

# Restoring mobility: theories, technologies and effective treatments

Manoj Sivan and Bipin Bhakta

## Manoj Sivan

MRCS, Academic  
Clinical Fellow,  
Specialist Trainee  
ST3 Rehabilitation  
Medicine

## Bipin Bhakta

FRCP, Professor in  
Rehabilitation  
Medicine

Leeds General  
Infirmary, Leeds

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This conference was jointly organised by the Royal College of Physicians and the British Society of Rehabilitation Medicine to focus on understanding loss of movement control in the context of acquired brain injury (ABI) and limb loss, its functional impact and innovations in preventive and restorative treatments. There was a very interesting mix of speakers ranging from experts in implantable technologies, bioengineering, physiotherapy, psychology, neurosurgery and rehabilitation medicine. Karl Sacks who was part of a team of disabled people who crossed the Nicaraguan jungle described his experi-

ences during this enormous challenge – their story was told through a documentary made by the BBC in 2005 entitled *Beyond boundaries*.

## Introduction

The World Health Organization's International Classification of Functioning, Disability and Health (ICF) shifts focus from cause to impact of disability emphasising the dynamic interaction between functioning and disability.<sup>1</sup> Using this framework we can obtain a better understanding of the scale of this problem. Mobility impairment in this context results in individuals having difficulty sitting, walking, or reaching and manipulating objects which affects activity and participation. The impact of this impairment is mediated by environmental and personal factors.

The prevalence of disabled adults in the UK is 135 per 1,000 adults over the age of 16.<sup>2</sup> The most commonly reported type of disability is locomotor disability among the five main types (locomotor, personal care, seeing, hearing and communication). The major contributors to locomotor disability are age, musculoskeletal disorders (arthritis, traumatic amputation), circulatory and respiratory (cardiovascular and peripheral vascular disease, chronic bronchitis), neurological (stroke, traumatic brain injury), obesity and diabetes among all other contributory medical conditions. Locomotor disability also increases the risk of falling. There are over 200,000 falls reported annually with 98% reported in organisations providing inpatient care for patient's services.<sup>3</sup>

## The science behind improving movement control

Upper limb recovery after stroke is unacceptably poor, particularly for survivors with severe paresis who are commonly left with a non-functional or minimally functional arm. In considering the neural processes that may drive restoration of function, it is useful to distinguish between 'use-dependent plasticity' and 'stimulation-induced plasticity'.

A number of studies have established that recovery is promoted in some circumstances by the active repetitive use of the paretic limb alone in task-

## Conference programme

### ■ Mobility problems: their epidemiology and impact on participation

Dr Vera Neumann, Leeds Teaching Hospitals NHS Trust and University of Leeds

### ■ Can abnormal movement control be made normal? The science behind movement control

Professor Richard Carson, Queen's University Belfast

### ■ Physiotherapy interventions and orthoses following stroke. What is the evidence?

Dr Elizabeth Condie, University of Strathclyde and Professor Ann Ashburn, University of Southampton

### ■ Falls in those with limb loss or deficiency

Dr Jai Kulkarni, University Hospitals of South Manchester

### ■ Deep brain stimulation for movement disorders

Mr Richard Selway, King's College Hospital, London

### ■ Targeted reinnervation for enhanced prosthetic function

Professor Todd Kuiken, Rehabilitation Institute of Chicago, USA

### ■ Cybernetics and robots in rehabilitation

Professor Kevin Warwick, University of Reading

### ■ Moving forward with technology

Dr Ruth Mayagoitia-Hill, King's College London

### ■ Crossing the Nicaraguan jungle with mobility problems

Mr Karl Sacks

directed training programmes. In the most well publicised variant of this approach (constraint-induced (CI) therapy), use of the paretic arm is enforced by physically constraining the non-impaired limb.<sup>4</sup> Unfortunately for many stroke survivors the degree of hemiparesis is so severe that they are unable to generate levels of muscular activity or control sufficient to employ this strategy. For those who are very severely impaired, and are unable to generate sufficient neural drive to produce any movement, it may be necessary to use techniques such as electromyography (EMG)-triggered functional electrical stimulation (FES). Work conducted recently has yielded substantial and clinically significant improvements in function and recovery.

