DEVELOPMENT OF A FUNCTIONAL NEUROMUSCULAR STIMULATION (FNS) MUSCLE TRAINING PROGRAM TO PREPARE PARAPLEGICS FOR STANDING

Thesis submitted to the University of Cape Town
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by

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ABSTRACT

Wheelchair-bound paraplegics are in an unnatural, almost all-day sitting position. This is physiologically disadvantageous as it may cause increased abdominal pressure, renal dysfunction, pressure sores, muscle atrophy and osteoporosis. Thus it would be beneficial, physiologically and psychologically, for a paraplegic to be able to stand for temporary periods of time. As a result of the muscle atrophy and functional degeneration that follows a spinal cord injury, it is essential for paraplegics to undergo a muscle restrengthening program, using Functional Neuromuscular Stimulation (FNS), before standing up under FNS control can be attempted.

Six healthy spinal cord injured subjects with spinal lesions between C5 and T9 (two tetraplegics and four paraplegics) exercised their quadriceps muscles at home using a portable two-channel FNS muscle stimulator. The muscles were exercised against an increasing load to maximise the training effect. Inclined standing exercise, under FNS control, was performed in the Inclistand. The subjects' general state of health and fitness were assessed, namely their responses during a maximal arm ergometry exercise test, arm muscle function, lung function, blood biochemistry and their dietary habits.

Subjects have shown improvement in quadriceps muscle strength, fatigue resistance and muscle bulk to varying degrees according to their individual circumstances. The tetraplegics responded in a different manner to that of the paraplegics. The muscle strength increased significantly by a mean ($\pm$SD) of 97,8 $\pm$ 59,6% and 171,2 $\pm$ 118,1% for the four paraplegics, left and right leg respectively. There was a mean improvement of 16% in fatigue

resistance in the left leg ($p=0,08$), while the mean response of the right leg varied. Quadriceps muscle bulk increased by $4,43 \pm 3,4\%$ (left) and $2,7 \pm 2,1\%$ (right) ($0,05<p<0,1$) . The amount of subcutaneous fat around the mid-thigh decreased significantly by $4,73 \pm 1,4\%$ (left) and $3,43 \pm 1,1\%$ (right leg). The group was in a state of general well-being, with the exception of one subject whose serum cholesterol concentration fell within the high risk category.

This study therefore showed that the FNS was sucessful in improving the quadriceps muscle strength, bulk and fatigue response of the SCI people in our research group. The valuable experience gained from this FNS study will be used to improve the present program.

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Finally, praise and thanks to the Lord for providing this valuable opportunity and the many lessons learned through it.

> "The Lord does not look at the things man looks at. Man looks at the outward appearance, but the Lord looks at the heart."
>
> (1 Samuel 16:76)

DECLARATION

I, ...CAROL LINDA SCHAFER....., hereby declare that the work on which this thesis is based is original (except where acknowledgements indicate otherwise) and that neither the whole nor any part of it has been, is being, or is to be submitted for another degree in this or any other University.

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Signed: signature removed

Date : 20 APRIL 1989

To Dawn, Heidi, Asta, Tony, Richard and Steve.
Who taught me what it means to overcome adversity
with courage, perseverance and determination.

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CHAPTER ONE

INTRODUCTION

"Spinal Cord Injury (SCI) is one of the most devastating and frustrating injuries of the nervous system - devastating to the patient because of the sudden and often irreversible changes in quality of life and frustrating to the family and attending medical team because of the lack of effective therapy" (Cybulski et al, 1984). The ideal solution is functional restoration of the spinal cord but as yet, no cure has been found (Ragnarsson, 1986).

A spinal cord injury can result in permanent paralysis. This is a loss of motor and sensory function in the trunk and limbs, the extent of which is dependent on the level of the lesion. Rehabilitation is aimed at the ultimate restoration of the disabled person to his or her maximum capacity - physical, emotional and vocational - in the minimum time and a return to the community as soon as possible.

The lack of voluntary control of the limbs due to spinal cord injury results in a lack of locomotor mobility. Coughlan (1980) reports a limited use of orthotics for standing and walking after the rehabilitation period. This is due to the difficulty and high energy expenditure involved in attaching these mechanical orthotics to the limbs. A wheelchair is generally the principal means of self-ambulation. Although the wheelchair provides independence, the wheelchair user is placed in an unnatural, almost all-day, sitting position. This leads to problems of increased abdominal pressure, renal dysfunction, pressure sores, muscle atrophy and osteoporosis. These problems would be improved if the paraplegic was able to stand for temporary periods

of time.

Functional Neuromuscular Stimulation (FNS) is defined as the external control of innervated but paretic or paralytic muscles by electrical stimulation of the corresponding intact peripheral nerves, to achieve functional movement for rehabilitation purposes (Kralj and Vodovnik, 1977 ; Benton et al, 1981). Due to the disuse atrophy it is necessary for the paraplegic to first undergo muscle restrengthening before standing up under FNS control can be attempted. This can be achieved by FNS exercise. As the functional movement is activated by the stimulation of the person's own muscles, their natural metabolic energy is used.

There are several FNS research groups worldwide. The research has followed two main directions namely, the restoration of hand function in quadriplegics and standing and gait in paraplegics. Equipment has been developed, such as a leg trainer (Heaton et al, 1983) and bicycle ergometer (Petrofsky et al, 1984 and Mulder et al, 1986) to train paralysed muscle using FNS. Standing and primitive biped gait have been achieved (Bajd and Kralj, 1982; Barnes, 1984; Cybulski et al, 1984; Isakov et al, 1986; Khawam et al, 1987 and Phillips, 1987). Unfortunately, the claims of gait restoration have, at times, been exaggerated by the media and given false hope to the SCI population.

In South Africa, a research project on FNS - Project REWALK - was initiated by the Universities of Cape Town (UCT) and Pretoria (UP) in 1983. REWALK was subdivided into projects that were to be completed at UCT and UP. By the end of 1986 the first three projects were completed at UCT. These included: the use of trunk electromyograms for control of FNS of the lower limb, the development of a quadricycle (the Paracycle) for patient conditioning

and the development of a six-channel computer-based programmable stimulator system. The results of the latter two were integrated in a trial in mid-1986 at the Conradie Hospital, Cape Town.

After the system proved to be successful, the present project, Project RESTAND, was initiated at the close of 1986. The aim of this project is the re-establishment of standing in paraplegic subjects. This entailed the integration of a further three projects namely: an FNS muscle training and fitness program to prepare a paraplegic for standing (present thesis), the design of a mathematical model on the biomechanics of standing and the design of the control systems to stimulate the standing process.

Aims of the Study

The musculoskeletal and cardiovascular systems are affected by the functional degeneration that follows a SCI. It is therefore important for the SCI person to participate in a muscle restrengthening and fitness program before the standing up procedure can be attempted. Thus, the aim of this study was to develop a FNS muscle training and fitness program to prepare a paraplegic for standing. This would serve to prepare the 'complete person' for standing.

This involves two aspects namely:

1. The development of an FNS leg exercise program to restore the muscle bulk, strength and fatigue resistance of the atrophied muscles in preparation for weight-bearing during standing.
2. The development of an upper body exercise program to improve strength (if necessary) and cardiovascular fitness in preparation for standing under FNS control.

The study would also serve to gain knowledge of and experience in the use and effects of FNS. The subjects were seen as co-workers and fellow researchers in the project - without their experience, participation, personal input and feedback, project RESTAND would not have been possible.

CHAPTER TWO

SPINAL CORD INJURY

2.1 HISTORY OF ATTITUDES TO SPINAL CORD INJURY (SCI)

A disability of any kind is a dreaded occurrence in anyone's life. Traumatic paraplegia is one of the most devastating and catastrophic injuries that can afflict a human being. It usually happens without warning to a healthy, active person full of aspirations and future dreams. He or she is suddenly changed from an ambulatory, self-supporting, independent being in control of his bodily functions, to someone half his previous height, unable to control some basic bodily functions and often entirely dependent on others for his existence. Few other injuries cause such a profound psychological and social impact on a human being or alter individual and family life patterns so dramatically (Pierce and Nickel, 1977).

The earliest known record of paraplegia is that of an Egyptian physician in the Edwin Smith Surgical Papyrus ($\pm$2500 BC) (Sutton,1973). He accurately described the clinical features of traumatic tetraplegia and the, then, awful prognosis as "an ailment not to be treated". This attitude prevailed amongst the medical profession right up to the early years of this century (Guttmann, 1976; Hughes, 1987).

The prognostic outlook from severe lesions was extremely poor and the mortality rate very high. It was seen as the physicians forlorn task to keep the patient alive for weeks or months on end, only to see him fade away despite their efforts (Sutton, 1973). The mortality rate from paraplegia during the Balkan Wars (1912-1913) was 95%. During World War I, 90% of patients with SCI died within one year and only 1% of patients survived for more than 20

years (Guttmann, 1973). This defeatist attitude was still prevalent up to the Second World War. Tetraplegics and paraplegics were viewed as hopeless cripples, unwanted, unemployable and with a short lifespan of no longer than two or three years. Their early deaths were caused by "inevitable" SCI complications, namely, general sepsis from bedsores and renal failure. Those who did survive were kept in institutions for incurables or as "burdens" at home with the general opinion that little or nothing could be done for them and the sooner they died the better for all concerned (Guttmann, 1976).

During World War II the mortality rate from SCI was still 80% (Sutton, 1973). A fundamental step was taken by the Peripheral Nerve Committee of the Medical Research Council of Great Britain who proposed to establish Spinal Injury Units. They considered that it was unsuitable for SCI war victims to be treated in general medical wards. Twelve units were set up during World War II but these early units proved unsatisfactory as, among other reasons, they lacked any definite rehabilitation plan or objective.

A turning point for SCI rehabilitation occured in 1944 with the opening of the Stoke Mandeville Spinal Unit in Great Britian under the leadership of Ludwig Guttmann. A new concept of comprehensive management and rehabilitation was introduced. The chief object was not just to preserve life, but to restore to patients with SCI, a purposeful life including a return, in spite of their profound disability, to the community as useful and respected citizens (Guttmann, 1973). Hospital staff were trained in meticulous care and treatment. Under the new management, complications such as bedsores and contractures could be controlled and prevented. Regular work and sport were introduced as

essential aspects for successful physical, psychological and social rehabilitation.

The two decades from 1945 to 1965 produced genuine progress in SCI patient care and in public awareness of the need for such care (Pierce and Nickel, 1977). The decade from 1965 to 1975 brought a large interest and change in the medical and surgical management of tetraplegia and paraplegia and the acceptance of the SCI Centre concept throughout the world. From 1965 to 1985 the comprehensive, multidisciplinary services improved rapidly.

Today, research into different aspects of SCI has increased and together therapists and engineers are developing methods of harnessing remaining function in SCI patients to enable their disability to be reduced to a handicap. Public awareness and attitudes towards the SCI population have changed, but there is still room for more improvement in this area.

2.2 BASIC ANATOMY OF THE VERTEBRAL COLUMN AND SPINAL CORD

A basic knowledge of spinal cord anatomy and the pattern of normal motor and sensory innervation is important in understanding SCI.

Vertebral column

The vertebral column is the basic distinctive feature of the phylum Chordata and subphylum Vertebrata to which mankind belongs. It forms the central axis of the body and supports the head and trunk. It is comprised of individual vertebra that typically consist of an anterior/ventral body and a posterior/dorsal vertebral (neural) arch extended by processes and enclosing a vertebral foramen. The vertebral foramen contains the spinal cord, meninges and associated vessels, protecting them

from external forces. The vertebra vary in size, shape and direction according to the functions of the various spinal regions, namely : cervical (7 vertebra), thoracic (12), lumbar (5), sacral (5 fused) and coccygeal (3-5 fused).

The opposed surfaces of adjacent vertebral bodies are strongly bound by fibrocartilaginous intervertebral discs and anterior and posterior longitudinal ligaments. The range of movement between adjacent vertebra is small, but together they allow a large degree of bending/rotation over the entire vertebral column.

The intervertebral discs are the sites of movement. Their elastic deformability permits slight tilting and torsion while providing an element of compressibility to the spinal column. This ability to absorb and neutralise compression stresses is augmented by the curvatures of the column (Williams and Warwick, 1983). These curves are : the primary thoracic and pelvic curves which are concave forward and the secondary, compensatory cervical and lumbar curves which are convex forward. The vertebral column follows the curves and is large and triangular in the cervical and lumbar regions where movement is free, but small and circular in the thoracic region where movement is limited.

Spinal Cord

The nervous system, although in essence a continuum and interdependent, can be divided into :

Central nervous system	:	brain and spinal cord
Peripheral nervous system	:	12 cranial and 31 spinal nerves and their ramifications

The spinal cord is elongated and cylindrical and occupies the cranial two-thirds of the vertebral column. It is shorter than the vertebral column with the caudal spinal roots forming the

cauda equina. The cord is considered to be continuous with the medulla oblongata and enclosed in three meninges - the dura, arachnoid and pia mater. Each of the spinal segments give rise to a pair of spinal nerves (31) : cervical (8), thoracic (12), lumbar (5) sacral (5) and coccygeal (1). This is shown in Figure 2.1.

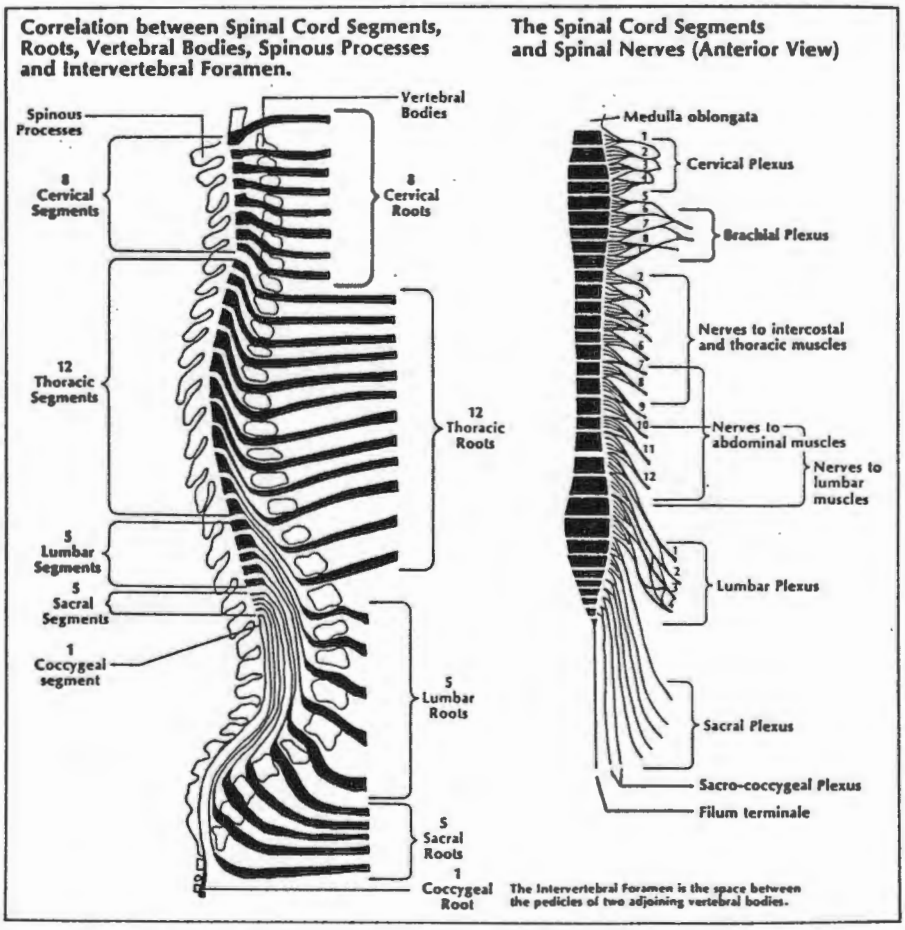


Figure 2.1 Relationship between spinal cord segments, nerves, roots and vertebral bodies (from Malick amd Meyer, 1978)

The cord comprises white and grey matter, the relative proportions of which vary at different spinal levels. The central grey matter contains cell bodies and consists of symmetrical right and left comma-shaped masses connected by a transverse grey commissure. The grey matter is surrounded by white matter containing a large percentage of myelinated fibres in ascending and descending tracts.

The Ascending (sensory) tracts include the :

Lateral Spinothalamic	: pain and temperature
Anterior Spinothalamic	: touch and pressure
Dorsal White Column	: proprioception

The Descending (motor) tracts are part of the efferent pathway controlling muscular action. They modify, facilitate or inhibit voluntary impulses according to the body's requirement. They lie in the anterior half of the spinal cord and are easily damaged by unstable injuries resulting in motor weakness and spasticity. These tracts include the :

Corticospinal : primary pathway for voluntary motor function

Vestibulospinal: facilitates extensor alpha motorneurons and inhibits flexors

Reticulospinal: complex system, implicated in muscle tone, voluntary movement and autonomic activity

Rubrospinal : facilitates flexor motor tone

Tectospinal : only in the cervical region, related to head and upper limb motion in response to audio-visual stimuli (Adkins, 1985).

Blood supply: The cervical region is supplied mainly by the vertebral arteries and the remaining regions from the radicular arteries originating from the aorta. Changes in blood flow at the time of injury can lead to severe spinal cord damage.

2.3 CAUSES OF SPINAL CORD INJURY

SCI may be the result of traumatic or nontraumatic causes. Paralyses by non-traumatic means include :

* Congenital and developmental conditions e.g. spina bifida
* Toxic and metabolic conditions e.g. chronic hepatic failure
* Inflammatory conditions e.g. poliomyelitis
* Demyelinated diseases e.g. multiple sclerosis
* Vascular causes e.g. infarction and ischemic necrosis
* Degenerative diseases e.g. motor neuronal diseases
* Neoplastic conditions e.g. osteosarcoma (Bedbrook, 1981).

The majority of SCIs are the result of trauma, that is from any physical cause excluding birth or psychic trauma, such as accidents and assaults (Co-ordinating Committee : Department of National Health and Population Development, 1987). The pathogenesis of the lesion is dependent on the nature of the bony injury which may be incurred by flexion, extension, rotation or a combination of these three. The severity of the injury, and the size of the spinal canal and spinal cord are factors that influence the extent of the damage to the cord. The effects on the spinal parenchyma are the same, irrespective of the nature of the bony injury, and include mechanical disruption of the cord tissue by compression or stretching with resulting necrosis or both. Secondary swelling (oedema) follows which may cause further impairment of blood flow. The associated biochemical and haemodynamic changes play a major role in altered spinal cord physiology in response to injury (Adkins, 1985).

Traumatic causes of SCIs include: road, rail and air traffic accidents, industrial and domestic accidents, sports injuries, falls, diving, gunshot and stab wounds. Alcohol consumption, high speeds and dangerous driving account for many road accidents

and resulting SCI which may have been prevented. Driver education and awareness, use of seatbelts, proper protection and safety in sports and checking the water depth before diving are just a few measures that could prevent some of these traumatic injuries.

2.4 STATISTICS

The relative contributions of the possible causes of SCI vary depending on the geographical location and the degree of industrialisation of the area. In industrialised countries, road, rail and air traffic accidents account for 30 - 50% of SCIs. Fracture dislocation of the vertebral column and stab wounds in the spinal cord are more common in South Africa than anywhere else in the world. By 1971, Baragwanath Hospital, Transvaal, South Africa had received 252 stab wound cases in 12 years whereas Guttmann at Stoke Mandeville, Great Britian, recorded only 4 such cases in 27 years (Guttmann, 1976). The high percentage of stab wound cases recorded at Baragwanath and Conradie Hospital, Cape Town, South Africa, were due to wounds from knives, screwdrivers, bicycle spokes, wire and scissors.

There are few available statistics in the literature concerning the causes of SCI in different regions of the world. This data was obtained for only three countries. The data is presented in Table 1 to provide some idea of the relative proportions of the causes of SCI in these three different areas.

(1) Conradie Hospital, Cape Town, South Africa (RSA) : Data from 3000 patients admitted between 1963 to 1983 (personal communication, Dr. Ray Shrosbee)

(2) United States of America (USA) : Data from the National SCI Statistical Centre reported in the Stifel Paralysis Research Foundation Annual Report (1987).

(3) Maryland (Australia) : Data reported by Cull and Hardy (1977).

Table 2.1: Relative contributions of different causes of SCI

CAUSE	RSA	USA	AUSTRALIA
road accidents	40%	47,7%	25%
falls	11	20,8	7
sports injuries	3	14,2	6
acts of violence:			
stabs	30	14,6	
gunshots	5		5
combat			6
industrial	15		4
other :		2,7	
polio			16
multiple sclerosis			7
tumors			4
TOTAL (%)	104	100,0	80

Bedbrook (1981) states that in Western Countries there are approximately 35 tetra- and paraplegics per million population. Reports estimating the SCI population in the USA vary greatly. The Stifel report (1987) claims that there are 3,5 million tetra- and paraplegics in the USA. The mean age at injury is 25 and 82% are males and 18% females. In contrast Heaton et al (1983) reports 500 000 spinal cord injured people in the USA. Cybulski et al (1984) reports estimations from the National SCI Association as 500 000 (1982) and from the National Institute of Handi-

capped Research as between 175 000 to 200 000 (1981) with 8 000 to 10 000 new cases annually.

Thus there is much discrepancy between the literature. The author was not able to obtain other information to ascertain which of these estimations is the most accurate. (The Stifel report data does seem exaggerated in relation to the other data.)

According to the 1980 census by the Department of National Health and Population Development, there are approximately 20 000 SCI tetra-, para- and hemiplegics in South Africa (Jaros, 1986). This figure is probably an underestimation.

2.5 RESULTS AND EFFECTS OF SPINAL CORD INJURY

The neurological level of injury is the lowest level at which sensory and motor function are normal. Thus a "C5" lesion means that spinal cord segments C1-5 are normal but that signs of injury with abnormal sensation and impaired motor function start at C6 level.

An incomplete lesion indicates that viable neural tissue crosses the area of injury to distal segments. Often the motor or sensory nerves of the sacral segments or both are the only ones spared. This is known as sacral sparing. A complete lesion causes complete loss of motor and sensory function below the neurological level of injury. A "zone of injury" exists in some complete injuries and is a short zone below the neurological level of injury where partial motor or sensory function or both is retained (Adkins, 1985).

A lesion above C4 may result in death due to respiratory failure from paralysis of the phrenic and intercostal nerves. Such patients are dependent on a respirator for adequate ventilation.

A lesion between C5 and T1 results in paralysis in all four limbs (tetraplegia). The degree of paralysis in the upper limb varies with the site of the lesion. A lesion below T1 results in paralysis of the trunk below the segmental level of the lesion and in both legs (paraplegia). A lesion below L1 may damage the caude equina but is usually confined to the nerve root at the level of the bony injury.

There are well illustrated body maps of the dermatomes (area of skin supplied by any one spinal nerve through both its rami) and myotomes (muscles supplied by each spinal segment) that are affected by lesions to the spinal cord at the various segmental levels. A sensory dermatome chart is shown in Figure 2.2.

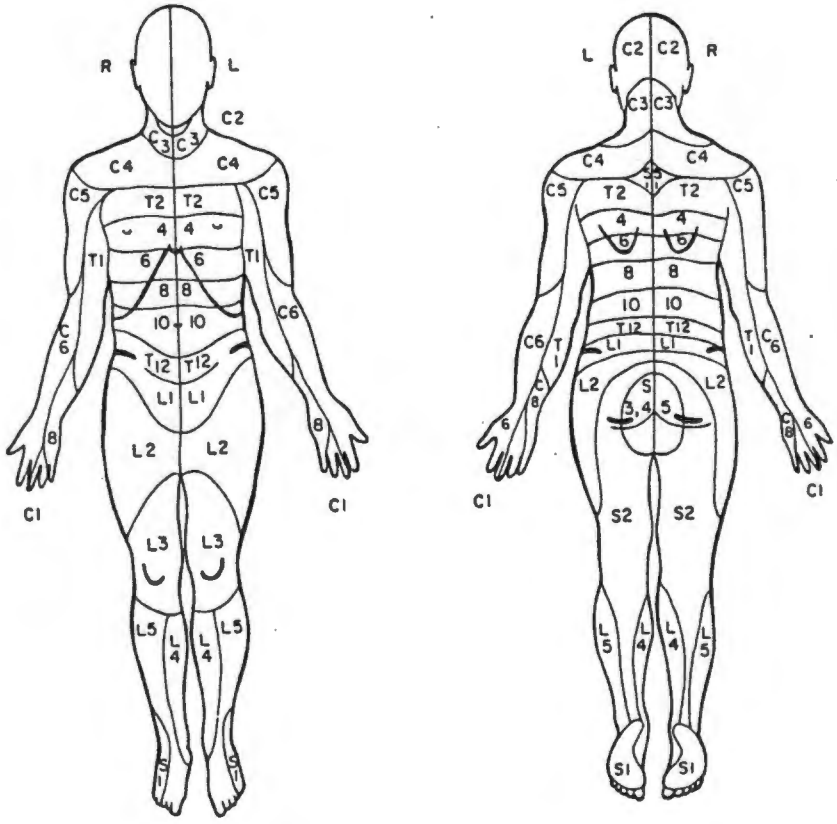


Figure 2.2 A sensory dermatome chart (from Adkins, 1985)

Incomplete lesions are complex, but there are several consistent patterns resulting from injury to certain portions of the spinal cord caused by various mechanism of injury. These result in different potentials for functional recovery. Anterior cord, central cord, posterior cord, Brown-Sequard and mixed cord syndromes are examples of these injuries.

Anterior cord syndrome is caused by bone or disc fragments contusing the anterior cord resulting in motor function loss, but preservation of sensation distal to the lesion. Light touch and proprioception remain intact.

Central cord syndrome results from hyperextension injuries to the neck. There is greater neurological functional loss in the upper extremity than in the lower, with the hands being the most severely affected.

Brown-Sequard syndrome is due to a cervical injury, typically a stab wound or a blow to the head or neck, which bends the cervical spine laterally or fractures the lateral vertebral masses. This causes injury localised primarily to one side of the cord. A characteristic feature is the loss of pain and temperature sensation on the contralateral side.

Posterior cord syndrome is rare and involves the loss of proprioception but motor function, pain and light touch are preserved.

Mixed cord syndrome involves a diffuse loss of motor and sensory functions which are not localised to a particular cross-sectional region of the cord (Adkins, 1985).

2.6 BASIC REHABILITATION

The correct immediate handling and treatment after the acute trauma is crucial as movement of the fractured spine may lead to futher damage; thus an initially incomplete lesion may become a complete one. An unconscious victim should be treated as having a SCI until it is proved otherwise by examination and radiography. The injured person should be taken to a Spinal Injury Unit within 24 to 48 hours for the most appropriate treatment and for rehabilitation.

Rehabilitation can be defined as "the ultimate restoration of the disabled to his maximum capacity - physical, emotional and vocational" (Ragnarsson, 1986). It is aimed at obtaining the maximum function in the minimum time and returning the patient to the community as soon as possible. It is undertaken by a multidisciplinary team that may include physicians, neurosurgeons, urologists, orthopaedic surgeons, psychiatrists, nurses, physiotherapists, occupational therapists, social workers and vocational counsellors. It begins with a thorough examination to determine the level of the patient's lesion and to set appropriate functional goals for his rehabilitation. Detailed accounts of the stages in the rehabilitation of SCI patients are given in some standard texts on SCI victims by authors such as Guttmann (1973 and 1976), Bedbrook (1981) and Pierce and Nickel (1978). A basic outline is presented here.

SCI affects many of the body's systems and functions including those of the urinary, gastrointestinal, sexual and respiratory systems. Each of these systems requires rehabilitation. The real extent of functional loss can be determined after the period of spinal shock - the transient loss of spinal cord reflex activity below the level of the lesion - has passed.

Proper bladder management is important to avoid bladder and kidney infection. Two types of bladder paralysis are recognised. These are dependent on the level of the lesion: An upper motor neuron lesion (T12 and above) causes a spastic or hypertonic bladder that is emptied by manual triggering of reflex activity, for example suprapubic tapping. A lower motor neuron lesion (S2 and below) causes a flaccid or hypotonic bladder which must be emptied by voluntary straining or crede. Males can use condom drainage with a legbag. Incontinence is a very difficult problem to manage in females as no suitable external urinary collecting device is available. Some may wear incontinence pads between voiding. Self-intermittent catheterization is thus especially suitable for women but is also successful in men.

Essential digestion, absorption and elimination are continued due to intrinsic gut function. Patients may make use of peristaltic activity in order to establish a routine program to achieve bowel movements at a predictable time suitable to their lifestyle. This requires careful adjustment of their diet to include a high fibre content and copious liquids in order to avoid constipation, diarrhoea or incontinence accidents. Patients with an upper motor neuron lesion may achieve reflex emptying of the bowel after using suppositories or digital stimulation. A lower motor neuron lesion causes a flaccid bowel which requires manual evacuation. Aperients are usually required and suppositories are ineffective.

Skin care is also very important. The primary cause of pressure sores is pressure on insensitive areas. Certain sites are more prone to pressure sores due to their situation and local anatomical features, for example the skin overlying bony prominences that are relatively superficial with little or no overlying

muscular or fatty tissue. The sacrococcygeal, ischial and trochanteric areas of the lower trunk are such areas at risk in a wheelchair user. In a recumbent position, the inner aspects of the knees, tibia and both sides of the ankles are at risk. Measures to avoid pressure sores include prone sleeping or turning every two hours, wheelchair push-ups to relieve pressure areas, together with frequent self-inspection and alertness to skin hygiene.

Sexual function is an area of concern in the majority of patients as they are often young - 72% are below 40 years of age. In females pregnancy is possible once menses return. Normal vaginal deliveries may require assistance in the second stage of labour due to abdominal muscle paralysis. In males with intact reflex function in S2-4, reflexogenic erections are possible. Cull and Hardy (1977) states that 3% of SCI males retain the ability to father children. Those with incomplete lesions are more sucessful. Spinal units offer sexual councelling programs for the patients and their family to aid with adjustments in their sexual activity.

A physiotherapist charts the remaining muscle function and implements a program to develop the muscles of the upper limbs and trunk above the level of injury. These become the primary means of mobility to carry out new activities to compensate for the loss of movement of the lower limbs. Daily range of motion exercises of the toes, ankles, knees and hips prevent contractures developing in the lower limbs. Breathing exercises develop the thoracic and diaphragmatic musculature in order to prevent respiratory infection. As rehabilitation progresses, the physiotherapy program becomes more active. Patients are trained in activities of daily living, for example dressing and wheelchair

dexterity. They learn necessary transfers, for example from chair to bed, from chair to car, from chair to toilet or bath and visa versa. They are encouraged to begin sporting activities and to begin ambulation training if applicable to their injury.

An occupational therapy program enhances their ability to perform tasks necessary for living, thereby increasing their independence in the activities of daily living. Orthotics are designed to aid in these tasks. The therapist sets realistic goals for each patient to explore adapted methods for a new lifestyle and to aid reintegration into the community.

A social worker will determine the personal and domestic details and position resulting from the accident. The home situation, employment and future living conditions are examined in order to achieve the optimal conditions for the individual's future care and wellbeing. A psychologist will aid with the psychological adjustment to the disability.

Rehabilitation has become more efficient and hospital stays have halved compared to practices 15 to 20 years ago. Ragnarsson (1986) states that patients with paraplegia or tetraplegia can be maximally functional within three and five months respectively.

2.7 POST DISCHARGE

The patient's whole personality, age, education, former occupation, family background and reaction to injury are important in determining his ultimate mode of life (Cull and Hardy, 1977). He has the responsibility of self-care (if not provided by an attendant) in order to prevent some of the many common medical problems and complications that SCI people may face.

These include :

Respiratory tract infections : for example broncho-pneumonia.

Urinary tract infections : This is the most common complication of a SCI. Urinary tract complications are the major cause of morbidity and mortality. Clinicians emphasise achieving continence if at all possible. The main aim is to preserve renal function (Grundy et al, 1986).

Pressure sores : especially in wheelchair users.

Heterotrophic ossification : The development of calcification in certain tissues that may limit joint movement, for example in the upper femoral area.

Contractures : These are due to shortening or tightening of muscles and structures around a joint causing a decreasing range of movement around the joint. Proper positioning and range of motion exercises help to prevent these.

Autonomic hyperflexia (dysreflexia) : This usually occurs in people whose lesions are at T5 and above. It is due to an increased sympathetic response to stimuli arising in the pelvis by, for example, overdistension of the bladder and rectum. It results in an increase in blood pressure and the cause of the stimulus must be removed.

Postural hypotension : This occurs mainly in tetraplegics and high paraplegics. A drop in blood supply to the brain results in dizziness and sometimes fainting.

Thermoregulation : Sweating due to sympathetic stimulation may occur on a segmental reflex basis as the result of bowel or bladder overdistension. Those with lesions at T10 or below

shiver in muscles innervated above the lesion level when the skin is cooled without a decrease in deep body temperature.

Spasticity : There is a decrease of voluntary control below the level of the lesion and this results in erratic spinal reflex activity which may be fired by a minimal stimulus, for example cold or touch.

Thrombophlebitis : Inflammation of a vein with the presence of a blood clot may be due to sluggish circulation from inactivity.

Oedema : This may be the result of prolonged sitting with legs down and due to the lack of muscle action to pump fluid out of the extremities.

The health and life expectancy of SCI patients is also compromised by avoidable and unavoidable complications. Atherosclerosis and its complications are a high cause of late death, but renal failure, pressure sores and respiratory tract infections particularly in tetraplegics, also feature prominently. Malick and Meyer (1978) states that renal failure is the major cause of late mortality. Due to improved health care, the life expectancy of SCI patients has increased markedly since the Second World War. According to Bedbrook (1981), tetraplegics and paraplegics, respectively, now have average lifespans of only ten and five years less than average.

2.7 RESEARCH

SCI affects the whole person and therefore covers a vast array of scientific disciplines. Research is directed into many areas to aid and improve the quality of life. The area of spinal cord regeneration is receiving increasing attention but false hopes must not be raised; there is, as yet, no cure for SCI. This

emphasis on research has resulted in changed attitudes amongst the SCI population. They are now reluctant to undergo destructive surgical procedures so that their bodies are in shape, ready for a possible cure.

Research into Functional Neuromuscular Stimulation (FNS) is one area that can provide some useful function and reverse some of the functional degeneration and deconditioning effects of a SCI. If this reconditioning cannot be achieved, the bodies of many SCI people would not be in suitable physical condition on which to apply a sucessful cure, should one be found. FNS may offer a new alternative to the present mode of rehabilitation until a biological method to restore function is found.

CHAPTER THREE

ELECTRICAL STIMULATION

3.1 PHYSIOLOGY OF NERVE AND MUSCLE FUNCTION

This overview provides a background knowledge of basic nerve and muscle physiology in order to understand the mechanisms of FNS.

Nerve

There are three main types of peripheral nerve fibres, designated as types A, B and C. The fibre diameter decreases from A to C and thus they differ in characteristics such as conduction velocity and excitation threshold. The type A alpha and gamma fibres are motor neurons concerned with motor function.

The neurons have four functionally distinguishable regions namely, a cell body, an axon that terminates in synaptic knobs, and a dendritic region. The nerve membrane has a voltage-sensitive permeability upon which its electrical excitability is dependent. The interior of the nerve cell (body) contains potassium ions in high concentration and sodium ions in low concentration due to active transport by the metabolic membrane pumps. In its resting state, the membrane is more permeable to potassium than to any other anions and has a resting membrane potential of approximately -70mv across it, that is, the inside of the membrane is negative with respect to the outside.

The nerve membrane operates on an all-or-none principle. It requires an adequate stimulus, that is, one that meets or exceeds its excitation threshold, to produce a response namely, depolarisation. The stimulus can be of a chemical, mechanical or electrical nature. The relationship between the adequate inten-

sity and sufficient duration of the stimulus is represented by a strength-duration curve.

The method of excitement is always a depolarisation of the nerve membrane resulting in the propogation of an action potential. This is a sequence of potential changes as follows:

On depolarisation, the membrane permeability to sodium increases and there is an influx of sodium ions along its electrochemical gradient. This sodium influx further depolarises the membrane and the membrane tends to its sodium equilibrium potential. The sodium influx decreases or ceases when the equilibrium potential is reached. The increased permeability to sodium is therefore transient and is followed by an increase in potassium permeability. This results in a rapid efflux of potassium ions from the cell which causes repolarisation of the membrane to the potassium equilibrium potential (Fidone, 1975).

Following the initial excitation of the nerve membrane, a refractory period exists. This consists of an absolute refractory period during which the nerve fibre is completely inexcitable to a second stimulus, and a relative refractory period during which only a stronger than normal stimulus can cause excitation. This property of nerve fibres prevents the development of a state of continuous excitation as fusion and summation of impulses do not occur in the nerve fibres.

Information coded as individual impulses is transferred via synapses to other nerve cells and to muscle cells via neuromuscular junctions. The impulse arriving at the nerve ending causes the release of a neurotransmitter from the presynaptic membrane vesicles. The neurotransmitter crosses the synaptic gap and attaches to the postsynaptic membrane receptors, thereby initia-

ting excitatory processes in the other tissue, for example, muscle.

Muscle

Muscle cells, like neurons, can be excited chemically, mechanically or electrically. In muscle, the adequate stimulus produces an action potential which in turn activates the contractile mechanism.

There are three types of muscle in the body namely, cardiac, smooth and skeletal muscle. Skeletal (striated) muscle consists of bundles of muscle fibres (cells). These multinucleated elongated fibres consist of myofibrils, made up of myofilaments. The filaments are comprised of contractile proteins - actin, myosin, tropomyosin and troponin - which are arranged in sarcomeres and are responsible for the contractility and force generation of the muscle.

The functional unit of muscle response is the motor unit, which includes the nerve cell originating in the grey matter of the spinal cord and the muscle fibres that it innervates. The number of motor units in a muscle vary according to its size and function. The motorneuron terminates on the muscle fibre at the motor end plate of the neuromuscular junction. An action potential in the motorneuron causes the release of neurotransmitter across the synaptic gap at the junction. The neurotransmitter is taken up by receptors on the muscle fibre. The depolarisation (end plate potential) starts at the motor end plate and is transmitted along the muscle fibre. Muscle fibres also respond according to an all-or-none principle. If the depolarisation is of an adequate stimulus (amplitude and duration) to meet the threshold of a particular fibre, it initiates a chemically-mediated con-

tractile response which results in muscle contraction (excitation-contraction coupling).

Basically, a contraction occurs as follows:
The action potential is transmitted to the myofibrils within the muscle fibre via the transverse tubular system (T-tubules). The T-tubules are internal extensions of the muscle cell membrane therefore ensuring the transmission of the action potential to the deep interior of the muscle fibre. The sarcoplasmic reticulum is composed of longitudinal tubules that terminate in chambers called terminal cisternae which abut the T-tubules. The action potential in the T-tubules triggers the release of calcium ions from the terminal cisternae into the surrounding sarcoplasm. These calcium ions in turn initiate the chemical events of the contractile process.

The released calcium ions diffuse to the adjacent myofibrils. Here they bind with troponin and thereby activate the contractile mechanism. The calcium-troponin complex undergoes a conformational change that removes tropomysin from the active sites of the actin. Thus the heads of the cross-bridges from the myosin filaments can bind to the active actin sites and this causes contraction to occur.

An active calcium pump located in the sarcoplasmic reticulum membrane pumps calcium ions out of the sarcoplasmic fluid back into the vesicular cavities of the reticulum. The muscle contraction ceases with this removal of calcium ions from the myofibrilar fluid as this deactivates the actin-myosin cross-bridges. This results in muscle relaxation (Guyton, 1982).

The contractile mechanism does not have a refractory period as found in nerve and muscle membranes; hence summation of contractions can occur. The individual responses fuse into one continous contraction, a tetanic contraction. Therefore, by modulating the stimulus frequency the magnitude of the muscle response can be increased.

Neural control of skeletal muscles is via nerves from the alpha motorneurons or anterior horn cells in the spinal cord. The alpha motorneurons in turn are controlled by descending tracts from the central nervous system. The alpha motorneurons control muscle contractility by modulating the frequency of the action potential and the number of fibres recruited.

There are two types of sensory organs that are involved in regulating the muscle response - the Golgi tendon organs and the muscle spindles. The Golgi tendon organ is a musculotendinous end-organ that sends proprioreceptive infomation from the muscle to the central nervous system. This organ measures the velocity of tension developed and the steady tension at a constant muscle stretch or muscle contraction. The Golgi tendon organ inhibits the alpha motorneuron in order to reduce muscle tension (Figure 3.1).

The muscle spindle is built around three to ten small intrafusal muscle fibres (very small skeletal muscle fibres) which are attached to the sheaths of the surrounding extrafusal skeletal muscle fibres. The central portion of the intrafusal fibres has few or no actin and myosin filaments and therefore this portion does not contract when the ends of the fibres do when they are excited by gamma efferent motor nerve fibres.

