REVIEW ARTICLE

ELECTRICAL STIMULATION FOR UPPER MOTOR FUNCTION RECOVERY IN STROKE PATIENTS A REVIEW

ABSTRACT: *The use of electrical stimulation to promote recovery following pathological disorders dates back to the first discovery of electrical current. However, the evidence for its use for promoting recovery following stroke is not well understood. Different types of research have been undertaken to investigate its effect on stroke recovery with different outcomes. This review is an attempt to highlight what is currently known about the effect of electrical stimulation on motor function recovery after stroke and to point out the areas needing research clarification.*

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INTRODUCTION

There is an increasing emphasis on evidence-based practice in all aspects of physiotherapy. Associated with this is a need to review the rationale for the commonly used techniques in physiotherapy and examine the evidence for their continued use. This will help physiotherapists offer a quality service based on sound scientific evidence. Neuro-rehabilitation, as an emerging clinical discipline within physiotherapy should not be left out of this evidence seeking exercise. Therefore, it becomes imperative to review the techniques used in rehabilitation.

Electrical stimulation is one of the myriads of useful techniques in rehabilitation, and although its use has been criticised by some (Bobath 1990) others have found it beneficial for promoting motor recovery in patients with stroke (Chae et al 1998; Powell et al 1999). This review examines the rationale for the use of electrical stimulation and highlights areas where there are gaps in the literature.

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ELECTRICAL STIMULATION TO PROMOTE STROKE RECOVERY

The use of electrical stimulation (ES) to facilitate restoration of motor control following stroke was first reported by Liberson and associates in the 1960s. They utilised it for functional electrical stimulation (FES), to co-ordinate the anterior tibial muscles with the gait cycle in patients who had a central foot drop. FES is now commonly used to substitute for lost function in some muscle groups in patients with stroke, Parkinson's disease and multiple sclerosis. A common example is its use to replace dorsiflexion action during the swing phase of the gait cycle (Burridge et al 1997). Significant functional benefits have been documented with continued FES use (Burridge et al 1997) and in addition to this, a 'carry over' of function has been reported (Waters et al 1985) after the stimulation is discontinued. The underlying mechanism of this phenomenon is not understood but it has prompted the use of ES therapeutically to elicit this 'carry over' effect for functional benefits in stroke patients. The results of these attempts are still not conclusive, but there is some evidence that peripheral electrical stimulation may facilitate recovery in stroke patients (Chae et al 1998, Powell et al 1999 and Cauraugh et al 2000). It has been recognised that understanding the processes underlying the 'carry over' phenomenon can provide guidelines on how to utilise ES to optimise rehabilitation outcomes (Waters 1984).

Electrical stimulation has also been used based on the repetitive motor relearning paradigm. The motor relearning approach emphasizes the relearning of normal pattern of movement with the view of facilitating the restoration of lost motor control. Active repetitive movement is a technique based on motor relearning suggested to be useful for retraining functional ability (Chae et al 1998). However, if there is a significant degree of hemiparesis many stroke survivors may not be able to perform active repetitive movements and this will limit the application of this strategy (Chae et al 1998). This limitation can been overcome by the use of neuromuscular electrical stimulation (ES). This way of using ES therefore aims to elicit therapeutic responses in contrast to the use in FES, which is for orthotic purposes. Clinical studies (Chae et al 1998; Powell et al 1999; Cauraugh et al 2000) have shown significant improvement in motor functions following this way of using ES in stroke patients. Other studies have reported that neuromuscular ES reduces spasticity (Levin et al 1992), enhances muscle strength of the hemiparetic limb (Powell et al 1999; Cauraugh et al 2000) and improves motor control (Chae et al 1998; Powell et al 1999; Cauraugh et al 2000). The underlying mechanisms of this form of stimulation are still not known, but there are speculations that it is similar to the processes that underlie motor learning and skill acquisition. In summary, the most beneficial way of using electrical stimulation has yet to be established.

Recent evidence from basic science research has also demonstrated that sensorimotor input from electrical stimulation can induce cortical plasticity. Plasticity in this sense implies an ability of the brain to alter structure and/ or function in response to demand of use or injury. Research results have shown that corticomotor excitability (Ridding et al 2000), cortical representation area of stimulated muscles (Hamdy et al 1998) and muscle force (Conforto et al 2002) can be significantly increased in normal subjects by electrical stimulation. This observation would suggest this as the underlying mechanism of the carry over effect of the FES and the motor control improvements following therapeutic electrical stimulation in stroke patients but there is no clinical research to support this. However, it is believed that these functionally significant plastic changes can be induced in the cortices of individuals who are affected by stroke using electrical stimulation. This is being investigated in an ongoing study.

