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# A Personal User's View of Functional Electrical Stimulation Cycling

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**Abstract:** Two years of functional electrical stimulation cycling (FESC) as a researcher and subject have given me an insight into the direction that future FESC should take as well as providing me with significant health benefits and an enjoyable and functional ability to cycle. If FESC is to benefit spinal cord injured persons (SCIPs), researchers must turn their attention to making the activity convenient and enjoyable. What follows is a personal view and will be

less scientifically rigorous than other presentations but hopefully still of value. It calls upon my experience as a general medical practitioner with a special interest in the value of exercise, a human powered vehicle enthusiast, an amateur FES researcher, but most importantly, an SCIP and FES cyclist. **Key Words:** Functional electrical stimulation—Spinal cord injured—Cycling.

A number of researchers have developed systems of functional electrical stimulation cycling (FESC) exercise and shown that most of the probable potential health benefits, both general and specific, do occur. Why then, when FESC is possible and the potential benefits enormous, are not a significant number of spinal cord injured persons (SCIPs) cycling around using their legs, not even in Holland?

Many studies failed to demonstrate sufficient power and endurance to make a significant cycle ride a possibility. However most of the studies had what I regarded as an inadequate training schedule, 20 min 3 times per week for 3 months being fairly typical. None of the papers I read used a cycle that was suitable for an open road cycle ride. All the protocols I read were laboratory based making it extremely inconvenient for the subjects to commit themselves to regular and long-term training. In fact none of these researchers had creating a take-home open road cycling function as an objective.

## MATERIALS AND METHODS

Before my accident I kept fit by recreational running and hill walking. Since then I have attempted to maintain health and fitness by playing wheelchair basketball (very badly), swimming, wheeling in the countryside, and hand cycling. Perhaps this is the reason that I have 2 golfers' elbows, 1 tennis elbow, and intermittently painful shoulders, neck, and wrists. These musculoskeletal problems have resulted in my giving up wheelchair basketball, and they are beginning to cause me problems when hand cycling.

After my recovery, I became interested in the potential of FESC to benefit health and create an additional sport, recreation, and transport option. I could see no reason why FESC should not confer all the health benefits on SCIPs that cycling confers on the able bodied (AB), such benefits as a decrease in all causes of morbidity and mortality, protection against cardiovascular disease, improved fitness, maintenance of function, help in preventing obesity and diabetes, elevation of mood, and prevention of depression. As the benefits of exercise obey the law of diminishing returns, SCIPs should benefit more from any given amount of exercise than the AB.

Much of the ill health and disability suffered by SCIPs is directly related to the inactivity of their large lower limb muscles. Lack of muscle padding together with poor circulation predisposes to pres-

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sure sores, gross muscle size decreases leading to thin unattractive limbs, blood circulation decreases and coagulability increases leading to vascular problems, and osteoporosis and joint contractures develop. FESC has the potential to minimize these problems.

In October 1998, I started surface FESC by the method described in the conference manuscript for the Vienna International FES workshop 2001 by Perkins et al. (1).

## RESULTS

In 1988, I received an injury that left me with an incomplete paraplegia at T11. Before the FESC my standard neurological classification motor score left leg was 0 (except for knee extensors 1, long toe extensors 3). My right leg scored 4 for all measurements. My sensory score was a uniform 1. Since the accident, I have been a wheelchair user but able to slowly walk short distances with 2 crutches.

Before I started my FESC training, I was able only to rotate the pedals of my recumbent tricycle less than 1 complete revolution, despite the fact that it was in its lowest gear on a flat, smooth, hard indoor surface. I was unable to rotate the pedals beyond right bottom dead center.

I have cycled over 10 km on the flat and continuously for over 2 h on my trainer. I have even used my FES cycle to accompany my family on a countryside walk. I know from my personal experience that with the assistance of hand cranking, a tandem companion, or a motor assist, I will be able to cycle as far as I would wish with my AB friends and family. As well as benefiting my health, this has and will bring me great pleasure.

### Muscle bulk, body image, and pressure sores

Muscle bulk has increased benefiting body image and decreased the likelihood of developing pressure sores. Ultrasound measurements have shown increases in the thickness of the lower limbs. My thighs showed an average increase in depth of 14.5%, and my calves showed an average increase of 6.5%. What was even more satisfying than this increase in size was that this increase was almost entirely of muscle bulk. The average thigh muscle depth increased by 21%, but the fat depth only increased by 3.75%. In the calves, the average muscle depth increased by 8.8% while the average fat depth decreased by 1.75%.

Left gastrocnemius and anterior tibialis were stimulated, but due to insufficient stimulator channels right lower leg muscles were not. Notably the nonstimulated calf muscles depth increased by only 3.5%, but the stimulated calf muscles by 14%.

The buttock musculature was not scanned, but the circumference measured across the anterior superior iliac spines increased from 93 to 96 cm, and the circumference across the greater trochanters from 96 to 98 cm, an average increase of 2.7%, perhaps not significant.