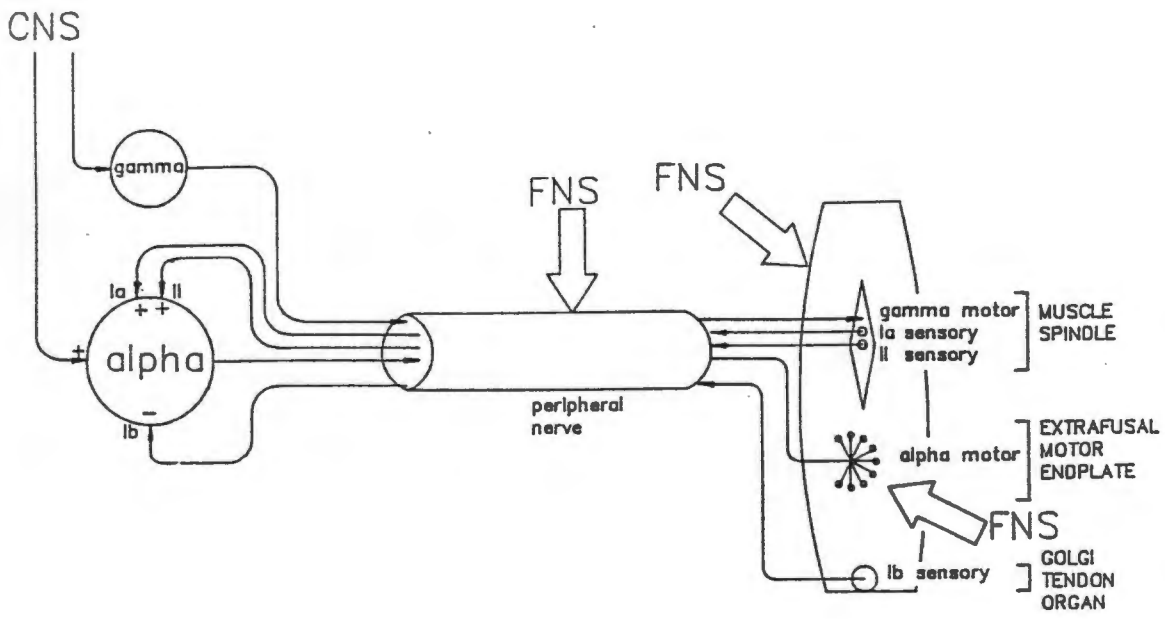


Figure 3.1 Neuromuscular physiology. Sites for FNS application are included (courtesy of Pons, 1986)

The central portion is the sensory receptor area of the spindle and has two types of sensory endings - the primary ending and two secondary endings. The primary ending is formed by the tip of a large type Ia sensory fibre which spirals around the intrafusal fibre. This sensory fibre innervates the centre of the muscle spindle and is stimulated when the central portion of the spindle is stretched. The two secondary endings are composed of type II nerve fibres which innervate the receptor region on either side of the primary ending. They too are stimulated when the central portion of the intrafusal fibres is stretched.

The muscle spindle is sensitive to changes in muscle length, that is, the static response of the spindle receptor from both ending types. A dynamic response is exhibited by the primary ending as it actively responds to the rate of this change in the muscle length.

The muscle spindle acts as a comparator of the lengths between the intrafusal and extrafusal muscle fibres. If the length of intrafusal fibres is greater than that of the extrafusal, the spindle is inhibited, but is excited when the opposite situation occurs (Guyton, 1982).

Once there is a desire to move, the appropriate neural signals are sent from the motor cortex of the cerebrum and cerebellum. From here the signal is sent via the descending spinal tracts to the alpha and gamma motorneurones. The alpha motorneuron signal causes the extrafusal muscle fibre to contract and the resulting muscle length is compared in the muscle spindle with the length of the intrafusal fibre set by the gamma motorneuron. If there is any discrepancy between these two muscle lengths the muscle spindle (as a comparator) is excited or stimulated accordingly in order to correct for the discrepancy.

There are three types of muscle contractions: An isometric (no change in muscle length during contraction), an isotonic (muscle shortens, but tension on the muscle remains constant) and isokinetic (constant velocity of shortening) contraction.

3.2 ELECTRICAL STIMULATION (ES)

Excitability of nerve and muscle is the basis of inducing functional motor responses by ES.

The processes of neurosecretion and chemoreception involved in the action potential conduction and the synaptic transmission are the same irrespective of the mechanism of the original excitation. Therefore, transcutaneously applied electrical stimulation may produce a muscle contraction similar to that evoked by normal voluntary physiological activity. Excitation by electrical sti-

mulation of a motor nerve is the typical method for the initiation of muscle contraction (Benton et al, 1981).

Although the contraction produced by ES is similar to a contraction induced voluntarily in a normal manner, there are certain features of the motor unit organisation and recruitment that differ from the physiological pattern when ES is used as the mechanism of muscle force production.

Firing pattern:

Under voluntary control, the motorneurons are asynchronously excited, that is, they are recruited and excited at different times and rates causing the motorunits they innervate to contract and relax at different times. The resulting total muscle response is a smooth contraction with force distributed rather uniformly across the muscle as the motor units, and individual fibres comprising them, are scattered throughout the whole muscle. This facilitates a maintained but slowly fatiguing contraction with the production of a steady state force (activity is not restricted to the continuous firing of one motorneuron).

Under ES control, the motorneurons are synchronously excited. A limited population of motorneurons and motor units are excited continuously, within the limits of their responsiveness, at the frequency of the external stimulus. This results in a rapid rate of fatigue of the contractile system. Furthermore it may be necessary to use a high intensity of stimulus to recruit motorunits with a higher threshold of excitation in order to evoke a specific, maintained force output from the whole muscle (Benton et al, 1981).

Motor unit excitability

Under voluntary control, generally the small motorneurons and then the small, slow motor units are excited first followed by the larger, faster, more powerful units.

Under ES control, the most excitable units fire first, that is, the large neural fibres that typically supply the large, fast and more easily fatiguable motor units. The smaller, slower motor units are only excited if the stimulus is increased or the stimulus parameters are altered to those that will reach the particular firing thresholds of these fibres. These small units are metabolically capable of more prolonged contraction without fatigue. Surface ES is most effective in stimulating the fast, fatiguable muscle fibres as, anatomically, these tend to be located superficial to the smaller, more fatigue-resistant fibres (Benton et al, 1981).

3.3 PRINCIPLES OF ELECTRICAL STIMULATION

Certain components and properties of the ES affect the quality of the motor response. These include the ion flow, impedance, electrode size and orientation.

Ion Flow

Nerve and muscle excitation is produced by ion movement across the tissue membrane under the influence of an electrical field. At the electrode-tissue interface there is a transfer from the current within the circuitry of the muscle stimulator to a flow of ions within the tissue. Generally, two electrodes are used, namely the anode (positive electrode) and the cathode (negative electrode). If the electrodes are of equal dimensions, they are called bipolar electrodes (Vodovnik, 1981). An electrolytic in-

terface is created between the electrodes and the skin's surface by the application of electrolyte gel to the undersurface of the electrode. The electrolyte lowers the skin's electrical resistance and provides a good conducting medium of non-toxic, physiological ions (Benton et al, 1981).

Excitation, that is, membrane depolarisation, occurs principally at the cathode. An ionic current is created as positive ions move into the tissue beneath the anode and out of the tissue at the cathode by the following mechanism: at the anode the positive ions (such as sodium and potassium) in the electrolyte interface and underlying skin tissue are repelled and the negative ions (such as chloride) are attracted. The cathode attracts the migrating postive ions and repels the negative ions.

The impedance, size and orientation of the electodes as well as the electrical stimulation parameters are some of the factors that determine whether the stimulation through the surface electrodes is sufficient for neural excitement (Benton et al, 1981).

Impedance

Impedance is composed of resistive, capacitive and inductive tissue components. The stratum corneum, a horny layer of the skin, is a good insulator and forms the chief resistance of the body. Tissues in the body differ in their relative conductivity according to their content of water and available ions. Current flows more easily through tissue with a low impedance.

Electrode size and orientation

Current density is the ion flow per unit area. It is a measure of the quantity of charged ions moved through a particular cross-sectional area of tissue. It is usually maximal at the tissue-electrode interface and decreases with the distance away from the

electrode. If the electrodes are small and close together, the effective area of stimulation is localised to the superficial tissues. If the electrodes are further apart, deeper tissues are stimulated. Current density increases as electode size decreases and visa versa.

Electrodes should be made of a pliable material that maintains constant skin contact during contraction. They should not produce toxic products. The electrolytic interface of a gel or paste is critical to facilitate current flow.

3.4 ELECTRICAL STIMULATION PARAMETERS

These parameters affect the success of an FNS program and therefore it is important to understand their effects on neuromuscular stimulation. Variation in parameters leads to the recruitment of different fibre types (Grant and Swain, 1985).

There are different types of waveforms that are used in ES namely, High Volt, Galvanic, Interferential, 'Russian' and Assymetrical Biphasic.

Basically:

High Volt : a twin spike, very narrow pulse width (10 usec), all positive pulse.

Interrupted Galvanic : purely positive, very wide pulse width (1-10 msec). Used for denervated muscle.

Interferential : two slightly different high frequency sine waves which are set to cross within the body, eg 4000 Hz and 4000-4100 Hz.

Russian or High Frequency Stimulation : the characteristics of this waveform are between that of the interferential and biphasic symmetrical. A sine wave is modulated

into pulses. It combines a low frequency pulse rate with a high frequency component.

Assymetrical Biphasic : positive component is larger than the negative. Similar to that generated in the body. No ion build-up which prevents skin irritation (Benton et al, 1981).

Pulse Shape:

Popp (1986) concluded from a survey on pulse shapes that a pulsatile current is currently the worldwide accepted waveform. It can be monophasic or biphasic. A rectangular monophasic wave has a sudden gradient which eliminates accommodation, ensuring firing. Its potential disadvantage is that, due to it being unidirectional, it causes polarisation under the electrodes due to unequal ion flow. This may lead to electrode deterioration and skin irritation with prolonged use. An assymetric biphasic waveform is a modification on this and provides a bidirectional flow with a monophasic stimulation effect (Figure 3.2).

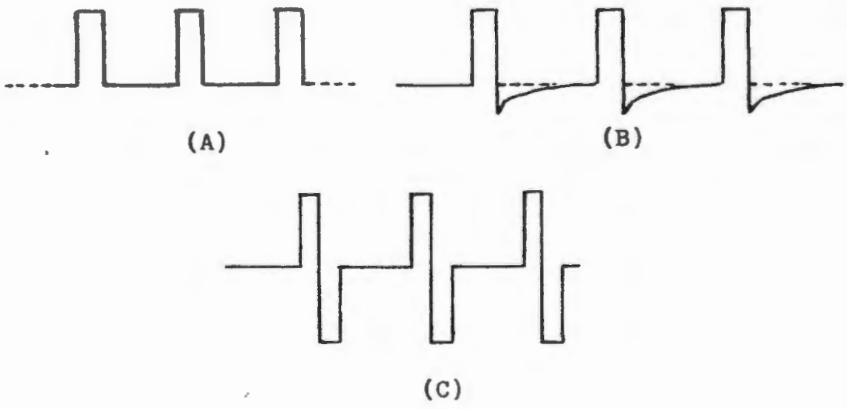


Figure 3.2 Types of pulsatile current.
(A) Monophasic (uni-directional)
(B) Asymmetrical biphasic
(C) Symmetrical biphasic
(adapted from Benton et al, 1981)

Symmetric biphasic waveforms allow both electrodes to be active during the respective alternating cycles. According to Popp (1986) there are limited studies (2) investigating the effects of different biphasic waveform types on FES. The results are contradictory and more research is needed.

Frequency:

Stimulation should produce a smooth tetanising contraction for functionally useful movement. Figure 3.3 illustrates that smooth tetanising contractions occur at $\pm$ 30 Hz. At higher frequencies, little extra force is gained from the contraction. There is a trade-off between moderate frequencies to create a smooth tetanising contraction and low frequencies to minimise fatigue. ES is metabolically expensive and fatiguing due to the synchronous firing of the same, few fibres. The time to fatigue varies according to the amplitude and frequency of the stimulation, the muscle fibre type composition and the patient's general state of health. Fatigue may be due to: decreased neurotransmitter release and failure of the synaptic junction (shown to occur at >30-40 Hz) or muscle fatigue due to contraction-produced ischaemia. Metabolic fatigue of the contractile mechanism has also been described (Benton et al, 1981). The higher the frequency, the more rapid is the rate of the onset of fatigue (Figure 3.4).

Duration (Pulsewidth):

The pulse characteristics, that is its duration and amplitude, determine the type of motor response that will occur. The duration and amplitude must be adequate to meet or exceed the excitability threshold of the tissue. The population of nerve fibres and motor units excited by the ES can be controlled by adjusting the duration and amplitude of the current pulse.

The pulse duration required to activate muscle is about two orders of magnitude greater than to activate nerve. Short pulses of 0,1 to 1 ms commonly activate nerve. Within a range of 20 µs to 1 ms, the pulse duration determines the amplitude required to produce a nerve and secondary muscle reaction. By maintaining a set amplitude and varying the pulse duration (such as from 500 µs to 50 µs) a near maximal strength contraction can be decreased to a minimal contraction (Figure 3.5) (Benton et al, 1981).

Pulse Rise time:

Due to accommodation, a gradual rise in the excitation threshold may occur in the presence of a slowly increasing stimulus and the nerve may fail to fire. An abrupt rise therefore prevents accommodation and activates the nerve more consistently.

Amplitude (intensity):

As previously stated, the combination of amplitude and pulse duration determine which nerve fibres will be activated by the ES. An adequate stimulus results in the excitement of those fibres nearest the electrode and of largest diameter (size ordering of nerve excitability to ES). When the amplitude is increased, additional fibres are excited - both smaller fibres nearer the electrode and larger fibres further away. Figure 3.6 shows the effects on a change of amplitude on the force produced - a characteristic S-shaped curve. No reaction occurs till threshold is reached, and beyond a certain amplitude there is little force increase as nearly all the motor units have been recruited.

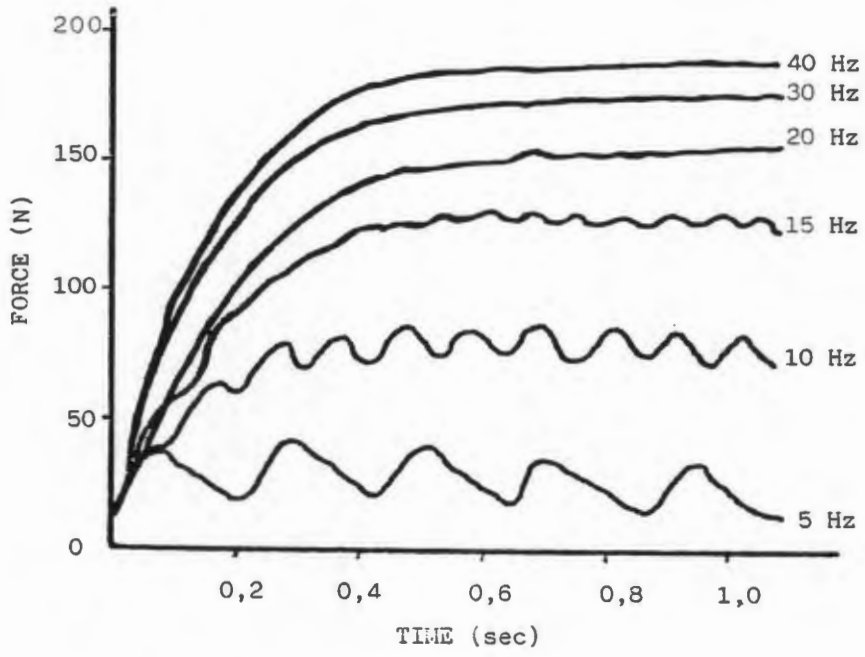


Figure 3.3 Effects of stimulation frequency on muscle force (adapted from Benton et al, 1981)

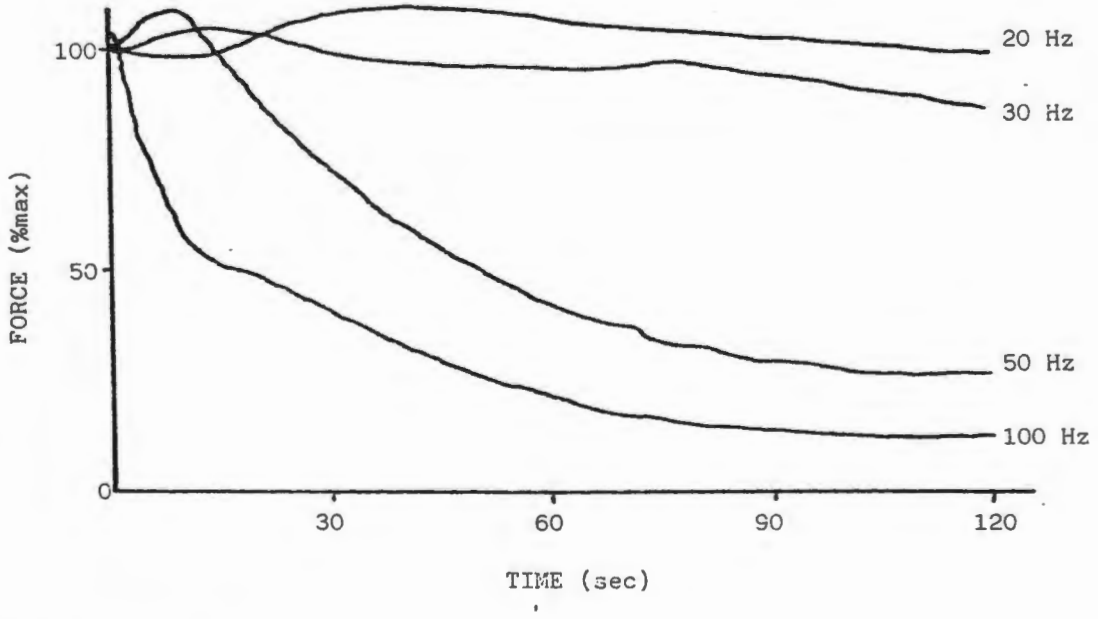


Figure 3.4 Effects of stimulation frequency on muscle fatigue (adapted from Benton et al, 1981)

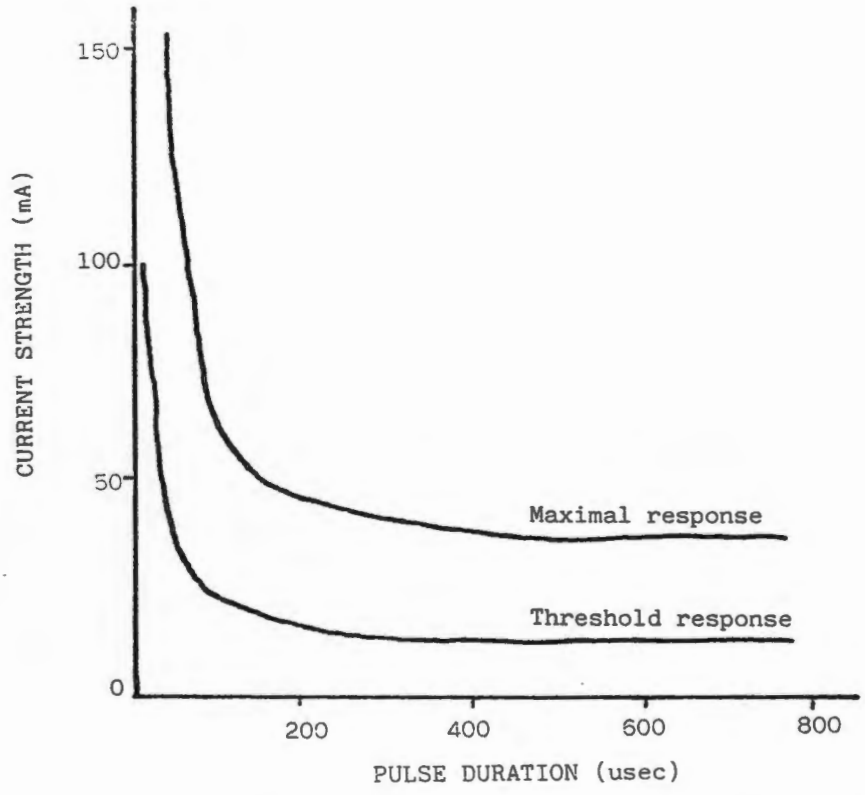


Figure 3.5 Effects of variation of stimulation pulsewidth and amplitude on muscle response (adapted from Benton et al, 1981)

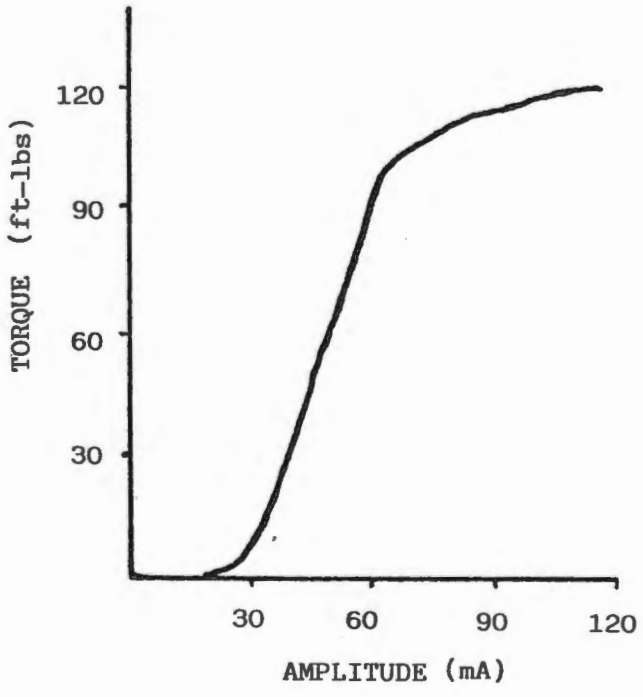


Figure 3.6 Effects of amplitudes on muscle force (adapted from Benton et al,1981)

Duty Cycle (on-off cycle):

This is the ratio of stimulation time to rest time. It affects the fatigue during prolonged ES. During "on" time, a train of individual pulses of the set amplitude, duration and frequency of the stimulator is supplied. Each pulse is a separate stimulus and determines whether a motor response will occur. The length of the pulse train determines how long the response will be maintained. A 1:1 ratio results in rapid fatigue due to insufficient recovery time. A 1:5 ratio results in the near maximum force being maintained for a longer period (Figure 3.7).

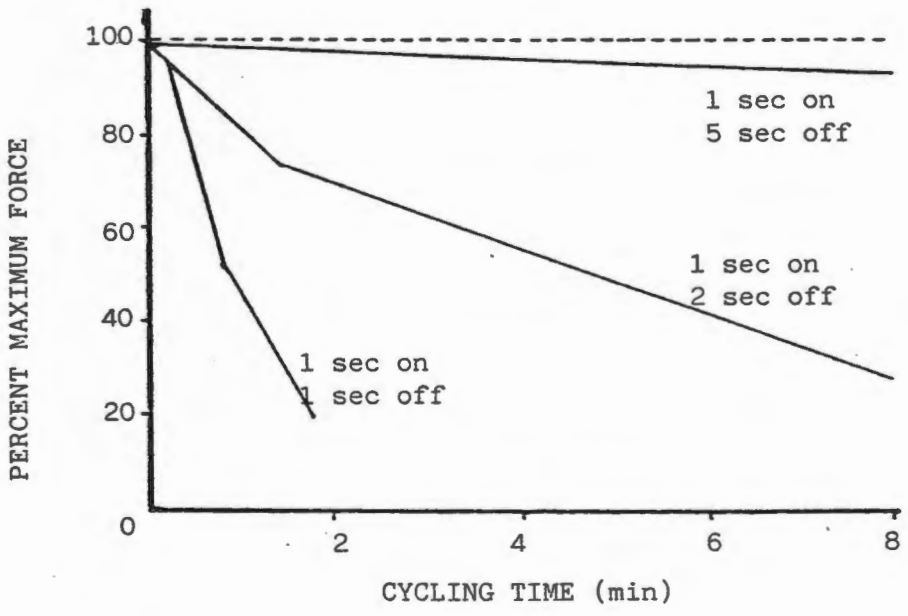


Figure 3.7 Effect of duty cycle on muscle fatigue (adapted from Benton et al, 1981)

Two features of stimulator design may serve to increase comfort:

amplitude rise time: amplitude is increased gradually to a preset level

duration rise time : duration is increased gradually to a predetermined width

Both of these features allow a gradual recruitment of the nerve fibres as the excitement thresholds of more fibres are reached as the intensity or pulse width increases (Benton et al, 1981).

3.5 ELECTRICAL STIMULATION (ES) IN THE ABLE-BODIED POPULATION

Generally, exercise programs utilising isotonic, isometric or isokinetic techniques are considered to be the most important means of developing power and strengthening muscle in healthy, able-bodied people.

There has been increased interest in the use of ES in strengthening normal muscle since the Soviet investigator Kotz published work on ES in athletes. Kotz used isometric ES training to strengthen healthy muscle and claimed that ES produced results that were superior to normal exercise programs alone. He theorised that an involuntary ES contraction could be 10-30% higher in strength than a maximum voluntary contraction (MVC) as the ES current is able to recruit more peripheral motor units than a MVC. Nobbs and Rhodes (1986) state that this is still a "somewhat unproven postulation". Kotz used a "10 second maximum tetranic contraction : 50 second rest, repeated 10 times" regime.

Numerous studies have been completed since Kotz's claims in an attempt to reproduce his results. A controversy exists in the literature as results have been conflicting and of lower magnitude than those reported by Kotz. Comparison of these studies and the drawing of valid conclusions is complicated by the lack of detail and standardisation of the ES current format, parameters and application techniques. Variations occur in the equipment (stimulators), subjects, training protocols, training factors (such as frequency and period of training sessions, duration and intensity of training contractions) and stimulus parame-

ters (frequency, amplitude, pulsewidth and waveform). This is illustrated by the fact that studies report the use of monophasic (Stefanovska, 1985), biphasic (Kramer, 1987), rectangular (Munsat et al, 1976; Currier et al, 1979) and square waves (Hartsell, 1986) of frequencies 25 (Currier et al, 1979; Stefanovska, 1985), 35 (McNeal and Baker, 1986), 50 (Halbach and Strauss, 1980), 60 (Nobbs and Rhodes, 1986), 65 (Hartsell, 1986), 75 (McMiken et al, 1983) and 100 Hz (Kramer, 1987). Sinusoidal waves of 2200 and 2500 Hz modulated by 10 msec "on" and 10 msec "off" to provide an effective motor stimulation frequency of 50 Hz are also reported (Laughman et al, 1983; Parker et al, 1986 and Selkowitz, 1985).

Choice of parameters in these studies on able-bodied people may be different from those used in FNS, as normal subjects have pain and sensory perception and therefore the stimulus used is limited by subject tolerance, such as shorter pulse durations may be more comfortable as they avoid stimulating sensory fibres.

A review of 18 articles on various aspects of ES in the able-bodied, revealed the following: Lloyd et al (1986) reported that only two studies have shown mean ES induced torque to be significantly greater than that of a maximum voluntary isometric contraction (MVIC):

* 10-30% higher in the triceps and biceps brachi of Sumo wrestlers
* 31% higher in adductor pollicus

Most other studies have been performed on the quadriceps femoris muscle. Besides the previously mentioned variations between the studies, the investigators also used different combinations of groups. The conclusions are presented according to these groups.

The following abbreviations are used.

C = control group

VE = voluntary exercise (isometric, isokinetic, MVC)

ES = electrical stimulation

SI = ES superimposed on VE

(a) C and ES:

Romero et al (1982) and Selkowitz (1985) (C:18% and ES:44%) both found a significant increase in isometric strength in the ES-trained group.

(b) VE and ES:

Halbach and Strauss (1980) showed an increase in power in both groups, but that of the VE group (isokinetic) (41%) was significantly greater than the ES (22%). McMiken et al (1983) used isometric exercise (VE) and found an increase in strength in both groups (VE:25% and ES:22%) but no significant difference between the two.

(c) C, VE and ES:

Both the VE (isometric) and ES groups showed significant increases in strength above the controls (VE:18%; ES:22% but no significant difference between the exercising or stimulated groups.

(d) C, VE, SI:

Currier et al (1979) reports that the SI (19%) had no greater effect in increasing strength than the VE alone (21%).

(e) VE, ES, SI:

Hartsell (1986) found that SI was more effective than no training, but did not have a greater effect than VE alone. Nobbs and Rhodes (1986), using isokinetic exercise, report that all the

groups showed improved power and strength, but there was no significant difference between them. In Kramer's study (1987), ES was compared at 20, 50, 100 Hz and SI at 20, 50, 100 Hz. The results showed that VE and SI at 50, 100 Hz were the most effective conditioning methods, but there was no significant difference between these conditions.

(f) C, VE, SI, ES:

Currier and Mann (1983) report that all experimental groups differed significantly from the control, but that there was no significant difference between the experimental groups.

Lloyd et al (1986) also mentions four other studies: one showed that mean ES torque was greater than VE torque only when faradic stimulation was used; two compared VE, ES and SI groups. Only the SI group produced similar results to the VE group but was not significantly different; the fourth reported that the VE group produced significantly greater torque than ES.

These studies show that ES can effectively develop muscle strength in normal muscle, but they do not appear to be greater or superior to VE as Kotz claimed.

ES is also used in the rehabilitation setting in the able-bodied population. It has been shown to retard muscle strength loss and increase muscle strength in innervated, weak or atrophied musculature after denervation injuries or knee pathologies. Lloyd et al (1986) reviewed 8 studies utilising ES after knee surgery/ trauma or in patients with knee pathology such as condromalacia patella. In these cases, SI and ES were shown to produce superior increases in muscle function than did VE alone.

It therefore appears that the greatest changes with ES occur in weaker muscle. Thus the greatest potential for ES in the able-bodied is possibly in the rehabilitation of weakened, or traumatised muscle and not to increase the strength of trained athletes. Selkowitz (1986) states that ES is useful for decreasing rehabilitation time and maximising the recovery potential of patients with decreased quadriceps strength. ES may be suited to the initial management of motor re-education (to decrease muscle strength loss), but in the able-bodied population, active exercise is the eventual objective in a rehabilitation progam.

ES, therefore, probably has its greatest benefit in providing function for the neurologically disabled population, such as in para-, tetra- and hemiplegics. This form of ES is termed Functional Electrical Stimulation (FES) or, as it will henceforth be referred to, Function Neuromuscular Stimulation (FNS).

CHAPTER FOUR

FUNCTIONAL NEUROMUSCULAR STIMULATION

4.1 DEFINITION

FNS is defined as the external control of innervated but paretic or paralytic muscles, by electrical stimulation of the corresponding intact peripheral nerves to achieve functional movement for rehabilitation purposes (Kralj and Vodovnik, 1977 ; Benton et al, 1981). Figure 4.1 illustrates the principles of FNS.

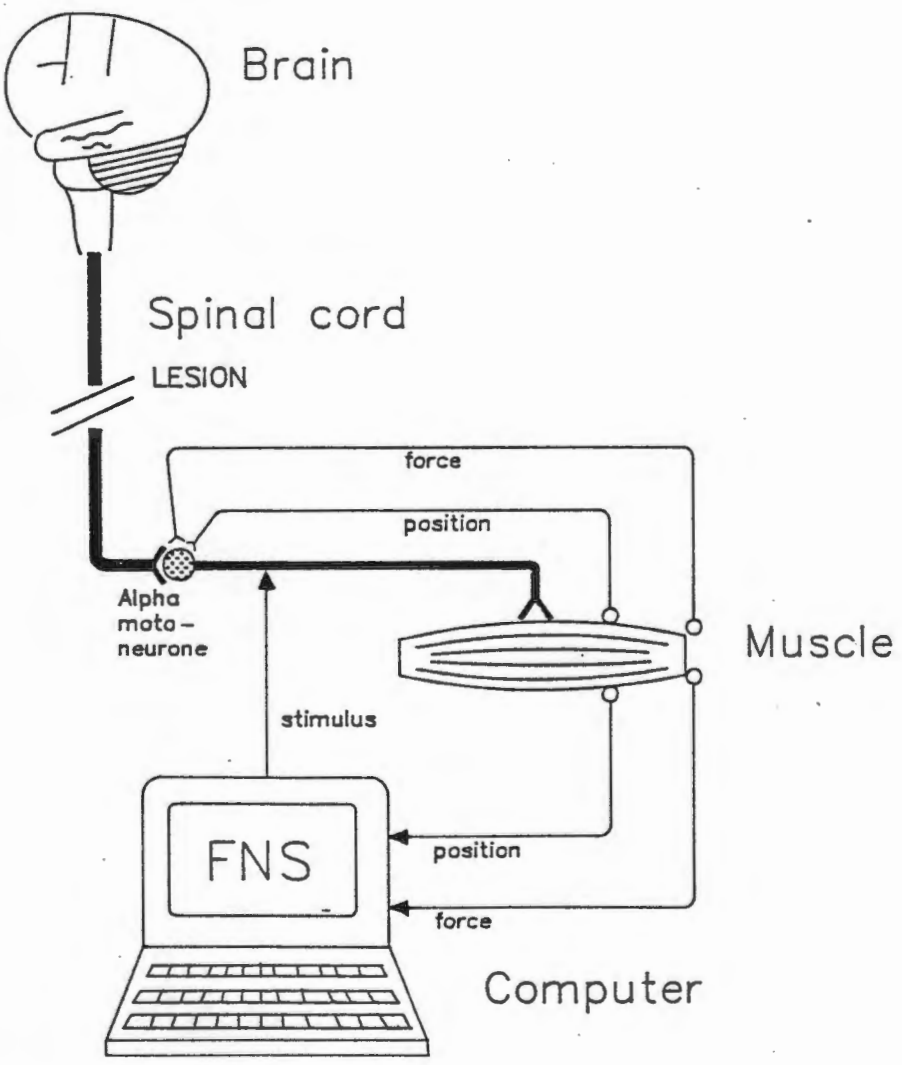


Figure 4.1 The Principles of FNS: Although signals from the brain are disrupted due to a lesion,if the pathway between the alpha motorneuron and the muscle is intact, FNS may cause muscle contraction. Feedback of muscle force and position should be provided to compensate for the loss of natural feedback (courtesy of Pons, 1986).

4.2 BRIEF HISTORY

The use of electricity to treat disease is not new, but there has been a vast improvement since the use of the electrical discharge of the torpedo fish in 400 BC (Benton et al, 1981). In medical history, electrical stimulation (ES) originates from the time of Luigi Galvani (1791) who discovered that ES resulted in skeletal muscle contraction (Heaton et al, 1983). In 1840 the introduction of electricity into muscles was recommended as a diagnostic tool. An increased understanding of ES and improved devices, including the battery and induction coil, led to attempts to cure numerous diseases and the late nineenth century was termed the "Golden age of medical electricity". After Einthoven's discovery of the electrocardiogram (1903) and inspite of previous misadventures, there were genuine therapeutic applications with the development of the first cardiac pacemaker by Zoll in 1952. This success led to increased scientific interest in electrotherapy.

The first clinical application of FNS was the development of a single channel stimulator to correct dropfoot in hemiplegia. In 1961 Lieberson adapted it and adopted the term "electrotherapy". In 1962 Moe and Post termed the phrase 'functional electrical stimulation ' which was later (1967) defined as 'the ES of muscles deprived of nervous control with a view to providing muscle contraction and producing functionally useful movement" (Vodovnik, 1981).

The first scientific application to SCI was by Kantrowitz in 1963 who reported that its use produced standing in a T3 paraplegic. Among other early reports are those of: in 1970 Willeman, from Rancho Los Amigos, reported on a T5 female who stood and walked with FES, crutches and short leg ankle orthosis; in 1972 Kralj studied muscle forces exerted by FES in 50 paraplegics; in 1978

Brindley reported patients with T7 and T12 spinal lesions who stood (35 and 75 minutes) and walked (15 and 5 minutes respectively) and Kralj et al (1980) reported on two paraplegics (T5 and T10) who achieved standing and primitive bipedal gait. Although these early studies achieved standing and in some cases used implanted electrodes, there was not a great demand due to insufficient information on ES, biomechanics, neurophysiology and medical and technical problems, which included cumbersome electrodes and limited functional gains.

Nevertheless, these advances introduced a new field of research and after the mid-seventies, FNS broadened with multi-institutional and interdisciplinary work. Improved technology and increased interest lead to an increase in the number of FNS research groups and more sophisticated research.

Applications of FNS

These include:

1. phrenic nerve stimulation for artificial ventilation of patients with high SCI lesions
2. bladder voiding by stimulation of the bladder muscles
3. urinary and anal incontinence prevention
4. implanted devices in cerebellum to decrease spasticity
5. treatment of scoliosis (Benton et al, 1981)

The major orthopaedic applications include:

1. correction of dropfoot in hemiplegics
2. maintenance of the gleno-humoral alignment in paretic shoulders
3. hip and knee extension for stance and reciprocal gait in SCI patients

4. external control of hand opening and prehension in tetraplegics with a high spinal cord lesion (Singer, 1987)

Research in SCI concentrates mainly on posture and walking assistance in paraplegics, manipulation orthoses (such as hand orthotics to improve hand function) in tetraplegics and the development of the necessary electronics and equipment to achieve these goals.

Peckham (1987) reported that there are now seventeen laboratories worldwide that are researching FNS in countries such as Austria, England, France, Israel, Japan, Netherlands, Scotland, United States of America, Wales and Yugoslavia. Table 4.1 presents a brief overview of some of the main research groups and their field of research.

4.3 FNS REVIEW

4.3.1 FITNESS LOSS WITH SCI

After a SCI, the following degenerative changes occur:

* Skeletal muscles: muscles undergo atrophy and biochemical changes that cause weakness, decreased fatigue resistance and shortening of the muscle twitch duration. There is a reduction in the number of Type 1 (slow or red) fibres below the level of the spinal lesion (Pacy et al, 1987). Those with intact lower motor neurons have muscle spasms.
* Skeletal system: The lack of mechanical stress results in bone remodelling with bone resorption exceeding bone formation, causing a net loss of bone mass. Osteoporosis can occur at rates in excess of 1% per month until, after 40-50% loss, a new steady state is reached (Glaser, 1986). The weak bones are easily fractured and have a decreased capabi-

lity for healing when damaged. Recent studies indicate almost one in ten people with long-term SCI develop some type of pathological fracture (Petrofsky and Phillips, 1984).

* Cardiopulmonary system: A diminished cardiopulmonary (aerobic) fitness may be the result of the inability, or lack of desire, to perform voluntary exercise of sufficient intensity or duration to stimulate substantial training effects (Glaser, 1986). Voluntary arm exercise (such as arm cranking) utilises a relatively small muscle mass which cannot increase aerobic metabolism to a sufficiently high rate for sufficently long to develop marked central training effects to the cardiovascular system. Improvements would mainly be due to peripheral adaptions. Diminished sympathetic outflow resulting from the SCI also reduces aerobic exercise capability. Sympathetically mediated reflexes, such as vasoconstriction in inactive tissues and venoconstriction, are important for appropriate cardiovascular adjustments to exercise. These adjustments contribute to enhanced delivery of blood, oxygen and fuel to the active muscles and the removal of metabolic end products from these muscles. After a SCI this reflex redistribution of blood is less functional. The inadequate blood flow to exercising muscles that results from a diminished cardiac output results in early fatigue and thermoregulatory capacity is also impaired (Glaser, 1986).

Thus, there is a need for muscular, skeletal and cardiovascular system reconditioning before standing or gait can be attempted.

TABLE 4.1: Overview of some of the main FNS research groups

Place	Main researchers	Field of Research/Recent Research
Austria: 2nd Surgical Clinic Vienna University	Thoma, Holle	implanted, multichannel stimulators on femoral and infragluteal nerves; reciprocal walking achieved.
Yugoslavia: Rehabilitation Engineering Centre Ljubljana University, Ljubljana	Kralj, Badj, Turk, Vodovnik, Gracanin, Strojnik	peroneal brace; developed the surface stimulation technique; recently implanted a single channel stimulator.
USA: Case Western Reserve University, Cleveland Ohio	Mortimer, Peckham, Crago	upper extremity in tetraplegics; intramuscular electrodes.
VA Medical Center, Cleveland Ohio	Marsolais, Edwards	percutaneous electrodes; achieved standing, level walking and stair climbing, complete paraplegics.
Rehabilitation Engineering Rancho Los Amigos Hospital Downey, California	McNeal, Benton, Baker, Nakai, Waters	upper and lower extremity; treatment programs; effects of stimulus parameters, joint movement control, implantable stimulator development.
Pritzker Institute of Medical Engineering, Illinois Institute of Technology, Chicago Illinois	Cybulski, Jaeger	lower extremity; standing and gait and feedback control for standing; muscle retraining.
Wright State University National Center for Rehabilitation Engineering (NCRE), Dayton, Ohio	Petrofsky, Phillips, Gruner	lower extremity standing and gait; active physical therapy and physiological responses to it.
Applied Physiology Dept. Wright State University Dayton, Ohio	Glaser	lower extremity: muscle retraining; leg muscle powered wheelchairs.
Louisiana State University Medical Center, New Orleans Louisana	Solomonow	fibre recruitment by high frequency blocking stimulation; walking with LSU gait orthosis.
Israel: Loewenstein Rehabilitation Hospital, Tel Aviv	Mizrahi, Isakov, Braun	lower extremity; standing and gait.

