BioMechanical Orthotic Knee Joint for Exoskeletons Thesis

Alex Tacescu

Masters Thesis in Robotics Engineering
Robotics Engineering Department
Worcester Polytechnic Institute

May 2021

Contents

List of Figures

List of Tables

Abstract

Chapter 1

Introduction

test

Chapter 2

Background

2.1 Paraplegia and Rehabilitation

Paraplegia is a medical term used to define where a patient loses feeling and/or movement in their lower two limbs. In comparison, quadriplegia (also sometimes known as tetraplegia) is the loss of control in all four limbs. It is important to note that not all feeling/movement needs to be lost in order for someone to be considered paraplegic [2]. Only 30% of all paraplegic and quadriplegic patients are considered complete lesions, where there is no sensation and no mobility in the lower limbs [6].

Paralysis is usually caused by trauma, such as sports injuries, vehicle accidents, or accidental falls, when the spine gets injured (see Figure 2.1). However, it can also be caused by specific diseases, including multiple sclerosis, amyotrophic lateral sclerosis, stroke, and in specific cases cancer [9]. Common effects of paraplegia include:

- Loss of mobility, reflexes, and sensation
- Muscular weakness and atrophy
- Hormonal variations
- Gastrointestinal and bowel/bladder problems
- Muscle spasms
- Reduced cardiorespiratory fitness and increased likelihood of cardiorespiratory issues

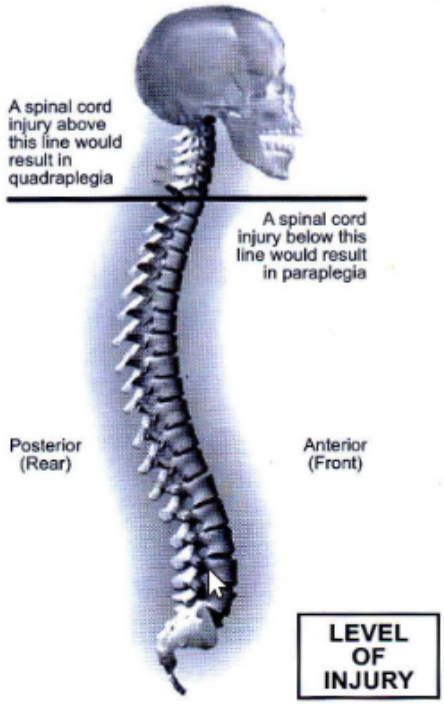

Figure 2.1: Location of spinal chord injury will determine type of paralysis [6]

Rehabilitation can play a key role in reducing these side effects in patients who experience paraplegia. Mainly, physical therapy for paralysis patients focus on three main types of exercises: stretching, strengthening, and aerobic. Additionally, paralysis patients may go through gait training with the assistance of medical devices.

2.1.1 Physical Therapy for Paralysis Patients

Stretching

Stretching is considered one of the most important exercises [6], more-so than any other form of exercise because it can be done often and at home. Carefully designed exercises (like seen in Figure 2.2) can improve flexibility, reduce muscle spasms, reduce the chance of injury, and relieve contractures [8] [5] [10]. Some common stretches include bilateral adductor stretches, quadriceps stretches, and hip flexor stretches.

