, Lewis G et al. Electromyogram triggered neuromuscular stimulation for improving the arm function of acute stroke survivors: a randomized pilot study. Archives of Physical Medicine and Rehabilitation 1988; 79: 570–575.
Gabr U, Levine P, Page SJ. Home based electromyography-triggered stimulation in chronic stroke. Clinical Rehabilitation 2005; 19: 737–745. DOI: 10.1191/0269215505cr909oa.
Glanz M, Klawansky S, Stason W, Berkey C, Chalmers TC. Functional electrostimulation in poststroke rehabilitation: a meta-analysis of the randomized controlled trials. Archives of Physical Medicine and Rehabilitation 1996; 77: 549–553.
Hartkopp A, Harridge S, Mizuno M, Ratkevicius A, Quistorff B, Kjaer M et al. Effect of training on contractile and metabolic properties of wrist extensors in spinal cord-injured individuals. Muscle and Nerve 2003; 27: 72–80.
Heckmann J, Mokrusch T, Krockel A, Warnke S, von Stockert T, Neundorfer B. EMG-triggered muscle stimulation in the treatment of central hemiparesis after stroke. European Journal of Physical Medicine and Rehabilitation 1997; 7: 138–141.
Herbert R. How to estimate treatment effects from reports of clinical trials. I: Continuous outcomes. Australian Journal of Physiotherapy 2000; 46: 229–313.
Hesse S, Jahnke MT, Luecke D, Mauritz KH. Short-term electrical stimulation enhances the effectiveness of botulinum toxin in the treatment of lower limb spasticity in hemiparetic patients. Neuroscience Letters 1995; 201: 37–40.
Hesse S, Reiter F, Konrad M, Jahnke MT. Botulinim toxin type A and short-term electrical stimulation in the treatment of upper limb flexor spasticity after stroke: a randomized, double blind, placebo controlled trial. Clinical Rehabilitation 1998; 12: 381–388.
Hesse S, Werner MA, Pohl M, Rueckriem S, Mehrholz J, Lingnau ML. Computerized arm training improves the motor control of the severely affects arm after stroke. A single-blinded randomized controlled trial in two centers. Stroke 2005; 36: 1960–1966. DOI: 10.1161/01.STR.0000177865.37334.ce.
Jacobs PL, Nash MS. Modes, benefits and risks of voluntary and electrically induced exercise in persons with spinal cord injury. Journal of Spinal Cord Medicine 2001; 24: 10–18.
Johnson CA, Wood DE, Swain ID, Tromans AM, Strike P, Burridge JH. A pilot study to investigate the combined use of botulinum toxin type A and functional electrical stimulation, with physiotherapy in the treatment of spastic dropped foot in the subacute stroke. Artificial Organs 2002; 26: 263–266.
Karmel-Ross K, Cooperman DR, Van Doren CL. The effect of electrical stimulation on quadriceps femoris muscle torque in children with spina bifida. Physical Therapy 1992; 72: 723–730.
Kerr C, McDowell B, McDonough S. Electrical stimulation in cerebral palsy: a review of the effects on strength and motor function. Developmental Medicine and Child Neurology 2004; 46: 205–213.
Kimberley TJ, Lewis SM, Auerbach EJ, Dorsey LL, Lojovich JM, Carey JR. Electrical stimulation driving functional improvements and cortical changes in subjects with stroke. Experimental Brain Research 2004; 154: 450–460. DOI 10.1007/s00221-003-1695-y.
Klose KJ, Schmidt DL, Needham BM, Brucker BS, Green BA, Ayyar DA. Rehabilitation therapy for patients with long term spinal cord injuries. Archives of Physical Medicine and Rehabilitation 1990; 71: 659–662.
Kobayashi H, Onishi H, Ihashi K, Yagi R, Handa Y. Reduction in the subluxation and improved muscle function of the hemiplegic shoulder joint after therapeutic electrical stimulation. Journal of Electromyography and Kinesiology 1999; 9: 327–336.
Kohlmeyer KM, Hill JP, Yarkony GM, Jaeger RJ. Electrical stimulation and biofeedback effect on recovery of tenodesis grasp: a controlled study. Archives of Physical Medicine and Rehabilitation 1996; 77: 702–706.
Kottink AI, Oostendorp LJ, Buurke JH, Hermens HJ, Ijzerman MJ. The orthotic effect of functional electrical stimulation on the improvement of walking in stroke patients with a dropped foot.

DOI: 10.1002/pri

A systematic review. Artificial Organs 2004; 28: 577–586.