4.3.2 MOTIVATION FOR FNS

Locomotor rehabilitation in SCI centres around the use of a wheelchair or caliper walking. Generally the wheelchair becomes a SCI person's primary means of mobility. Although it provides a degree of independence, it means the wheelchair user is in an unnatural, almost all-day, sitting position. This is disadvantageous as it may lead to pressure sores, muscle atrophy, osteoporosis and decreased cardiovascular fitness.

Thus, there are advantages for SCI persons to be able to stand for temporary periods of time.

Standing is thought to help:

1. prevent joint contractures by serving as a form of range of motion exercise at the hips and ankles
2. prevent osteoporosis by loading the long bones of the legs
3. improve the position of the internal organs and perhaps aid bowel and bladder function
4. reduce the chance of pressure sores by relieving pressure
5. increase functional ability to reach while standing
6. enhance personal esteem (Bromley, 1981)

Most patients are supplied with appropriate calipers but the majority are discarded due to, among other reasons, the inconvenience experienced in attatching them (Coughlan et al, 1980). Hence, FNS may provide an alternative method of standing. The advantages with FNS are that the functional movement is achieved by the stimulation of the person's own muscle, and therefore their natural metabolic energy is used. Improvements of other physiological functions, such as the blood supply of the paralysed body parts may also be attained (Kralj et al, 1980).

Standing and primitive gait with FNS has been achieved by various research groups. Some, in their haste to achieve the end results, have neglected to incorporate an appropriate muscle restrengthening program. This is essential to recondition the atrophied muscles and osteoporotic bones in order to produce functional movement.

Research over the past ten years has provided a scientific knowledge base for clinical studies (Peckham, 1987).

4.3.3 PATIENT SELECTION

Most studies have been performed on small numbers of SCI subjects who meet the necessary selection criteria. The following list of selection criteria is compiled from those of Ragnarrson (1986), Turk and Obreza (1985), Cybulski et al (1984), Robinson et al (1984), Kralj et al (1980), Isakov et al (1986) and Braun et al (1985).

1. The neurological lesion must be an upper motor lesion with intact lower motor neurons and reflex arcs.
2. A mid to low thoracic lesion, namely T3 - T12 (especially for truncal stability in standing).
3. Muscle response to electrical stimulation.
4. Lower extremity joints stable and free of contractures.
5. Free of significant osteoporosis.
6. No history of pathological fractures.
7. No pressure sores.
8. Be of general good health.
9. Extant bladder function.
10. Passed a standard rehabilitation program (an independent wheelchair user and trained caliper walker).

11. Psychologically stable.
12. Motivation for cooperation.

Some contra-indications would include:

1. heterotrophic ossifications
2. poor spinal mobility
3. deformities, such as shortend extremities
4. severe spasticity
5. medical complications, such as urinary tract infections or severe peripheral vascular or cardiovascular disease
6. unrealistic expectations
7. obesity
8. lower motor neuron lesion with severe atrophy resulting in electrical unresponsiveness
9. cutaneous disorder over an area of electrode application.

Phillips (1987) provides a detailed list of medical criteria and initial evaluations for selection. Heineman et al (1985) presents a psychological screening protocol for FNS research candidates. FNS may promise increased quality of life and therefore place participants at risk for providing uninformed consent due to unclear distinctions between treatment and research. Participants should have acquired sufficient coping skills and the ability to tolerate uncertainty and provide truly informed consent.

4.3.4 FNS PROGRAMS

Researchers do not always provide exact details of their particular programs.

Braun et al (1985) and Isakov et al (1986) report on the FNS research program at Loewenstein Rehabilitation Hospital in Ra'anana, Israel. The comprehensive training program is shorter

than six months. It begins with muscle strengthening and ends with supported standing and walking.

Stage One:

(a) Search for motor points on quadriceps and gluteus muscles and triggering points on the leg which serve to provoke the flexion response.

(b) Muscle strengthening: Isotonic contractions in sitting position. Sandbags are (500 grams) added to ankle after approximately two weeks to increase resistance. Training is initially ten minutes twice daily, increasing later to thirty minutes.

Stage Two: Training to stand up and maintain the standing position by quadriceps stimulation and in some patients, stimulation of the gluteus maximus. Initially parallel bars are used, then a walker or Canadian crutches.

Stage Three: Ambulation training with support on a walking aid.

Their 4 patients progressed as shown in Table 4.2.

Table 4.2 : Training days at different stages of FNS Program of Loewenstein Rehabilitation Hospital, Ra'anana

Patient	A	B	C	D
Stages				
1	10	14	27	21
2	14	10	30	7
3	14	150	-	30

In Austria, Kern et al (1983) work on a one year program with an implanted eight-channel FNS stimulator (Table 4.3). The results, namely the level of FNS walking that is achieved, are assessed after one year.

Table 4.3 : One year FNS Program of the University of Vienna, Austria

	Op	Healing Period	Muscle Training	Start Rising	Rehab. Centre	Start Walking	Two Crutches
Muscle tests			*	*	*	*	*
Months			2	4	5	6	9

Key: Op = operation of implanting the electrodes
Rehab = rehabilitation

After nine months of training, the quadriceps muscle force and endurance of the two paraplegics had increased by approximately 400 and 3000% respectively.

The Ljubljana group commence with a muscle strengthening program of isotonic exercise sessions of intially thirty minutes twice daily. This is increased by thirty minutes per week to six hours. This training ends when the muscle force reaches a plateau or saturation level within one or two months (at approximately 6 weeks) (Kralj et al, 1980). Once this plateau is reached, or after achieving a level of 30-40 Nm of torque, FNS enabled standing training is started using bilateral quadriceps stimulation. Once sufficient standing time and safety is obtained, the patients proceed to FNS gait training in a walking frame (Kralj et al ,1987).

The Rancho Los Amigos group in Downey, California have published a practical clinical guide to FES (Benton et al, 1981), but no detailed FNS program for paraplegics was included in this guide. Some of their recently published literature concentrates on the effects of stimulus parameters on electrically stimulated muscles

(McNeal et al, 1986; Baker et al, 1986 and Nakai and McNeal, 1987).

The Wright State University team in Dayton, Ohio has an Active Physical Therapy (APT) program consisting of four modalities: an isokinetic leg trainer, a stationary bicycle ergometer, an outdoor exercise bicycle and an FNS-orthosis for ambulation (Phillips, 1987). They have designed the equipment utilised (Heaton et al, 1983; Petrofsky and Phillips, 1984; Glaser et al, 1987) and examined the physiological responses to APT (Petrofsky and Phillips, 1984; Glaser, 1986). They developed a system for evaluating and exercising (for strength and endurance) paralysed leg muscles on the isokinetic leg trainer (Gruner et al, 1983). This is presented in Figure 4.2.

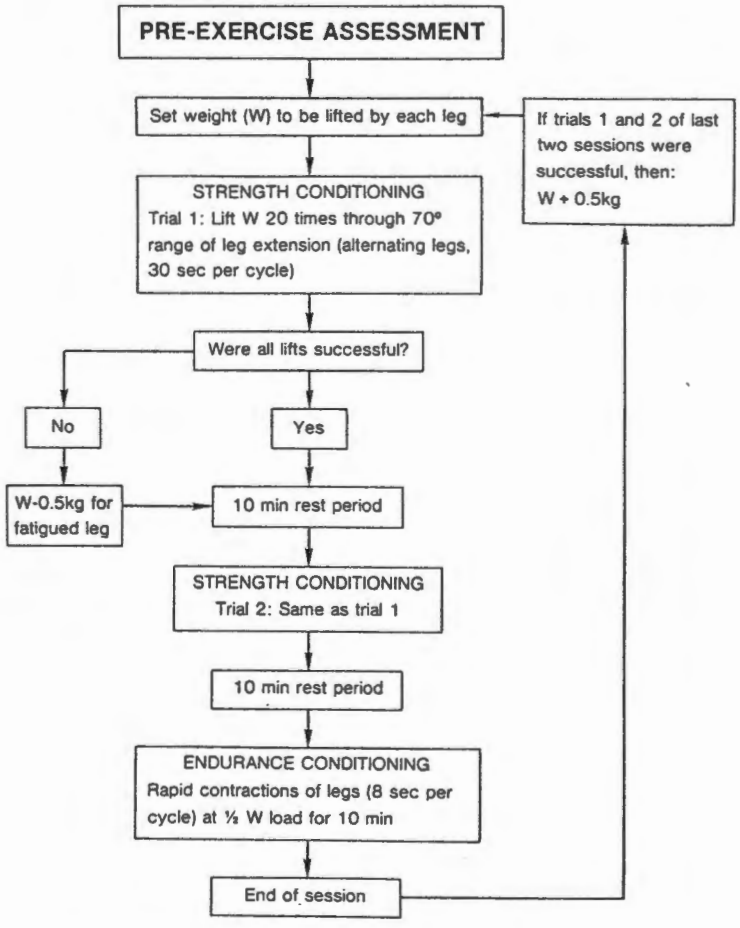


Figure 4.2. A safe, progressive exercise protocol to evaluate and condition paralysed muscle (Gruner et al, 1983).

The Pritzker team have been aided by researchers from Ljubljana (Yarkony et al, 1987) and therefore follow a similar program, that is an average strengthening time of approximately one month and a minimal strength of 40 Nm before standing is attempted. FNS-assisted bipedal gait follows successful standing (Cybulski et al, 1984).

Subjects in the Cleveland Veterans Adminstration (VA) program undergo strengthening for the first two or three months followed by a two month period during which they progress to standing. If this is satisfactory, subjects begin the walking training in parallel bars, then with the aid of a walker, then crutches. It generally takes three months until ambulation with the aid of the walker is achieved (Khavam et al, 1987).

The Ljubljana, Israel (Loewenstein), Pritzker and Wright State groups provide the main guidelines for a strengthening program.

4.3.5 FNS STRENGTHENING PROTOCOLS

Exercise training of paralysed muscles is the simplest application of FNS. There are however, few studies available on safe and effective protocols and procedures for such training (Gruner et al, 1983; Glaser, 1986). Early studies, prior to the 1980's, utilised isometric and dynamic contractions without load resistance. In the 1980's, the approach has been to incorporate well-established weight training principles in conjunction with FNS. This appears to produce more effective results (Glaser, 1986).

Generally there are two types of muscle training:

1. Strength training: Progressive resistance exercise is used lifting heavy weights (25 to 50% of maximum voluntary strength) at a slow rate. Muscle strength is increased due to hypertrophy of fast twitch muscle fibres.

2. Endurance training: This requires aerobic exercise, in which the muscles work rapidly at a light load, such as cycling. Slow twitch muscle fibres are trained and there is an increase in capillary density, and in the content of mitochondrial and oxidative enzymes. A secondary benefit is the improvement in cardiovascular and respiratory fitness (Phillips and Petrofsky, 1983; Petrofsky and Phillips, 1983 and 1984).

A balanced training program is a combination of these two types of training. Mulder et al (1986), Phillips and Petrofsky (1983) and Pacy et al (1987) have designed or modified equipment (a leg exerciser and exercise bicycle) to achieve this training.

Increases in muscle strength, endurance and fatigue resistance of subjects on FNS strengthening programs have been reported by Kralj et al (1980), Gruner et al (1983), Cybulski et al (1984), Petrofsky and Phillips (1984), Isakov et al (1986) and others.

Table 4.4 presents a summary of the protocols and parameters used in these and other studies. Abbreviations used in Table 4.4

Pp = paraplegic

Tp = tetraplegic

max = maximum

The Table reveals the following details on the FNS strengthening programs:

* Research has been based on small subject numbers, such as two to four subjects.
* Most groups (Israel, Pritzker, Yugoslavia) use isotonic contractions, Wright State use isokinetic contractions. Kralj et al (1980) found isotonic exercise to be more effective than isometic.

Table 4.4 Summary of the protocols and parameters from FNS studies.

REFERENCE Group	SUBJECTS	PROTOCOL	WAVEFORM	Frequency Hz	Amplitude mA	Pulsewidth uS	Voltage V	On:Off secs	POSITION	ELECTRODES
WRIGHT STATE Gruner et al (1983)	2Pp 2Tp	isokinetic leg trainer sessions 3x/week; 9 weeks load as per protocol to a max of 18 kg	monophasic square	30	150 max	200			sitting in leg trainer	surface carbonised 3:2 cathodes,1 anode 30 cm^2
Haeton et al (1983)		isokinetic leg trainer 15 mins; 3x/week; 1 month	square	50 (10-50)		300 (100-1000)	0-225	6:6		
Glaser et al (1987)		portable stimulator		35	150	300	150 max			
Petrofsky & Phillips (1984)		bike ergometer 10-15 mins, 3x/week	biphasic square	40		300				
LOEWENSTEIN Braun et al (1985) Isakov et al (1986)	4Pp	isokinetic 2 x 10 mins/day - 2 x 30 mins/day, loaded after 2 weeks (500 g sandbags)	rectangular	24	±200	300	0-120	3:3	sitting in wheelchair	surface conductive rubber with Karaya gum self-adhering electrode pads
PRITZKER Cybulski et al (1984)		isotonic 10-15 mins/day	rectangular	20 (15-40)		300 (500 - 0.5 ms)	80 (40-120)		supine	surface water soaked sponge covered with carbon rubber
Yarkony et al (1987)		2x5 mins/day - 60-90 mins/day		20		400	0-120		recumbent, knees elevated 25-30cm	
LJUBLJANA Turk et al (1980) Kralj et al (1980)	2Pp	isotonic 30 mins; 2x/day; - up to 6 hours/day (30mins/week)	monophasic rectangular	20-40	30	300 (500-1ms)	0-120	4:8	supine	surface water soaked foam rubber covered metal plate 10-25cm^2 25-70cm^2
OTHER: Pacy et al (1987)	 4Pp	 15 mins; 5 days/week; 10 weeks loaded (1,4-11,4 kgs)		40		300	65-90	6:6		
Narkai & McNeal (1987)	4Pp	isometric up to 2 hours/day loaded after 3 weeks (0,5-1 lb increments)	rectangular	30		300	0-110	10:10	sitting	surface

* Parameters: There is variation in the stimulus parameters used, but they fall within the following ranges:

  waveform: rectangular or square, monophasic or biphasic

  frequency (Hz): stimulators range: 10-60 Hz; 20-40 Hz were most commonly used. Grant and Swain (1985) reports that 20-30 Hz are universally used

  amplitude (mA): variable, not well recorded; maximum between 150-200 mA

  pulsewidth: 100 µs to 1 ms. 300 µs is virtually universally used (Grant and Swain, 1985)

  voltage (V): 0-225 V, but 0-120 V more commonly used

  on/off ratio: generally a 1:1 ratio

* Exercise position: for quadriceps - sitting or recumbent/supine position.

* Session duration: (1) 10-15 minutes daily
  (2) 30 minutes daily (increasing 30 mins a week to six hours
  (3) 10-30 minutes twice daily
  (4) 10-15 minutes 3 days per week
  (5) 15 minutes 5 days per week

* Weights: The ankle is loaded:

  (1) in 0,5 kg increments by a weight tray incorporated in the isokinetic leg exerciser, according to a prescribed program (Gruner et al, 1983).
  Maximum load anticipated is 18 kg.

  (2) after two weeks using 0,5 kg sandbags (Braun et al, 1985)

  (3) with a range of 1,4 - 11,4 kgs (Pacy et al, 1987)

  (4) after three weeks in 0,5 or 1.0 lb increments (Nakai and McNeal, 1987)

  (5) other studies: Kern et al (1983) used 1,2 to 3 kgs

Safety is a very important factor in determining when and how much load to apply. Rapid increases in muscle strength may result in fractures of the osteoporotic bones (Petrofsky et al, 1985).

* Electrodes:

These play an important part in determining the effectiveness of FNS (Benton et al, 1981). Surface electrodes are the most commonly used in ES orthotic devices, in therapeutic applications and generally used for strengthening programs. The biggest advantage is their ease of application. This often outweighs their weak points: poor cosmetic appearance, movements during muscle contraction, possible hazards from the relatively high voltages (sometimes in excess of 100V) between electrode pairs, and uneven electrode gel or water on the electrode surfaces which causes uneven current density distribution that may result in skin burns or irritation (Vodovnik et al, 1981).

Different surface electrodes used include: metal plates covered with water-tapped foam rubber and carbon rubber electrodes used with water-soaked sponge, self-adhering electrode pads or electrode gel. Electrodes are fastened with adhesive tape or velcro straps. Different size electrodes may be used for various muscle groups.

The electrodes are positioned on the skin surface above the motor point of the muscle or along the appropriate innervating nerve. McNeal and Baker (1985) utilised a 40 cell grid system to identify motor points of the quadriceps and hamstrings. The quadriceps have a motor point over the femoral nerve and a second broader region of excitability over the rectus and vastus lateralis.

METHODS OF EVALUATION

Muscle Strength:

* The isokinetic leg trainer system (Gruner et al, 1983) served to evaluate both strength and endurance.
* Kralj et al (1980) measured force by special joint torque measuring braces. Joint torque was also measured as a function of time to provide a measure of stimulated muscle fatigue.
* Braun et al (1985) and Cybulski et al (1984) do not record their methods of evaluation and testing.

Other Studies:

* McNeal and Baker (1985) measured isometric knee torque with a torque transducer designed and fabricated in their laboratory. Subjects were seated in a slightly reclined position with the hips in 120 degrees of flexion and knees in 60 degree flexion.
* Kern et al (1983) used a strain-gauged load cell to measure isometric muscle force in the quadriceps muscles in subjects with the knee flexed to 70 degrees.
* Streeter et al (1985) used a Cybex II dynamometer on paraplegic subjects who had complete spinal cord lesions.

Muscle Endurance (or fatigue resistance):

* Edwards and Marsolais (1987) used a Cybex dynamometer (with FNS on complete paraplegics) to collect quadriceps muscle torque data to determine fatigue characteristics. The fatigue indices used were the rate of fatigue of the quadriceps to 50% and 20% (T50% and T20%) of the intial peak torque.
* Robinson et al (1986) do not record their method of torque measurement but present three relative measures of fatigue:

T50%, T20% (the rate of fatigue to 50% and 20% of initial peak torque) and the percentage of peak torque remaining after 20 minutes of stimulation.

* Nakai and McNeal (1987) used an endurance test of 50 cycles of 1:1 on:off stimulation. Their three measures of fatigue were:

endurance ratio: ratio moment at cycle 50 to the maximum moment

endurance area : moments normalised to the maximum moment averaged over 50 cycles

T_{50} : number of cycles to 50% of the maximum moment

Limb Girth:

Petrofsky and Phillips (1983) measured increases in limb girth.

Physiological evaluation:

FNS exercise stresses other body systems besides the musculoskeletal system. In addition to the muscle parameters measured, Gruner et al (1983) monitored heart rate, skin-surface temperature over the active muscles and the arterial blood pressure of their subjects.

RESULTS

Muscle Parameters:

The six subjects on Gruner et al's (1983) program increased the strength and endurance to varying degrees depending on their initial strength and endurance capabilities. Braun et al (1985), Cybulski et al (1984) and Turk et al (1980) all report increases in strength and endurance sufficient to commence standing training.

Physiological:

Gruner et al (1983) report that during exercise at an average load weight of 5,4 kg, mean heart rate (HR) did not rise above rest; systolic blood pressure (BP) increased approximately 20 mmHg and skin temperature over the active muscles increased by 1,75 degrees C. They conclude that the exercising conditions appear to be safe, but that as HR does not provide a valid index of exercise stress in SCI subjects, arterial blood pressure should be monitored to minimise any risk. It is also advisable to monitor the skin temperature over the active muscles in order to prevent any possible risk due to impaired thermoregulatory mechanisms.

4.4 ACTIVE PHYSICAL THERAPY

Since the 1983 study, the Wright State group have published studies on the physiological responses to their Active Physical Therapy programs on the isokinetic leg trainer, the bicycle ergometer. Table 4.6 presents a summary of some of their results. The abbreviations used in Table 4.6 are listed in the following key.

Key to the abbreviations used in Table 4.6

$\bar{x}$	mean
sg	significant
P_p	paraplegic
T_p	tetraplegic
C^p	control group
BP	blood pressure
RBP	resting blood pressure
ExBP	exercising blood pressure
HR	heart rate
CO	cardiac output
VE	pulmonary ventilation
TV	tidal volume
VO_2	oxygen consumption
pCO_2	partial pressure of oxygen
pCO_2	partial pressure of carbon dioxide
LA	lactic acid
s	seconds
kp	kilopond

Figure 4.5 Summary of the results of FNS Active Physical Therapy.

		RESULTS	
SOURCE	Modality	Muscle	Cardiovascular/Pulmonary
Phillips & Petrofsky 1983	leg trainer (1 month)	$\bar{x}$ ↑ 1½ inches in leg size x ↑ ± 100% in strength (13-25 lbs)	
	bike (1 month)	$\bar{x}$ ↑ 10-fold in muscular endurance (2-20 mins)	sg ↑ $\bar{x}$ RBP at rest; ↑ stability during exercise $4T_p$: $\bar{x}$ RBP ↑ 11 mmHg; $\bar{x}$ ExBP ↓ 22 mmHg
Petrofsky & Phillips 1983	leg trainer (1 month) bike	± ↑ 1½ inches in limb girth ± 2 x ↑ in leg strength ± ↑ 10-fold in endurance	↑ cardiovascular stability as above
Phillips, Petrofsky, Henderson, Stafford 1984	leg trainer		$2P_p$: BP: ↑ markedly (between resting & fatigue values) HR, VE, VO_2: ↑ minimally $4T_p$: BP + HR: as for P_p VE + VO_2: 2 x ↑
	bike ergometer		$2P_p$: BP + HR: ↑ moderately VE : ↑ markedly VO_2 : ↑ 4x LA^2 : ↑ 5x; ↑ blood pH; pO_2 ↑ ; pCO_2 ± unchanged $4T_p$: BP + HR: ↑ markedly VE, VO_2: ↑ 4x LA, pH, pCO_2: as for P_p; pO_2 ↓
Petrofsky, Phillips, Heaton, Glaser 1984	bike (30 days)	$\bar{x}$ ↑ girth of 1,9cm (41,4-43,4cm) ↑ endurance: 59s at 0 kp to 135s at 1/8 Kp	
Petrofsky, Phillips, 1984	leg trainer (1 month) bike	$\bar{x}$ ↑ 1 inch in circumference $\bar{x}$ ↑ 100% strength (1 month) x ↑ 400% strength (3 months) ± ↑ 1000% endurance at given workload	T_p : RBP ↓ by $\bar{x}$ 21 mmHg; overall ↓ in ExBP: 30 mmHg
Petrofsky, Phillips, Hendershot 1985	bike (6 weeks) 4 P_p, 4 T_p 4 controls	↑ 100%-fold in endurance	HR + BP: ↑ CO : ↑ ∝ workload VE_1, VE_2: ↑ ∝ workload P_p: VE ↑ by ↑ TV T_p: VE ↑ by ↑ respiratory rate pO_2, pCO_2: little change
Glaser, 1986 (review)	leg trainer		VO_2: negligible ↑; VE: ↑ linearly with load HR^2: no ↑ BP : ↑ CO : no ↑ found
	bike		VO_2: 3-4-fold ↑ LA^2: 5-fold ↑ ($2P_p$) HR : variable response BP : ↑ CO : 2x rest value
Phillips 1987 (review)	leg trainer	chronic effects: ± 2x ↑ in strength (3 weeks)	acute effects: HR: no sg Δ in P_p, T_p, C BP: ↑'s in T_p; no sg ↑ in P_p, C
	bike	chronic: 10x ↑ endurance	acute: BP + HR: response in T_p, P_p > C chronic: $\bar{x}$ RBP ↑ so (T_p) $\bar{x}$ ExBP ↓

In summary (from Table 4.6)

Training on the leg trainer results in:

* Muscular:

  Increases in muscle strength, fatigue resistance associated with histochemical adaptations in the muscle, and limb girth.

* Cardiovascular:

  Heart Rate: No change or minimal increase or decrease. There may be only slight cardiac adjustments to FNS exercise. Lowering of the heart rate may be the result of increased vagal activity due to the initiation of the barorecepter reflex by increases in arterial blood pressure. Substantial cardioacceleration by vagal inhibition and sympathetic stimulation of the Sino-Atrial node is not achieved due to afferent pathway loss from peripheral receptors and deficient sympathetic outflow (Glaser, 1986). Thus, heart rate does not provide a valid stress index for SCI subjects during FNS exercise.

  Blood Pressure: Increases in arterial blood pressure. It may be due to an increase in total peripheral resistance by, primarily, reflex splanchnic vasoconstriction initiated by receptors in the active muscles. The response may be related to lesion level as tetraplegics respond more than paraplegics. In paraplegics, the reflex pathways arising from the legs are disrupted. In tetraplegics, the injury is in the neck region and therefore normal reflexes arising between the skeletal muscle in the leg and the splanchnic bed are intact (Petrofsky and Phillips, 1984). Blood pressure may be a more valid indicator of FNS exercise stress.

  Cardiac Output: No increase was found.

* Pulmonary Ventilation: It increases linearly with load. It appears to correspond to the metabolic rate of the muscles.

* Metabolic: Oxygen Consumption: small increases that tend to be linear with the intensity of FNS-induced exercise.

Training on the bicycle ergometer:

* Muscular: It increases muscular endurance.

* Cardiovascular:

  Heart Rate: A variable response that may be dependent on the level and degree of lesion such that the higher and more complete the lesion is, the lower is the heart rate response.

  Blood Pressure: Greater increase than with the leg trainer.

  Cardiac Output: Increases to twice the rest value for fatiguing exercise.

* Pulmonary Ventilation: As for leg trainer.

* Oxygen Consumption: Greater increases than those with the leg trainer. This may be due to the multiple muscles used and higher contraction rate.

These studies indicate that there may only be slight to moderate increases in aerobic metabolism and cardiopulmonary responses with FNS exercise. Voluntary arm exercise produces greater responses. FNS cannot currently be considered a major training method to promote cardiovascular fitness (Glaser, 1986).

Currently, FNS exercise is beneficial in increasing the strength and endurance of paralysed muscles. Other potential health and fitness benefits include:

* increased cardiovascular and pulmonary fitness

* improved lower extremity circulation which may prevent deep venous thrombosis and pressure sores
* alleviation of muscle spasms
* improved voluntary function for incomplete SCI lesions
* improved self-image and psychological benefits

It is important to differentiate between potential benefits and scientifically documented benefits. To retain the benefits, FNS exercise must be part of one's lifestyle.

4.5 GUIDELINES

In addition to the guidelines taken from the FNS review, the following points are noted from Benton et al (1981).

* The stimulation:
  - should not cause injury
  - should be within the patient's level of tolerance
* The parameters should be re-evaluated as the patient's clinical picture changes
* The session length depends on the goals of the program and the patient's status within the program
* The electrodes:
  - with the electrolyte medium should provide a low impedance, durable interface between the body and the stimulator
  - should be pliable to conform to body contours during muscle deformation with contraction and limb movement
  - should be placed over muscle bulk rather than bony prominences
  - should have adequate electrolytic interface to prevent burning due to local sites of increased current density
  - should not be placed over an open wound and resulting

contractions should not stress an incision site or impede healing

* Be alert for unexpected complications, such as dysreflexia
* Avoid unnecessary subject frustration due to gradual gains being shadowed or unrecognised
* Exercise can be performed without direct supervision, but with regular re-evaluations of the subject's progress

CHAPTER FIVE

EXERCISE AND SPINAL CORD INJURY

5.1 EXERCISE

During rehabilitation, the SCI person undergoes a training program to strengthen his/her remaining functional musculature and to increase his/her ability to perform routine activities of daily living (Huang et al, 1983). It appears that improving the cardiopulmonary health is a neglected area in rehabilitation programs (Di Carlo, 1982) as many centres lack formal aerobic conditioning programs (Di Carlo et al, 1983). Once discharged from hospital, it is the individual's responsibility to maintain or improve his/her fitness. Due to the lack of suitable available exercise facilities and programs for wheelchair users (Taylor et al, 1986) this might entail a self-supervised maintenance program which requires a large amount of self-discipline. Thus, the majority of SCI people do not engage in any form of formal exercise training after discharge from hospital.

Functional Degeneration and Cardiovascular Disease Risk

Prolonged immobilisation has a deleterious effect on the circulatory response to exercise. The physiological and metabolic changes due to the functional degenerative process following SCI and the nature of their restrictive sedentary lifestyles include:

* a decrease in lean body mass (LBM). This is primarily due to the muscle atrophy as a result of inactivity.
* a decrease in weight which is principally due to a loss of water, fat and protein, (Cardus and Taggart, 1985). This initial weight loss is eventually replaced by a total body weight gain as the atrophied muscle is replaced with connective tissue and filled with lipids and water.

* an increase in percentage body fat.
* an increase in the extracellular fluid/intracellular fluid ratio.
* decreases in exchangeable K^+; increases in exchangeable Na^- (Cowell et al, 1986).
* a lower basal metabolic rate (BMR).
* a decrease in high density lipoprotein cholesterol (HDL) concentrations.
* increase in resting electrocardiographic (ECG) abnormalities.
* pressure sores, urinary tract infections, calculi, thrombophlebitis, spasticity and joint contractures can be compounded by inactivity (Hoffman, 1986).

Thus the effects of functional degeneration following SCI are vast, resulting in greatly reduced overall health, and the risk of cardiovascular disease.

In addition to the general risks of cardiovascular deconditioning attributable to a sendentary lifestyle, these risks are compounded by certain specific SCI-related problems, for example spinal shock, emotional distress and the vascular effects of autonomic hyperflexia. Thus, SCI people may be at an even greater danger of developing cardiovascular disease (Cowell et al, 1986). Indeed, in a recent study (Hoffman, 1986) it was suggested that cardiovascular disorders are now the major cause of death in the SCI population; other sources indicate renal complications as the major cause of death (Malick and Meyer, 1978 and Grundy et al, 1986). Risk factors for the development of cardiovascular disease in SCI people include:

* a non-physiological diet (quantity and quality)

* abuse of tobacco and alcohol
* stress
* lack of physical exercise (Jochheim and Strohkendl, 1973).

There is strong evidence for the able-bodied population that higher levels of physical activity are associated with a reduced risk of cardiovascular disease, obesity and osteoporosis (La Porte et al, 1985; Blair, 1985). Serum HDL cholesterol, which appears to be an important determinant of coronary heart disease risk, increases with greater fitness levels in the able-bodied (McConney, 1987) and SCI population (Brenes et al, 1986; Dearwater et al, 1986). As in the able-bodied, fitness is related to level of activity in the SCI population. It has been shown that sedentary paraplegics are less fit than their active counterparts (Zwiren and Bar-or, 1975).

Wheelchair Locomotion

A wheelchair is the principal means of self-ambulation for the vast majority of SCI people. Some assume that their daily bouts of wheelchair propulsion are sufficient exercise to improve cardiovascular fitness. This does not appear to be the case according to available literature.

The user's characteristics, wheelchair and locomotive environment affect locomotion efficiency. Glaser (1985) states that the use of arms for locomotion purposes, as in wheelchair propulsion, is inefficient and stressful to the muscular, cardiovascular and pulmonary systems. This is due to the particular muscles used, namely the relatively small upper body musculature and its inherent histochemical characteristics, which include a high concentration of fatiguable fast twitch fibres.

The normal daily activities of SCI people may not be sufficient to maintain cardiovascular fitness. The average strain of daily activities is low requiring only 15-24% of heart rate reserve. It takes activity requiring 50-60% of heart rate reserve to contribute to the maintenance of circulatory fitness in paraplegics (Cowell et al, 1986). Studies have shown that a greater cardiovascular stress is elicited by wheelchair locomotion compared to normal walking (Glaser, 1986). Thus, although the imposed circulatory stress is higher in comparison to walking, the daily effort for wheelchair locomotion is still generally inadequate in intensity and duration for cardiorespiratory training (Hjeltnes and Vokac, 1979). It is therefore important to maintain cardiovascular fitness in wheelchair-dependent people. In order to maintain or improve their cardiovascular fitness they need to participate in a sports or training program.

Exercise Capability

Muscle paralysis and sensory loss resulting from a SCI is accompanied by Autonomic Nervous System (ANS) dysfunction, the degree of which is dependent on the level of the lesion (Figure 5.1). SCI people may have severely limited exercise capability due to the direct effects of skeletal muscle dysfunction plus a loss of sympathetic control to the cardiovascular and other organ systems that are necessary to support the increased metabolic rate of contracting muscles. The cardiovascular adjustments to exercise that may be affected include:

* A lesion at T4 or above may disturb the sympathetic drive to the cardiovascular system. Cardio-acceleration and myocardial contractility are limited and therefore the ability to increase cardiac output during exercise is reduced. A lesion

between T1 and T4 may greatly affect the autonomic control of the cardiovascular system and the sympathetic activity of the body.

In paraplegics, disruption of sympathetic tone leads to unopposed activity of the parasympathetic systems and results in a low maximal exercise heart rate and stroke volume. The latter is due to a loss of vasomotor tone and subsequent peripheral blood pooling, resulting in a decreased venous return (Cowell et al, 1986).

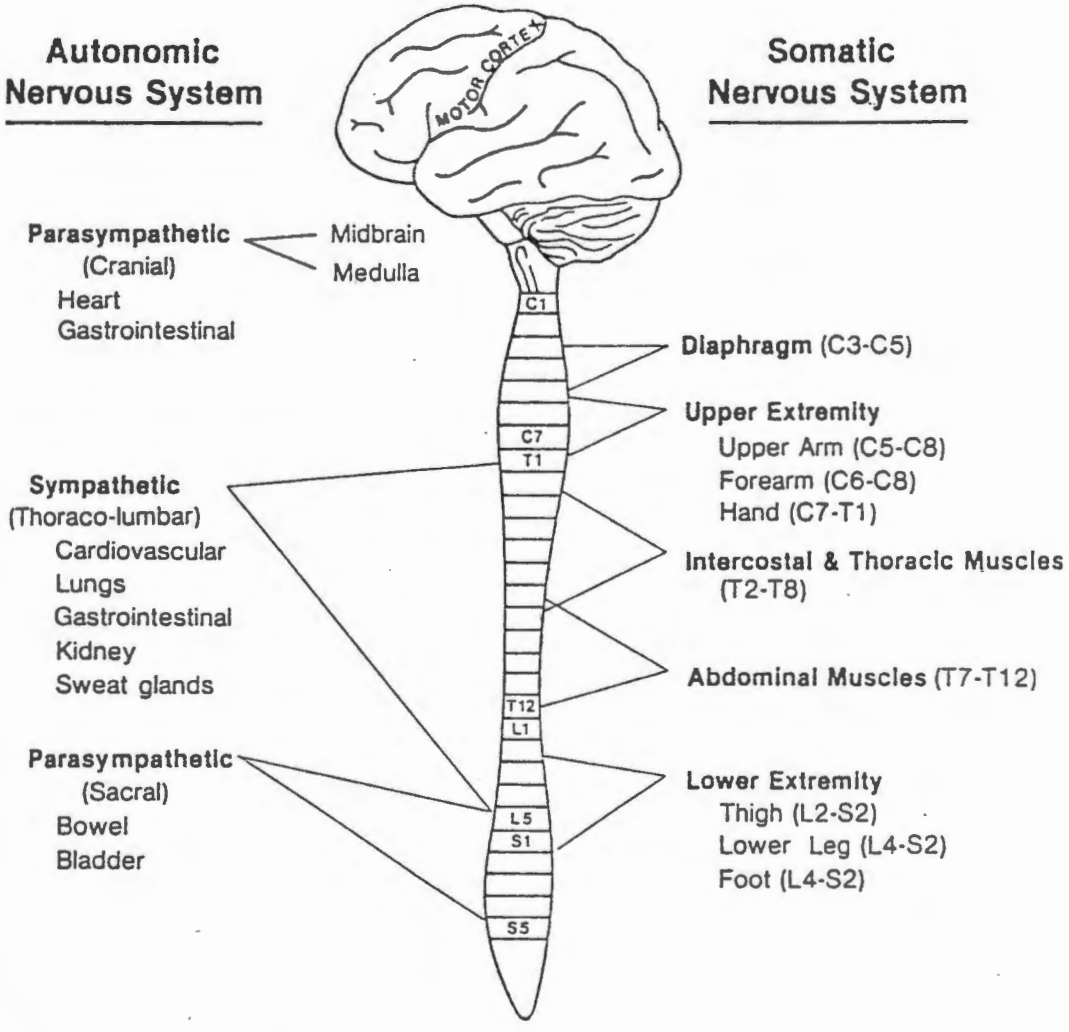


Figure 5.1: A diagramatic illustration of the central nervous systems and the outflow levels for the somatic and autonomic nervous system neurons. General innervations from each spinal cord level are indicated (Glaser, 1985)

* Reflex distribution of blood (increased blood flow to the exercising muscles for the delivery of oxygen and fuel and the removal of metabolic end products) is absent to varying degrees.
* The resulting inadequate blood flow could result in a greater dependence on oxygen-independent energy production, accumulation of lactic acid and hydrogen ions in the muscle, and the early onset of fatigue.
* Inadequate blood flow to the active muscles and the inability to activate sufficient sweatglands by cholinergic sympathetic stimulation could reduce the thermoregulatory capacity during exercise (Glaser, 1986).

Other factors that may affect exercise capability include:

* age, sex and heredity (probably similar to able-bodied individuals)
* site of injury: The amount of functional muscle mass appears to play a significant role. In lesions above T5, the sympathetic regulation to the cardiovascular system is impaired and there is smaller amount of muscle to tax the cardiovascular oxygen and thus the rate of oxygen consumption (VO_2) would be reduced. In lesions below T5, sympathetic outflow to the heart is normal and there is full use of the arms and upper trunk (Cowell et al, 1986).
* Level of activity: Individuals who ambulate with crutches or leg braces will be more likely to have higher aerobic capacities than those confined to wheelchairs (Nilsson et al, 1975; Cowell et al, 1986). Upper body fatigue may discourage SCI individuals from wheelchair locomotion of sufficient intensity and duration to maintain muscular and cardiovascular fitness. This would lead to a further reduction

in exercise capability.

* Respiratory function may approach a limiting level in well-trained, low-level paraplegics (not in those with high SCI lesions) (Glaser, 1986)).

Exercise Testing

Although there are numerous well-established stress-testing protocols for the able-bodied, there is an absence of similar protocols to test physical exercise capacity and cardiopulmonary fitness (aerobic, endurance) in people with a lower-limb disability. Tests must utilise arm exercise and thus a small muscle mass. Aerobic performance tends to be limited by the resulting localised fatigue rather than the ability of the cardiovascular system to deliver blood and oxygen to the active muscles. The term peak VO_2 is often used in preference to VO_2 max as the resulting values are lower than a true physiological maximum. The tests may be more valuable to determine muscular performance than cardiopulmonary fitness.

Muscle strength tests are also important as muscle strength is a primary factor determining locomotive capability. Tests may be performed using equipment and protocols similar to those for the able-bodied.

Arm Exercise Modes:

Protocols for exercise testing have used a number of different techniques that include: arm crank ergometry (Di Carlo, 1982; Di Carlo et al, 1983; Zwiren and Bar-or, 1975; Gass and Camp, 1984; Pollock et al, 1975), wheelchair ergometry, freewheeling on the ground or on the treadmill (Gass et al, 1980) or rollers (Coutts et al, 1985; Lundberg, 1980), and tethered swimming (Di Rocco et al, 1985).

Arm pedalling on a modified bicycle ergometer or a rehabilitation arm crank ergometer is possibly the simplest and most readily available method of testing. Modifications to the initial and incremental workloads used for leg exercise testing will enable the same basic protocols to be used for arm ergometer testing. As far as specificity for exercise stress-testing is concerned, wheelchair ergometry is the desired mode, but this requires special equipment. Both modes elicit similar peak VO_2 values and may provide a valid estimation of the aerobic energy potential for wheelchair-type exercise (Glaser, 1985).