EFFECT OF THERAPEUTIC ELECTRICAL STIMULATION ON MOTOR FUNCTION RECOVERY

A few clinical studies based on the above rationales have evaluated the effect of electrical stimulation on motor and functional recovery following stroke. Two main types of ES have been used for motor recovery (Chae et al 2002). The first is cyclical ES, which electrically activates paretic muscles at a set duty cycle for a preset time period. The patient is generally a passive participant and does not assist the ES by volitionally contracting the muscle during stimulation. The second type encompasses various forms of biofeedback with the aim of coupling afferent feedback during ES induced contractions with cognitive intent to further enhance motor learning. Randomised clinical trials (RCTs) have assessed the efficacy of lower extremity applications (Merletti et al 1978; Winchester et al 1983; Cozean et al 1988; Levin et al 1992; Bogataj et al 1995) and upper extremity applications of ES (Kraft et al 1992, Francisco et al 1998, Chae et al 1998, Powell et al 1999, Sonde et al 2000 and Cauraugh et al 2000) in enhancing motor recovery following stroke. The effect of upper limb applications will be discussed in this review.

EFFECT ON MOTOR FUNCTION

Improvements in upper limb motor function have been demonstrated using the Fugl- Meyer Assessment (FMA) of motor function, muscle strength and other laboratory measure of motor function. Chae et al (1998) reported an average of 10 ± 13.1 points on the FMA scale gained by stimulated patients against 6.5 ± 6.1 in the control group following passive ES to the wrist extensor muscles, in post acute patients within 2 to 3 weeks after stroke. Mild to moderately impaired patients were reported to benefit the most. Similarly, Powell et al (1999) using a different outcome measure of wrist extensors isometric strength found a significant increase ($p=0.004$) in strength following 8 weeks stimulation with cyclical ES in patients within 3 to 4 weeks after stroke. This trend has also been seen in patients in the chronic phase. Kraft et al (1992) reported increases of 10 ± 3.3 points and 8.2 ± 2.1 points on the FMA scale after the use of EMG triggered and cyclical ES stimulation respectively in chronic patients. Cauraugh et al (2000) found similar results in chronic patients with EMG triggered stimulation. They observed higher isometric force in the treated group than the control group. Furthermore, enduring improvements of motor impairments were reported by 2 studies at 12 and 32 weeks post treatment evaluations (Chae et al 1998; Powell et al 1999). However, one study reporting a 3-year follow up data of an earlier study demonstrated no significant difference between treatment and control groups in terms of motor control as measured by FMA (Sonde et al 2000). All these papers give evidence that suggest that ES affects motor control following stroke, but the functional relevance of this improved motor control and the long-term benefits are yet to be conclusive.

Some of the mechanisms through which electrical stimulation promotes recovery following stroke are still not clear and the optimum electrical stimulation parameters required to achieve the effects are still unknown. Future studies are required to investigate these areas (Chae et al 1998; Cauraugh et al 2000). Such studies should carefully define the participant's population in terms of their motor impairments and evaluate immediate and long-term outcomes using valid and reliable measures of impairment, disability, handicap and quality of life (Glanz et al 1996). It should also include multiple treatment arms to assess the effects of various types of stimulation (Chae et al 2002).

EFFECT ON FUNCTIONAL ABILITY

The functional benefits following the use of electrical stimulation for the upper limb is still subject to some controversies. Some trials reported a significant effect (Tekeoglu et al. 1998; Powell et al 1999; Cauraugh et al 2000) while some others reported little or no effects (Hummelsheim et al 1992; Chae et al 1998; Sonde et al 1998; Powell et al 1999). The reason for these different outcomes may be due to the differences in the outcome measures used in the different trials, patient population treated and the type of stimulator used. For instance, insignificant effect in functional ability may be due to the fact that some of the papers used outcome measures of function that are not specific to the upper limb. For instance, in the Chae et al's (1998) paper the Functional Independence Measure (FIM) was used, as this is a global measure. Changes in the function of the arm will not be significant if other parts of the body are still the same. Similar reasons can be said for the Sonde et al's (2000) paper, where the Barthel index was used to assess changes in functional ability and there was no significant change. Powell et al (1999) on the other hand used a focal measure Action Research Arm Test

(ARAT) and reported significant improvements in the grasp and grip subcomponent of this measure in the stimulated group. The trend here is that studies that have reported functional benefits of electrical stimulation for stroke upper limb rehabilitation have used focal measures.