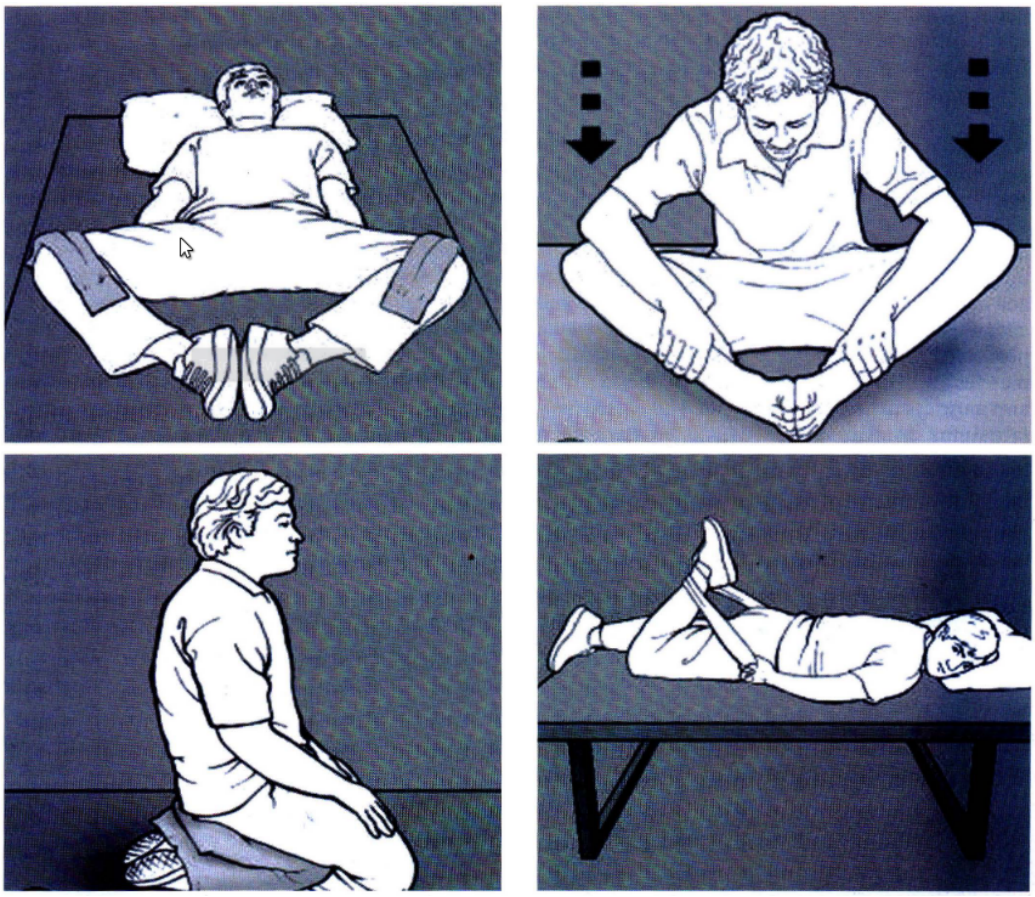

Figure 2.2: Bilateral Adductor Stretches (top) and Quadriceps Stretches (bottom) for paraplegic and quadriplegic patients [6]

Cardiorespiratory and Cardiovascular Training

Due to the difficulty of exercise, cardiovascular and cardiorespiratory activities are also very important to maintain health in paralysis patients. Aerobic exercises can increase energy levels, improve lung and heart function, control body weight, and reduce fatigue [6] [3]. A study showed that patients who suffer from neuromuscular deficiencies such as paraplegia suffered decreasing VO_2 max compared to control subjects with no issues [3]. VO_2 max a common metric that measures the maximum rate of oxygen utilization during heavy exercise. Combination of the upper body and lower body in paraplegic patients can strengthen the paralyzed

limbs while also activating healthy limbs. Some researchers have even proposed introducing wheelchair racing as a sport in an effort to help with rehabilitation after paraplegia [7].

Strength Training

Improving strength in muscles may actually partially reverse the loss of mobility in partially paralyzed patients, while also improving muscle tone [3] and preventing bone atrophy [8]. This type of exercise can be split into two major regions: training of affected limbs and muscles, and the training of non-affected regions. Affected limbs can benefit from an increase in mobility and definition, and can generally reduce the likelihood of muscular atrophy. Additionally, strong hip and leg muscles in partially paraplegic patients can help in gait training and increase the possibility of usage in life. On the other side, increasing or maintaining strength in unaffected regions can help with quality of life improvement. Often, paraplegic patients may elect to use crutches or canes as an assisted mobility device in the real world. Increasing arm/shoulder strength and endurance will also increase capability for patients to use some of these assisted devices. Finally, back and abdomen muscles are very important to strengthen to maintain posture and improve gait performance [1].

Hydrotherapy

Hydrotherapy (exercising in water) is a notable way for patients suffering from paraplegia to better strengthen muscles and improve cardiovascular health. Due to similar buoyancy, water can reduce the effects of gravity without any external assistive devices. At the same time, the increased density of the water (in comparison to air) creates a natural resistance without the use of weights or elastics. Therefore, hydrotherapy is used in paraplegic patients to increase muscle power, increase endurance, and even help with gait training (see subsection 2.1.2). In minor cases of paralysis, some patients even use swimming as a way to exercise [6] [11].