Exercise Training

It appears that wheelchair locomotion could become less stressful if the SCI individual's fitness was increased by means of an exercise program. Cowell et al (1986) states that the cardiorespiratory weakness of sedentary paraplegics could be reversed by the implementation of a regular exercise program for the upper extremities.

Generally, cardiovascular improvements depend on the frequency, intensity and duration of the training program, as well as the type of exercise, the person's age and the initial state of fitness. Other important factors for the wheelchair-dependent population include their initial skill in wheelchair propulsion and the extent of wasted movements due to muscle spasm and abnormal motor patterns (Hoffman, 1986).

VO_2 max, the maximum rate of oxygen consumption, is an indication of physical work capacity and cardiovascular fitness. Besides the influence of age, sex and state of training, additional factors such as impairment of skeletal muscle, respiratory, cardiac and autonomic function resulting from SCI must be taken into

account for the SCI population.

Guidelines for exercise for the able-bodied population from the American College for Sports Medicine (ACSM) include 15 to 60 minutes of rhythmic exercise, 3 to 5 times a week, at 60 to 90% of maximum heart rate or 50 to 80% of VO_2 max. Based on studies using these standards, it appears that these guidelines are suitable for the SCI population as well. They show that training at 60 to 70% of maximum heart rate reserve provides a sound basis for the design of an endurance program for SCI individuals (Hoffman, 1986).

Previous studies on cardiorespiratory training in the SCI population report improved exercise capacity with increased VO_2 max and work performance. They indicate the exercise capacity in tetra- and paraplegics can be significantly improved in 4 to 20 weeks using exercise modes such as arm crank ergometry (Hjeltnes, 1977; Di Carlo, 1982) wheelchair propulsion (Gass et al, 1980 (continuous or interval) and swimming. In a survey of 13 studies, Hoffman (1986) found the average improvements in VO_2 max and physical work capacity after 4 to 20 weeks of training were 20% (0-61%) and 40% (31-64%) respectively. Both interval and continuous modes of wheelchair ergonomy and arm crank exercise appear to be capable of inducing a training effect.

It is unclear whether this training can lead to a central training effect in paraplegics. In tetraplegics, only peripheral training adaptations can be expected. Practically, the training effects mean that the performance of the activities of daily living will be less stressful and could result in greater independence, as the degree of dependence depends not only on the

prevention of complications, but also on physical fitness (Chawla et al, 1979).

Generally, training programs induce central (systemic) and peripheral (local) adaptations in proportion to the degree of stress placed on the heart and skeletal muscles. Central changes (manifested by reductions in heart rate at rest and during submaximal exercise and increases in maximal cardiac output) are elicited only by dynamic exercise training with large muscle groups. Peripheral changes including increases in mitochondrial oxidative metabolic capacity, oxygen extraction and alterations in blood flow patterns in exercising muscles, are more clearly demonstrated after training with smaller muscle groups. Peripheral circulatory adaptations which are highly specific to the trained muscles, account for a large component of the training response observed after arm training. Central changes appear to be possible, but are less pronounced (Hoffman, 1986).

Although the long term effects of endurance training in the SCI population are unclear, there is some evidence that the metabolic changes may be similar to those of the able-bodied population. Increased serum HDL-C concentrations (Brenes et al, 1986; Dearwater et al, 1986) and decreased percentage body fat (Pollock et al, 1975) have been reported. Improved psychological characteristics were also reported in wheelchair athletes compared to their sedentary counterparts (Horvat et al, 1986).

It is important to remember that the exercise prescription and evaluation must be individualised as goals and level of participation vary depending on the individual's health status, cardiovascular fitness, level of spinal cord injury, motivation, and time availability (Hoffman, 1986).

5.2 SPORT

It was only during the latter stages of World War II that sport was introduced by Ludwig Guttmann as a part of the medical treatment for those with a SCI at Stoke-Mandeville Hospital. Sport was a fundamentally new concept in Guttmann's "Comprehensive Management and Rehabilitation" (Guttmann, 1976). It has since played an important role in the physical, psychological and social rehabilitation of SCI people. Guttmann's initial experimentation with sports including wheelchair polo, basketball, archery and table-tennis, were the beginning of a systematic development of competitive sport for the SCI population.

The first Stoke-Mandeville Games for the Paralysed were held in 1948 with 16 British paraplegics. The first Olympic Games for the Physically Disabled were held in Rome with 400 wheelchair competitors from 22 countries. By the 1984 New York Olympics for the Physically Disabled, there were over 2500 competitors from over 40 countries (Steadward and Walsh, 1986). The 1988 Olympics were expected to attract over 4000 competitors. Classification systems such as The International System (developed at the International Stoke-Mandeville Games) and the National Wheelchair Athletic Association (NWAA) have been developed to allow for evenly matched competition between competitors with different levels of SCI. Some of the Olympic events include: archery, dartchery (a combination of darts and archery), table-tennis, snooker, fencing, weightlifting, swimming, basketball, wheelchair dash, relay and slalom, bowling and field events.

The popularity of sports participation by the physically disabled continues to increase. Depending on the interest, motivation and physical capability, rules and equipment may be modified to enable SCI athletes to participate in many sports.

These include:

* team sports: including basketball (Burke et al, 1985), football, softball and volleyball
* endurance activities: including long distance wheelchair racing, (Madorsky and Madorsky, 1983; Asayama et al, 1985) and swimming
* skill and speed sports: including archery, fencing, table-tennis, bowling, golf and karate
* strength sports: including weightlifting (Chawla et al, 1979)
* field sports: including javelin, shotput and discus
* outdoor activities: including wheelchair mountaineering (Madorsky and Killey, 1984), horse riding, water sports, sit skiing and hang gliding.

Risks of Exercise and Sport Activities

Two recent studies (Curtis and Dillon, 1985; Nilsen et al, 1985) suggest that the risks of serious injury or complication is low in wheelchair athletes participating in sports. The most common associated complications were soft tissue injuries, including sprains, strains, tendonitis and bursitis, blisters, abrasions and lacerations. Urinary tract infections and pressure sores ranked next. Serious complications, such as fractures and thermoregulatory disorders appear to be less common. These, together with autonomic hyperreflexia and orthostatic hypotension are potentially serious conditions. The risk of serious complications appears to be low, but coaches and athletes should be properly educated about these risks to promote optimal performance and safe participation.

Benefits of Participation in Sports

The benefits of participation in sports are both psychosocial and physiological. Psychosocially, the physical well-being and sense of accomplishment help to alleviate depression (Nilsson et al, 1975) and offers an outlet for emotional stress and relief from boredom. It helps to promote psychological equilibrium, enabling the disabled to come to terms with their disability (Jackson, 1987). It counteracts negative psychological attitudes and develops self-confidence, self-dignity, self-discipline and comradeship, thereby removing the "self-centred, isolation" attitude. Sport also facilitates social re-integration. Thus, sport contributes to a fuller, more personally productive lifestyle (Guttmann, 1976).

Physiologically, it is a natural form of physical therapy and helps to restore physical fitness including strength, coordination, speed and endurance. Some forms of skill sports such as archery and table-tennis may have limited value in improving cardiovascular health due to their low intensity. Swimming, long distance wheelchair racing and wheelchair basketball are the main activities that fulfil the requirements needed for good cardiovascular training (dynamic exercise, high intensity, long performance time and use of many large muscle groups) (Jochheim and Strohkendl, 1973).

Another benefit of the increased sports participation is the increased awareness of the physical capabilities of the disabled and possibly increased acceptance by the community and awareness of the contribution the disabled can make to the community. This may help to encourage the elimination of architectural barriers, thereby increasing accessibility. The achievements of wheelchair

athletes help to teach the able-bodied community that sickness and disability are not synonomous (Davis et al, 1981). These attitudinal adjustments are very important and will benefit the average wheelchair user in the future.

Sport for disabled athletes is still growing. Much has been achieved over the past 40 years, but there are still many developments to take place. Integration into normal sport is the goal of most of the competitive wheelchair athletes (Jackson, 1987), so that some wheelchair events would be included in the able-bodied Olympics and not just as exhibition events. Perhaps, one day, sport for the disabled will have a more permanent place alongside able-bodied competitions.

CHAPTER SIX

PROJECT RESTAND AT THE BIOMEDICAL ENGINEERING DEPARTMENT (UCT)

SECTION A. FNS

6.1 INTRODUCTION

In South Africa, there has been interest in FNS since 1983. A joint committee from various departments from the Universities of Cape Town (UCT) and Pretoria (UP), initiated project REWALK. The projects aim was to develop FNS for clinical purposes with its eventual use for gait restoration in SCI patients (Jaros, 1985).

REWALK was subdivided into projects that are to be completed by UCT and UP. During 1986, three MSc theses on FNS had been completed at UCT:

1. The development of a quadricycle (the Paracycle, Project 1) for patient conditioning (Pons, 1986).
2. The use of trunk electromyograms for control of FNS of the lower limb (Project 2) (Hefftner, 1986).
3. The development of a six-channel computer-based programmable stimulation system (Project 3) (Popp, 1986).

The results of these studies were integrated in a trial between May and July 1986 at the Conradie Hospital, Cape Town. The leg-powered quadricycle project (Project 4) investigated the practical problems involved with the system in a small group of paraplegics (five) from the hospital. Their lesions were of recent origin (one to six months).

After the system proved successful, Project RESTAND (Project 7) was initiated. The aim of this project is the re-establishment of standing in paraplegic subjects, whose lesions are of less recent origin (ranging from 2,5 to 30 years). A further three

projects need to be integrated to achieve the standing process which involves standing up, standing and sitting down.

These projects include:

1. a muscle training and fitness program using FNS to prepare a paraplegic for standing (present thesis)
2. the design of a mathematical model on the biomechanics of standing
3. the design of the control systems to stimulate the standing process.

Prospective participants were provided with a project outline providing the basic aims, proposed program and potential benefits. Two papers (Gruner et al, 1983 and Kralj et al, 1980) that described similar research were provided to illustrate the nature of these programs and the results which could be expected. The Conradie trial revealed that subjects should be intelligent, readjusted, active and mobile. Six subjects were selected after an initial muscle response test and a medical examination, by Dr Ray Shrosbree of the Conradie Hospital, Pinelands, to determine any conditions that may preclude participation. Each subject was supplied with a portable muscle stimulator between October and December 1986.

The initial plan was that subjects would exercise at home for the first three months, and attend weekly assessment sessions. Once sufficient strength had been developed, subjects would exercise under electrical stimulation on the Paracycle for one hour, three times a week. According to a basic timetable, the standing-up routine was to be achieved by the end of 1987:

October 1986 : test subject's response to FNS
fitness test
muscle biopsies

Oct 1986 - Nov 1986 : home exercise program using portable stimulators. Quadriceps only. Weekly assessments.

Dec 1986 - Jan 1987 : home exercise program for quadriceps and hamstrings using the portable stimulators and the exercising device. Weekly assessments.

February 1987 : muscle biopsies
begin Paracycle sessions.

March 1987 : begin development of second generation paracycle.

August 1987 : muscle biopsies
standing up routine.

This muscle training and fitness program was originally undertaken by a full-time researcher who started with the selection of the original six subjects and their initial muscle response test to FNS. When that researcher left the Department at the end of 1986, the lack of a full-time coordinator necessitated a complete revision of the plans. It was at the beginning of 1987 that the project was offered as the present MSc thesis.

6.2 DEVELOPMENT OF A MUSCLE TRAINING AND FITNESS PROGRAM

Due to the functional degeneration following a SCI, it is essential to undergo restrengthening and reconditioning before standing can be attempted. The program is aimed at preparing the 'whole person' and this includes:

* FNS leg exercise to restore muscle bulk, strength and

fatigue resistance

* Upper body exercise to improve strength and cardiovascular fitness (see chapter 5)
* Any necessary physiotherapy to optimise the individual's standing position
* Psychological monitoring as the program progresses.

The program is geared to the 'home situation'. This has advantages in that it is easier and more convenient for the subjects. These subjects are instructed on the use of the muscle stimulator and the correct electrode positions (Figure 6.1a). They perform the exercises (initially knee extension by quadriceps stimulation) daily, if possible, by means of the portable two-channel muscle stimulator (Kelly, 1986). The FNS exercise can be performed in a sitting position, for example in a wheelchair (Figure 6.1b) or on the edge of a bed, or in a recumbent position on a bed. If a sitting position is used, there must be sufficient padding behind the legs for protection when the leg relaxes. Subjects are required to complete a logbook to record their exercise data. The quadriceps are exercised against an increasing load (progressive resistance exercise) in order to maximise the training effect.

The protection of the osteoporotic bones is important and therefore exercise must be initiated with caution to prevent fractures due to a too rapid increase in muscle strength. Subjects begin stimulating for only three minutes and progress to longer sessions as muscle strength improves. The criterion for progression is the maintenance of full leg extension for the duration of the session, for three consecutive sessions of that particular session length. Once this is achieved, weights are added in 0,5 kg or 1 kg increments, and the program continues as before. The

Figure 6.1a Instruction on the use of the FNS stimulator

Figure 6.1b Initiation of a FNS quadriceps exercise session

program is individualised according to the subject's initial strength and fatigue, but is standardised for the complete group.

The subjects are assessed at regular intervals (every three to four weeks) for improvements in strength and fatigue resistance. This assessment is performed at the Department of Biomedical Engineering and typically involves:

* a ten minute 'warm up' of passive, motor driven exercise on the Paracycle
* strength tests
* fatigue tests.

The muscle bulk is assessed by means of Nuclear Magnetic Resonance scans that are subsequently digitised and analysed. Scans are taken approximately bi-annually.

A monthly meeting is held of the subject group and other members of the multidisciplinary team . These provide an opportunity to provide feedback, discuss problems and determine future research direction for the project.

Standing was not achieved by the close of 1987 as originally planned. This was due, in part, to the revised plans in the absence of the full-time coordinator and the delay in completion of the biomechanical model of the standing process. An Inclistand exerciser, developed at the Department, led to a previously unintended "interim phase" to standing. This provides a means of moving from a sitting to an inclined standing posture under FNS control (Figure 2a and 2b). The incline of the frame can be increased towards the vertical as muscle strength develops. The subject can remain standing by locking the knee-pad and using alternative stimulation. Each subject has been donated one for home use. No research data have been collected on the benefits

Figure 6.2a Subject prepares to "stand" under FNS control

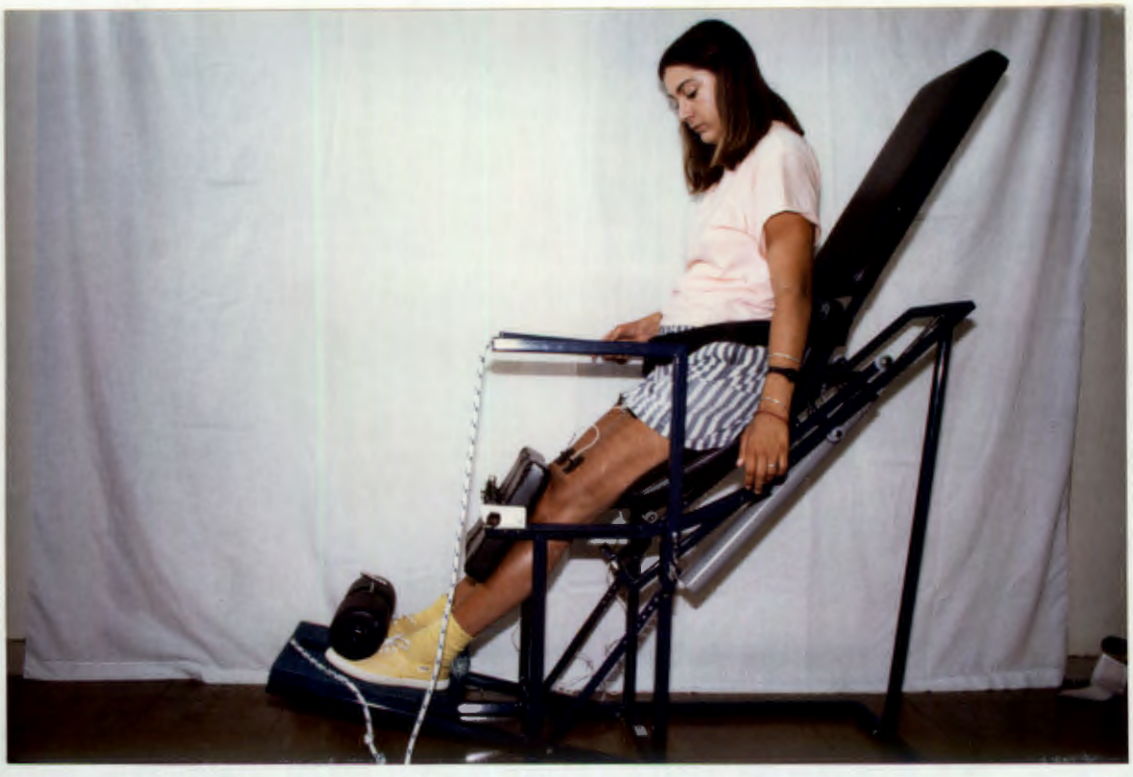


Figure 6.2b An inclined standing position

or effects of the Inclistand yet. This will be an aspect of future research for Project Restand.

6.3 EQUIPMENT

Due to the project's limited budget, most of the equipment utilised in Project RESTAND has been designed and manufactured by members of the Biomedical Engineering Department.

Equipment supplied to each subject includes the following:

Stimulator:

This was designed by Kelly (1986) according to the requirements of the REWALK research team at that time (Figure 6.3). Its specifications include:

* two isolated channels for biphasic stimulation
* current regulated and symmetrical (bipolar) stimulation to prevent charge accumulation within the tissue
* amplitude: up to 100 mA into 1000 ohms (maximum electrode impedance) per channel
* simultaneous sequence: 'ON' time 10s, 'OFF' time 10s and ramp time 5s
* stimulation frequency: 25 Hz
* Pulsewidth: 200 µs
* inter-pulse interval: 1 ms
* session time: 3, 6, 12, 24 and 48 minutes.

It is powered by a rechargeable battery and is supplied with a battery charger, electrode leads and a set of operating instructions. At the time of design, the cost was approximately R250 per unit.

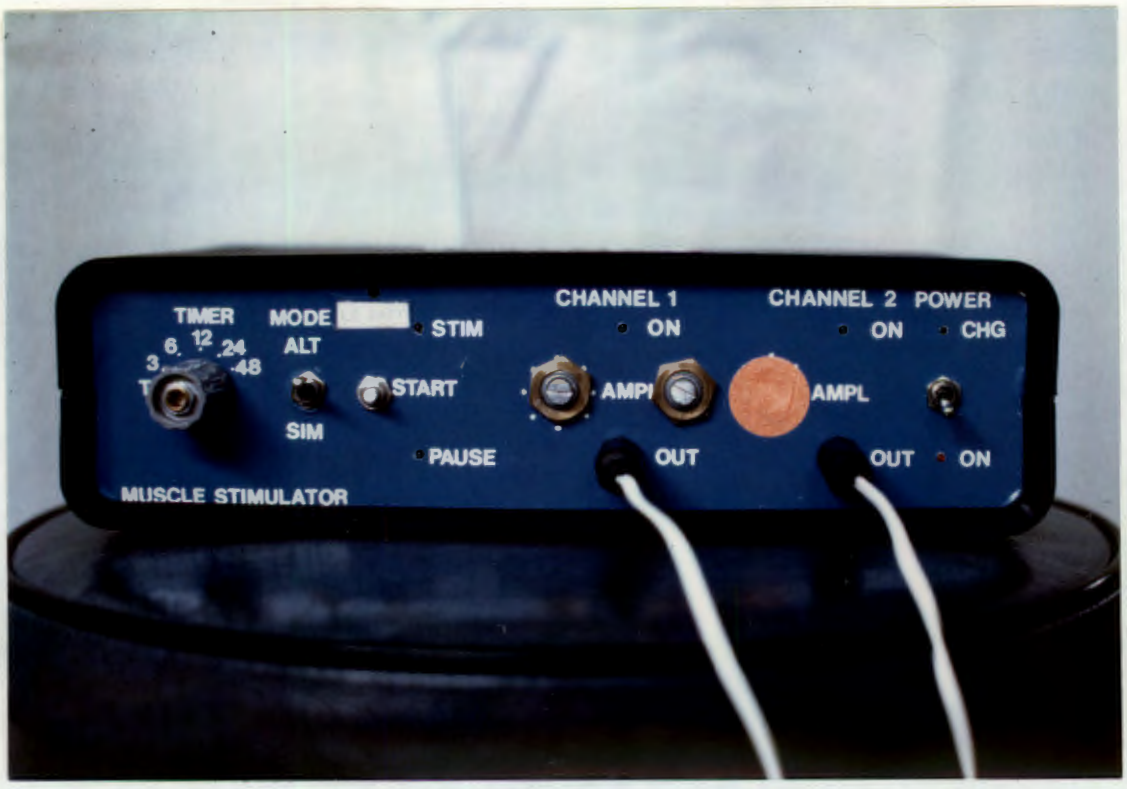


Figure 6.3 A two-channel FNS muscle stimulator

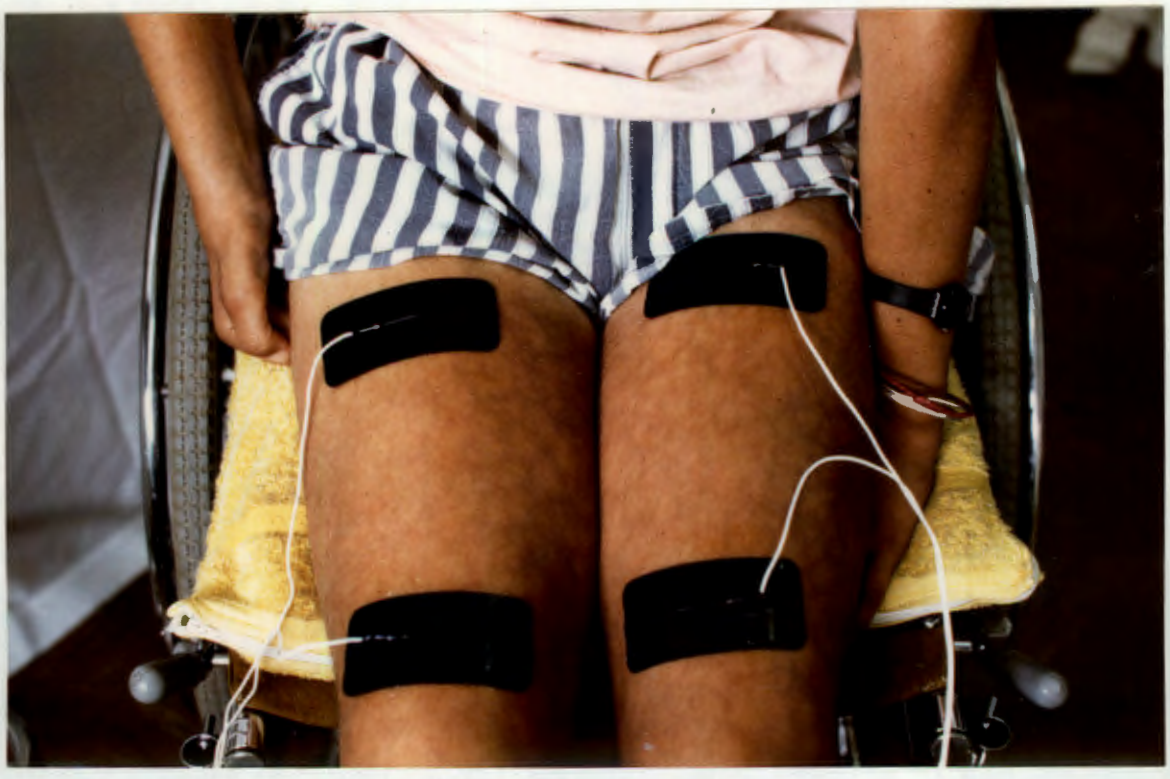


Figure 6.4 Carbon-rubber surface electrodes

Electrodes:

Carbon rubber electrodes size 5cm x 10cm are used (Medtronic, model 3793, non-sterile) together with electrode gel (such as multipurpose gel or Electrogel (cat.no. 447025)) (Figure 6.4).

Weights:

The initial "wrap-around" design consisted of a long length of 5cm wide webbing, onto which two weights were threaded and held secure with Velcro strapping at appropriate places. The padding on the leg was rubber (6mm x 10cm x ±30cm). This model did not provide sufficient padding when used, was cumbersome to attach and generally not well suited to its purpose!

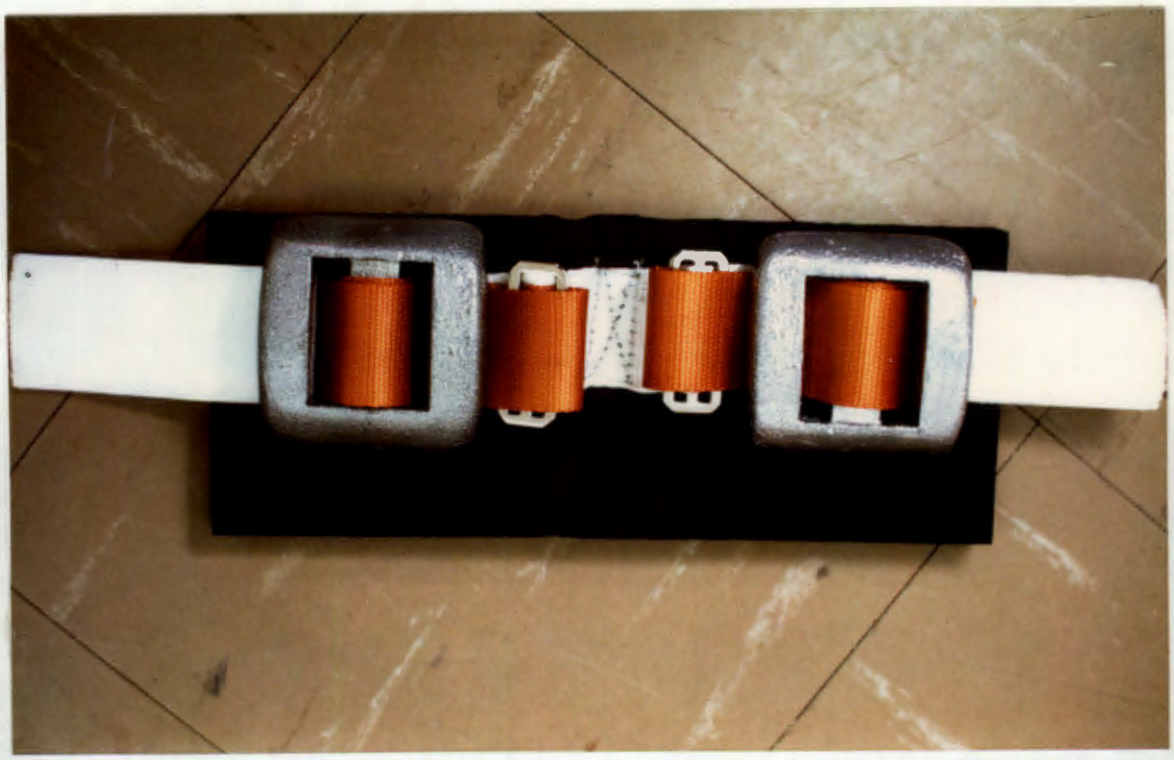


Figure 6.5 Padded ankle weights

The second, improved, model was made of thicker rubber (12mm x 12mm x ± 30cm) and one short webbing strap with just one Velcro fastening. The weights were fastened by means of a webbing and

buckle arrangement (Figure 6.5). This model has so far proved successful. Each subject was supplied with a pair of ankle weights. (Rubber - Cape Town Rubber Company, Cape Town; Buckles - Maisners, Cape Town; Webbing - kindly donated by Titan Textiles, Epping; weights - moulded at the Biomedical Engineering Department; webbing was sewn on to rubber by Sid Gersman of Hood sails).

Inclistand:

This sitting-standing frame was designed and manufactured by a team from the Biomedical Engineering Department (Figure 6.2b). It was demonstrated by Price at the 1988 Biomedical Engineering Society of South Africa (BESSA) Conference . Some of its features include:

* a hydraulic breaking system to ensure safety if stimulation should fail while the user is in the standing position
* a knee-pad, with handle to facilitate locking it, to support the knees
* a lever system to release knee-pad when stimulation session has terminated
* armrests that fold back to allow transfer to and from the Inclistand
* a footrest to secure feet
* a seatbelt
* padded set and backrest
* frame that allows increase of incline towards the vertical.

Campus Industries manufactured six Inclistands from the prototype designed by the Department.

Equipment used in the laboratory:

The six-channel programmable stimulator and the Paracycle are described elsewhere (Pons, 1986 and Popp, 1986). A set of moul-

ded, padded "boots" were manufactured by the CPA Orthotic and Prosthetic Centre, to replace the original ones on the Paracycle.

Testing Chair:

Originally, a modified hospital trolley with a backrest was used. This was replaced with the testing chair made at the Biomedical Engineering Department (Figure 6.6). This is more comfortable, less cumbersome and is an improvement both aesthetically and psychologically. Its one disadvantage is the arm rests which hinder transfer to and from the equipment.

Strength test equipment:

A strainguage (Force-displacement transducer, FT 10C, Grass Instrument Company, Quincy, Mass., USA, serial no. 14208B) connected to a strainguage amplifier (a 4-channel DC Coupled Differential Amplifier, built at the Biomedical Engineering Department) is used to monitor the muscle force produced by the stimulated contraction. It is connected via a chain and padded ankle guard (a surfer's leash) to the subject's ankle (Figure 6.7). The accompanying software was written at the Biomedical Engineering Department (Force 2) for use with an IBM compatible SPERRY personal computer and stimulation hardware (Popp, 1986).

Fatigue test equipment:

A potentiometer system designed at the Biomedical Engineering Department (Figure 6.8) is utilised in the fatigue test to measure the droop angle. This is used in conjunction with the "Droop angle test" software program.

Thus, the basic equipment is mostly supplied by and developed in the Department's mechanical workshop.

Figure 6.6 Testing chair for strength and fatigue tests

Figure 6.7 Straingauge equipment used for the strength test

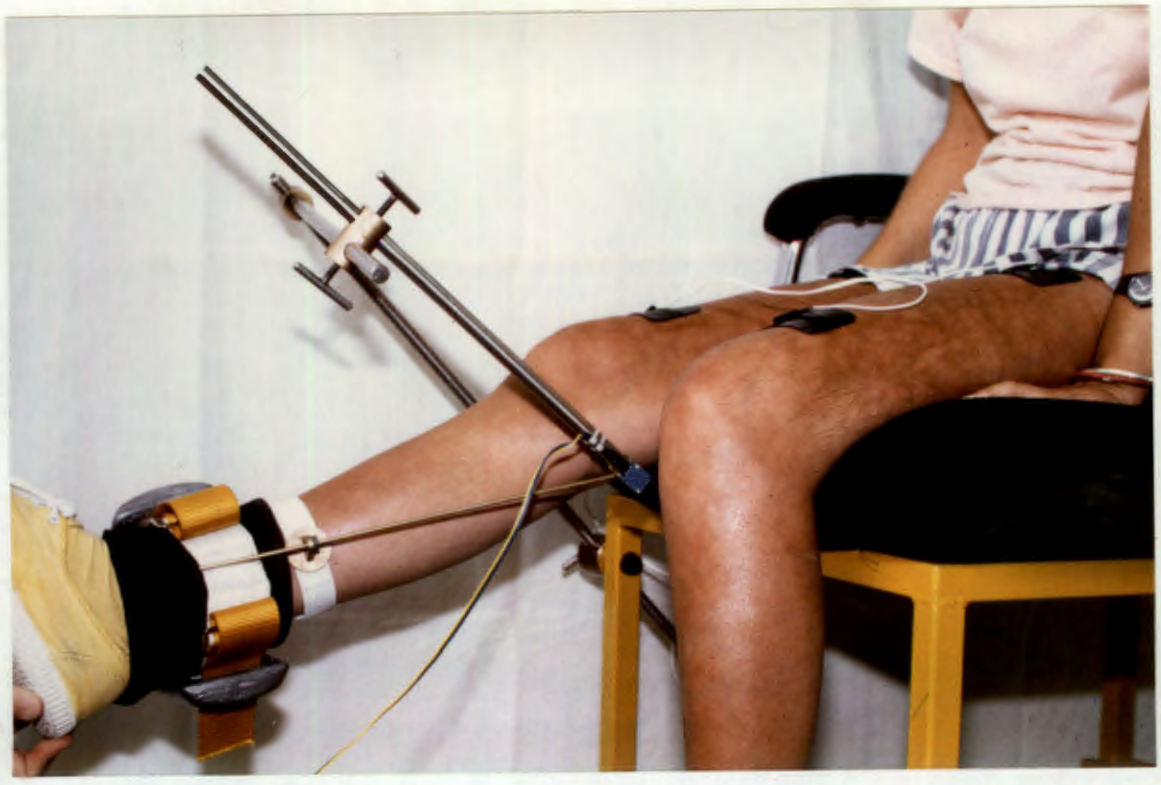


Figure 6.8 Potentiometer system used for the fatigue test

6.4 STAGES IN THE PROGRAM IN ITS PRESENT FORMAT

The following program stages have been developed and initiated and comprise the standard 'course' that is followed in the programs present format.

1. Subject selection
   * Provide background information on the project, with a video to explain the nature of the research project and what is involved.
   * Assess each subjects personal and medical history with an information sheet or discussion (Appendix 2) to determine the details such as the level and nature of injury, any medical or psychological complications and involvement in sport or exercise.
   * Initial FNS test: a strength test to determine if the subject's muscles respond to FNS and the subject's initial muscle strength.

* If subject responds and is a suitable candidate, a medical examination is necessary to determine if there are any conditions that may preclude that person from participating in the project.
* Once the subject is approved for participation and clearly understands the nature, implications and their commitment to the project, a consent form is signed (Appendix 3).

At this stage, if necessary, any required initial "pre-training" data could be collected including NMR scans, a muscle biopsy or a test to determine their maximum rate of oxygen uptake during arm exercise (VO_2 max).

2. Equipment issued: stimulator, electrodes and electrode gel
   * Stimulator channels are set to produce full extension in both legs.

   Subjects are instructed in:
   * the use and operation of the stimulator (supplied with operating instructions)
   * electrode positioning, application and care
   * the use of the logbook

3. The exercise program (Stage A):

   Subjects begin gradually, by exercising for 3 minutes and increasing the session length according to the following criterion: If the leg achieves full knee extension for the duration of the present session length for three consecutive sessions, they proceed to next session length.

Subjects were told to notify the program coordinator of any problems experienced, such as a faulty stimulator, persisting red marks from electrodes after a session or if their legs were not responding correctly (full extension) to the stimulation.

4. Assessments:

* At the initial session, suitable electrode positions that produce a strong muscle response are located.
* They are performed every 2, 3 or 4 weeks depending on subject's availability
* These assessments consist of: 10 minute 'warm up' of passive, motor driven cycling in Paracycle
  Strength tests
  Fatigue tests
* Data is recorded on a data sheet, any unusual responses are noted and the test response is stored on disc for future comparison and analysis.

5. Loading (Stage B)

* Once 'sufficient' strength is reached , weights are issued in 0,5 or 1 kg increments. Subjects proceed according to Stage A criterion. 'Sufficient' strength is judged according to the individual subject's progress and improvement to date - when the muscle strength response has reached a plateau on stage A.
* Fatigue tests are then performed with a load of 2 kg.
* Loads are gradually increased according to improvements assessed.

6. Inclistand (Stage C)

* Once 'sufficient' strength is built up, subjects proceed to use the Inclistand (IS). At this stage, no 'sufficient value' has been calculated and each subject's situation is judged individually.
* They are instructed in the use of the IS.

* Subjects have a short session of standing in the laboratory after an assessment appointment in order to make any necessary adjustments to their particular IS to ensure an optimal position for comfort and function.
* When familiar and confident with the IS, subjects receive their IS for home use.

Stage D would be the initiation of the standing routine, between parallel bars, under the control of a FNS microprocessor.

As subjects proceed through the stages of the program, information is gathered that will aid in improving the program. It differs from that which was initially planned due to the need to adapt to the present circumstances.

6.5 EXPERIMENTAL METHODS

Activity level:

The following scale was developed to rate the activity level of the FNS exercise at the time of each assessment:

Activity level	Load (kg)	Frequency (x/week)	Duration (mins)
0	no stimulation		
1	-	1-3	3-24
2	-	4-7	3-24
3	-	1-3	27-48
4	-	4-7	27-48
5	1	1-3	3-24
6	1	4-7	3-24
7	1	1-3	27-48
8	1	4-7	27-48
9	2	1-3	3-24
10	2	4-7	3-24
11	2	1-3	27-48
12	2	4-7	27-48

A scale was used to rate the level of use (standing) of the Inclistand.

Inclistand(IS) use:

Activity level	Frequency (x/week)	Duration (mins)
ISo without stimulation		
1 with stimulation	1-3	0-20
2	4-7	0-20
3	1-3	20-40
4	4-7	20-40

This serves as a general indication as some subjects did not always keep a strict, detailed record of stimulation sessions.

Strength test:

The subject is seated on the testing chair, with the ankle guard (attached to the strainguage) fastened around his ankle. At the first test, the subject is tested to determine the electrode positions that produce the strongest muscle response. A grid similar to that of McNeal and Baker (1985) is used . Once found, these electrode positions are used in all future muscle tests. The computer, Force 2 software program and the programmable stimulator are used to supply the stimulus of the following parameters:

frequency: 25 Hz

amplitude: 80 mA

pulsewidth: increasing to a maximum of 999 µs. In the initial studies this was set to 200 or 300 µs, but later changed on the discovery that, at this pulsewidth, the muscle did not reach its maximum force.

on:off ratio: 1:1

test duration: 20 seconds

The data is stored on disc and later plotted by means of a Forceplot program (written at the Biomedical Engineering Department) on a Hewlett-Packard 7475A plotter. An example of a strength test result is shown in Figure 6.9.

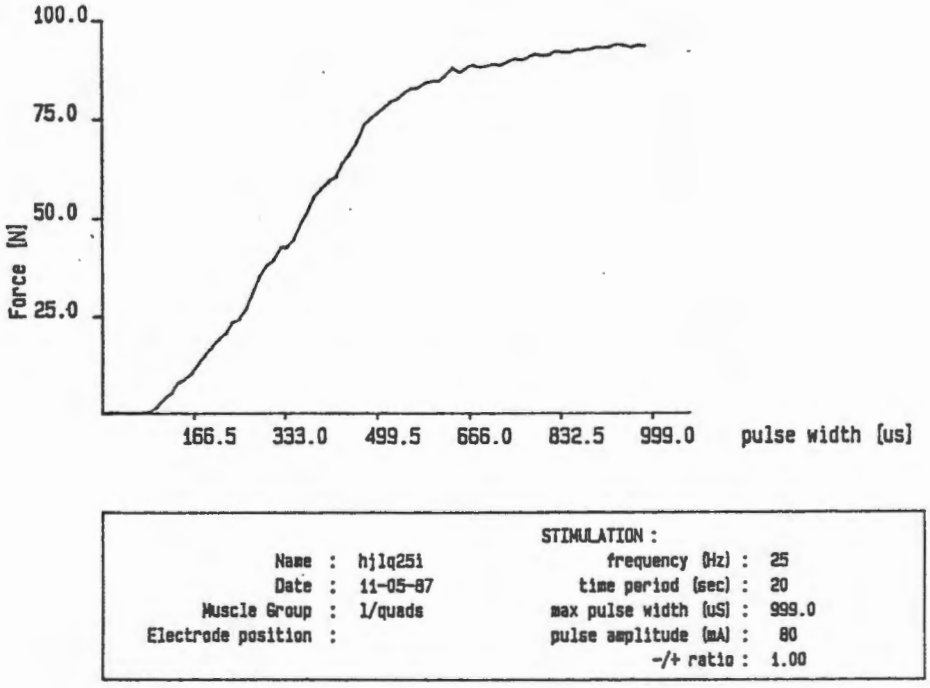


Figure 6.9 Example of a strength test result

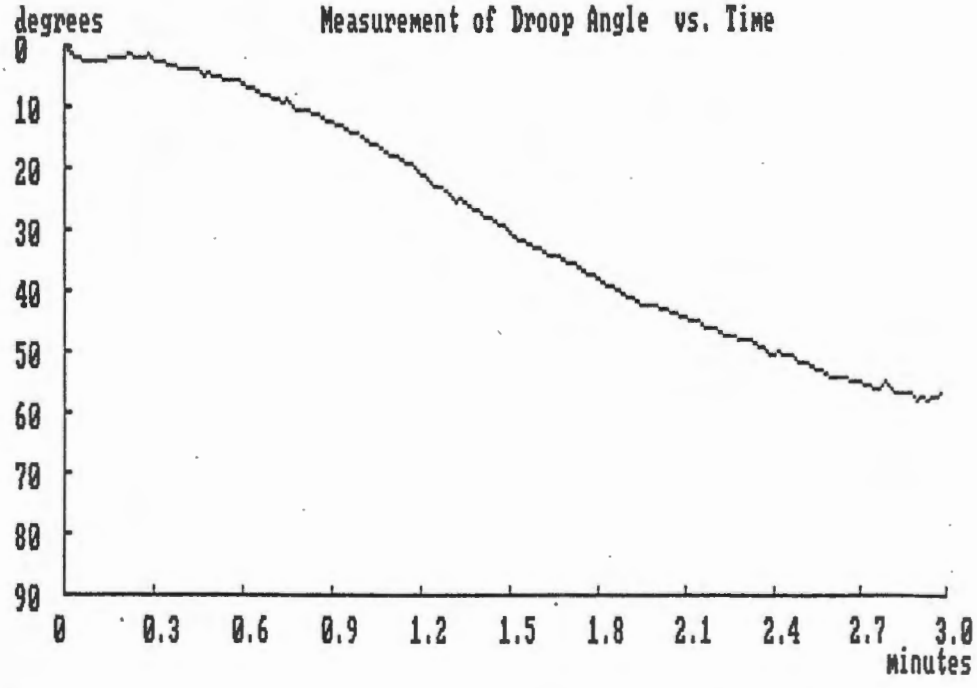


Figure 6.10 Example of a fatigue test result

Fatigue test:

The potentiometer system is fitted to the subject's leg and is adjusted so that possible medial rotation of the leg would not interfere with the device. A 2 kg ankle weight is fastened around the subject's ankle. The system is calibrated in the vertical (0^{o}) and horizontal (90^{o}). The subject's leg is extended manually and held until the stimulation is initiated. As the leg gradually fatigues, the droop angle is monitored (0^{o} -90^{o}) and displayed on the computer monitor. The stimulation parameters for this test are:

frequency:	25 Hz
amplitude:	80 mA
pulsewidth:	600 µs
test duration:	3 minutes

The data are stored on disc for comparison purposes. Figure 6.10 shows an example of a fatigue test result.