For others who retain some upper limb function, yet are unable to benefit from CI therapy, bilateral movement therapy appears to provide a promising alternative. The rationale for this mode of intervention is based upon the tendency for the two upper limbs to behave as a single functional unit when they are moved simultaneously. It has as its physiological basis inter-hemispheric interactions between cortical motor areas.<sup>5</sup>

Alterations in neural plasticity may also be induced by a variety of electrophysiological techniques, including indirect stimulation of tissue in damaged regions of the brain by transient magnetic fields or weak electrical currents. Interactions that occur when contractions performed by the muscles of one limb are accompanied by simultaneous stimulation of the motor areas that innervate homologous muscles of the opposite limb significantly enhance the changes in cortical excitability brought about by such stimulation.

### Physical therapy interventions to improve walking in stroke

Locomotor recovery tends to occur more rapidly in the first few months after ABI. The key interventions within the process of locomotor rehabilitation after brain injury are those directed at improving balance, weight bearing through the paretic leg, cardiovascular fitness, muscle strength and confidence to overcome fear of falling. Clearly specific attention must be directed at compensatory approaches for those whose recovery is incomplete including home adaptations and provision of assistive technology (AT). Physiotherapy interventions are goal directed and based on individual needs.

The two main approaches in neurophysiotherapy are Bobath technique and movement science approach.<sup>6</sup> The Bobath approach aims to re-educate normal movements and function, by the use of appropriate sensory and proprioceptive input by the handling skills of the therapist and using goal-oriented activities. In the movement science-based approach, the patient is regarded as an active learner in the rehabilitation process. The therapist trains the patient in task-specific exercises and encourages self-monitored practice outside training sessions. There is no published evidence to suggest one approach is superior to the other in terms of patient outcomes. Other approaches involve the use of mechanised systems to provide an environment in which intensive mobility training can be undertaken. Partial body support systems and use of driven orthosis used in con-

junction with a low speed treadmill can allow patients who are unable to weight bear fully to walk.<sup>7,8</sup> Peripheral FES using surface or implanted electrodes to stimulate specific muscle groups, such as ankle dorsiflexors, can improve walking considerably by enhancing cyclical control of ankle movement.<sup>9</sup>

### Use of orthoses to improve mobility

An orthosis is a device attached externally to a limb to aid/correct function. A foot orthosis for example can provide a biomechanical advantage by placing the foot and the lower extremity in a more advantageous position thus altering applied tissue stresses. Various orthotic appliances can be prescribed to patients with neurological impairments. In the paretic lower limb, use of an orthosis encourages balanced standing, postural alignment, early weight bearing and speed of walking. In 2004 the international consensus group on orthotic management of stroke patients in the Netherlands suggested recommendations for clinical practice and gaps in knowledge based on the published evidence and clinical experience at that time.<sup>10</sup>

Ankle foot orthosis (AFO) is commonly used in stroke patients. This orthosis can be manufactured with a number of modifications such as the degree of flexibility at the ankle joint taking into account the degree of ankle stability, presence of active movement or contracture in an individual person with stroke. A knee-ankle-foot orthosis (KAFO) is preferred if there is added moderate/severe genu recurvatum. Although KAFO can provide increased limb control the price is an increase in weight and difficulty in attaching or removing the orthosis which limit the use by those with impaired hand movement. The alignment of a lower limb orthosis is critical and will influence the step length, symmetry, speed and energy consumption. Use of pre- and post-gait analysis is recommended.

### Assistive technology to improve mobility

Assistive technology is an enormous area with many hundreds of small and large devices to improve mobility. Since the introduction of the first powered wheelchair in 1956, there have been major innovations in the field of AT to enhance the mobility of those people with the greatest mobility restrictions. Recent advances are described below.

Current ATs for climbing stairs range from the simple (eg stair rails) to the complex (eg powered chairs). A new non-electric stair walker has been designed which is propelled by the user for safe climbing up or down stairs. It employs adjustable ascent and descent handles in different positions, depending on the height of the individual and whether they are climbing or descending.<sup>11</sup>

For people who have no functionally useful upper limb movement to self propel their wheelchair, a new user interface has been developed to control movement. The 'tongue controller' device has an earpiece sensor which tracks changes in the pressure of the middle ear with tongue movements. These signals are then used to direct the wheelchair.<sup>12</sup> A preliminary clinical study showed less than one collision per 1,000 runs for every test

subject. Testing in a noisy environment, however, has not yet been completed.