Another reason can be said to be insufficient time for stimulation, the paper by Hummelsheim et al (1992) applied electrical stimulation for just 2 weeks which is probably insufficient to induce a change in functional ability, other studies utilised a minimum of 8 weeks (Chae et al 1998).

In another study by Tekeoglu et al (1998) the outcome of 8 weeks of TENS (Transcutaneous Electrical Nervous Stimulation) in patients between 30 and 240 days after stroke, was reported. Although both groups of patients had significant changes in the Barthel Index after rehabilitation, the difference between the groups was still significant ($p<0.001$). This is a highly significant effect, particularly as the Barthel Index was used to assess functional ability. Kraft et al (1998) using EMG triggered stimulation reported a significant increase in some aspects of the FIM (feeding, grooming and upper dressing items). Chronic patients have also been reported to improve their ability to transport more blocks after 12 EMG triggered stimulation sessions. (Cauraugh et al 2000). The weight of evidence seems to suggest that ES can promote recovery of functional ability in the upper limb of stroke patients, this improvement will however need to be evaluated by appropriate outcome measures that are sensitive enough to determine the benefits. Furthermore, there is also evidence to suggest that both acute and chronic patients can benefit from the use electrical stimulation. It is however not known whether altering the treatment parameters can further optimise with the benefits of electrical stimulation.

EFFECT OF OTHER PARAMETERS OF ELECTRICAL STIMULATION (ES) ON MOTOR FUNCTION

Much of the available evidence for the potential role of ES on the motor function is not clear on the role of parameters on the effects. Different RCTs has employed either EMG triggered stimulation or cyclical ES and the weight of evidence suggests that EMG triggered stimulation might be better than cyclical stimulation, but the reasons for this are unknown (Woldag et al 2002). Furthermore, the fact that ES can activate different axons in the afferent pathways depending on its parameters suggests that parameters of ES can have a potential role in its effects in stroke rehabilitation. No clinical studies have attempted to investigate the effect of parameters on outcome of ES. However, some studies have investigated the differences in the excitability changes of the motor cortex to different patterns of electrical stimulation using either TMS or functional Magnetic Resonance Imaging (fMRI). These studies provide more insight into the role of different patterns of electrical stimulation. Although these studies have their limitations in extrapolation to stroke population, some inferences can be made about stroke recovery. Fraser et al (2002) investigated the effect of different aspects of ES parameters on the cortical motor representation of the pharyngeal muscles using both TMS and fMRI. They discovered that stimulating at 5Hz, for 10 minutes at 75% of maximal perceptual threshold induced the biggest sustained increases of cortical excitability in normal subjects. The therapeutic effect of this pattern of stimulation was further investigated in stroke patients with dysphagia and significant clinical improvement was obtained.

Several other studies have reported the effect of stimulation with trains of 1ms pulses at 10Hz for 50% duty cycle for 2hours. These studies found significant increases in cortical excitability and the representation area of the stimulated muscle in the hand muscles (Ridding et al 2000; Ridding et al 2001; McKay et al 2002), tibialis anterior muscles (Khaslavskaia et al 2002). Further studies have also identified a paired stimulation protocol of this pattern of peripheral stimulation with TMS delayed for 25ms to be able to facilitate similar increases in cortical excitability within a shorter period of 30 minutes (Waters 1984; Tekeoglu et al 1998; Stephan et al 2000; Backes et al 2000; McKay et al 2002; Pitcher et al 2003; Smith et al 2003). These effects of different patterns of ES show a clear role of parameters but the characteristics of this role is not clear.

Further research using fMRI have shown more insights into the role of parameters. Evidence suggests that the greatest activation of the corresponding cortical areas occurs when electrical stimulation intensity that caused maximal motor response is used (Backes et al 2000; Smith et al 2003). In another study by Pitcher et al (2003) by using the paired stimulation paradigm of TMS with peripheral stimulation to induce plastic changes in human motor cortex, they found out that low frequency of 3Hz induced prolonged depression of excitability while high frequency (30Hz) induced prolonged facilitation. This is how much is known about the role of parameters, but there is a further need to know if there are threshold frequencies for initiating cortical plasticity with ES, and if all muscle types respond similarly or differently. In addition, the optimum treatment duration required for the therapeutic effectiveness and how and when to utilise the increased cortical excitability during rehabilitation sessions needs to be investigated. Also the relationship between promoting plasticity and functional recovery should be further investigated.

CONCLUSION

Neuromuscular electrical stimulation may have an important role in improving the motor function of stroke survivors. However, in the current healthcare environment, it will require close collaboration between scientists and clinicians to optimise the relationship between the cost of developing and utilizing this technology and an improvement in the patients' abilities. This review has highlighted areas where focussed research is required.

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