Muscle bulk:

One method of assessing changes in muscle bulk is to take regular measurements at specific points on the limb with a tape measure. In this Project use was made of Nuclear Magnetic Resonance (NMR) scans. The NMR scans were taken approximately bi-annually on the Gyrex at the Research Institute for Medical Biophysics (RIMB) of the Medical Research Council (MRC), Tygerberg. A reference point was fixed in order to position the scans at the same location each time. Five individual "cuts" (at 7mm intervals) were taken of each leg at each scan session (Figure 6.11a and b). The Medical Research Council enlarged and printed scans to a fixed cursor distance to facilitate further analysis.

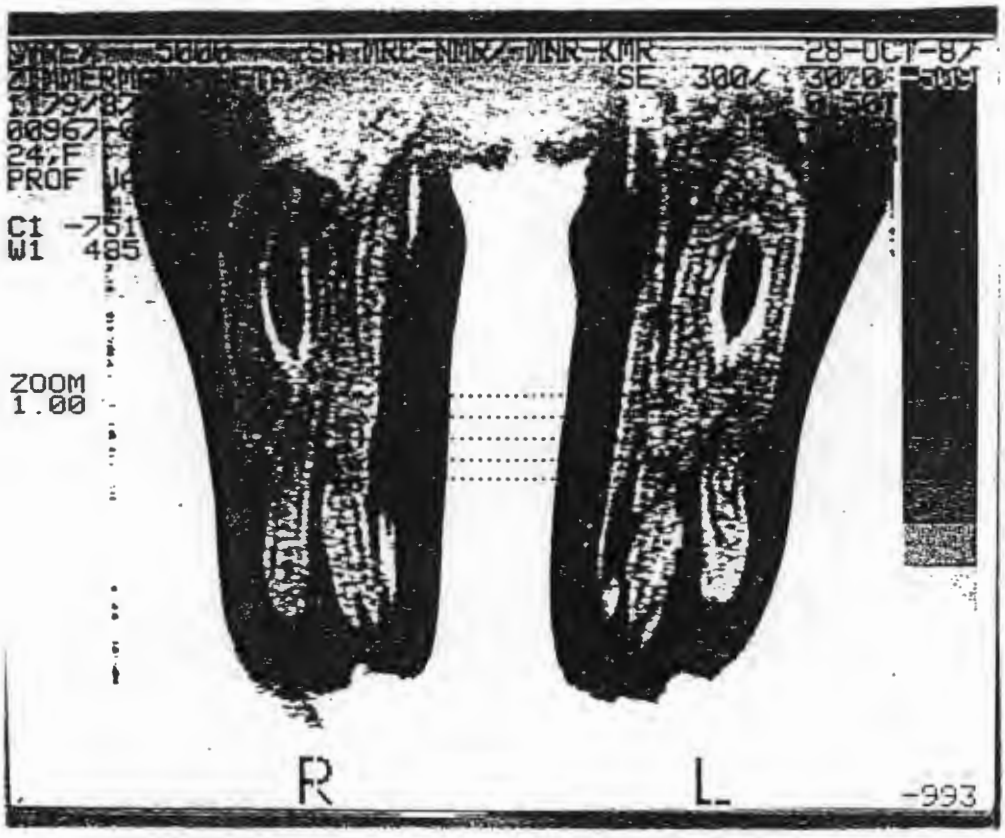


Figure 6.11a Position of five NMR scan 'cuts' for each leg

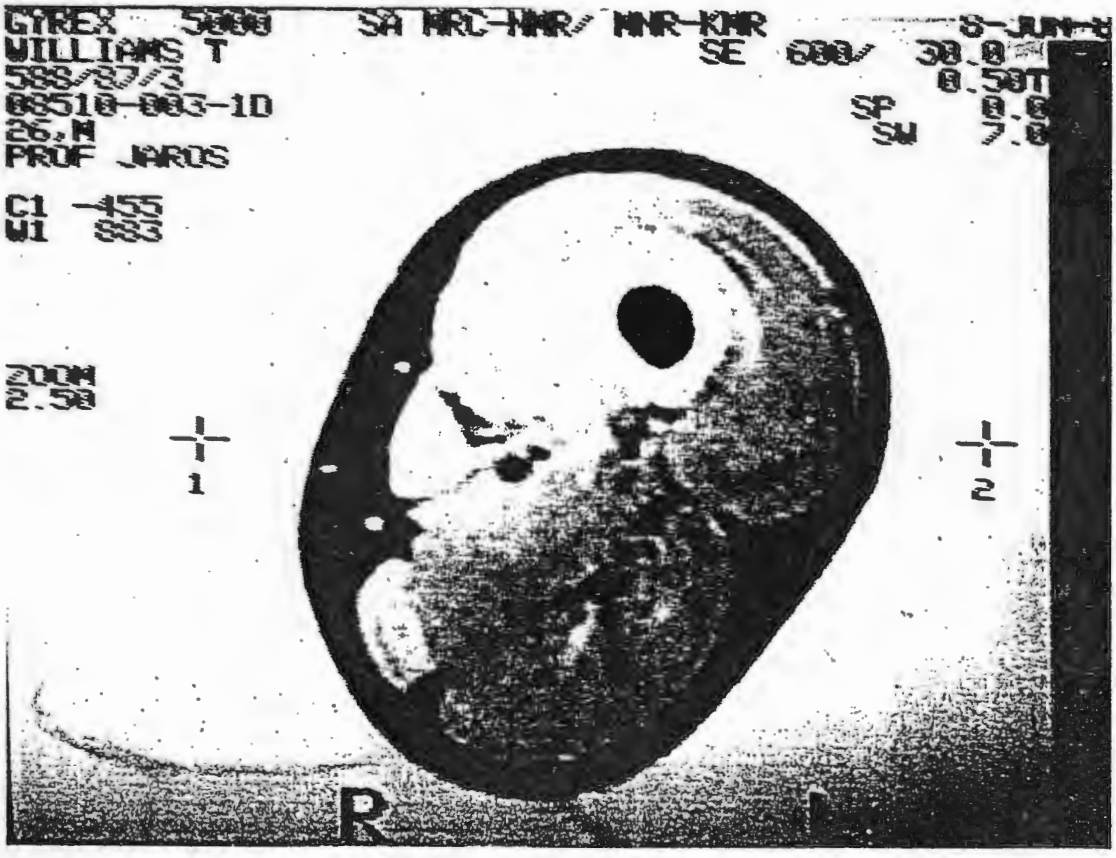


Figure 6.11b One cross-sectional scan 'cut'

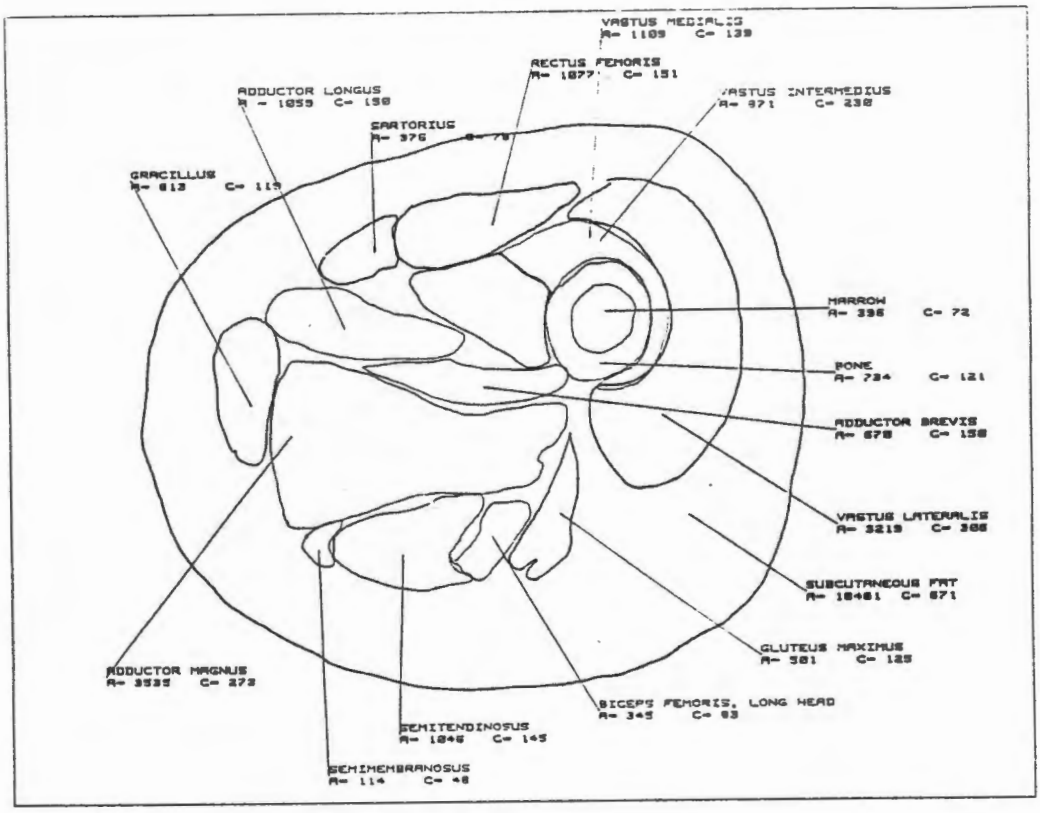


Figure 6.12a Original digitisation format

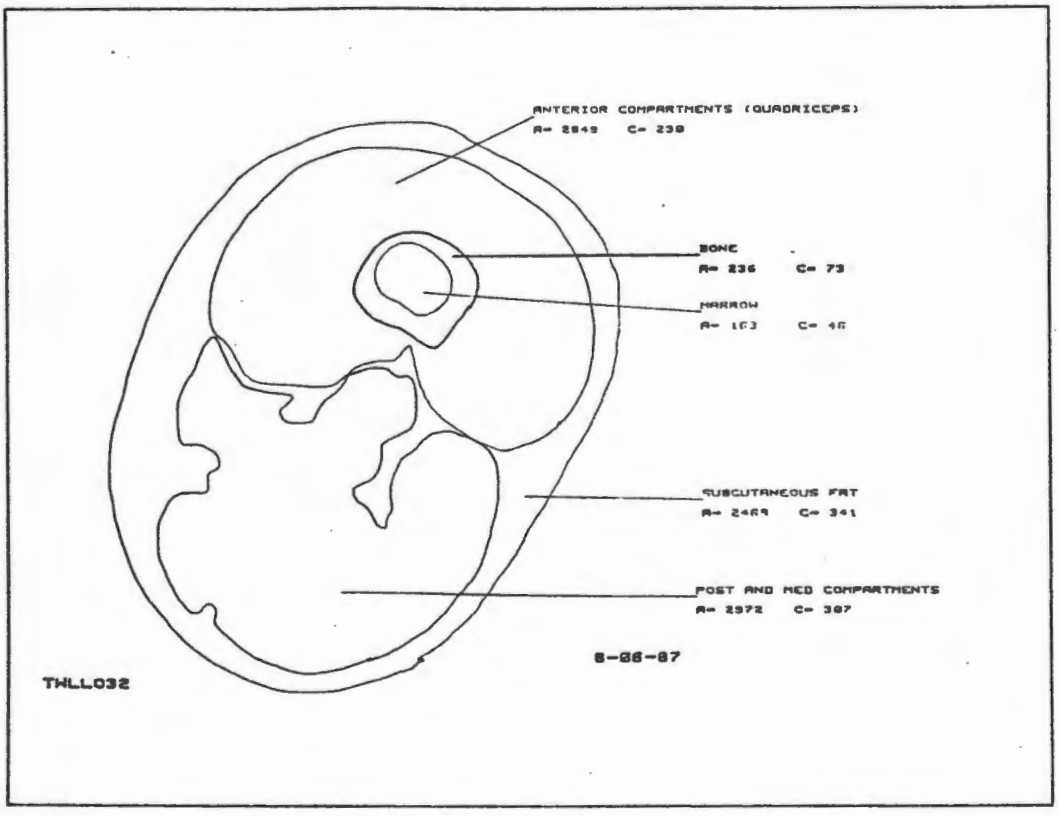


Figure 6.12b Revised digitisation format

This analysis involved digitising each individual scan with a program written by Ann Tregidga and Professor LP Adams of the Department of Surveying, University of Cape Town. The original program was written to digitise each individual muscle (Figure 6.12a), but due to muscle atropy and the poor focus of the prints, this proved impossible. A revised version allowed for the following compartments to be identified and analysed (Figure 6.12b):

* Anterior compartment (quadriceps)
* Posterior and Lateral compartment
* Bone
* Marrow
* Subcutaneous fat

The program calculated the area and circumference of each of these compartments.

Consecutive NMR scan prints were not the exact same size and therefore direct comparison between them was not possible. As an alternative solution, the area of the individual compartments were calculated as a percentage of the total cross-sectional area of the leg for that particular scan print. An average of these 'relative percentages of the area' were calculated from the five individual 'cuts' of each leg from each scan appointment. These average percentage areas from the left and right legs were compared with the equivalent averages from the NMR scans taken at the subject's next scan appointment.

SECTION B: EXERCISE

6.6 PROJECT RESTAND

As the large muscle mass in the lower limb was being exercised, the workload of the cardiovascular system would be increased. Taking this into account it was deemed necessary to include an upper body fitness program in order to improve the cardiovascular fitness of the RESTAND group. This was part of the plan to prepare the "whole person" so that the subject would be in optimal physical condition for standing.

The initial idea was for the group to undergo a fitness training program, in addition to their FNS muscle stimulation, and to monitor improvements in fitness by means of pre- and post-training measurements of: VO_2 max, exercising blood lactate levels, upper body strength, serum cholesterol levels and respiratory function.

Possible Options

The Department of Biomedical Engineering had no equipment for a fitness program and therefore a suitable venue had to be found. Local facilities for the disabled and able-bodied gyms were the first option considered. The Access Committee (involved in determining the accessibility of different buildings for wheelchair dependent people) had no record of accessible local gyms as there had never been a demand for these or any such facilities specifically for disabled people. Indeed, this project showed that there is a distinct lack of suitable facilities for exercise training for the disabled.

The equipment in able-bodied gyms is generally unsuitable as it has insufficient padding and the benches are too narrow, and are arranged in such a manner that does not permit easy wheelchair

manoeuvering. One local gym was prepared to allow the group to exercise there, provided they were accompanied by another person as the gym would not accept responsibility should anything happen. This posed a problem as each person wanted to be independent and attend the gym at times suited to their particular lifestyle. The need to be accompanied made it inconvenient. Obviously another problem with able-bodied gyms is the lack of appropriate cloakroom facilities for the disabled.

The University of Cape Town Weightlifting Club was another possible venue, but this also proved to be inaccessible with unsuitable facilities. A group of Occupational Therapy students had recently completed a project on the accessibility problems of the gym. Thus, there appeared to be no suitable "external venues".

The other option was to develop suitable equipment at the Department of Biomedical Engineering. Modifications on "rowing machine exercisers" were proposed, but these proved unsuitable as did a pedalling device (arms used to pedal the legs). When the Inclistand was developed, the concept of it serving as a multipurpose device arose. The seat and backrest were padded and could be lowered to serve as a weightlifting/exercise bench on which the subjects could exercise at home at their convenience. An idea of placing an Inclistand at a local Sports Club for disabled people, namely the Protea Sports Club, Retreat, Cape Town, for general use was not met with much enthusiasm due to its inconvenient location. Subjects would be required to provide their own dumbells or weights. An Inclistand was transported to the weightlifting club of Mr Tony Asaro who kindly showed three of the subjects a few of the exercises they could perform. As a result, one subject (who had experience of working in a gym prior

to her accident) purchased a pair of dumbells to exercise with, and another did some exercise with springs.

As previously stated, exercise prescription should be individualised according to individual goals that depend on health status, cardiovascular fitness, level of SCI, motivation and time availability. Personal preference could perhaps be inserted in this list as, just as in able-bodied people, those with SCI's prefer different types of exercise and not all subjects were interested in the particular exercise mode that was presented. Motivation and time availability proved to be important factors. The subjects all led full lives and were already setting time aside for FNS exercise. They either lacked the motivation , interest or the available time to set aside additional time for an extra commitment in the form of exercise training sessions.

On the realisation that in the present situation a fixed exercise program would not be feasible, subjects were encouraged to continue in any forms of exercise that they were presently involved in. This included: TW - wheelchair racing training; SB - used a home gym; RM - archery (does not promote cardiovascular fitness); AZ - used a pedalling device and a set of springs on occasion; HV - bought a set of dumbells (not frequently used) and DH - an incomplete tetraplegic who did not perform any "formal" exercise but regularly walked with support.

Unlike the lack of facilities for arm exercise training, there are sports clubs for the disabled. The three main clubs in Cape Town are: Protea Sports Club, Retreat; St Giles, Rondebosch and Unitie, Athlone. A program of the available sports they offer is included in Appendix one).

6.7 EXPERIMENTAL METHODS

Due to the fact that the subjects did not undergo a standard regimented, carefully monitored training program, no post-training measurements were taken. The original pre-training measurements are therefore presented as an indication of the general health and fitness of the subjects. (Not all the subjects performed each test).

1. Maximal arm ergometer exercise test

This was performed at the MRC/UCT Bioenergetics of Exercise Research Unit, University of Cape Town (UCT) Medical School, on a Monark Rehab Trainer 881.

Exercising heart rates were measured using disposable electrodes in the CMS configuration and a Life-Trace 12 Monitor (Albany Instruments Ltd., London). A 22G Jelco teflon intravenous catheter placement unit (Critikon, Tampa, Florida, USA) was inserted into a subcutaneous forearm vein. It was then connected via a preheparinised tubing to an Eyela Microtube Pump MP-3 (Rikakikai Co. Ltd., Tokyo, Japan). A 1 ml blood sample was taken every minute, into a test tube containing 2 ml ice-cold 70% perchloric acid, during exercise and for 1-4 minutes during the post-exercise recovery period.

The subjects were seated in their wheelchairs with the arm ergometer clamped to a table for stability. After a short warm-up period to familiarise themselves with the ergometer, subjects exercised progressively until volitional exhaustion. The workload was increased from 0W in approximately 12W increments every two to four minutes, depending on the subject's known upper body strength, in order to avoid premature exhaustion due to arm muscle fatigue.

The subjects sat with a model no. 2766 Counterbalance head support holding a model no. 2770 Rudolph valve (both by Hans Rudolph Inc., Kansas City, USA). A noseclip prevented nasal breathing. Air was exhaled through clear bore 35 mm tubing into a 15 litre perspex mixing chamber with baffles. Expired air from the mixing chamber was continuously sampled through Drierite anhydrous $CaSO_4$ (Vacumed Inc., Ventura, California, USA) to the pick-up heads of an Ametek oxygen analyser model S-3A1 and an Ametek carbon dioxide analyser model CD-3A (both Applied Electro-chemistry, Ametek Inc., Pittsburgh, Pennsylvania, USA). Both analysers were calibrated before and after each test using gases of known composition using the Haldane technique.

Inspiratory volume and expiratory rate were recorded from a Morgan ventilation monitor (P K Morgan Ltd., Kent, UK) that had been calibrated against a Collins chain-compressed gasometer (Collins Inc., Braintree, Massachussetts, USA).

The blood samples drawn for lactate analysis were mixed, then centrifuged for 10 minutes at 2000 rmp in a refrigerated Beckman Centrifuge model TJ-6 (Mervue, Galway, Ireland). After being weighed, the supernatant was decanted for later analysis of lactate levels according to the method of Gutmann and Wahlefeld (1974).

Individual graphs of venous lactate levels versus workload were used to determine visually the blood lactate turnpoint. The lactate turnpoint is that workload at which the blood lactate level is clearly elevated above preceeding values.

2. Muscle Function

The six subjects underwent testing on a Cybex II Isokinetic

dynamometer with a Cybex Reduction Computer (Cybex, 1982). The tests were administered by Biokineticians at the Department of Biokinetics at II Military Hospital, Wynberg, Cape Town. Tests were performed to measure shoulder extension and flexion (Code 7) and elbow extension and flexion.

The subjects were positioned on the upper body exercise testing table (U.B.X.T). Pelvic and torso straps were fastened tight in order to isolate the movement to the shoulder and elbow joints respectively. The fulcrum of the lever was positioned in line with the axis of rotation of the shoulder (the compromise axis used is approximately at the acromion process when the limb is in the 0^{o} position) and elbow (immediately distal to the lateral epicondyle) for the respective tests.

Each subject was given a practise bout to allow the arm muscles to warm up and for the subject to familiarise themself with the testing procedure. A short rest followed in which any necessary adjustments to the equipment were made. During the test, the subject was encouraged to perform maximally. The measurements of muscle power were measured for 5 repetitions at a speed of $60^{o}.sec^{-1}$ for both the shoulder and elbow. The calculations were made by the Cybex Data Reduction Computer.

3. Lung Function

Peak flow, forced vital capacity (FVC) and force expiratory volume in one second (FEV_1), from which FEV% was calculated, were measured with subjects seated in their wheelchairs, using a Pneumoscan S-300 Spirometer (KL Engineering Co., Sylmar, California). Subjects were instructed on the testing procedure, had a practise attempt, and then after a brief rest, performed four tests from which a mean was calculated.

4. Blood Biochemical Parameters

Five of the six subjects participated in these measurements. TW was on the "WALK and WHEEL" marathon. (This was a wheelchair marathon from Cape Town to Johannesburg, South Africa, to raise funds for Project REWALK.) The subjects ate a collagen and gelatin-free diet for four days. This is essentially a vegetarian diet as meat, chicken and fish are excluded. Protein was obtained in the form of eggs, cheese, soya and beans. On the final day of this diet, a 24-hour urine sample was collected. Two fasting blood samples were taken the following morning between 07h30 and 09h00.

One blood sample was analysed by a sequential multiple analyser and computer (SMAC) at the Department of Chemical Pathology, Groote Schuur Hospital (GSH). The other was analysed for cholestrol concentration at the Department of Chemical Pathology, Red Cross Memorial Children's Hospital to obtain a more accurate measure of cholestrol levels. The urine sample was analysed at GSH for creatinine and hyroxyproline concentrations.

5. Dietary Analysis

Four subjects (HV, RM, AZ, SB) completed a 7-day dietary record. A standardised balance and measuring cup was used to measure the mass or volume of all food eaten during this 7-day period. Each food item was coded according to the dietary composition tables compiled by the National Research for Nutritional Diseases (NRIND) (Gouws et al, 1982). The coded data was computer processed with the Floro Diet Data Plan (Unilever Research Laboratory, 1987) in order to obtain the daily average intake.

CHAPTER SEVEN

RESULTS

7.1 SUBJECT CHARACTERISTICS

The original RESTAND group, chosen in late 1986, comprised 6 members (due to the fact that there were only 6 FNS-muscle stimulators available):

1 incomplete tetraplegic (C6) female (DH)

5 complete paraplegics (T4 - L2): 1 female (HV) and 4 males (TW, RM, RB, DG).

After a three month trial period, RB and DG (L1,2) had not responded to the FNS quadriceps stimulation, and therefore discontinued stimulation. According to the list of selection criteria in Chapter Four, RB and DG would not have been suitable FNS candidates as their lesions (L1,2) are outside the range suggested (T3 - T12) and they may have had lower motor neuron lesions.

Two paraplegics (EB, female and LA, male) replaced RB and DG in May and July 1987. Both discontinued participation by the end of July due to personal reasons. Two replacements (CG, female paraplegic and AZ, female tetraplegic) commenced in September 1987. CG had to discontinue participation as she moved from Cape Town. In January 1988, SB (male paraplegic) joined the RESTAND group. AZ and SB, together with the remaining four from the original group (DH, HV, TW, RM) now comprise the present RESTAND group. Table 7.1 lists the sex, age, weight, height, occupation and marital status of the group. Table 7.2 provides details of the nature and type of lesion and Table 7.3 provides information on the activity levels and medical complications of the group.

Table 7.1 The sex, age, weight, height, occupation and marital status of the RESTAND group.

Subject	Sex	Age	Height (cm)	Weight (kg)	Occupation pre-injury	Occupation present	Marital Status
DH	F	48	180	61	Scholar	Voluntary Worker	Single
HV	F	26	170	56	Student	Product developer	Married
AZ	F	25	168	48	Student	UNISA student	Single
TW	M	27	173	59	Student	Owns a panel-beating business	Married
RM	M	26	152	70	Scholar	Actuarial Clerk	Single
SB	M	17	178	55	Scholar	Student	Single
$\bar{x}$		28	170	58			
$\pm$ SD		10	10	7			

Table 7.2 The nature and type of lesion

Subject	Cause	Date (mnth/yr)	Years post-injury (approx)	Lesion level	Spinal fusion (date)	Metal plates/ pins
DH	Diving	2/1955	33,5	C5,6 (inc)	-	-
HV	MVA	7/1984	4,0	T5,6	7/1984	Harrington Rod
AZ	MVA	7/1982	6,0	C7	-	-
TW	M-cycle	2/1984	4,5	T4	2/1984	-
RM	MVA	2/1973	15,5	T8,9	1976	Both femurs
SB	M-cycle	12/1986	1,6	T9	12/1986	Harrington Rod; Pin, plate in right ankle

MVA = motor vehicle accident
M-cycle = motor cycle accident
\- = not performed
approx = approximately
inc = incomplete

Table 7.3 The level of activity, sports/exercise participation and medical complications experienced

Subject	Stand/Walk	Sport/Exercise Type, level, frequency	Complications
DH	3x/wk; 30 mins	Bowls, Table-tennis Social Infrequently	-
HV	-	-	Kidney and bladder stone, occasional bladder infection
AZ	2x/wk; 2 hours (with calipers)	"Cycling" 2 or 3x/week	-
TW	-	Athletics Social and competitive 5x/week	-
RM	-	Archery Social and competitive 1 or 2x/week	Pressure sore, bladder infection. Torn tendon in right foot in 1983
SB	1x/wk; 30 mins	Home gym 5x/week; 30 minutes	-

"Cycling" refers to exercising on a portable, stationary cycling device. The subject cycles by manually moving her legs with her hands.

Statistical Analysis

These tables show that the RESTAND group is very heterogenous, in many aspects such as lesion level and years since injury. The group was not selected for the purpose of a statistical study which requires a homogenous group to minimise the variables that may affect the response to FNS. Thus, the results are presented individually for six case studies and where possible, the data for the group has been analysed with the appropriate statistical test. The paired Students' T-test was used for paired data (initial and final values) and the unpaired students' T-test to analyse change such as increases in strength and improvements in

the fatigue resistance. A value of $p<0,05$ was regarded as statistically significant.

SECTION A. FNS STIMULATION

7.2 QUADRICEPS MUSCLE STRENGTH

The original four subjects (DH, HV, TW, RM) were initially assessed for strength with parameters chosen by the 1986 FNS research group. These were a maximum stimulation pulsewidth of 200 or 300 µs and an amplitude of 60 or 90 mA. Examination of the resulting strength graphs indicated that these parameters did not produce the maximum force and they were therefore adjusted to a maximum of 999 µs and 80 mA in April/May 1987. This change of parameters makes analysis and comparison of the maximum strength at consecutive tests more complex as the new parameters themselves would result in the production of higher maximum strength values. Thus, for these four subjects, the strength values at 300 µs (as for the initial test) in successive tests are provided for comparison purposes. AZ and SB joined the RESTAND project subsequent to the parameter change and were thus assessed with these parameters from the start.

In the stimulation program used to assess strength, a safety feature in the form of a cut-off "stimulation point" at 100N exists. The program does record the maximum strength reached, such as 104N. Once this 100 N mark is reached, another index, PWmax, was developed to monitor further improvements. PWmax is defined as the pulsewidth at which the maximum strength is reached. Further improvements would be noted as a decrease in PWmax. This index was necessary mainly for TW.

Figures 7.1a to 7.1f represent the strength assessments for each individual subject. The bar graphs represent the maximum

strength at each assessment. The left and right leg are represented by the left and right bar respectively. A table containing a list of the stimulation parameters (pulsewidth = µs; amplitude = mA) and the strength at 300 us (for comparison with the initial test) are provided for DH, HV, TW and RM as well as PWmax values for TW.

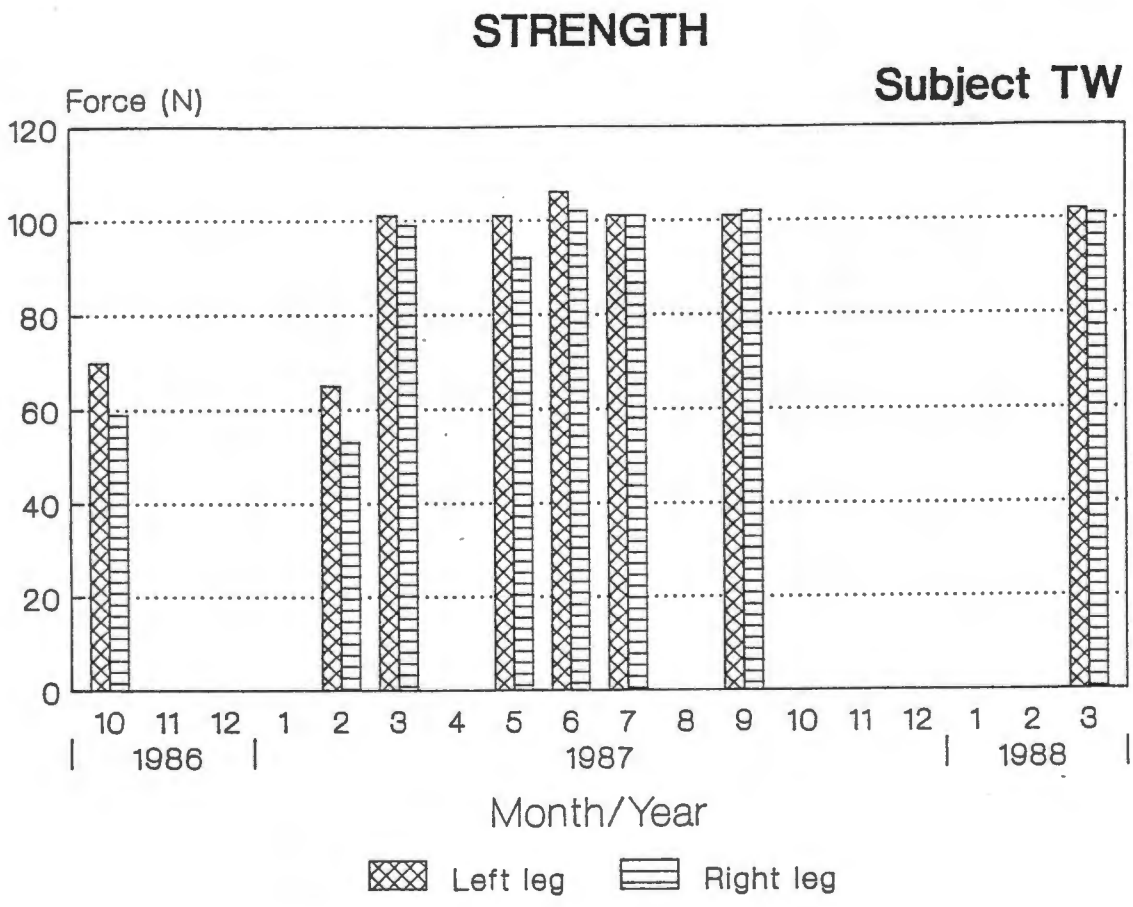


Figure 7.1a. The maximum force (N) recorded at each strength test for subject TW.

Key to Figure 7.1a:

Date	Parameters (us)	(mA)	Force at 300 us (N) LL	RL	PWmax (µs) LL	RL	Activity level
10/86	300	60	70	59			0
2/87	300	80	65	53			2
3/87	600	80	101	77	247	425	4
5/87	999	80	N/A	N/A	N/A	N/A	11
6/87	999	80	75	75	462	440	10
7/87	999	80	101	101	212	212	9
9/87	999	80	101	102	212	225	9
3/88	999	80	102	101	210	210	0

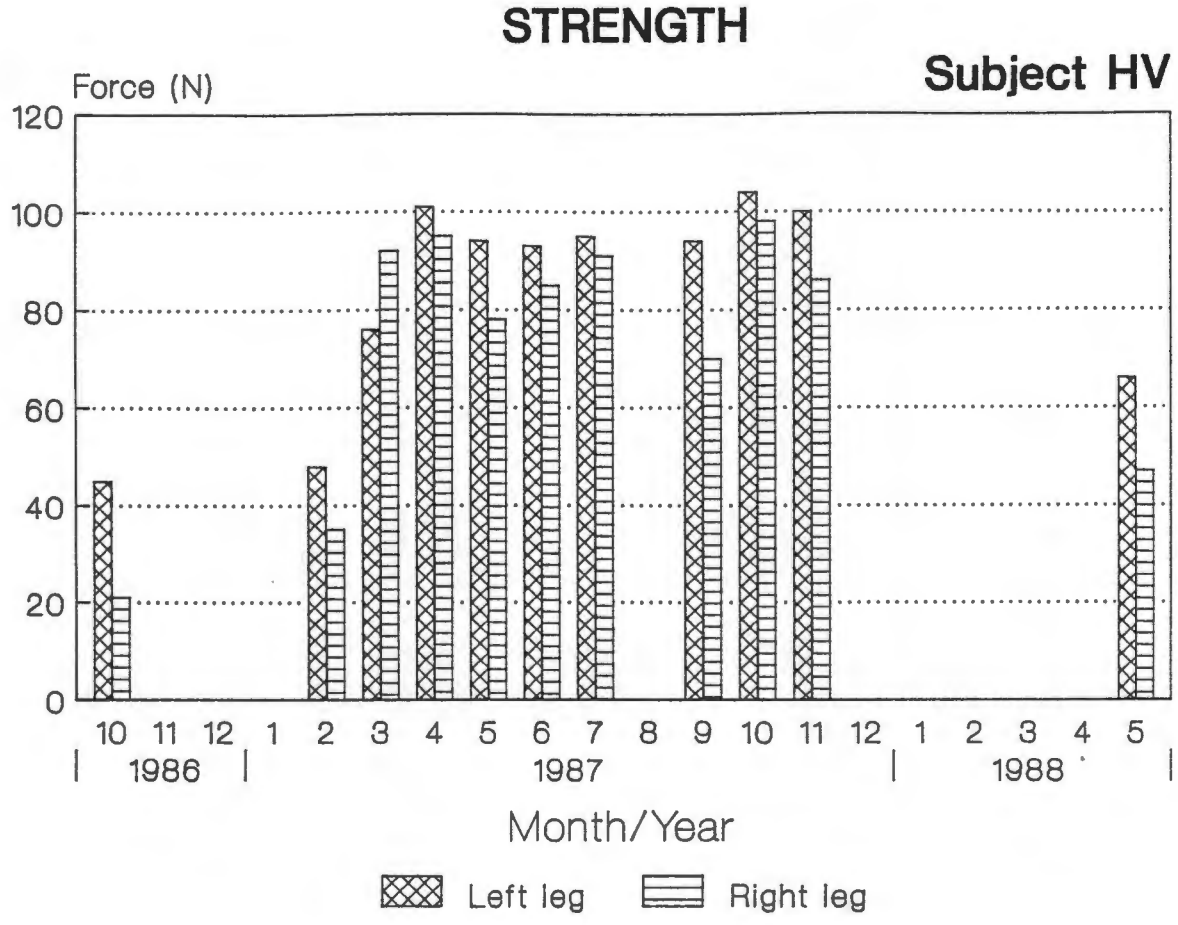


Figure 7.1b. The maximum force (N) recorded at each strength test for subject HV.

Key to Figure 7.1b:

Date	Parameters (us)	(mA)	Force at 300 µs (N) LL	RL	Activity level
10/86	300	90	45	21	0
2/87	300	80	48	35	4
3/87	600	80	57	N/A	11
4/87	999	80	N/A	39	11
5/87	999	80	38	28	11
6/87	999	80	52	44	11
7/87	999	80	53	60	11
9/87	999	80	90	65	0
10/87	999	80	104	93	IS1
11/87	999	80	100	84	0
5/88	999	80	60	41	0

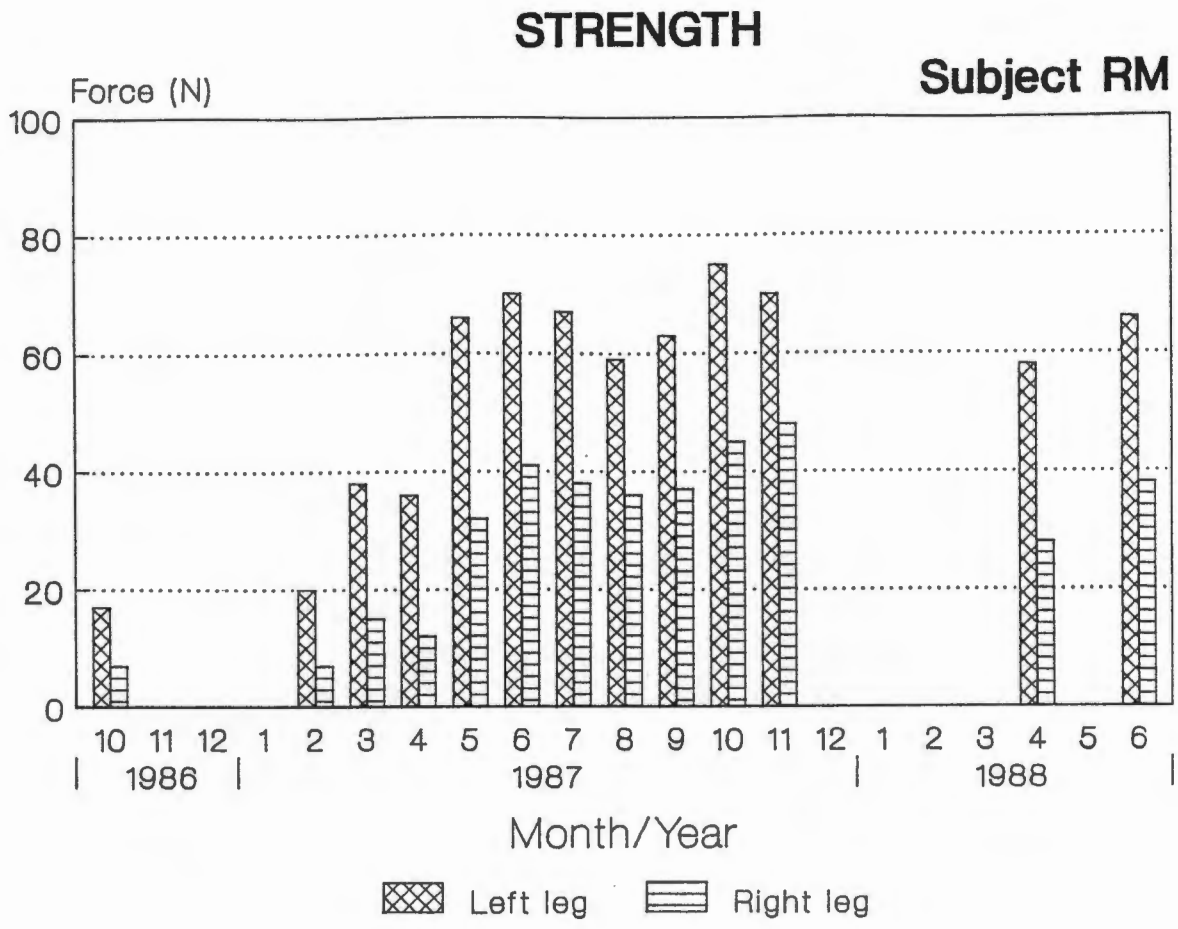


Figure 7.1c. The maximum force (N) recorded at each strength test for subject RM.