### Osteoporosis

Significant changes have occurred in my bone density. Lumbar spine density decreased by 6.1% from 110% of age and sex adjusted average normal (ASAAN). Left hip increased by 4.3% (from 87% ASAAN), but the right hip (the good leg) showed no significant change (from 91% ASAAN). The left knee region showed an increase in bone density of 26%. The greatest increases in bone density were seen in the areas of insertion of the muscles stimulated. There was an increase of 44% around the insertion of the left patella ligament. I was pleased to see that the least dense areas of my scanned bones showed an increase and that the indications were that bone density increases were a result of FESC muscle activity.

### Cardiovascular health and fitness

I believe the FESC exercise is benefiting my cardiovascular health and fitness. My resting pulse rate is normally in the low 60s. During FESC exercise, I become warm and maintain a pulse rate of around 100. I believe that since my FESC exercise, my legs have been less cold.

### Mood

I always feel better after my FESC exercise even when it is indoors on the trainer which I find boring. It is the same mood improvement that I used to experience after running.

### Function

I have had significant improvements in my voluntary function. It was expected that FES generated knee extension forces would increase after FESC, and they did, the right by 48% from 69 to 102 Nm and the left by 32% from 72 to 95 Nm. However, what was not expected was the increase in voluntary strength. The right increased by 45% from 59 to 85.5 Nm while the left increased from 0 to 33.5 Nm. This measured quantitative increase in voluntary strength has been mirrored in a qualitative increase in functional ability. I can now pick things up from the floor more easily when standing, walk short distances with 1 crutch, and I use my crutches more and my wheelchair less. I can now voluntarily move my left leg, something I find very useful to relieve cramp when sitting.

I no longer get any clonus in my left leg nor inversion spasm about the left ankle, something that

used to be very troublesome and would on occasions prevent me from crutch walking.

### Problems and disadvantages

The 2 major problems with FESC are the relative boredom of indoor FESC exercise and the time taken. Typically a 1 h FESC exercise session at home takes me 2.5 h mostly because of the time taken to apply and remove electrodes.

## DISCUSSION

FES walking programs often have a high profile and get reported by the media. A typical response from most non-SCIPs to such reports is very positive, the researchers and research are *brilliant*, and the subject *brave*. Many SCIPs respond differently; typically the research might be described as “a waste of resources that could be better spent” and the subject as “mad or sad.” Indeed, high profile FES walking research is one of the reasons responsible for the negative and cynical attitude that many U.K. SCIPs have about spinal cord injury research. They see researchers not as having the aim of improving the quality of life for SCIPs but rather attempting to make them as much like their AB selves as possible.

I do not share these views, but I empathize with them. At our present level of technology, it is difficult to see how FES walking can be more functional than a wheelchair, and thus it is difficult to see what benefits it can offer. It is highly inconvenient, demands enormous energy expenditure, and looks grotesque. It is more disabling than enabling. FES walking and the training required do of course offer some health benefits. However, because FES walking is so functionally useless and so extremely inconvenient it is doubtful if it will ever significantly benefit the health of SCIPs in the foreseeable future.

By contrast FES cycling can be made functional, enjoyable, and health promoting with today's technology. It has been received very well by the U.K. Spinal Injuries Association and many SCIPs have expressed a strong desire to participate.

SCIPs want to enjoy a good quality of life, and the means by which that is achieved is not of prime importance. Many if not most are not overly concerned with being “able bodied” or “being able to walk.” What they desire is to be able to access conveniently and do those things that are important to them.

## CONCLUSIONS

Despite the enormous health benefits of exercise, SCIPs, like most other people, will not exercise unless that exercise is convenient and enjoyable. Thus research and development's prime objective should

be to create an FESC function that is convenient and enjoyable enough to attract a significant numbers of SCIPs.

The FESC function should be capable of being used on the open road with or without friends and family and be easily usable without any more assistance than that already required for the activities of daily living. To achieve this objective, it is necessary that the training period is of sufficient duration, frequency, and intensity to allow the development of adequate muscle strength and endurance. This requires that the bulk of the training be done at home. The application of electrodes and connecting to the cycle must be reasonably quick and easy. The cycle should be attractive, efficient, and look like a piece of recreational or sports equipment, not like a piece of disability or hospital equipment. The FES cycle system must also be capable of the required speed and distance. This will often require an alternative power source such as an ancillary motor, a hand cranking arrangement, a tandem arrangement, or any combination of the three.

For many years we have had, through FES, the ability to exercise muscles paralyzed through spinal cord injury, and through FESC we have had the potential to develop a convenient and enjoyable method of doing so. When FESC becomes convenient, attractive, and readily available, there will be soon a significant population of SCIPs whose lower limbs will not be wasted. This population will provide the material for much useful research, and we will be able to assess accurately and reliably the long-term health benefits of frequent and continued FES exercise.

The equipment developed and expertise gained in creating user-friendly FESC surely will be of benefit in other FES applications. Perhaps it even will assist in the eventual development of a useful and functional FES walking capacity although I suspect a wheeled orthosis will be needed!

The limbs of SCIPs continue to wither. The development and widespread provision of a functional, convenient, and enjoyable FES exercise is long overdue.

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## REFERENCE

1. Perkins TA, Donaldson N, Fitzwater R, Phillips GF, Wood DE. Leg powered paraplegic cycling system using surface functional electrical stimulation. In: Mayr W, Bijak M, Jancik C, eds. *Proceedings of the Seventh Vienna International Workshop on Functional Electrical Stimulation*. Vienna, 2001:36-9.