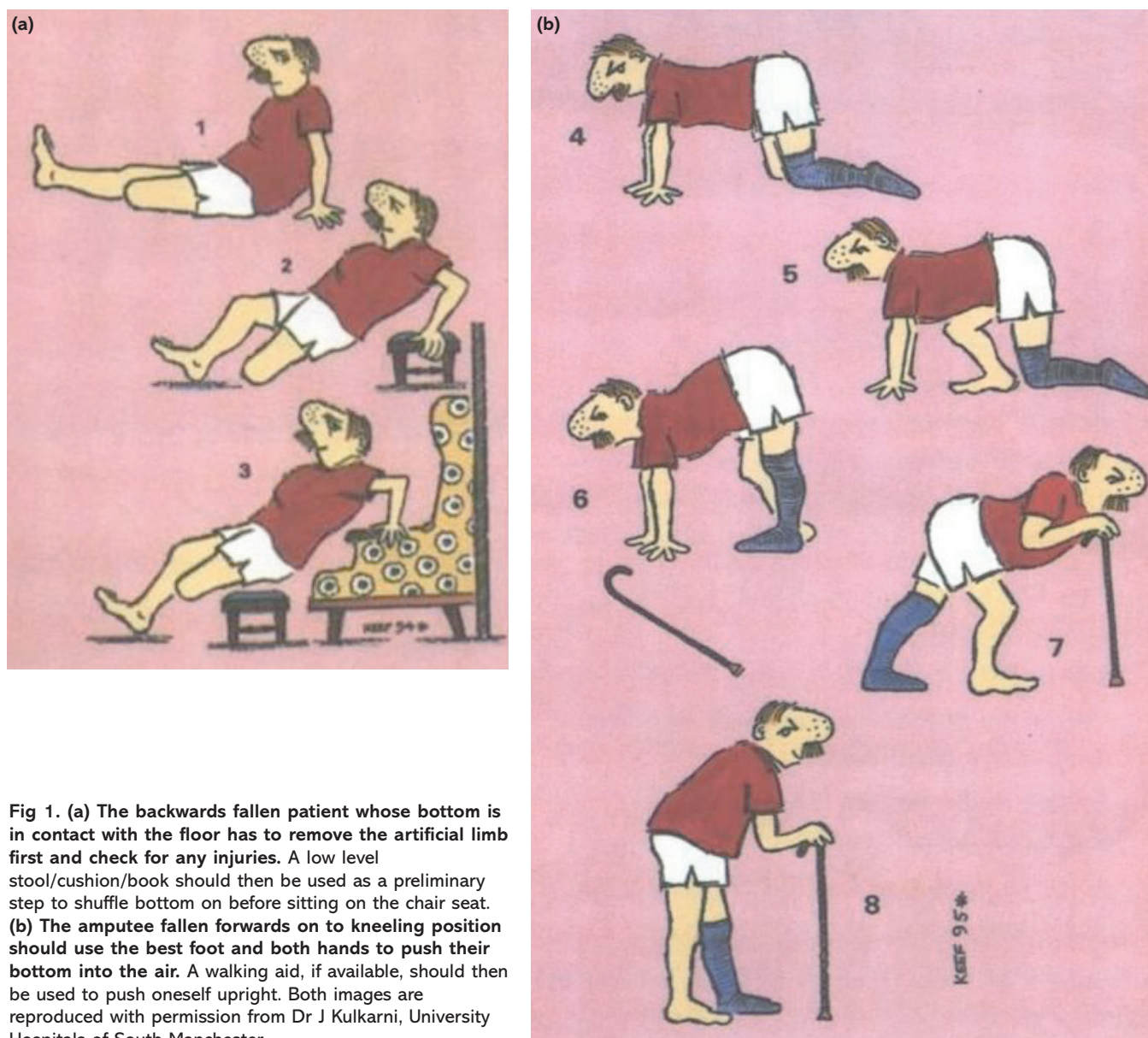
Currently children with restriction in independent mobility from conditions such as cerebral palsy are not offered 'powered' mobility aids until they are five or six years of age. A baby robot has been developed for children aged 18 months and over.<sup>13</sup> The tiny robot is controlled mainly by joystick and is ringed with sensors that can determine the obstacle-free roaming space. It will either allow infants to bump obstacles or will take control from the infant and drive around the obstacle itself.