Key to Figure 7.1c:

Date	Parameters (us)	(mA)	Force at 300 µs (N) LL	RL	Activity level
10/86	300	80	17	7	0
2/87	300	80	20	7	3
3/87	600	80	26	9	4
4/87	600	80	20	4	6
5/87	999	80	40	23	5
6/87	999	80	46	31	0
7/87	999	80	48	23	0
8/87	999	80	35	25	5
9/87	999	80	49	20	5;ISo
10/87	999	80	35	25	0;ISo
11/87	999	80	46	24	5
4/88	999	80	49	25	0
6/88	999	80	49	30	0

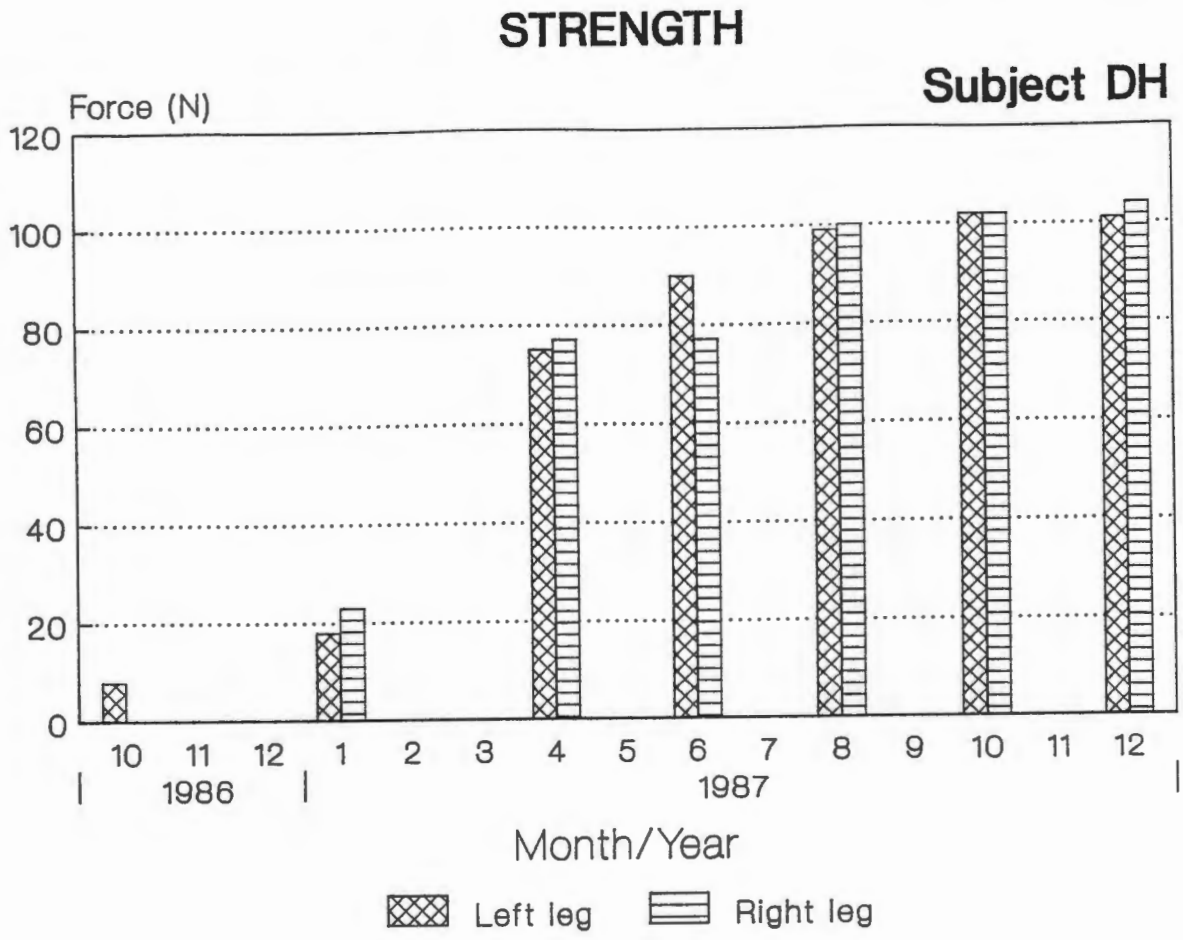


Figure 7.1d. The maximum force (N) recorded at each strength test for subject DH.

Key to Figure 7.1d:

Date	Parameters (us)	(mA)	Force at 300 µs (N) LL	RL	Activity level
10/86	200	60	8	0	0
1/87	300	60	18	23	2
4/87	300	40	77	77	6
6/87	999	5	57	52	6
8/87	999	5	82	66	9
10/87	999	5	102	102	9;IS1
12/87	999	5	101	104	9;IS1

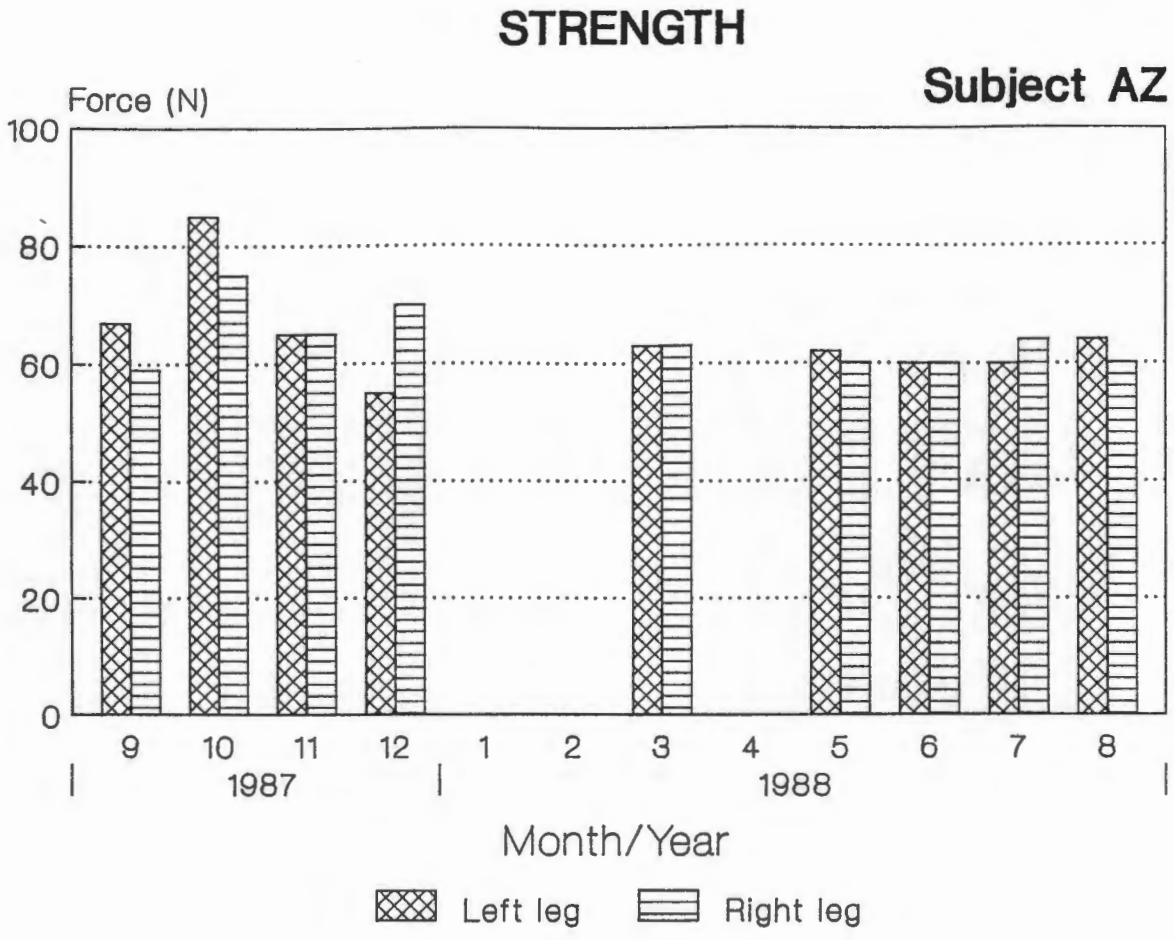


Figure 7.1e. The maximum force (N) recorded at each strength test for subject AZ.

Key to Figure 7.1e:

For subjects AZ and SB, all tests were performed with parameters of 999 µs and 80 mA and this it is unnecessary to present the 'Force at 300 µs' in the key.

Date	Parameters (µs)	(mA)	Activity level
9/87	999	80	0
10/87	999	80	2
11/87	999	80	2
12/87	999	80	2
3/88	999	80	6
5/88	999	80	9
6/88	999	80	10
7/88	999	80	10
8/88	999	80	9

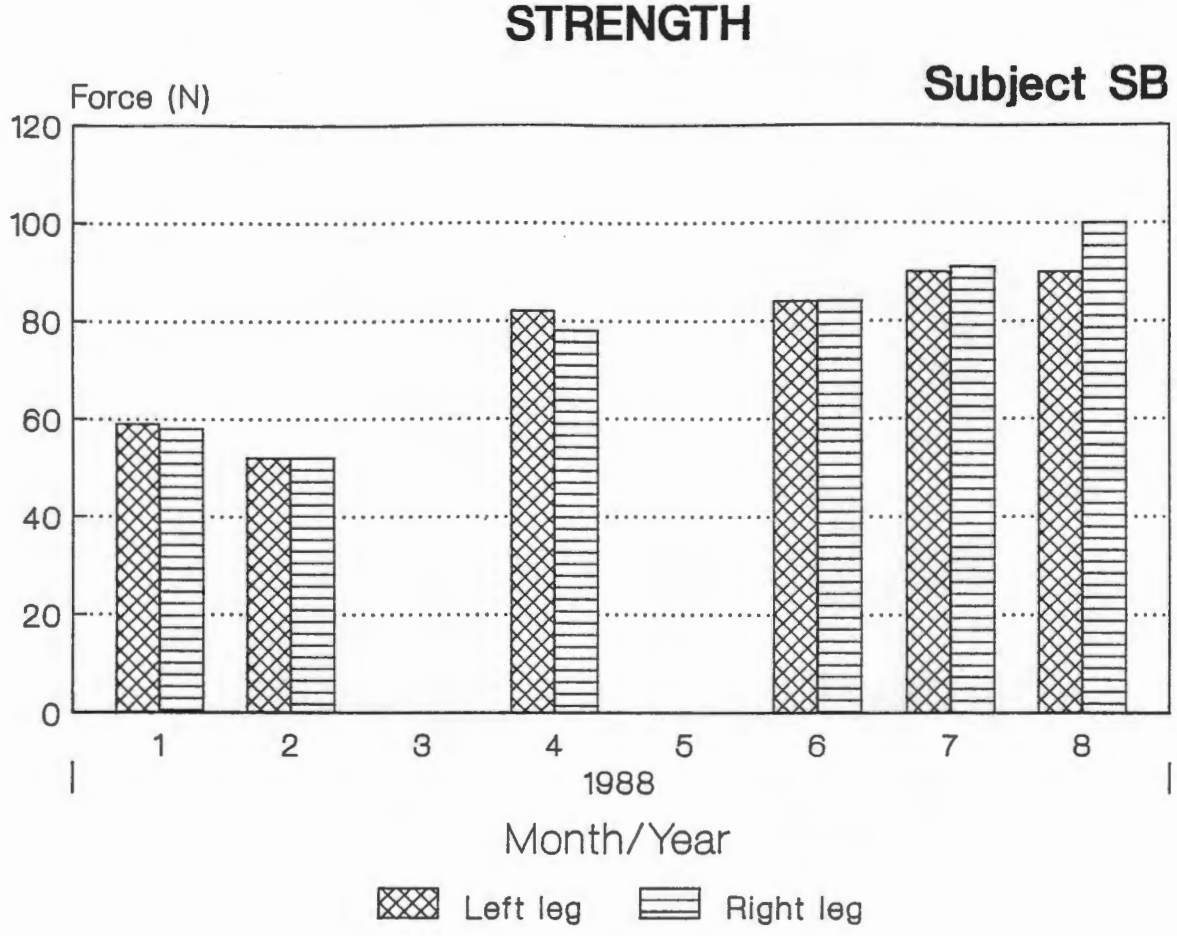


Figure 7.1f. The maximum force (N) recorded at each strength test for subject SB.

Key to Figure 7.1f:

Date	Parameters (μs)	(mA)	Activity level
1/88	999	80	0
2/88	999	80	2
4/88	999	80	2
6/88	999	80	5
7/88	999	80	5;ISo
8/88	999	80	IS1

Table 7.4 provides a summary of the effects of FNS on the muscle strength of the RESTAND group. Due to the change in the parameters (amplitude and pulsewidth) during the study, two sets of data are provided for subjects TW, HV, RM and DH. The first set is the force measured at the initial test (PW = 300µs) and the force at 300µs from the final test. The set in brackets is the force at 999µs from the first test using the new parameters and the force at 999µs from the final test of the study. The increase in the muscle force between the initial and final tests is presented in Newtons and as a percentage increase of the initial test.

The average strength for the left and right legs increased by 40 ± 32N (241,51 ± 406,9%) and 45 ± 36N (1847,74 ± 4191,3%) respectively (p=0,0148, both legs). When the two tetraplegics are excluded (their response differed from the paraplegics) the increase is 53 ± 29N (97,76 ± 59,6%) and 41 ± 19 (171,21 ± 118,1%) for the left and right legs respectively (p<0,05).

Table 7.4 Summary of the effects of FNS on muscle strength

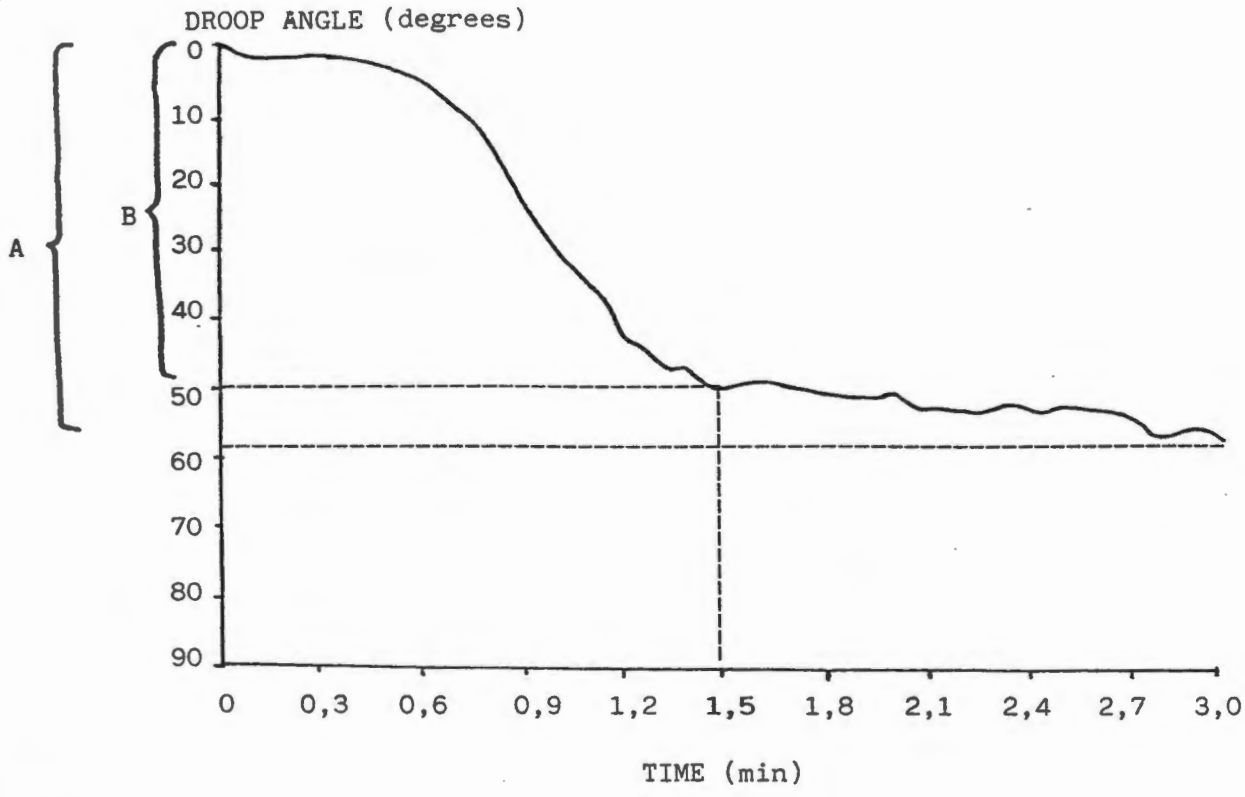
Subject	Initial Test (N)		Final Test (N)		Increase			
	LL	RL	LL	RL	LL (N)	LL (%)	RL (N)	RL (%)
TW	70 (101)	59 (92)	102 (102)	100 (101)	32	45,71	41	69,49
HV	45 (101)	21 (95)	100 (100)	84 (86)	55	122.22	63	300,00
RM	17 (66)	7 (32)	46 (70)	24 (48)	29	170,58	17	242,85
DH	8 (90)	0 (77)	101 (101)	104 (104)	93	1062,50	104	10400,00
AZ	67	59	64	60	-3	-4,48	1	1,69
SB	59	58	90	100	31	52,54	42	72,49
$\bar{x}$(n=6)	44 (81)	34 (68)	83 (87)	79 (83)	40	241,51	45	1847,74
± SD	26 (19)	27 (24)	23 (17)	31 (24)	32	406,90	36	4191,28
$\bar{x}$(n=4)	(for paraplegics, ie not AZ, DH)				53	97,76	41	171,21
± SD					29	59,60	19	118,06

7.3 QUADRICEPS MUSCLE FATIGUE

The initial fatigue test (from October 1986) consisted of two 60-second tests, at 25 and 99 Hz, with parameters of 300 μs and 80 mA. As with the strength tests, this test was adapted in April/May 1987. The new test was a 'Droop-angle Test' of three minutes duration with parameters constant at 600 μs and 80 mA. The first tests were performed with no load attached otherwise the leg fatigued too rapidly. Later a 1 kg or 2 kg weight was added. In the case of the fatigue curves, no comparison is possible for DH, HV, TW and RM with the few tests performed between October 1986 and April 1987 and therefore only tests performed with the new method are presented. Thus any initial improvements for these four during that time could not be documented.

Finding a suitable way to analyse and present the responses of muscle fatigue to FNS proved to be a problem. Plotting individual curves on a common axis and calculating area under the curve proved unsuitable, as did analysing the curves in quarterly segments. Other studies (Edwards and Marsolais,1987;Robinson et al,1986), using a different method of monitoring fatigue, have used a T50% index - the time taken for the torque to drop to 50% of the initial torque measured. This idea was adapted for the present situation and a %TD(ht) index was used which denotes the percentage of the total droop that had occured by the "half-test" (90 second) mark as illustrated in Figure 7.2.

The individual responses of the group for both left and right legs are presented in Figures 7.3a-f. The bars indicate the %TD(ht) value. A decrease in the %TD(ht) value indicates an improvement in the muscle fatigue response. The figures in the key indicate the total number of degrees that the leg drooped (0-90^{o})



%TD(ht) = B/A x 100

Figure 7.2. The fatigue index - %TD(ht).

during each test. The load values (kg) indicate the load of the ankleweight used for the test.

Tables 7.5, 7.6 and 7.7 serve to summarise the effects of FNS on muscle fatigue for the whole group. The means and SD for the group (n=6) and the group excluding DH (n=5) are supplied. DH had an incomplete lesion and could therefore perform the test without stimulation.

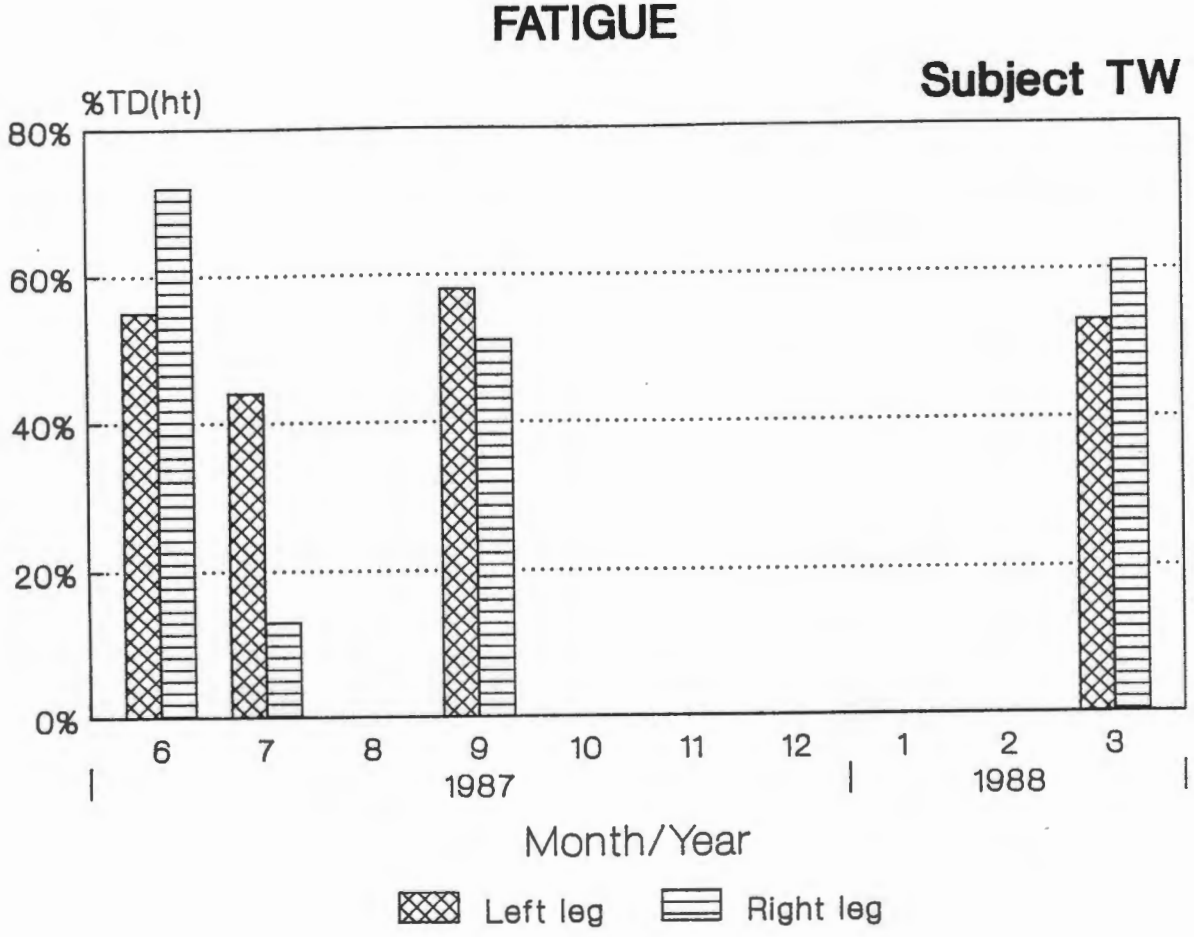


Figure 7.3a Fatigue results (%TD(ht)) for subject TW

Key to Figure 7.3a:

Date	Load (kg)	Degrees of droop (0-90°) LL	RL
6/87	2	64	51
7/87	2	90	90
9/87	2	60	37
3/88	2	53	55

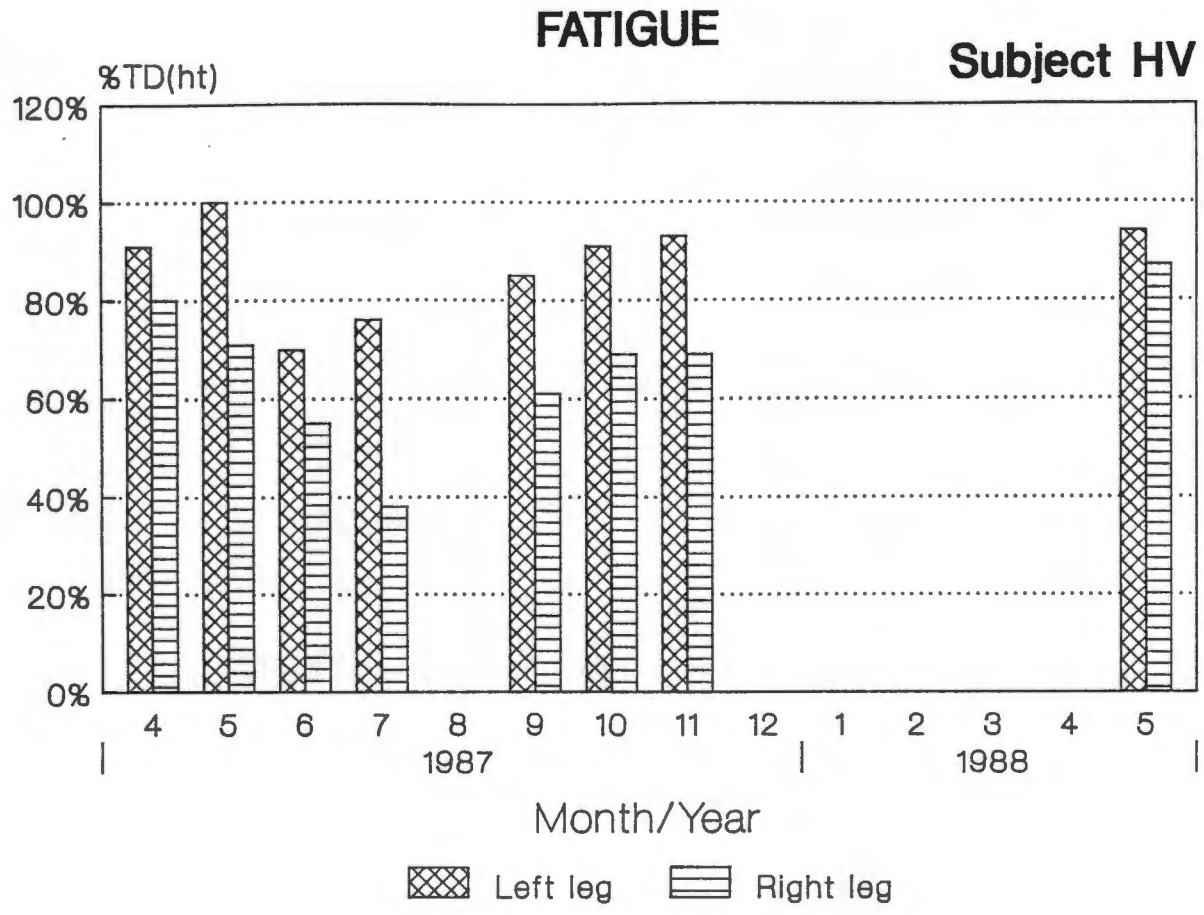


Figure 7.3b Fatigue results (%TD(ht)) for subject HV

Key to Figure 7.3b:

Date	Load (kg)	Degrees of droop (0-90°) LL	RL
4/87	2	67	43
5/87	2	40	34
6/87	2	41	27
7/87	2	41	71
9/87	2	73	53
10/87	2	90	51
11/87	2	68	70
5/88	2	77	78

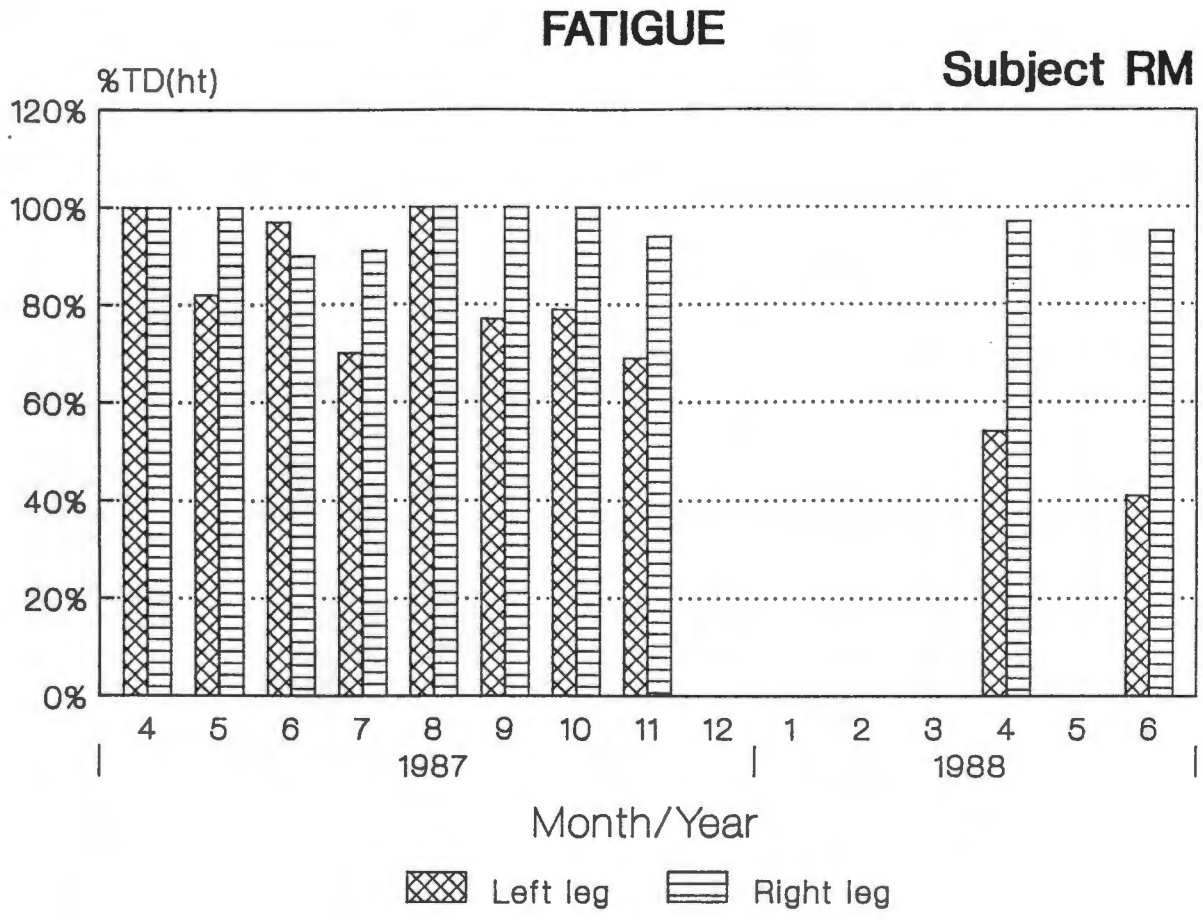


Figure 7.3c Fatigue results (%TD(ht)) for subject RM

Key to Figure 7.3c:

Date	Load (kg)	Degrees of droop (0-90°) LL	RL
4/87	2	85	87
5/87	1	70	81
6/87	1	76	77
7/87	1	55	60
8/87	1	81	89
9/87	1	74	90
10/87	1	86	90
11/87	1	69	77
4/88	1	55	70
6/88	1	69	86

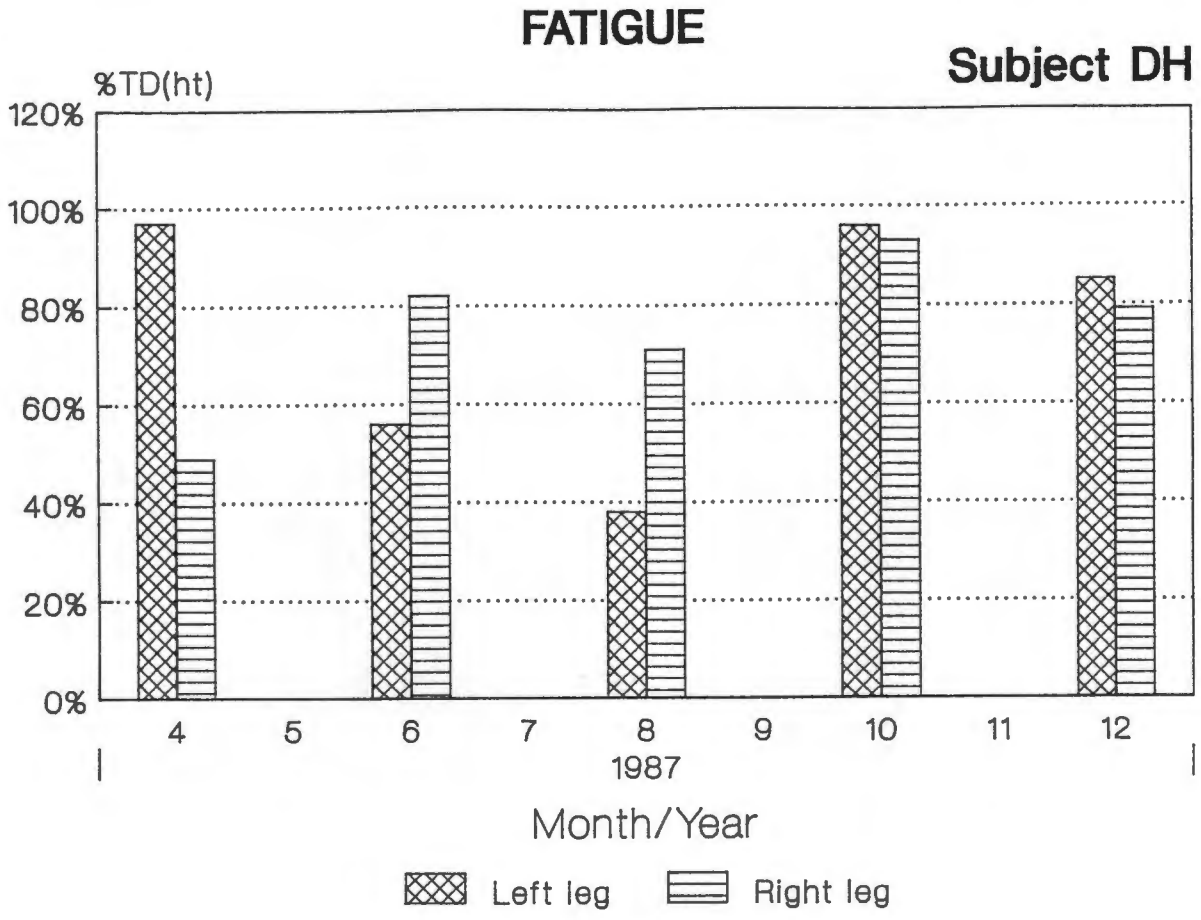


Figure 7.3d Fatigue results (%TD(ht)) for subject DH

Key to Figure 7.3d:

Date	Load (kg)	Degrees of droop (0-90°) LL	RL
4/87	2	8	4
6/87	2	9	24
8/87	2	15	30
10/87	2	15	24
12/87	2	27	32

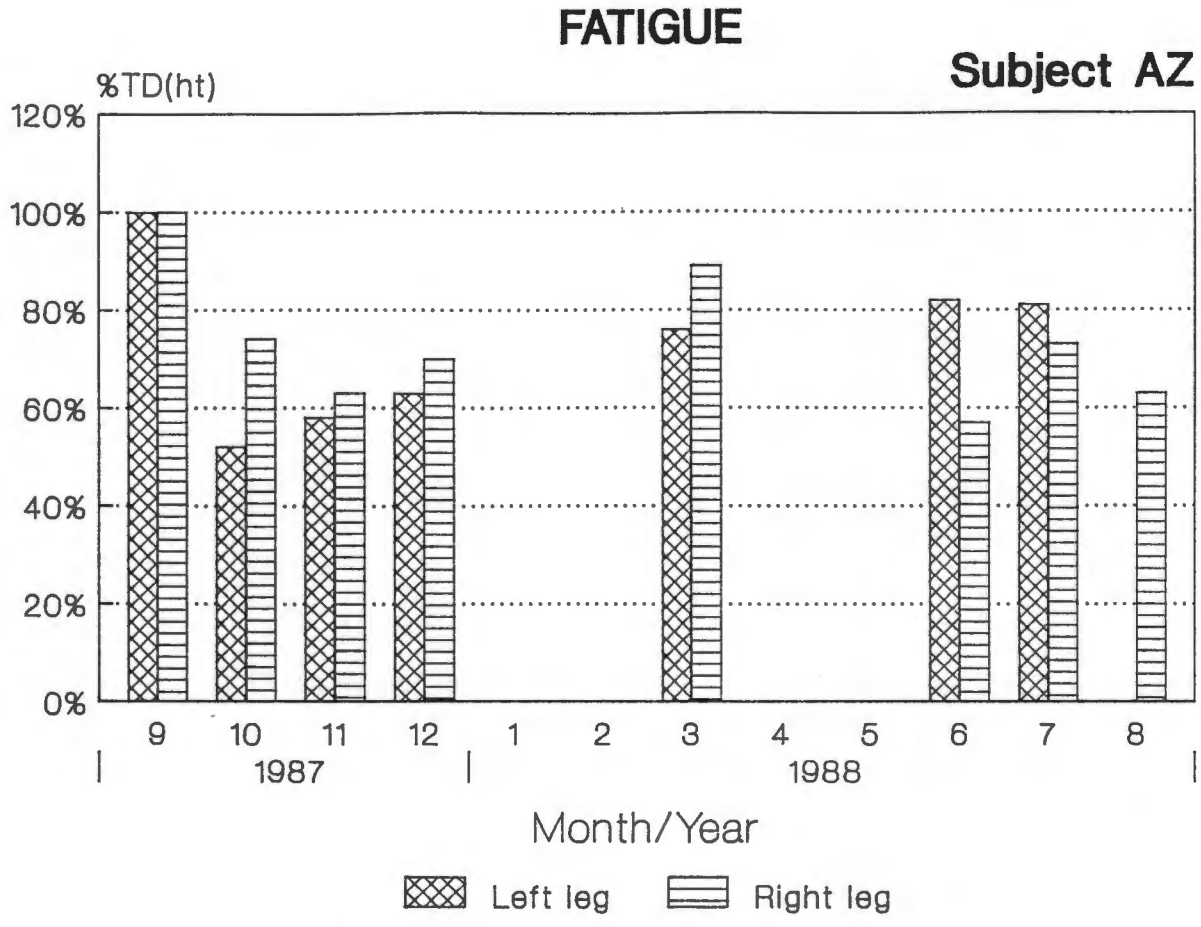


Figure 7.3e Fatigue results (%TD(ht)) for subject AZ

Key to Figure 7.3e:

Date	Load (kg)	Degrees of droop (0-90°) LL	RL
9/87	2	69	68
10/87	0	46	80
11/87	0	34	38
12/87	1	52	69
3/88	1	49	47
6/88	1	51	47
7/88	2	53	57
8/88	2	N/A	44

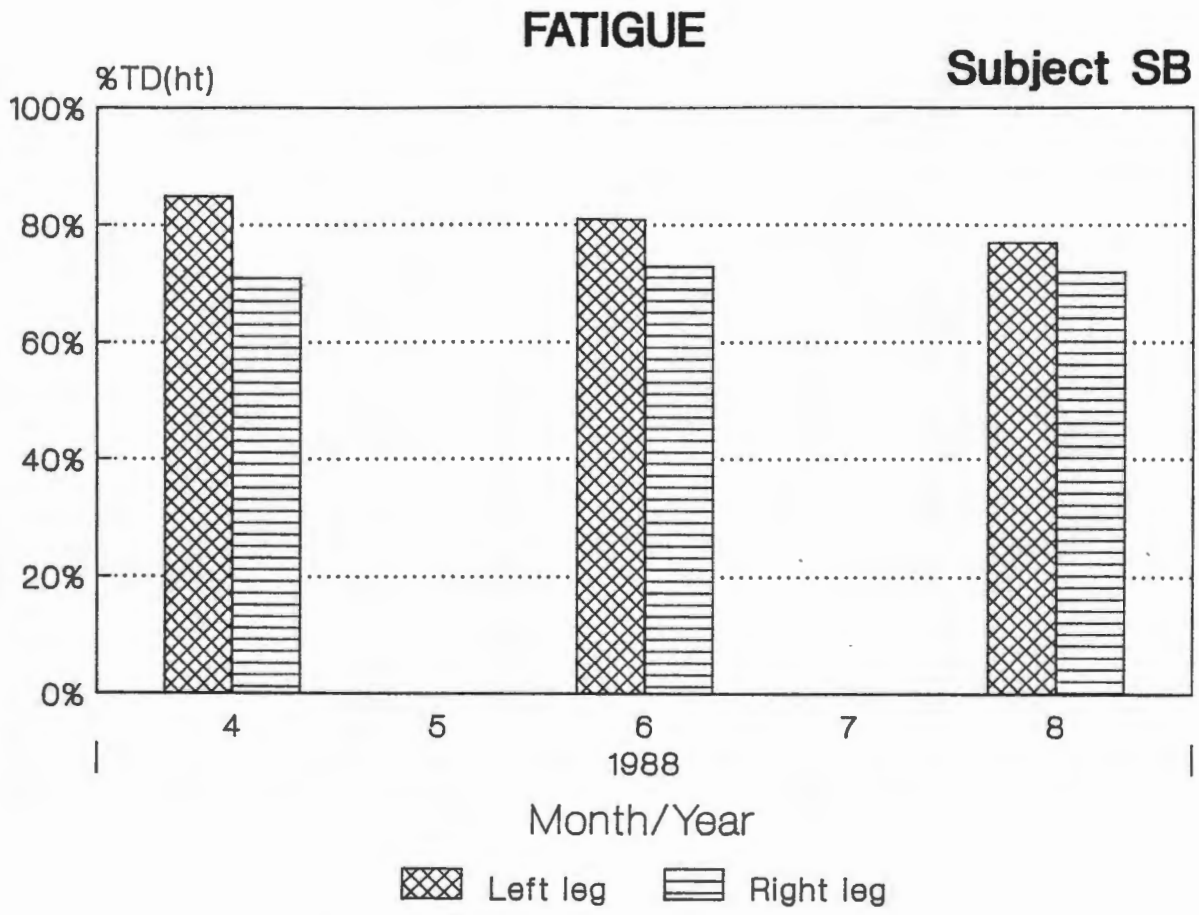


Figure 7.3f Fatigue results (%TD(ht)) for subject SB

Key to Figure 7.3f:

Date	Load (kg)	Degrees of droop (0-90°) LL	RL
4/88	0	16	19
6/88	2	28	32
8/88	1	28	22

Table 7.5 The initial (I) and final (F) test values for droop (degrees) and %TD(ht)

Subject	Left Leg				Right Leg			
	Droop (o)		%TD(ht) (%)		Droop (o)		%TD(ht) (%)	
	I	F	I	F	I	F	I	F
TW	64	53	55	53	51	55	72	61
HV	43	78	80	87	67	77	91	94
RM	85	69	100	41	87	86	100	95
DH	8	27	97	85	4	32	49	79
AZ	69	53	100	81	68	44	100	63
SB	16	28	85	77	19	22	71	72
$\bar{x}$	47	51	86	71	49	53	81	77
$\pm$ SD	31	21	17	19	32	25	20	15
$\bar{x}$*	55	56	84	68	58	57	87	77
$\pm$ SD	27	19	19	20	25	26	14	17

* excluding DH (incomplete lesion)

There was no significant difference between the means when DH was excluded. There was no significant difference between the initial and final values for droop or %TD(ht) for either leg. The significance level for the %TD(ht) of the left leg fell between $p<0,1$ and $p>0,05$ indicating a trend towards an improvement in resistance to muscle fatigue.

