Chapter 9
Lower-Limb Neuroprostheses: Restoring Walking after Spinal Cord Injury

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ABSTRACT

Regaining lower-limb functionality such as walking is one of the highest priorities among all the disabilities of paraplegics following Spinal Cord Injury (SCI). Though the ultimate recovery would be repairing or regenerating new axons across the spinal lesion (potentially by stem cells or other transplants and neurotropic factors), challenges to achieve this as well as recent technological advancements demand the development of new neuroprosthetic devices to restore such motor functions following the injuries. In this chapter, the authors discuss available therapies for the rehabilitation of SCI paraplegics and some new potential interventions that still require clinical tests. They also propose brain-machine-spinal cord interface as a future neuroprosthesis following motor complete SCI.

INTRODUCTION

Spinal Cord Injury (SCI) is a devastating neural dysfunction affecting a large population worldwide. Though the exact prevalence of SCI is unknown, according to recent statistics, it is estimated that the number of injuries between 236 and 1009 per million (Lee et al., 2013). Considering the current world population at about 7 billion, the total SCI number ranges from 1.65 to 7.06 million worldwide. Unfortunately, the incidence of SCI is not registered in most countries (Cripps et al., 2011). In the United States, 10,000 to 12,000 new injuries occur every year (according to NIH, US department of Health and Human Services, 2012); in China, this number is much larger; over 60,000 new injuries are added each year (Qiu, 2009). It is also estimated that currently 12,000 Australians are living with spinal cord injuries, while 350-400 new cases are added each year (O'Connor, 2005.

The world report on disability (WHO, 2011) stated that the average lifetime cost is estimated to be $5 million for paraplegia and $9.5 million for quadriplegia per incidence. At the same time, in the USA, the average lifetime cost of patients with SCI is estimated to be around $9.7 million, and

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the annual medical cost ranges from $15,000 to $30,000 per year (French et al., 2007). In contrast, the total lifetime cost for SCI is very high in Australia compared to other countries; it's estimated to be $2 billion (AUD) per year (O'Donnell et al., 2009, Collie et al., 2010).

According to statistics, among all spinal cord injuries, roughly half of the patients are paraplegics (Mirahmadi et al., 1982). It is also found that these patients prefer restoration of walking as one of the top priorities among all other complications such as pressure sores, inability of temperature and blood pressure regulation, and loss of bladder and bowel control (Anderson, 2004). Furthermore, sexual function is frequently impaired or lost with SCI (Benevento and Sipski, 2002). Hence, it is very important to find out the solution to "cure paralysis".

Unfortunately, there is no complete cure for SCI at the moment (Thuret et al., 2006). However, physical rehabilitation following SCI aims to restore sensorimotor functions of these individuals so that they are able to become independent in their daily activities. There are two main strategies to accomplish this; one is functional recovery and the other comprises compensatory strategies. These strategies are used during an individual's rehabilitation program. The recovery strategies are dependent on several factors including severity of the injury, level of the lesion, resource availability, level of family and community support, and clinical practice guidelines developed by physiotherapists and physicians. In cases of severe or complete paraplegia, daily activities like transferring body weight from one place to another (such as from bed to wheelchair or car) are typically accomplished using compensatory strategies, such as focusing on strengthening and utilizing unaffected arms and hands. Less severe or incomplete injuries offer a greater chance of recovery of functions, thereby warranting the use of functional recovery strategies (Harkema et al., 2012). In this chapter, we are going to discuss available therapies for the rehabilitation of paraplegic patients, and a new neuroprosthetic approach for restoring walking after complete SCI.

Background

SCI usually occurs due to a contusion on the spinal cord resulting from a traumatic fracture or dislocated vertebra (Quencer and Hawighorst, 2001, Kreykes and Letton, 2010, Parizel et al., 2010, Wilne and Walker, 2010). This is mainly from motor vehicle accidents, falls (especially elderly), sports injuries, work related accidents, violence like stabs or gunshots etc. SCI also can occur due to non-traumatic diseases such as cancer, infection, intervertebral disc disease, etc. The rate of SCI is over four times higher in men than women (Shackelford et al., 1998).

Paralysis following SCI can completely disrupt the neural communication from the brain to the body resulting in disability of movements and sensation. For the incomplete injuries, some sensorimotor functions may be retained and improved by extensive physical rehabilitation. However, this intervention fails to restore any function for the motor complete injuries (Tansey, 2010).

The first edition of International Standards of Neurological and Functional Classification of spinal cord Injury (ISNCSCI) was published in 1982 by The American Spinal Cord Injury Association (ASIA). Nowadays, the ISNCSCI 6^{th} edition is widely used to identify motor and sensory impairment following the injury. According to the neurological assessment of ISNCSCI, ten key muscles and key sensory points of touch and pinprick are to be tested in each dermatome on each side of the body (Thuret et al., 2006). A complete classification of SCI is illustrated in Figure 1 (adapted from Thuret et al., 2006).

Although locomotion such as walking seems to be a simple repetitive motor activity, the neural

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