## Preventing falls in amputees

Falls are a common and anticipated problem in people with lower limb amputation, yet very little scientific study has been undertaken in the area. Having a prosthetic limb adds to the difficulties

patients experience after a fall. An important observational study completed in Manchester in 1996 reported greater falls in prosthetics users who had an unilateral amputation (58%) when compared to those with bilateral amputations (27%).<sup>14</sup> Fifty per cent of the falls were due to intrinsic factors including medication and 34% were attributable to the prosthesis or the person's environment.

A key aspect of preventing serious injury following a fall is prevention. The multidisciplinary team (MDT) has an important role in training the patient on core balance exercises, how to prevent injury if falls occurs, strategies to get up after falling (to prevent secondary complications of lying on the floor such as decubitus ulcers) (Figs 1a and 1b), and to review medications. Technology can be used to notify health and social services if a fall occurs through the use of sensor alarms and appropriate automated lighting in the persons home to prevent falls.<sup>15</sup>



**Fig 1. (a) The backwards fallen patient whose bottom is in contact with the floor has to remove the artificial limb first and check for any injuries. A low level stool/cushion/book should then be used as a preliminary step to shuffle bottom on before sitting on the chair seat. (b) The amputee fallen forwards on to kneeling position should use the best foot and both hands to push their bottom into the air. A walking aid, if available, should then be used to push oneself upright. Both images are reproduced with permission from Dr J Kulkarni, University Hospitals of South Manchester.**



## Enhancing upper limb prosthesis control

Traditional myoelectric prosthesis utilising surface EMG signals from the voluntarily activated residual limb muscles can perform only one action at a time and are not very efficient for multiple movements of different joints of the prosthesis. This disadvantage is overcome by targeted reinnervation where multiple muscles can be used to target multiple simultaneous movements of the prosthesis.<sup>16</sup>

Todd Kuiken delivered an excellent and stimulating lecture on pioneering work undertaken on development of the targeted muscle reinnervation (TMR) prosthesis at the Rehabilitation Institute of Chicago. This involves targeted reinnervation of motor and sensory neural components. TMR involves surgical relocation of the residual nerves of the amputated limb to muscles of the upper chest wall. After a period of training the target muscle responds like a muscle of the amputated limb to produce EMG signals that can be identified by sensors which control movement of the prosthesis. Targeted nerve reinnervation is undertaken by severing the nerves supplying the skin over the targeted muscle and reinnervating it with afferent nerves of the

amputated limb. This area of the skin then becomes the sensory representation area of the amputated limb providing sensory feedback from the prosthesis.

The first patient to trial this new technique had bilateral amputations involving shoulder disarticulation and underwent the above described surgery. Five months post-surgery, he had training sessions to learn the different movements of the upper limb (Fig 2).<sup>17</sup> The patient was fitted with standard body-powered prosthesis on the right side and the TMR prosthesis on the left. The speed at which TMR prosthesis could be used to move the blocks in a 'box and block test' was approximately 2.5 times faster than the standard body-powered prosthesis. This translated into direct benefit to the patient in terms of carrying shopping, picking up toys from the floor and putting on glasses/hat. The patient was also able to feed himself, shave, put socks on, water the garden, open small jars, use handicap scissors and throw a ball. The patient's subjective impression was, 'Now I don't have to think about what I'm doing so much – I just do it'. Since this initial success 12 further patients have had the TMR prosthesis fitted.