Table 7.6 summarises the changes in the droop (degrees) and the %TD(ht) between the initial and the final test. These changes are also expressed as a percentage of the initial test value. A negative denotes a decrease which indicates an improvement.

Table 7.6 The change in droop and %TD(ht) (initial to final test)

Subject	Left leg				Right leg			
	Droop change	%	%TD(ht) change	%	Droop change	%	%TD(ht) change	%
TW	-11	-17,19	-2	-3,63	4	7,84	-11	-15,28
HV	35	69,77	7	8,75	10	14,93	3	3,30
RM	-16	-18,82	-59	-59,00	-1	-1,15	-5	-5,00
DH	19	237,50	-12	-12,37	28	700	30	61,22
AZ	-16	-23,19	-19	-19,00	-24	-35,29	-37	-37
SB	12	75	-12	-9,41	3	15,79	1	1,41
$\bar{x}$	4	53,85	-16	-15,78	3	117,02	-3	1,44
$\pm$ SD	21	100,69	22	23,15	17	286,22	22	32,79
$\bar{x}$*	1	17,11	-17	-16,46	-2	0,42	-10	-3,85
$\pm$ SD	22	50,54	25	25,82	13	21,09	16	7,26

* Excluding DH

The significance level for %TD(ht) for the left leg was p = 0,080.

The following system was used to analyse the individual effects

1 = a decrease in both degrees of droop and %TD(ht) (greatest improvement)

2 = an increase in degrees of droop with a decrease in %TD(ht)

3 = an increase in both degrees of droop and %TD(ht)

Table 7.7 lists this analysis for the group

Table 7.7 Analysis of individual responses in droop and %TD(ht)

Subject	Left leg	Right leg	Total
TW	1	2	3
HV	3	3	6
RM	1	1	2
DH	2	3	5
AZ	1	1	2
SB	2	3	5

Thus, subjects rank in improvements in muscle fatigue in both legs as follows:

2 : RM, AZ (most improvement)

3 : TW

5 : DH, SB

6 : HV

7.4 MUSCLE BULK

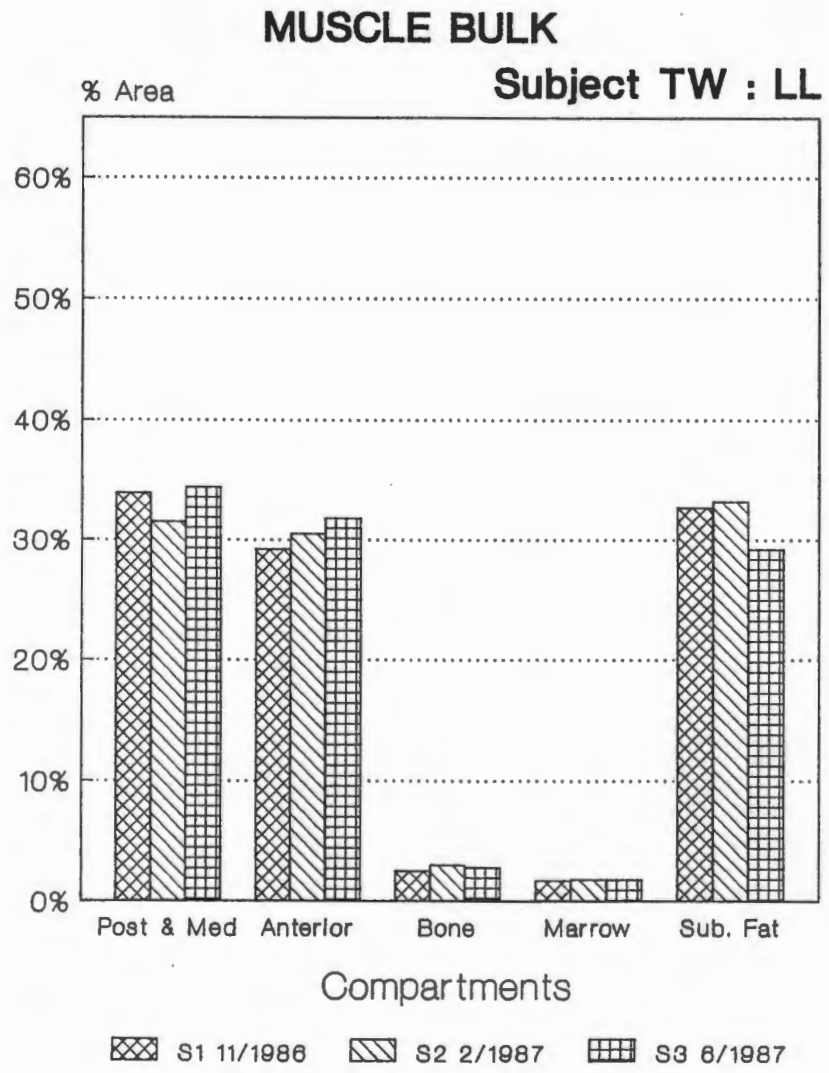
The results of the NMR scans for three subjects (TW, HV, AZ) are presented as:

DH : was claustrophobic and therefore only underwent one scan

RM : had metal pins in his femurs and therefore could not undergo NMR scan

SB : has, to date, had only the initial scan.

The results for individual subjects are presented in Figures 7.4a-c. The individual bars represent the mean percentage compartmental area of the five "cuts" from each scan session, as a percentage of the total area (cross-sectional) of the leg. Table 7.8 and 7.9 summarise these results for the three subjects.



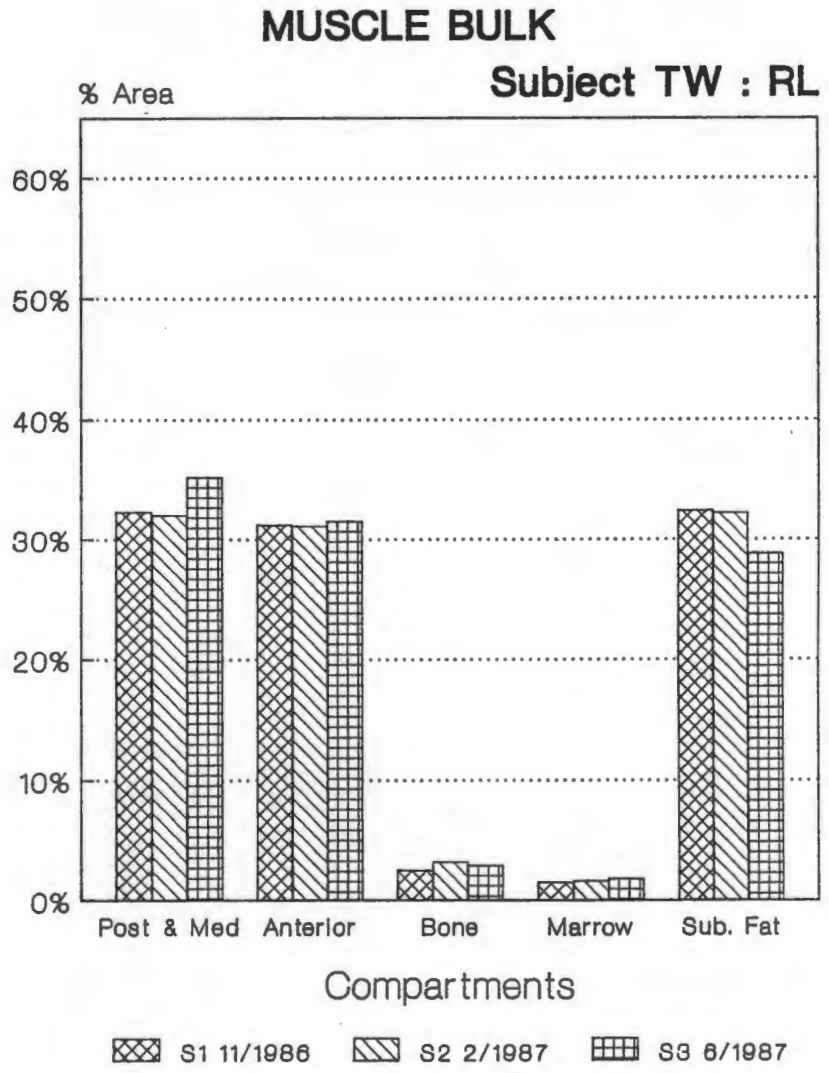
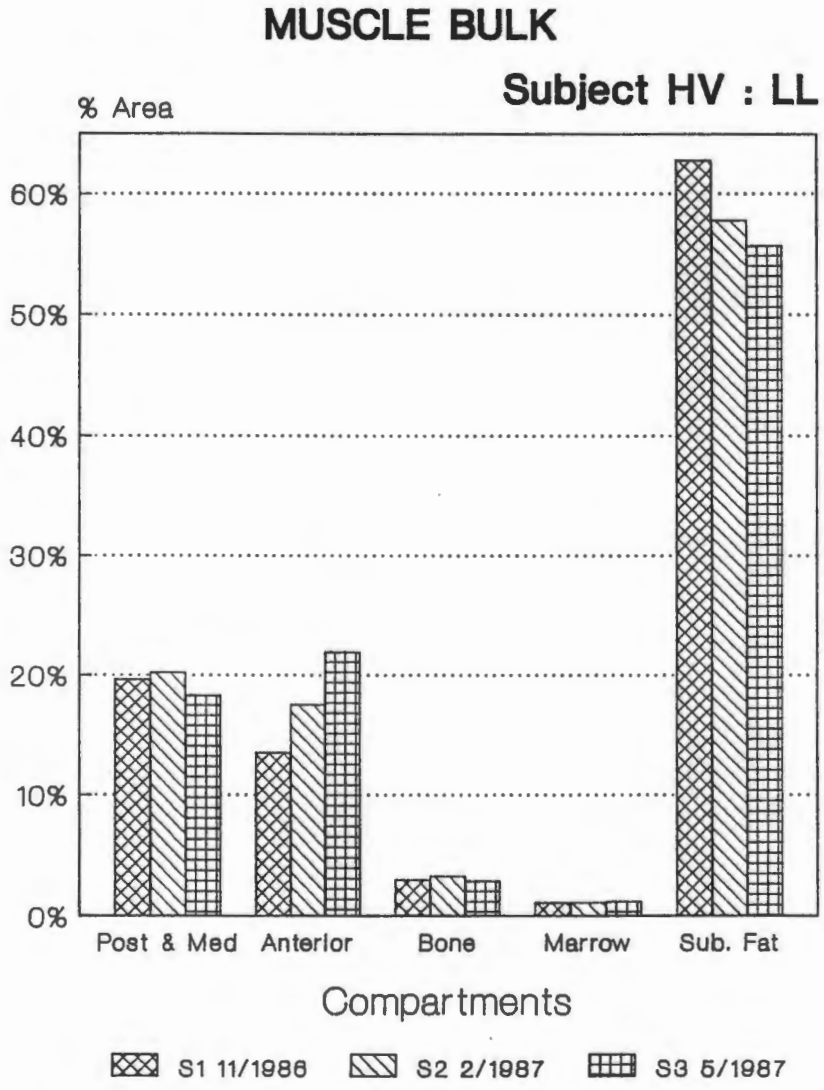


Figure 7.4a Muscle bulk results of subject TW



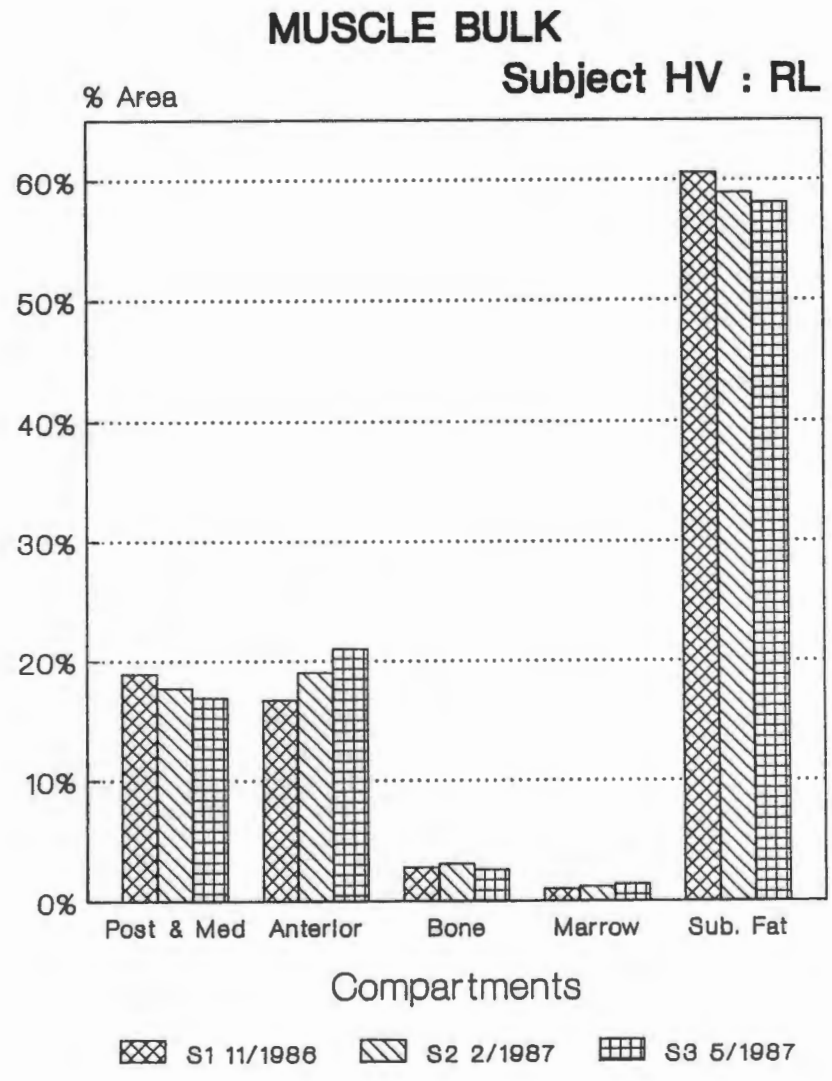
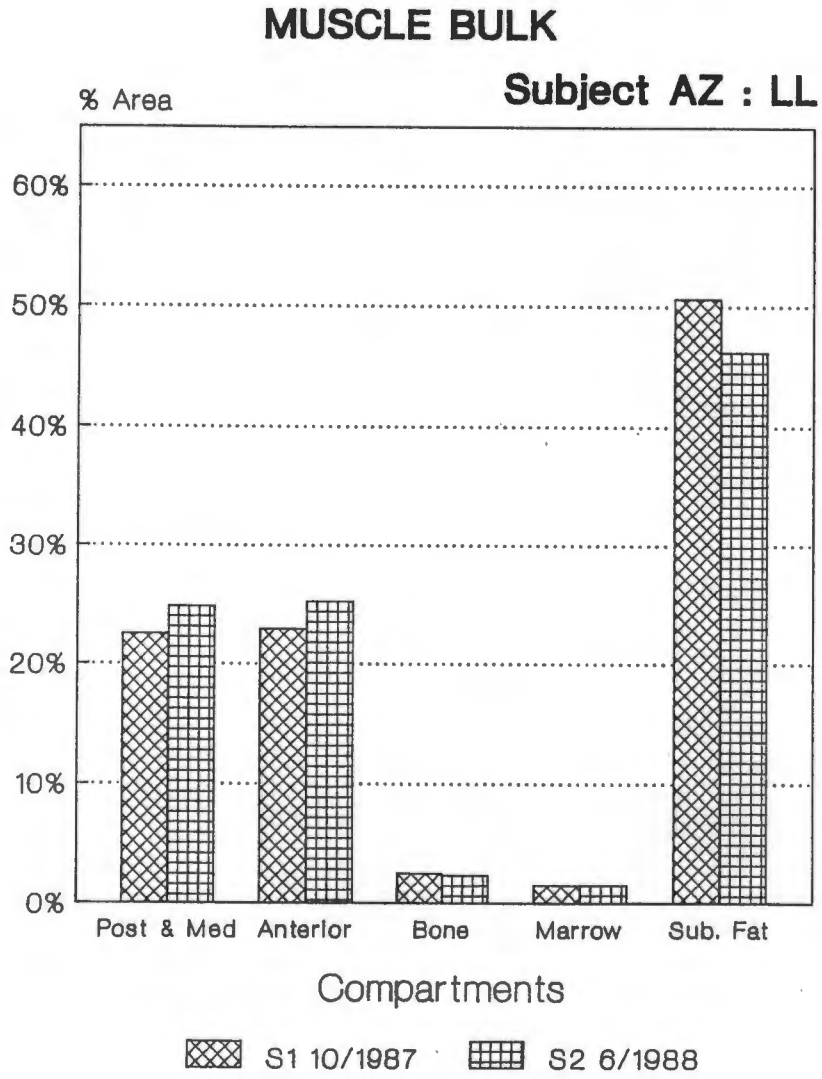


Figure 7.4b Muscle bulk results of subject HV



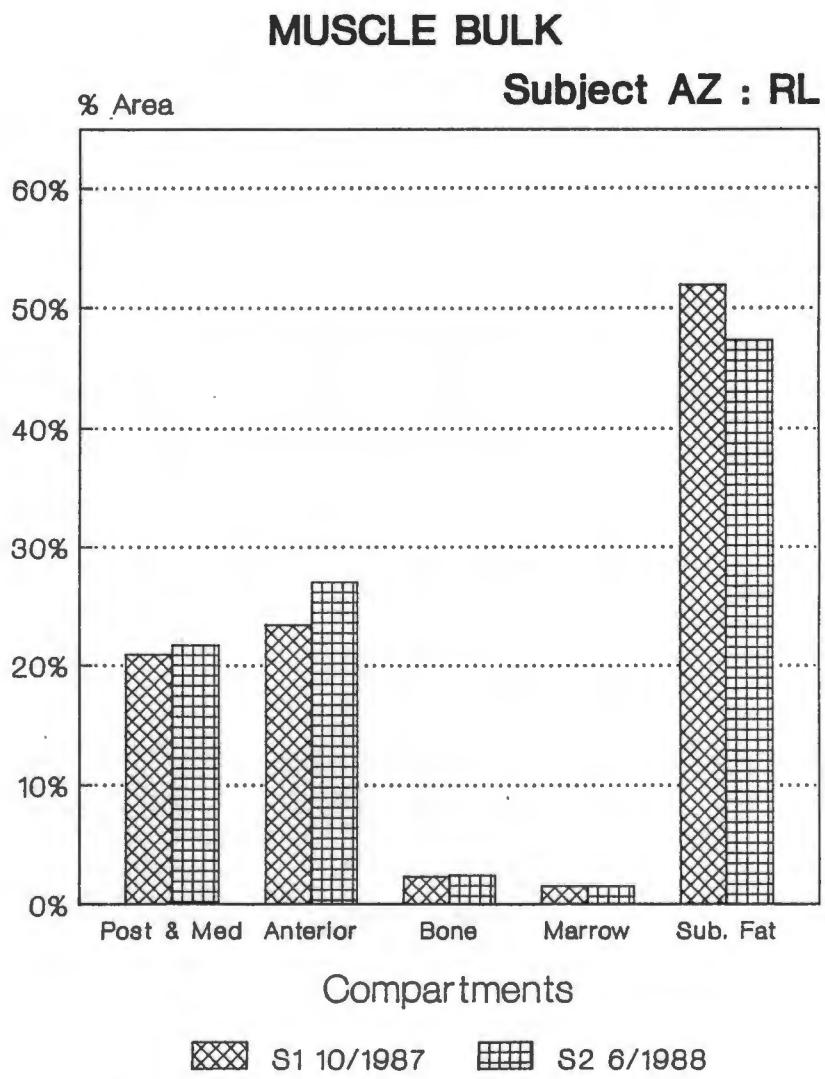


Figure 7.4c Muscle bulk results of subject AZ

Table 7.8 The initial and final scan values (mean (percent total area) ± SD for TW, HV, AZ)

Compartment	Left leg Initial	Left leg Final	Right leg Initial	Right leg Final
Posterior & Medial	25,33 7,56	25,83 8,10	24,03 7,23	24,60 9,49
Anterior	21,87 7,90	26,30 5,04	23,77 7,26	26,50 5,27
Bone	2,67 0,29	2,67 0,32	2,53 0,25	2,63 0,25
Marrow	1,43 0,31	1,50 0,30	1,33 0,29	1,50 0,10
Subcutaneous Fat	48,70 15,14	43,70 13,43	48,30 14,44	44,73 14,82

There was no significant difference between the initial and final scans in the area of the posterior and medial, bone and marrow compartments. The significance level ($0,05<p<0,1$) for the change in area for the anterior compartment indicated a trend towards an increase in the quadriceps muscle area. The subcutaneous fat compartment decreased in area significantly for both the left ($p=0,022$) and right ($p=0,014$) legs.

Table 7.9 The mean change (percent total area) ± SD between the initial and final scan (TW, HV, AZ)

Compartment	Left leg	Right leg
Posterior & Medial	0,57 1,80	0,57 2,46
Anterior	4,43 3,44	2,73 2,14
Bone	0,07 0,38	0,03 0,32
Marrow	0,07 0,06	0,17 0,21
Fat	-4,73 1,43	-3,43 1,07

To summarise, the significance levels of these mean changes in area were:

Compartment	Left leg	Right leg
Posterior & Medial	-	-
Anterior	(0,05<p<0,1)	(0,05<p<0,1)
Bone	-	-
Marrow	-	-
Fat	p = 0,022	p = 0,014

SECTION B. GENERAL HEALTH AND FITNESS

As previously mentioned, these data were originally intended as pre-training measurements. They now serve as a general indication of health and fitness. Due to the subjects personal circumstances and limited availability, not all six subjects completed each set of measurements.

7.5 MAXIMAL ARM ERGOMETER EXERCISE TEST

TW and HV performed two tests (1986 and 1987), the rest performed one. The means are calculated using only the first test for TW and HV. Data from DG and RB are also included in Table 7.10.

The following list is an explanation of the terms which are used in Table 7.10:

The predicted VO_2 max and heart rate (HR) are those calculated for able-bodied people based on the subject's sex and age.

VO_2 = oxygen consumption ($l.min^{-1}$) at the workload at which the 'VO max' was reached.

HR = heart rate ($b.min^{-1}$)

RQ = respiratory quotient which is defined as VCO_2/VO_2

LTP = blood lactate concentration lactate turnpoint ($mmol.l^{-1}$).
The LTP is usually described in terms of the workload level ($km.hr^{-1}$ or Watts). Due to the fact that the test protocol was not totally standardised in terms of workload and the duration of exercise at each workload, the LTP was represented in terms of the blood lactate concentration ($mmol.l^{-1}$). The reason for the lack in protocol standardisation was that no record was available of the protocol used for the first six tests in 1986. In addition to this, the two tetraplegics were limited in arm function and strength and therefore in the level and duration of exercise they could achieve in comparison to the paraplegics. The workloads were lowered accordingly for them.

Peak lactate = the highest blood lactate concentration ($mmol.l^{-1}$) that was recorded for the duration of the exercise test.

Attempts at obtaining sufficient blood samples for lactate analysis were not always successful as the venous blood flow often stopped during the arm pedalling. Records of lactate samples to corresponding workloads and resting period were not available for tests performed in 1986 (DH, HV, TW, RM, DG, RB; before this thesis commenced) and thus correlation of lactate turnpoint (LTP) with workload or percentage oxygen consumption is not possible.

The mean "VO_2 max", VO_2, maximum HR, and RQ for the three females were $12,23 \pm 3,2\ ml.kg^{-1}.min^{-1}$, $0,62 \pm 0,2\ l.min^{-1}$, $144 \pm 50\ b.min^{-1}$ and $0,85 \pm 0,03$ units respectively. For the males these

Table 7.10 Arm Ergometer Test Results

Subjects	Predicted VO2max *	"VO2max" *	VO2 **	Predicted HR ***	HR ***	RQ ****	lact.conc. LTP *****	Peak lactate *****
DH	30,98	8,96	0,52	174	91	0,81	-	-
HV (1)	39,12	15,34	0,87	196	150	0,87	-	-
(2)	38,75	19,28	1,08	195	184	1,08	1,619	6,455
AZ	38,75	12,40	0,62	195	190	0,87	-	-
$\bar{x}$(F)n=3	36,28	12,23	0,67	188	144	0,85	-	-
± SD	4,60	3,19	0,18	12	50	0,03	-	-
TW (1)	46,80	22,24	1,29	196	192	1,19	-	-
(2)	45,70	25,51	1,41	194	190	1,18	0,981	4,490
RM	47,35	15,42	1,02	197	157	0,97	-	-
SB	50,65	23,00	1,38	203	200	1,16	-	-
DG	42,40	28,30	1,84	188	212	1,84	1,842	10,959
RB	41,30	18,71	1,31	186	187	1,14	2,100	7,556
$\bar{x}$(M)n=5	45,70	21,53	1,37	194	189	1,26	1,641	7,668
± SD	3,83	4,84	0,30	7	21	0,34	0,586	3,236

Key to units in Table 7.10:

* = $ml.kg^{-1}.min^{-1}$

** = $l.min^{-1}$

*** = $b.min^{-1}$

**** = units

***** = $mmol.l^{-1}$

means were 21,53 ± 4,8 ml.kg^{-1}.min^{-1}, 1,37 ± 0,3 l.min^{-1}, 189 ± 21 b.min^{-1} and 1,3 ± 0,3 units. The mean lactate turnpoint concentration for the three available results was 1,64 ± 0,6 mmol.l^{-1}. The mean peak lactate concentration reached was 7,66 ± 3,2 mmol.l^{-1}.

The predicted VO_2 max, actual VO_2 max and the VO_2 were significantly higher for the males than the females ($p<0,025$). The actual maximum HR and the RQ showed a similar trend ($0,05<p<0,1$). Table 7.11 lists the relative percentages of the predicted VO_2 max (for treadmill running) and maximum HR that were reached for the arm ergometer test.

Table 7.11 Relative percentages of predicted VO2max and HR obtained during arm ergometry exercise.

Subject	% VO_2 max	% maximum HR
DH	28,92	52,30
HV (1)	39,21	76,53
(2)	49,75	97,44
AZ	32,00	97,44
$\bar{x}$(F)n=3	33,38	75,42
± SD	5,28	22,59
TW (1)	47,52	97,96
(2)	55,82	97,94
RM	32,57	79,70
SB	45,41	98,52
DG	66,74	112,77
RB	45,30	100,54
$\bar{x}$(M)n=5	47,51	97,90
± SD	12,27	11,83

The differences between male and female show a trend ($0,05<p<0,1$) towards the males reaching higher percentages of their predicted VO_2 max and HR during arm ergometer testing than the females.

7.6 MUSCLE FUNCTION

Table 7.12 and 7.13 list the extension (Ext) and flexion (Flex) results, expressed in units of Newton metres (NWTM), of the group for isokinetic tests on the Cybex for the shoulders and elbows. Results for DG and RB are included.

Table 7.12 Isokinetic test of muscle function (Ext and Flex) for the shoulder (unit = NWTM)

	Left Shoulder			Right Shoulder		
Subject	Ext	Flex	%Flex/Ext	Ext	Flex	%Flex/Ext
DH	21	16	75	16	14	92
HV	47	33	71	55	28	51
AZ	37	33	89	37	27	73
$\bar{x}$(F)n=3	35	27	78	36	23	72
$\pm$ SD	13	10	9	20	8	21
TW	67	55	82	82	59	72
RM	70	50	71	61	54	89
SB	67	66	99	67	67	100
DG	107	50	47	101	54	53
RB	109	67	62	122	78	64
$\bar{x}$(M)n=5	84	58	72	87	62	76
$\pm$ SD	22	8	20	25	10	19

The mean values ± SD of extension and flexion for the left and right shoulders in the females were (in order: extension, flexion (left), extension, flexion (right): 35 ± 13, 27 ± 10, 36 ± 20 and 23 ± 8 Nwtm respectively. The equivalent means for the males were: 84 ± 22, 58 ± 8, 87 ± 25 and 62 ± 10 Nwtm. Means for the males were statistically larger than the females namely $p<0,0125$, $p<0,005$, $p<0,025$ and $p<0,01$ respectively.

Table 7.13 Isokinetic test of muscle function (Ext and Flex) of the elbow (unit = NWTM)

	Left Elbow			Right Elbow		
Subject	Ext	Flex	% Flex/Ext	Ext	Flex	% Flex/Ext
DH	10	12	120	8	12	150
HV	29	28	97	31	28	90
AZ	23	20	87	23	17	74
$\bar{x}$(F)n=3	21	20	101	21	19	105
± SD	10	8	17	12	8	40
TW	65	55	85	55	52	95
RM	51	42	82	48	42	88
SB	44	50	114	42	52	124
DG	58	43	74	70	51	73
RB	88	58	66	80	59	74
$\bar{x}$(M)n=5	61	50	84	59	51	91
± SD	17	7	18	16	6	21

In this test, the means ± SD of extension and flexion for the left and right elbows of the females were 21 ± 10, 20 ± 8, 21 ± 12 and 19 ± 8 Nwtm. The means ± SD (in the same order) for the

males were 61 ± 17, 50 ± 9, 59 ± 16 and 51 ± 6 Nwtm. As for the shoulder tests, the males were statistically stronger than the females namely $p<0,01$, $p<0,0025$, $p<0,0125$ and $p<0,0025$.

7.7 LUNG FUNCTION

Table 7.14 lists the expiratory lung function capacities namely, peak flow, vital capacity, FEV1 and FEV% (FEV1/VC) for the five subjects. DH was unavailable to perform the test.

Table 7.14 Expiratory lung function capacities

Subject	Peak flow 1.sec-1	Vital Capacity (VC) 1	FEV1 1.sec-1	FEV%
HV	7,55 0,44	3,65 0,13	3,63 0,1	99,5
AZ	4,28 0,38	2,15 0,13	2,15 0,13	100,0
$\bar{x}$(F)	5,92	2,90	2,89	99,8
± SD	2,31	1,06	1,05	0,4
TW	6,00 0,95	3,33 0,42	2,15 2,90	85,0
RM	5,55 0,77	2,77 0,25	2,68 0,13	96,7
SB	7,45 0,57	2,60 0,28	2,60 0,26	100,0
$\bar{x}$(M)	6,33	2,90	2,70	93,9
± SD	0,99	0,38	0,12	7,9

The mean peak flow, VC, FEV_1 and FEV% were 5,92 ± 2,3 $1.sec^{-1}$, 2,90 ± 1,1 1, 2,89 ± 1,1 $1.sec^{-1}$, 99,8 ± 0,4% and 6,33 ± 1,0 $1.sec^{-1}$, 2,90 ± 0,4 1, 2,70 ± 0,1 $1.sec^{-1}$, 93,9 ± 7,9% for the males and females respectively.

7.8 BLOOD BIOCHEMICAL PARAMETERS

The sample analysed at Red Cross Children's Hospital (RCCH) was analysed for total cholesterol (T Chol), triglyceride (TG), high- and low-density lipoprotein (HDL and LDL) concentration as shown in Table 7.15. The results from the SMAC analyses are listed in Table 7.16.

Table 7.15 Cholesterol concentrations of RESTAND group

Subject	TChol ($mmol.l^{-1}$)	TG ($mmol.l^{-1}$)	HDL ($mmol.l^{-1}$)	LDL ($mmol.l^{-1}$)
DH	5,62	0,86	1,43	3,80
HV	4,43	0,65	1,97	2,16
AZ	4,29	0,74	1,35	2,60
$\bar{x}$(F)n=3	4,78	0,75	1,58	2,85
$\pm$ SD	0,73	0,11	0,34	0,85
RM	6,66	1,96	0,90	4,86
SB	3,61	1,00	1,29	1,86
$\bar{x}$(M)n=2	5,14	1,48	1,10	3,36
$\pm$ SD	2,16	0,68	0,28	2,12

The mean total cholesterol, triglyceride, high- and low-density lipoprotein concentrations for the females and males were 4,78 $\pm$ 0,7, 0,75 $\pm$ 0,1, 1,58 $\pm$ 0,3, 2,85 $\pm$ 0,9 $mmol.l^{-1}$, and 5,14 $\pm$ 2,2, 1,48 $\pm$ 0,7, 1,10 $\pm$ 0,3, 3,36 $\pm$ 2,1 $mmol.l^{-1}$ respectively.

Table 7.16 SMAC Analysis of RESTAND group

Parameter	Adult reference range	Units	DH	HV	AZ	RM	SB	x ± SD	
Sodium	135 - 145	$mmol.l^{-1}$	141	145	143	144	143	143	2
Potassium	3,5 - 5,5	"	3,8	4,1	3,7	3,5	4,0	3,8	0,2
Chloride	97 - 107	"	104	108*	110*	104	106	106	3
Bicarbonate	22 - 30	"	27	27	28	29	31*	28	2
Urea	1,7 - 6,7	"	2,5	3,9	2,1	4,6	3,2	3,3	1,0
Creatinine	75 - 115	$umol.l^{-1}$	62*	88	62*	106	88	81	19
Total protein	60 - 80	$g.l^{-1}$	65	67	71	77	75	71	5
Albumin	35 - 50	$g.l^{-1}$	43	47	47	55*	47	48	4
Calcium	10 - 2,60	$mmol.l^{-1}$	2,30	2,45	2,4	2,60	2,5	2,45	0,11
Inorganic phosphate	0,80 - 1,40	"	1,22	1,18	1,22	1,12	1,28	1,20	0,06
Cholesterol	3,1 - 7,1	"	5,5	4,8	4,9	7,7*	4,0	5,4	1,4
Urate	0,12 - 0,50	"	0,20	0,30	0,24	0,41	0,44	0,32	1,10
Total bilirubin	1 - 17	$umol.l^{-1}$	12	10	10	12	17	12	3
Congugated bilirubin	1 - 17	"	2	2	2	2	3	2	0
Alkaline phosphate	30 - 115	units	86	72	64	117*	128	93	28
LDH (screen)	100 - 350	$units.l^{-1}$	193	207	198	312	151	212	60
AST (screen)	0 - 40	"	21	19	10	22	9	16	6
ALT (screen)	0 - 53	"	18	31	24	84*	17	35	28
Gamma GT	0 - 50	"	4	7	1	22	3	7	8
Urine 24 hour volume		ml	1800	1310	1200	1310	1030	1330	287
Hydroxyproline	110 - 330	$umol.l^{-1}$	74,4	106,9	76,5	57,3	212,6	105,5	62,5
Creatinine		$mmol.l^{-1}$	3,6	4,4	4,1	5,9	8,2	5,2	1,9

* out of range

As only one general adult reference range is available, a mean for the whole group was calculated and not separate means for the males and females.

7.9 DIETARY ANALYSIS

Table 7.17 and 7.18 contain a comparison of some of the average daily nutrient intakes for the four subjects who completed the dietary record. The recommended intakes are those of the Dietary Goals of the USA (National Research Council, Food and Nutrition Board, 1980).

Table 7.17 Dietary analysis of HV and AZ (females)

Nutrient	Recommended Intake	Average Intake HV	Average Intake AZ	Comment HV	Comment AZ
Energy	2000 cal	1321	1282	low	low
Protein	44g	43,2	31	normal	low
Fat as % of energy	30%	36	35	normal	normal
CHO	55%	50	54	normal	normal
Cholesterol	<300mg	99	124	normal	normal
Fibre	> 20g	17	8,9	normal	low
Calcium	800mg	457	237	normal	very low
Iron	18mg	6,8	7,8	very low	very low
Sodium	1100-3300mg	1273	1911	normal	normal

CHO = Carbohydrate

Table 7.18 Dietary analysis of RM and SB (males)

Nutrient	Recommended Intake	Average Intake RM	SB	Comment RM	SB
Energy	2500 cal	2067	1784	slightly low	low
Protein	56g	82	68,5	normal	normal
Fat as % of energy	30%	37	44,8	normal	high
CHO	55%	47	38,5	normal	low
Cholesterol	<300mg	245	300	normal	normal
Fibre	> 20g	10	9,7	low	low
Calcium	RM: 800mg SB: 1200mg	867	325	normal	very low
Iron	RM: 10mg SB: 10-18mg	9	10	slightly low	low
Sodium	1100-3300mg	2341	1576	normal	normal

CHAPTER EIGHT

DISCUSSION

The initial aim of this study was to develop a muscle training (FNS) and a fitness program in order to prepare the 'whole person' before standing under FNS control could be attempted. The restrengthening and reconditioning was to have taken the form of FNS leg exercise and upper body exercise. Due to the practical problems encountered in initiating this program, it was necessary to adapt the initial aim to exclude the formalised upper body fitness program. Thus the results are discussed in Section A in terms of the nature of the program, the general characteristics of the RESTAND group and their response to FNS.

In Section B, the general health/fitness status of the RESTAND group is discussed.

SECTION A. FNS

8.1 THE FORMAT OF THE PROGRAM

The existing format had both advantages and disadvantages. The most advantageous feature was its convenience for a "home-use" situation in that the stimulation exercises could be performed at home at a time suitable to the individual subject. Thus the exercise sessions could be performed without the need of full-time observation and this format suited the absence of full-time personnel for project RESTAND.

One disadvantage was the need to rely on the subjects to keep a logbook of their exercise sessions. This was important as it was the only record of the intensity, duration and frequency of their exercise. Unfortunately not all the subjects kept a consistent, accurate record. Secondly, motivation and discipline were needed

to set aside time for these regular individual exercise sessions. This is a task that people often find easier to achieve if there is a fixed class or group session that they attend. Such an 'on-site' group session would also have provided a better opportunity for a more accurate record of the subjects' exercise data but it was impractical, due to the nature of the RESTAND group, to find a common time suitable for such group sessions.