Kraft GH, Fitts SS, Hammond MC. Techniques to improve function of the arm and hand in chronic hemiplegia. Archives of Physical Medicine and Rehabilitation 1992; 73: 220–227.

de Kroon JR, van der Lee JH, Ijzerman MJ, Lankhorst GJ. Therapeutic electrical stimulation to improve motor control and functional abilities of the upper extremity after stroke: a systematic review. Clinical Rehabilitation 2002; 16: 350–360. DOI: 10.1191/0269215502cr504oa.

de Kroon JR, Ijzerman MJ, Lankhorst GJ, Zilvold G. Electrical stimulation of the upper limb in stroke: stimulation of the extensors of the hand vs alternate stimulation of flexors and extensors. American Journal of Physical Medicine and Rehabilitation 2004; 83: 592–600.

Linn SL, Granat MH, Lees KR. Stroke 1999; 30: 963–968.

Livesley E. Electrical neuromuscular stimulation on functional performance in patients with multiple sclerosis. Physiotherapy 1992; 78: 914–917.

Macdonell RA, Triggs WJ, Leikauskas J, Bourque M, Robb K, Day BJ et al. Functional electrical stimulation to the affected lower limb and recovery after cerebral infarction. Journal of Stroke and Cerebrovascular Disease 1994; 4: 155–160.

Mann GE, Burridge JH, Malone LJ, Strike PW. A pilot study to investigate the effects of electrical stimulation on recovery of hand function and sensation in subacute stroke patients. Neuromodulation 2005; 3: 193–202.

Merletti R, Zelaschi F, Latella D, Galli M, Angeli S, Sessa MB. A control study of muscle force recovery in hemiparetic patients during treatment with functional electrical stimulation. Scandinavian Journal of Rehabilitation Medicine 1978; 10: 147–154.

Milner-Brown HS, Miller RG. Muscle strengthening through electric stimulation combined with low resistance weights in patients with neuromuscular disorders. Archives of Physical Medicine and Rehabilitation 1988; 69: 20–24.

Moseley AM, Herbert RD, Sherrington C, Maher CG. Evidence for physiotherapy practice: a survey of the physiotherapy evidence based database (PEDro). Australian Journal of Physiotherapy 2002; 48: 43–50.

Needham-Shropshire BM, Broton JG, Cameron TL, Klose J. Improved motor function in tetraplegics following neuromuscular stimulation-assisted arm ergometry. Journal of Spinal Cord Medicine 1996; 20: 49–55.

Newsam CJ, Baker LL. Effect of an electric stimulation facilitation program on quadriceps motor unit recruitment after stroke. Archives of Physical Medicine and Rehabilitation 2004; 85: 2040–2045.

Paillard T, Noe F, Passelergue P, Dupui P. Electrical stimulation superimposed onto voluntary muscular contraction. Sports Medicine 2005; 35: 951–966.

Pape KE, Kirsch SE, Bugaresti JM. New therapies in spastic cerebral palsy. Contemporary Pediatrics 1990; 6: 13.

Peri CV, Shaffrey ME, Farace E, Cooper E, Alves WM, Cooper JB et al. Pilot study of electrical stimulation on the median nerve in comatose severe brain injured patients: 3 month outcome. Brain Injury 2001; 15: 903–910.

Peurala SH, Tarrka IM, Pitkanen K, Sivenius J. The effectiveness of body weight supported gait training and floor walking in patients with chronic stroke. Archives of Physical Medicine and Rehabilitation 2005; 86: 1557–1564. DOI: 10.1016/j.apmr.2005.02.005.

Peurala SH, Pitkanen K, Sivenius J, Tarkka IM. Cutaneous electrical stimulation may enhance sensorimotor recovery in chronic stroke. Clinical Rehabilitation 2002; 16: 709–716.

Pomeroy VM, King L, Pollock A, Baily-Hallam A, Langhorne P. Electrostimualtion for promoting recovery of movement or functional ability after stroke. Cochrane Database of Systematic Reviews 2006, Issue 2. Art. No.: CD003241. DOI: 10.1002/14651858.CD003241.pub2.

Popovic MB, Popovic DB, Sinkjaer T, Stefanovic A, Schwirtlich L. Clinical Evaluation of functional electrical therapy in acute hemiplegic subjects. Journal of Rehabilitation Research and Development 2003; 40: 443–453.

Popovic DJ, Popovic HB, Sinkjaer T, Stefanovic A, Schwistlich L. Therapy of paretic arm in hemiplegia subjects augmented with neural prosthesis: a cross-over study. Canadian Journal of Physiology and Pharmacology 2004; 82: 749–756. DOI: 10.1139/Y04-057.