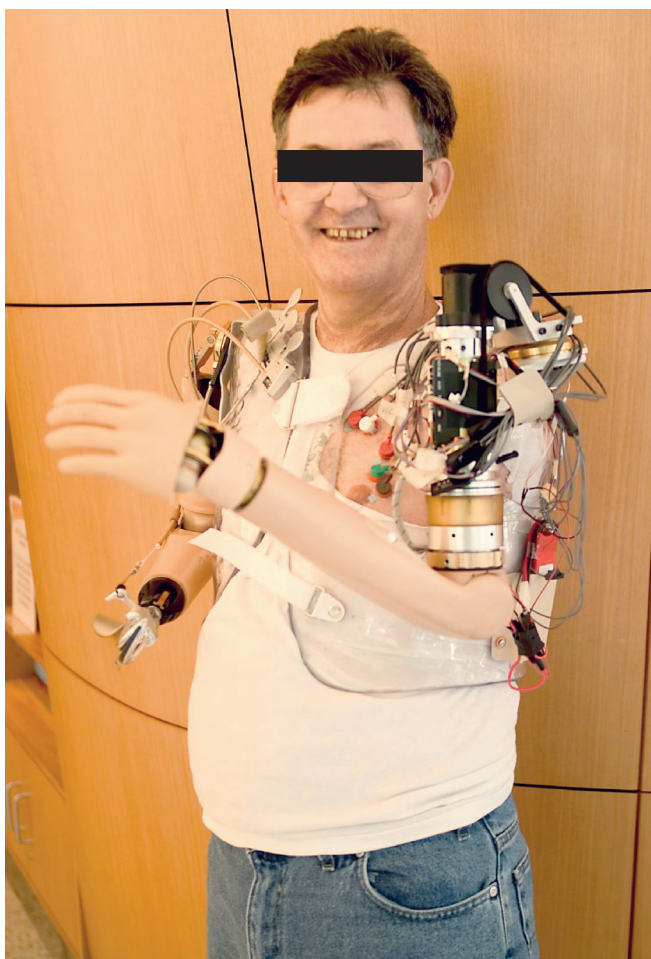
## Deep brain stimulation to control abnormal limb movement

Deep brain stimulation (DBS) can provide therapeutic benefits in people with pharmacological resistant movement disorders such as Parkinson's disease, tremor and dystonia.<sup>18</sup> Although the mechanism of DBS is not clear, current evidence indicates that it is a reversible process which inhibits neuronal activity in specific subcortical structures such as the thalamus, subthalamic nuclei, and globus pallidus. The target of DBS depends on the symptom (tremor, rigidity, bradykinesia or dystonia) being treated. The high frequency electrical stimulus is continuously delivered by implanted electrodes connected to a pacemaker system which can be used to adjust the magnitude of electrical stimulation based on symptom response. Surgical implantation is carried out under general anaesthesia but can also be performed under local anaesthesia.

Selection of people most likely to benefit is a key part of the preoperative assessment process. For example in Parkinson's disease the response to DBS is seen primarily in those whose symptoms are dopamine responsive. Non-progressive, non-fixed primary dystonia in the absence of spasticity and tremor respond best to DBS. Tremor (eg essential tremor) has also been reported to improve dramatically following DBS. People with multiple sclerosis who have disabling tremor respond less well to DBS. The selection of patients and use of DBS requires a MDT with appropriate post-surgical rehabilitation.

## Cybernetics and implanted technology

Alongside advances in electrical and mechanical systems there has been a growing interest in using implanted technology which can sense and control sequential functionally useful muscle activity. Kevin Warwick from Reading University shared his unique experience of controlling the external environment by



**Fig 2. First targeted muscle reinnervation prosthesis in a bilateral shoulder amputee.** Reproduced with permission from Professor TA Kuiken, Rehabilitation Institute of Chicago.

surgical implantation of a sensing radiofrequency identification device into his median nerve.<sup>19</sup> The 100-pin electrode transmitted signals bi-directionally between his nervous system and a computer. Electrical signals recorded by the sensor from the median nerve during various upper limb movements were transmitted to a computer and analysed. These processed signals were then used to control the environment. For purposes of demonstration he was able to open and close an articulated artificial robotic hand merely by brain activity sensed through the median nerve. A further demonstration of this was presented by the ability of the system to transmit these signals from the University of Columbia (USA) across the internet to successfully move the robot hand in the UK. He also demonstrated how he could undertake the basic daily activities of a disabled person just by thinking about them such as directing an electric wheelchair, opening doors and controlling lighting in a room. Implantable technologies such as this pave the way for microchip transplants which will provide a viable route for people to regain the use of their limbs in the future.

## Summary

Movement impairment affects the independence and lifestyle of a significant number of people worldwide. A MDT approach towards the problem is needed for optimal restoration of mobility. Educating vulnerable people on preventive strategies and safe techniques after a fall is imperative. Use of appropriate orthosis, assistive technology, physiotherapy and surgical interventions should be timely and evidence based. Assessment of the patient is critical to ensure successful outcomes of technological interventions. Novel technologies such as targeted reinnervation prosthesis and implantable technologies, although at a very early stage in their development, have huge potential to help people with movement impairments due to disorders of neuromuscular control or limb loss.

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