8.2 THE RESTAND GROUP

Some of the selection criteria required that prospective subjects should be intelligent, motivated, rehabilitated and re-integrated into society, such as having employment. It became apparent, as the study progressed, that these criteria posed a hidden disadvantage in that the subjects led such busy lives that they had limited time to devote to stimulation exercise and later to the Inclistand and upper body exercise. The assessments of strength and fatigue generally had to be performed after regular working hours, which presented some practical problems for those involved.

The RESTAND group was heterogenous in many aspects such as the level, type and duration of the SCI. This was not the ideal situation for a pilot study (too many variables) to isolate the effects of FNS, but it did provide the opportunity to study the response to FNS on a wide range of different types of subjects.

Tables 7.1 and 7.2 show that the SCI were all a result of accidents with motor vehicle and motor-cycle accidents accounting for a total of 83%. All the accidents occurred during the group's scholar/student years. The mean age at injury was 17,5 $\pm$ 4 years. To date, the mean years post-injury is 11,1 $\pm$ 11 years. The level of the SCI lesion of the group ranged from C5,6 to T9.

A lesion at the level C5,6 (DH) and C7 (AZ) is beyond the range suggested in section 4.3.3, namely T3-T12. In addition, DH has an incomplete lesion and therefore had a degree of voluntary function in her legs. The graphs of strength and fatigue assessments show that these two subjects responded in a different (atypical) manner when compared with the other four subjects.

Most of the subjects, excluding HV, had some level of participation in sport of a form of exercise (Table 7.3). With the exception of DH, who could walk without calipers but aided by a helper, only two subjects (AZ, SB) walked regularly using their calipers.

In addition to the heterogenous nature of the RESTAND group, the program was adapted (such as the change in stimulus parameters in April/May 1987 and the introduction of the new fatigue test) as the study progressed and experience in FNS and its effects were gained. This compounded the difficulties in analysing the results. The data were analysed statistically, were possible. The discussion of the six individual RESTAND group members is presented in the next section.

8.3 CASE STUDIES OF THE SIX RESTAND SUBJECTS

1. QUADRICEPS MUSCLE STRENGTH AND FATIGUE

The individual subjects' strength and fatigue response to the FNS exercise will be examined in the light of their individual circumstances.

Subject TW:

Quadriceps Muscle Strength (Figure 7.1a)

TW had been disabled for 2,5 years at the initiation of the project. His initial strength (LL:70N; RL:59) was the highest

that was recorded for the RESTAND group. The strength in both legs increased to 100N on the introduction of the new parameters and remained consistently at ± 100N. The PWmax index was used to determine any further improvements. PWmax decreased from 247(LL) and 425(RL) to 210 μs (both legs) indicating that the 100N was reached at a shorter stimulus pulsewidth/duration. Thus the same strength (100N) was achieved with a weaker stimulus indicating further improvement. Strengths of equal magnitude were recorded for both legs compared to the initial tests in which the left leg proved to be the strongest.

During October 1987, TW left to participate in the WALK 'n WHEEL Marathon. During the next six months of the marathon, he discontinued FNS exercise. On his return in March 1988, the strength test showed that the quadriceps muscle strength had been maintained at the 100N level. On comparison of this test with the initial test in October 1986 (comparing at 300 μs), the strength had increased from 70 to 102N in the left leg and 59 to 101 in the right leg. This indicates a 45,7% and 69,5% improvement in the left and right legs respectively (Table 7.4).

Muscle Fatigue (Figure 7.3a)

A general trend of an improvement in the muscle fatigue was indicated in both legs between June and September 1987. This is shown by a decrease in the total number of degrees droop and the total droop that had occurred in the leg by the half-test point (%TD(ht)). After the six month absence (August 1987 to March 1988) from FNS exercise, the fatigue response in the right leg showed a small decrease, while that in the left leg showed a small improvement. The right leg had initially been weaker than the left leg (June 1987 test). The March 1988 tests show an

overall improvement in the fatigue response in both legs when compared with the first test in June 1987.

Subject HV:

Quadriceps Muscle Strength (Figure 7.1b)

HV had been disabled for 2 years prior to the initial strength test in October 1986. Her right leg (21N) was approximately 50% weaker than her left leg (45N) at this first test. Higher strengths were recorded on the introduction of the new stimulation parameters in March and April 1987. The right leg increased in strength and was approximately equal in strength with the left in July 1987.

In July 1987, after a long FNS session in the Inclistand, HV presented with a swollen left knee and ankle. X-rays and a bone scan of the knee did not indicate any fracture or evidence of an acute inflammatory process. HV discontinued FNS exercise for the following two months. Interestingly, at the following test in September, the left leg (injured one) remained at its previously recorded strength level and the right leg decreased in strength. HV did not return to her original level of stimulation activity as she preferred to exercise on her Inclistand during October 1987. The October test showed a further increase in strength (left leg reached 100N) and an improvement in the right leg. Even after the injury, the left leg was still the stronger of the two. Between November 1987 and May 1988, HV discontinued FNS. During this time she was involved with wedding preparations then moved to a new home and so had the extra responsibility of a husband and home to care for in an already busy schedule.

After this six month break from FNS exercise, the strength in both legs decreased by approximately 40N, that is a 35% and 45%

decrease in strength in the left and right leg respectively from the November 1987 test. The May 1988 test indicated that even after FNS had been discontinued, the strength was maintained at 33% and 95% higher for the left and right leg respectively than that of the initial test in October 1986.

Muscle Fatigue (Figure 7.3b)

Both legs showed a similar pattern of response to fatigue. Fatigue resistance improved between April and July 1987. After the first period without FNS, between July and September 1987, the fatigue resistance deteriorated. A further decline in fatigue resistance followed after the second six month period without FNS.

Subject RM:

Quadriceps Muscle Strength (Figure 7.1c)

RM had been disabled for almost fourteen years and had metal pins in both femurs. The intital strength in both legs was considerably lower (LL:17N; RL:7N) than those of TW and HV and the 100N level was not reached in subsequent test. The strength of his right leg was consistently 40-45% weaker than that of the left leg. As in the previous two cases (TW and HV), higher forces were recorded when the stimulus parameters were altered in March and May 1987. During June and July 1987, RM discontinued FNS due to an overseas holiday and then to a faulty stimulator. The strength decreased slightly over this time. The strength in both legs increased in September/ October which corresponded with use of the Inclistand at home for 'standing'. Between December 1987 and February 1988, RM's exercise under FNS was minimal and after March, FNS activity was discontinued. The tests in April and June showed a resulting decrease in strength from the previous

tests (October/November 1987). The force measured in the final test in June 1988 was 188% and 328% higher than that at the initial test (compared at 300 μs) for the left and right leg respectively.

Muscle Fatigue (Figure 7.3c)

Right leg: This leg was the weakest in both strength and fatigue resistance. The leg consistently fatigued rapidly, drooping 90-100% of the total degrees of droop by the half-test point. The best test results were those of June and July 1987 when there was improvement in both the degrees of droop during the test and the %TD(ht).

Left leg: This leg showed a general trend of an improvement in the resistance to fatigue for the tests between April and November 1987. This was seen in a decrease in both %TH(ht) and the total number of degrees of droop during the test. An interesting observation was the further improvement in fatigue in April and June 1988 that followed after a limited use of FNS.

Subject DH:

Quadriceps Muscle Strength (Figure 7.1d)

DH was an exception in the RESTAND group - although she had been disabled for the longest period (almost 32 years), she had an incomplete spinal cord lesion. She therefore had limited hand function and some degree of voluntary movement in her lower limbs. Only the left leg showed a weak response at the intital test in October 1986. At the following test in January 1987, the response of the right leg was in fact greater than that of the left leg. Due to the fact that DH experienced some pain when the new parameters of 999 us and 80 mA were first tried, the ampli-

tude was decreased to 5 mA. DH then performed the test with this decreased stimulus to assist her voluntary effort. The test in October and December were performed with her voluntary effort alone (no electrical stimulus). The forces measured in these latter tests were consistently ± 100N. On comparison with the initial test (at 300 μs) the strength had improved 1162% and 10400% in the left and right leg respectively.

Muscle Fatigue (Figure 7.3d)

Right leg: The leg showed an overall decrease in the resistance to fatigue between April and December 1987. The fatigue resistance decreased as the strength of the stimulus was lowered in June 1987. The fatigue resistance declined further when the stimulus was removed and DH performed the tests with voluntary effort only.

Left leg: There was a steady improvement in %TD(ht) from April to August 1987. As for the right leg, the termination of the use of the stimulus during testing was accompanied by a decrease in the fatigue resistance.

The fatigue test was always performed after the strength test during the assessment. If two or three strength tests were performed on one leg, the fatigue test following this showed increased fatigue.

Subject AZ:

Quadriceps Muscle Strength (Figure 7.1e)

AZ was a tetraplegic who was disabled for 4 years prior to her participation in the project. She occasionally experienced a rush/sensation of "dizziness" at the onset of stimulation during a test. Both legs were of similar strength to that of TW at the

inital test. On examination of Figure 7.1e, it appears that after an inital improvement in strength in October 1987, the strength in both legs remained at ± 60N for all other tests. In June 1988, the 2 kg weights were issued and AZ doubled the duration of her exercise sessions. This was, perhaps, a too rapid increase in FNS activity level and may have led to 'overtraining' of the muscles. Unlike the other subjects, AZ exercised each leg under FNS separately, whereas the others exercised both legs together with either simultaneous or alternative stimulation (either both legs extend at the same time or out of phase). At this stage, no definite explanation is available for the results obtained - one might question whether the legs had in fact reached their maximum strength or whether the legs responded to the stimulation at all.

Muscle Fatigue

Right leg: After fatiguing rapidly in the initial test, there was an improvement in fatigue resistance between October and December 1987. In March 1988 the leg drooped fewer degrees during the test. Between June and August 1988, the response was varied, but there was an overall improvement when compared to the initial test.

Left leg: This leg also fatigued rapidly in the initial test prior to stimulation. Fatigue improved in the period until December 1987. In the March test, the leg responded in the same pattern as the right leg namely, a decrease in the degrees of droop but a small increase in %TD(ht). The tests in June and July showed little change.

Subject SB:

Quadriceps Muscle Strength (Figure 7.1f)

SB was the youngest subject and had been disabled one year prior to his initial participation in project RESTAND. Prior to stimulation (January 1988) the strength in both legs measured ± 60N, similar to that of TW and AZ. Except for a slight decrease in the strength in February 1988, the strength increased consistently in both legs with the right leg measuring 100N in August 1988.

Muscle Fatigue (Figure 7.3f)

Right leg: The bar graph shows a small improvement in %TD(ht) over the three tests.

Left leg: There was little change in fatigue resistance over the three tests.

Summary of the six case studies.

Quadriceps Muscle Strength (Table 7.4):

The FNS exercise resulted in an increase in quadriceps muscle force in five of the six RESTAND subjects, namely TW, HV, RM, DH and SB. AZ appeared to respond atypically to the FNS and the exact reasons for this are still to be discovered. DH was an exception in that she had a degree of voluntary function in her lower limbs. Both AZ and DH were tetraplegics. Excluding AZ and DH (Table 7.4), the mean increases of force for the group were 53 ± 29N (97,8 ± 59,6%) and 41 ± 19N (171,2 ± 118,1%) for the left and right legs respectively.

Subjects TW, HV and RM all underwent periods during which FNS exercise was discontinued. TW maintained the same level of muscle force in both legs after his six months absence. HV had

one short break (two months) after which the force in her right leg (weakest leg) decreased by ± 20N while that in the left leg remained constant. The force in both legs increased during the next two months. After the second, longer break from FNS, the force in both the left and right legs decreased by 35 and 45% respectively. RM responded to a break from FNS (± 4-5 months) by a decrease in the force in both legs of 19 and 41% respectively, with the largest decrease in the right leg (weakest leg) .

HV and RM were two subjects for whom the force in their right leg was consistently weaker than that in the left. The muscle force was of equal magnitude in both legs in the other four subjects.

Muscle Fatigue:

The improvement in the response of the resistance to fatigue as a result of FNS exercise was more complex to analyse than the strength response.

TW, HV and AZ showed overall improvements in fatigue in varying degrees in both legs. RW, DH and SB showed different levels of improvement in the left leg, while the right leg had a varied pattern of response (DH) or showed no real change in response (RM, SB).

The fatigue resistance response was also affected in those subjects who underwent periods of discontinued FNS use. In subject TW, the left leg response improved slightly while the right leg response to fatigue had deteriorated a little. For subject HV, each period without the use of FNS resulted in a decrease in fatigue resistance of both legs. In subject RM the fatigue resistance in the left leg actually improved, while that of the right leg remained unchanged.

On comparison between the strength and fatigue responses of the individual subjects to FNS, a pattern emerged for some subjects in the relationship between these responses. The fatigue response appears to be inversely related to the strength response - when the strength improved, there was an accompanied improvement in fatigue resistance and a decrease in strength was often accompanied by a decrease in the fatigue resistance response (an increase in %TD(ht) and degrees of droop). This pattern was observed in the full set of results or sections of the results of the following subjects: TW, HV and RM (left and right legs) and in the left leg of DH and SB. Although AZ had reacted atypically in relation to strength, both legs showed a general trend toward an improvement in fatigue resistance.

According to the ranking scale, Table 7.7 indicates that AZ and RM improved in both fatigue parameters (degrees of droop and %TD(ht)) for both legs. The greatest magnitude of improvement in fatigue occurred in the left leg of RM which showed a 19% improvement in the degrees of droop and a 59% improvement in the %TD(ht). This ranking scale was based on the change from the initial to the final fatigue test for each subject and therefore for TW, HV and RM includes the results from discontinued use of FNS. When these results are excluded (final test is taken as the one before FNS was discontinued), the only change to the present ranking is that HV would rank second with a ranking of three on a par with TW.

2. MUSCLE BULK

A consistent pattern of changes emerged from the NMR scans of TW, HV and AZ (Figure 7.4a-c), namely an increase in the area of the Anterior Compartment and a decrease in the area of the Subcuta-

neous Fat Compartment. The increase in the Anterior Compartment approached the $p<0,05$ significance level ($p=0,08$). The decrease in subcutaneous fat was significant ($p<0,05$) for both legs. Possibly a larger subject number and more NMR scans per subject, the increase in area of the Anterior Compartment would have been significant ($p<0,05$). FNS appeared to produce the desired effects of an increase in quadriceps muscle bulk and a decrease in subcutaneous fat.

Thus in general, taking into consideration the variety in the individual subject's condition and circumstances during the study, these preliminary findings show that the subjects responded to FNS with a statistically significant increase in muscle strength, a trend towards an improvement in fatigue resistance, an increase in quadriceps muscle bulk ($p=0,08$) and a significant decrease is subcutaneous fat.

8.4 COMPARISON OF THE RESULTS WITH OTHER STUDIES

MUSCLE STRENGTH

It is difficult to compare the present results from the RESTAND program with those of other FNS studies in the literature. Very few studies report the actual forces or torques measured during strength testing. Some studies merely report sufficient increases in strength (a torque of 30-40 Nm) and endurance to commence standing training (Braun et al, 1985; Cybulski et al, 1984 ; Turk et al, 1980 and Kralj et al, 1987). Kralj et al, (1980) report that the increase in muscle torque reached saturation level after six weeks of exercising, but do not state the value of the torque. Kern et al (1983) report a 400% and 3000% increase in force and endurance respectively after nine months of FNS training. A mean of 100% increase after one month and 500%

increase after three months of FNS training was recorded by Petrofsky and Phillips (1984). Phillips (1987) reports on a study by Collins who measured a seven-fold increase in muscle strength over twelve weeks of FNS training.

Grenfell (1983) is the only study encountered that reported strength values measured. He reports a maximum force of 112.2 N and 157.5 N for the right and left legs respectively of a C6/7 tetraplegic using FNS 14 years after injury.

In project RESTAND, a safety cut-off point was installed in the stimulation program so that stimulation ceased when a force of 100N was reached. Thus, the true maximum force (above 100N) of the subjects is unknown and not available for comparison purposes.

According to Table 7.4, the mean increases in strength for the four paraplegics for the duration of the program were 97,8 $\pm$ 59,6% and 171,21 $\pm$ 118,1% for the left and right legs respectively. These values may have been higher if there had not been a 100N cut-off point for the strength test.

MUSCLE FATIGUE

No comparison can be presented between the fatigue results of project RESTAND and those of other groups. Other groups such as Edwards and Marsolais (1987), Robinson et al (1986) and Nakai and McNeal (1987) utilise different methods to test fatigue such as a Cybex dynamometer and a test of 50 cycles of 1:1 on:off stimulation. The fatigue indices used were, for example, T20%, T50% and an endurance ratio (section 4.3.4). Project RESTAND used a test that had been developed during the early months of 1987 (section 6.5) which later proved to be complex to analyse (section 7.3)

and an adapted fatigue index was used.

In retrospect, the choice of this particular type of fatigue test is perhaps questionable. No other study utilises the droop angle during a maximum contraction over three minutes to assess fatigue. Possibilities to improve the present test include an attempt to develop a better method of analysing the fatigue response, other than by %TD(ht) and the total number of degrees of droop, or changing the present test format to one similar to that of Nakai and McNeal (1987). This test measures the drop in torque over 50 cycles of leg extension.

MUSCLE BULK

Few other studies present results of changes in muscle bulk due to FNS exercise. Petrofsky and Phillips (1984) report that the leg size of four subjects increased by an average of one inch in circumference. Pacy et al (1987) used cross-sectional serial compyterised axial tomography (CT) scans to determine changes in quadriceps muscle area. They measured a 62,7% increase in the quadriceps muscle of both legs of four subjects over a period of ten weeks of FNS exercise. Robinson et al (1984) reported some preliminary results from their study which was still in its early stages. After one CT scan and a measurement of the three subjects' initial response to FNS, they state that the preliminary results suggest a possible correlation between residual muscle mass (as determined by the CT scan) and the inital response to FNS. Ross-Duggan et al (1986) performed a pilot study to determine the feasibility of using magnetic resonance imaging (MRI) for the early detection of changes induced by FNS on four subjects. They concluded that the increase in muscle mass appeared to correlate with the treatment time but not to years post-injury

and that accurate determination of this needed additional attention.

The following table (8.1) summarises relevant parameters relating to the initial response to FNS and the NMR scans by HV, TW and AZ. Muscle area refers to the percentage area of the quadriceps muscle at the initial NMR scan. Data for both left and right legs are provided for muscle area and initial strength.

Table 8.1 Summary of subject, initial strength and NMR data for HV, TW and AZ.

Subject	Lesion level	Years post-injury	Muscle area %	Initial strength N
HV	T5,6	4,0	13,5	45
			16,7	21
TW	T4	4,5	29,2	70
			31,2	59
AZ	C7	6,0	22,9	68
			23,4	59

Based on this limited number of subjects, it appears that the remaining muscle area (bulk) and the initial strength response to FNS may be related. Data from a larger number of subjects would be needed to verify this relationship.

THE PROGRAM

Due to the change in stimulation parameters at two stages during the program, one is unable to determine how rapidly the "genuine" increases in strength occurred (not those due to the parameter changes). The program progressed at a slower rate than those

studies who report that subjects were ready to stand within two months (Kralj et al, 1986; Braun et al, 1985 and Yarkony et al, 1987). The reasons for the slower progress in project RESTAND include:

* The project was still in its early developmental stages with the first group of subjects. It was an experimental stage and a time to gain experience into FNS.
* The only staff available were two full-time Master degree students who were employed on a quarter-time basis to monitor the program - limited staff with limited time to devote to developing the project further.
* Safety was an important factor to consider. To avoid risk of fractures in the legs, the ankle weights were kept at a light weight. The heaviest weights used during 1987 and 1988 were two kilograms. This was, perhaps, overcautious when compared to Gruner et al (1983). In their program (see Figure 4.1), the lowest weights used after 30 exercise sessions was two kilograms (by a 22 year old C6 tetraplegic, two years post-injury) while highest was nine kilograms (by a 25 year old paraplegic male (T5-8), three years after injury). Greater increases in strength may have been achieved by the subjects in project RESTAND if heavier weights had been issued as the program progressed.

The experience gained from this initial study will allow the RESTAND team to develop an improved program for the future

SECTION B: GENERAL HEALTH AND FITNESS

8.5 MAXIMAL ARM ERGOMETRY EXERCISE

The mean VO_2 and VO_2 max were statistically higher for the males than the females. The mean VO_2 max of the females (12,2 $\pm$ 3,2 $ml.kg^{-1}.min^{-1}$) was 33,4 $\pm$ 5,3% of their predicted VO_2 max (Table 7.11). The males achieved 46,5 $\pm$ 12,3% (21,5 $\pm$ 4.8 $ml.kg^{-1}.min^{-1}$) of their predicted VO_2 max. Thus both sexes achieved a VO_2 max during arm ergometer exercise that was less than 50% of the predicted value for leg exercise in able-bodied people. According to Davis (1981), able-bodied subjects performing forearm exercise typically achieve a VO_2 max of less than 70% of that for lower limb exercise such as uphill treadmill running.

One reason for the RESTAND group achieving lower VO_2 max results (less than 70%) than able-bodied subjects is their added disadvantage of limited balance and stability due to paralysis of their trunk musculature. Secondly, the female group included two tetraplegics (AZ and DH) whose limited hand function in turn limited their capability to perform the arm ergometry exercise. The RESTAND results do compare favourably with the VO_2 max results of other studies on SCI subjects, namely:22,8 $\pm$ 4.6 $ml.kg^{-1}.min^{-1}$ for ten male paraplegics (Taylor et al, 1986); approximately 19 $\pm$ 3 $ml.kg^{-1}.min^{-1}$ for a group of six male and four female SCI subjects (Cooney and Walker, 1986); 30,1 $\pm$ 2,1 $ml.kg^{-1}.min^{-1}$ for ten physically active male paraplegics (Gass and Camp, 1984) and 9,5 $\pm$ 4,6 $ml.kg^{-1}.min^{-1}$ for seven chronically institutionalised high level SCI subjects (Gass et al, 1980). Davis et al (1980) reports on a study by Wicks on Olympic-calibre wheelchair athletes whose VO_2 max ranged from 15,9 for quadriplegics to 39,0 $ml.kg^{-1}.min^{-1}$ for minimally disabled paraplegics.

As in the VO_2 max values, the subjects achieved lower maximum heart rates during the arm ergometer exercise test than their predicted maximum heart rates. The females achieved 75,4 ± 22,6% (144 ± 50 $b.min^{-1}$) while the males achieved 97,9 ± 11,8% (189 ± 21 $b.min^{-1}$) of their predicted maximal heart rates. Thus the males' maximum heart rates were 20% more of their predicted values than the females.

The results of the respiratory quotient (RQ) showed a similar pattern of response in that the values for the males (1,3 ± 0,3 units) were higher than those of the females (0,9 ± 0,03 units). These differences between the male and female groups for heart rate and the RQ, approached the $p<0,05$ significance level ($0,05<p<0,1$).

The RESTAND results for heart rate and RQ are similar to those reported from other studies on SCI namely: 100-146 $b.min^{-1}$ for subjects with high spinal cord lesions (C4-8) (Hoffman, 1986) and 181 ± 3 $b.min^{-1}$ for ten physically active male paraplegics (Gass and Camp, 1984). Huang et al (1983) report an RQ of 1,3 ± 0,2 for twelve male paraplegics during graded arm exercise.

As previously mentioned in section 5.1, the aerobic performance during an arm ergometry test tends to be limited by resulting localised fatigue in the small muscle mass of the arms, rather than by the cardivoascular system (Davis et al, 1981). This would explain, in part, the large differences in the results between the male and female RESTAND groups. The females, especially the two tetraplegics, terminated the exercise test earlier due to limited hand function and muscle fatigue in their arm. The males generally had well developed arm musculature and thus localised fatigue occured later than in the females.

Subject DG (male) performed the arm ergometer test well and reached the highest values of VO_2 max, heart rate and respiratory quotient of the RESTAND group.

8.6 MUSCLE FUNCTION

Upper body strength and endurance are important factors that may limit the daily activities of SCI people who are confined to wheelchairs. In the RESTAND group, there was no difference between the results of the left and right shoulders or the elbows for both the males and females. Significantly more power in extension and flexion of both the shoulders and the elbows was measured in the male group than the female group. The fact that two of three females were tetraplegics with limited arm function and that males TW, RB and DG had well developed arm muscles may account for some of the differences between the two groups.

No other such studies that presented similar data were found to serve as a comparison with the RESTAND results. Davis et al (1986) reported that the evaluation of muscle function in the SCI population has received little attention. He did refer to two studies who reported a significant relationship between habitual activity and upper body isometric strength in paraplegics.

8.7 LUNG FUNCTION

In the RESTAND group, the males had a higher peak expiratory flow rate than the females, and a similar vital capacity. The FEV_1 and thus the FEV% was highest in the female group. Table 8.2 lists the lung function values reported in other studies on SCI subjects.

Table 8.2 Lung Function Data for SCI subjects (mean ± SD)

Study	Subjects	Peak flow (1.sec-1)	VC (1)	FEV1 (1)	FEV%
Gass et al, 1980	high lesion-level males	6,05	3,2 ± 1,1	2,6 ± 1,0	80 ± 12
Gass and Camp, 1984	males, paraplegics	9,05	5,0 ± 0,4	4,0 ± 0,3	80
Zwiren & Bar-or, 1975	male athletes		5,0 ± 0,7	4,1 ± 0,7	82 ± 9
	male sedentary		4,3 ± 1,0	3,3 ± 0,9	77 ± 10
Hjeltness, 1977	males		4,3 ± 0,9		83,1 ± 7

The VC and FEV_1 of the RESTAND group (Table 7.14) are consistently lower than those reported in Table 8.2. The FEV% values were between 10-20% higher for the RESTAND group (99,8 ± 0,4 and 93,9 ± 7,9%). According to Adkins (1985) the FEV_1/FVC ratio is normally 80%. SCI patients, like other patients with restrictive pulmonary problems, should have a ratio of 90% or better if there is not airway resistance and only decreased muscle activity. Thus, the high FEV% in the present study (between 90 and 100%) indicate that the pulmonary mechanics were unimpaired (Hjeltnes, 1977).

Adkins (1985) reports that tetraplegics with a C6-C8 lesion have a VC between 50-70% of normal and paraplegics have a VC of 75% of the normal VC. The RESTAND results correspond with these values as AZ (tetraplegic) had a lower FVC than the other four subjects (paraplegics).

8.8 BLOOD BIOCHEMICAL PARAMETERS

Serum Cholesterol concentrations:

The female group had improved cholesterol profiles in comparison

to the males, namely lower total cholesterol, triglyceride and low density lipoprotein and higher high-density lipoprotein concentrations. According to the action limits for total cholesterol concentrations (Rossouw et al, 1988), subjects SB and AZ have cholesterol concentrations in the desirable range while those of DH and HV border the desirable-moderate risk range (Figure 8.1). The cholesterol level of RM fell above the reference range values and within the high risk action limits.

RM was informed of his cholesterol concentration and issued with a low cholesterol diet sheet from the Department of Dietetics at Groote Schuur Hospital to serve as a guideline for healthy dietary patterns.

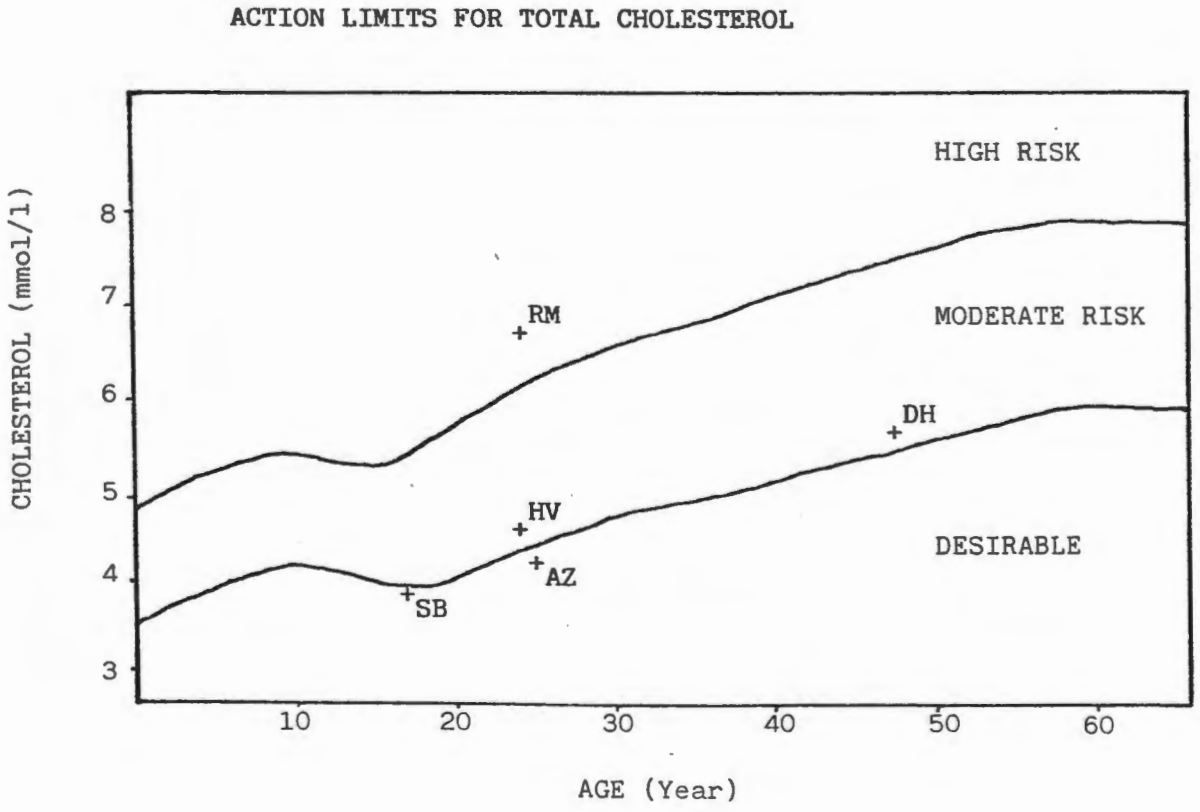


Figure 8.1 Action limits of total cholesterol concenteration (adapted from Rossouw et al, 1988)

Blood Biochemical parameters:

The results of the SMAC tests for the RESTAND group (Table 7.16) were acceptable as the means of the five subjects all fell within the adult reference range. The urea, creatinine and albumin parameters are important as they give an indication of kidney function which is important in SCI people. The parameters for the RESTAND group fell within or close to the adult reference range indicating intact kidney function.

8.9 DIETARY ANALYSIS

After the diets had been analysed they were examined for comment by Mrs Lauren Bock of the Department of Dietetics, Groote Schuur Hospital. The females (HV and AZ) both had low average energy intakes, normal to low calcium intake and very low iron intake. The same pattern was found in the males (RM and SB) who also had a low fibre intake. SCI individuals who are wheelchair-confined generally are less active during the day and so the lower average energy intakes for the group are acceptable. The low calcium intake is due to a decrease in the intake of dairy products in order to avoid kidney and bladder stone formation.

The subjects were given guidelines of how to improve their dietary habits where necessary.

8.10 SUMMARY

The results indicated that the RESTAND group was in a state of general good health. The high cholesterol concentrations of RM was the only exception to this. Subjects were informed and given guidelines in situations where improvement may have been necessary.

CHAPTER NINE

SUMMARY AND CONCLUSIONS

9.1 PROS AND CONS OF THE NATURE OF PROJECT RESTAND

Pro:

The format of the program was convenient for both subjects and project personnel in that it was geared to the home situation.

Cons:

The subject group was heterogenous. Their busy lives meant they had limited time to devote to FNS.

The project was experimental and developmental in nature. Thus, together with the lack of full-time personnel, meant that the program in the project was slow-moving. Thus, motivation to continue FNS exercise fluctuated during the duration of the project.

Only the quadriceps muscle group was exercised.

9.2 SUMMARY

The study showed the following responses to FNS exercise:

1. Quadriceps muscle strength was increased significantly ($p<0,05$).
2. Fatigue resistance of the quadriceps muscle improved ($0,05<p<0,1$).
3. The muscle bulk of the quadriceps muscle (Anterior Compartment increased ($0,05<p<0,1$).
4. There was a significant decrease in the quantity of Subcutaneous fat in the thigh ($p<0,05$).

The large degree of variation in these improvements between the RESTAND subjects can be attributed to the heterogenous nature of the group.

The study also showed that the RESTAND group was in a state of general good health with the exception of the elevated serum cholesterol concentration of subject RM.

9.3 CONCLUSIONS

The study showed that the FNS was sucessful in improving the quadriceps muscle strength, bulk and fatigue response of the SCI people in the Project RESTAND research group.

There was a large improvement in the muscle strength, namely a mean ($\pm$ SD) of 97,8 $\pm$ 59,6% and 171,2 $\pm$ 118,1% for the left and right legs respectively. The RESTAND subjects who fulfill the other criteria for standing, such as, good truncal stability and the absence of contractures of the lower limb, can now procede to the standing phase of Project RESTAND.

The study provided necessary experience in many aspects of an FNS program, such as, the use of electrodes and stimulators, the effects of the stimulation parameters, the development of suitable tests and the necessary equipment (mechanical and electrical) to assess the effects of FNS, insight into the practicalities involved in a "home-use" FNS program, and the need for suitable selection criteria (such as time availability).

Thus the study achieved its FNS goal. A basic FNS muscle training program was developed and the experience gained during this study will aid in improving the present program to optimise the preparation of future SCI subjects for standing under FNS control.

CHAPTER TEN

FUTURE DEVELOPMENTS AND SUGGESTIONS

The past two years have served to provide experience and knowledge of FNS and its effects on the quadriceps muscle. The present subjects have been patient in participating when progress was, at times, slow. The prospects for 1989 and future years are exciting and include a three month visit between March and June 1989 by Dr E Isakov of the Loewenstein Rehabilitation Hospital, Ra'anana, Israel. This visit will provide valuable input, guidance and experience for project RESTAND.

The development of a new, improved muscle stimulator is nearing completion at the Department of Biomedical Engineering. This will replace the present stimulator and provide additional modes of stimulation such as for cycling. The new stimulator can be used in conjunction with a new version of the existing Paracycle that is also undergoing development at the Department of Biomedical Engineering. This cycling will provide a form of dynamic, aerobic exercise. The new stimulator will also be used to provide standing and exercise in the Inclistand.

A Masters thesis on the biomechanics of standing-up and sitting-down in persons with lower limb paralysis, with the aid of FNS, has been completed (Johnson, 1988). The results of this thesis will aid in the preparation for standing in the RESTAND group.

Additional funding has permitted the employment of extra personnel for project RESTAND, namely a full-time coordinator and part-time staff, who will aid in the future progress of the project.

Future suggestions for the project include:

1. Adapting the present FNS leg exercise format by adjusting the subject's ankle weights so that the leg exercises for at least ten minutes but fatigues within a fifteen minute period (Phillips, 1987). The advantages of this format are that the exercise session is not longer than fifteen minutes, an important factor for subjects who have limited time. The load of ankle weights would be increased and the muscles would improve in strength.

2. The present fatigue test could be adapted to a format similar to that of Naikai and McNeal (1987). They used an endurance test of 50 cycles of 1:1 on:off stimulation and three measures of fatigue, namely an endurance ratio, area and T50 index.

3. The use of the present stimulus parameters could be re-evaluated in relation to those listed in Table 4.4.

4. Physiological monitoring, such as heart rate, blood pressure and oxygen consumption, could be introduced as the FNS exercise intensity increases.

One would anticipate that, with the future prospects of development and progress for the future, that the RESTAND subject's patience during the last two years will in some way be rewarded.

APPENDIX ONE

LIST OF SPORTS CLUB FACILITIES

* The Protea Sports Club, Main Road Retreat (ph 755520)

  A basic guide to the sports offered is:

Monday	17h30 Basketball	19h30 Airgun shooting
Tuesday	18h30 Gym	19h30 Badminton
Wednesday	18h30 Gym	19h30 Basketball (para)
Thursday	18h30 Gym	19h30 Table-tennis/Archery
Saturday	14h00 Archery	
Sunday	10h00 Archery and Table-tennis	

  They host various competitions over weekends. A joint basketball team for the 3 clubs practices at Protea. Dawn Hare (a member) is at present Chairman of the Western Province Sports Association for the Disabled (ph 881882).

* St Giles Sports Club, 71 Klipfontein Road, Rondebosch (ph 689-9815)

  They offer:

Tuesday	19h30 - 22h00 : Table-tennis and weightlifting
Wednesday	19h30 - 22h00 : Airgun shooting
Saturday	10h00 : Tennis at Red Cross Hospital courts
	13h30 - 17h00 : Bowls and field events
	(indoor sports if it rains)

* Unitie, Laurie Road, Bridgetown, Athlone

  (Chairman: ph 637-7845). They meet at 14h30 on Saturday afternoons. They offer field events, archery, table-tennis, power lifting and informal basketball practise.

For those interested in weightlifting training, one possibility is a new gym run by Mr Tony Asaro at 28 Marine Drive, Paarden Eiland (ph 51-7344). He does train disabled people. This gym is open Monday to Friday, 15h30 - 19h00 and Saturday, 12h00 - 15h00.

APPENDIX TWO

INFORMATION SHEET

Full Name:

Date of Birth:

Height:

Weight (and approximate date when last weighed):

Occupation:
(1) prior to accident
(2) at present
Are you self-supporting? If not, what percentage?

What are your hobbies/recreation activities:

Are you health and/or weight conscious?

If you participate in any sport or exercise activities:

Type:

Level (social/competitive):

How often:

Nature of your accident:

Date (month, year):

Level of lesion:

Do you have any muscle spasms?

Do you go to physiotherapy?

How regularly?

Do you have any metal plates or pins?

Have you had a spinal fusion?

If so, when?

Do you stand or walk with calipers or parallel bars?

If so, which?

how often?

for how long?

Do you have good trunk stability?

Have you had any medical/psychological complications, eg pressure sores, kidney/bladder infections, fractures of limbs, prolonged periods of depression?

If so, state briefly:

Other relevant information?

Thank you. We appreciate all your help and cooperation with Project RESTAND.

APPENDIX THREE

CONSENT FORM

FNS - PROJECT No. 7 : RESTAND - INFORMED CONSENT FOR SUBJECTS

Phase I: Muscle strengthening and fitness training in preparation for standing (Phase II).

1. I am satisfied with the aims and details of Phase I of Project No. 7 (RESTAND) which have been adequately explained to me.

2. I am aware of all the points relevant to this consent, as laid out in the enclosed fact sheet below.

3. My questions have been satisfactorily answered.

4. I am prepared to participate in the project.

SIGNATURE

WITNESS 1.

WITNESS 2.

DATE

FACT SHEET:

1. This is an experimental programme and we should be careful not to generate unrealistic hopes.

2. Although strength and endurance of muscles have been demonstrated to occur as the result of FNS, this cannot be guaranteed to occur in all subjects.

3. Other benefits of FNS have not been fully substantiated and will have to be evaluated for each subject separately.

4. Subjects with complete lesions will be preferred for the project. In incomplete lesion pain may be experienced due to electrical stimulation. Decision will have to be made about continued participation in these subjects.

5. Final admission to the programme will be granted only after assessment of suitability as determined by muscle, fitness, neurological and medical tests.

6. There will be no costs to subjects to participate in the lower limb muscle strengthening part of the programme. However, personal transport costs are expected to be borne by the subjects.

7. It is expected that the subjects undergo upper body strengthening as well as general fitness exercises as prescribed.

8. Subjects will undergo regular tests in order to determine:

   (a) Lower body muscle improvement
   (b) General health and fitness
   (c) Upper body muscle strength.

9. Due care will be taken to avoid any inconvenience, complications or injury to subjects.

10. The only serious problem reported and discussed overseas was the fracture of bones, which occurred with premature placement of total body weight onto the limbs. Glaser (1986) has shown that with FNS generated knee extension subjects were able to lift in excess of 10 kg with one leg after 12 weeks of training without any breakages. Special care will be taken to avoid breakages. by keeping the loading well below this figure.

11. Throughout the project subjects will be evaluated in all respects, viz, lower and upper muscle strength as well as general fitness.

12. Subjects will be expected to do their prescribed exercises regularly in order to reach the required criteria to enter Phase II which is FNS enabled standing in a special frame with hands holding on. It must be remembered that the beneficial effects of training will be lost in a short time (ten - twenty days) after exercise is discontinued.

13. All subjects will have the freedom to withdraw from the project at any time.

14. It has to be appreciated that continuation of the project as well as its progress depends on research funds as well as personnel. There can also be unforseen problems with design, manufacture and procurement of equipment.

15. No free standing or walking is envisaged at this stage.

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