Popovic MR, Thrasher TA, Zivanovic V, Takaki J, Hajek V. Neuroprosthesis for retraining reaching and grasping functions in severe hemiplegic patients. Neuromodulation 2005; 8: 58–72.

Postans NJ, Hasler JP, Granat MH, Maxwell DJ. Functional electric stimulation to augment partial

DOI: 10.1002/pri

weight bearing supported treadmill training for patients with acute incomplete spinal cord injury: a pilot study. Archives of Physical Medicine and Rehabilitation 2004; 85: 604–610. DOI: 10.1016/j.apmr.2003.08.083.

Powell J, Pandyan D, Granat M, Cameron M, Stott DJ. Electrical stimulation of wrist extensors in post-stroke hemiplegia. Stroke 1999; 30: 1384–1389.

Price CI, Pandyan A. Electrical stimulation for preventing and treating post-stroke shoulder pain: a systematic Cochrane review. Clinical Rehabilitation 2001; 15: 5–19. DOI: 0269-2155(01)CR3780A.

Quinn R, Cramp F. The efficacy of electrotherapy for Bell's palsy: a systematic review. Physical Therapy Reviews 2003; 8: 151–164.

Ramos LE, Zell JP. Rehabilitation program for children with brachial plexus and peripheral nerve injury. Seminars in Pediatric Neurology 2000; 7: 52–57.

Ring H, Rosenthal N. Controlled study of neuroprosthetic functional electrical stimulation in sub-acute post-stroke rehabilitation. Journal of Rehabilitation Medicine 2005; 37: 32–36.

Seeger BR, Law D, Crewell JE, Stern LM, Potter G. Functional electrical stimulation for upper limb strengthening in traumatic quadriplegia. Archives of Physical Medicine and Rehabilitation 1989; 70: 663–667.

Singer B. Functional electrical stimulation of the extremities in the neurological patient. Australian Journal of Physiotherapy 1987; 33: 33–42.

Skol C, Harms-Ringdahl K, Hultling C, Levi R, Nash M, Seiger A. Effects of functional electrical stimulation training for six months on body composition and spasticity in motor complete tetraplegic spinal cord-injured individuals. Journal of Rehabilitation Medicine 2002; 34: 25–32.

Sommerfelt K, Markestad T, Berg K, Saetesdal I. Therapeutic electrical stimulation in cerebral palsy: a randomised, controlled, crossover trial. Developmental Medicine and Child Neurology 2001; 43: 609–613.

Steinbok P, Reiner A, Kestle JR. Therapeutic electrical stimulation following selective posterior rhizotomy in children with spastic diplegic cerebral palsy: a randomized clinical trial. Developmental Medicine and Child Neurology 1997; 39: 515–520.

Targan RS, Alon G, Kay SL. Effect of long-term electrical stimulation on motor recovery and improvement of clinical residuals in patients with unresolved facial nerve palsy. Otolaryngology-Head and Neck Surgery 2000; February: 246–252.

Taylor NF, Todd KJ, Damiano DL. Progressive resistance exercise in physical therapy. A summary of systematic reviews. Physical Therapy 2005; 85: 1208–1223.

Van der Linden ML, Hazlewood ME, Aitchison AM, Hillman SJ, Robb JE. Electrical stimulation of gluteus maximus in children with cerebral palsy: effects on gait characteristics and muscle strength. Developmental Medicine and Child Neurology 2003; 45: 385–390. DOI: 10.1017/S0012162203000732.

Verhagen AP, de Vet HC, de Bie RA, Kessels AG, Boers M, Bouter LM et al. The Delphi list: a criteria list for quality assessment of randomized clinical trials for conducting systematic reviews developed by Delphi consensus. Journal of Clinical Epidemiology 1998; 51: 1235–1241.

Wang RY, Chan RC, Tsai MW. Functional electrical stimulation on chronic and acute shoulder subluxation. American Journal of Physical Medicine and Rehabilitation 2000; 79: 385–390.

Winchester P, Montgomery J, Bowman B, Hislop H. Effects of feedback stimulation training and cyclical electrical stimulation on knee extension in hemiparetic patients. Physical Therapy 1983; 63: 1096–1103.

Yan T, Hui-Chan C, Li L. Functional electrical stimulation improves motor recovery of the lower extremity and walking ability of subjects with first acute stroke. Stroke 2005; 36: 80–85.

Yu D, Chae J. Neuromuscular stimulation for treating shoulder dysfunction in hemiplegia. Critical Reviews in Physical and Rehabilitation Medicine 2002; 14: 1–23.

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