2.1.2 Gait Training

Gait training has become the best way to improve motor functions in those who have partially or fully lost mobility in their legs and torso. The premise of this exercise is to have patients do similar movements to what one would do without

their disability, like walking and climbing stairs. Essentially, the goal is to help the patient relearn the gaits they previously knew. Spinal neuronal circuits degrade quickly - in just a year, they can lose most of their potency, essentially unlearning any gait abilities the patient had in the past [4] [6] [1]. Gait training can help reconnect the broken spinal neurons, and improve motor function and balance in a patient. In fact, several studies have show that some patients with full spinal chord injuries have been able to recover part or even all of their walking capabilities through gait training [4] [12]! [1]

Since most patients suffering from paralysis won't be able to hold themselves up, there have been many different proposals to compensate for gravity. At lower levels of paralysis

Use of Assistive Devices for Gait Training

2.2 Robotics for Paraplegia Rehabilitation

2.3 Previous work on Exoskeleton Orthosis

Exoskeletons are an interesting application to help those with walking disabilities rehabilitate and exercise their muscles.

2.3.1 Rewalk

2.3.2 Esko

2.3.3 Indigo

2.4 WPI LARRE Exoskeleton

2.5 Research in the Human Knee Joint

2.5.1 Active Human Knee Orthosis

[1] There is significant research in the benefits of gait training for paraplegic and quadriplegic patients. Not all prior work is cited here.

References

[1] A. Bjerkefors, M. Carpenter, A. Cresswell, and A. Thorstensson, "Trunk muscle activation in a person with clinically complete thoracic spinal cord injury," *Journal of rehabilitation medicine : official journal of the UEMS European Board of Physical and Rehabilitation Medicine*, vol. 41, pp. 390–2, May 2009. DOI: 10.2340/16501977-0336.

[2] A. Bosch, "Incomplete traumatic quadriplegia. a ten-year review," *JAMA: The Journal of the American Medical Association*, vol. 216, no. 3, pp. 473–478, 1971. DOI: 10.1001/jama.216.3.473.

[3] M. M. B. S. D Wrisley, "Aerobic capacity in early paraplegia: Implications for rehabilitation," *Spinal Cord*, vol. 27, no. 4, pp. 261–268, 1989. DOI: https://doi.org/10.1038/sc.1989.39.

[4] V. Dietz, "Body weight supported gait training: From laboratory to clinical setting," *Brain Research Bulletin*, vol. 76, no. 5, pp. 459–463, 2008, ISSN: 0361-9230. DOI: https://doi.org/10.1016/j.brainresbull.2008.02.034. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0361923008001111.

[5] L. Harvey, R. Herbert, and J. Crosbie, "Does stretching induce lasting increases in joint rom? a systematic review.," *Physiotherapy research international : the journal for researchers and clinicians in physical therapy*, vol. 7 1, pp. 1–13, 2002.

[6] F. Ishaque and M. Shamim, "Rehabilitation of paraplegia," *J. Baqai Medical University Health Science*, vol. 11, no. 1, pp. 23–29, Jun. 2008. [Online]. Available: https://applications.emro.who.int/imemrf/Baqai_J_Health_Sci/Baqai_J_Health_Sci_2008_11_1_23_29.pdf.

[7] J. Madorsky and A. Madorsky, "Wheelchair racing: An important modality in acute rehabilitation after paraplegia," *Archives of physical medicine and rehabilitation*, vol. 64, no. 4, pp. 186–187, Apr. 1983, ISSN: 0003-9993. [Online]. Available: http://europepmc.org/abstract/MED/6838349.

[8] I. Odéen and E. Knutsson, "Evaluation of the effects of muscle stretch and weight load in patients with spastic paraplegia," *Scandinavian journal of rehabilitation medicine*, vol. 13, no. 4, pp. 117–121, 1981, ISSN: 0036-5505. [Online]. Available: http://europepmc.org/abstract/MED/7347432.

[9] *Quadriplegia and paraplegia*. [Online]. Available: https://www.winchesterhospital.org/health-library/article?id=96908.

[10] *Spinal cord injury: Flexibility exercises*. [Online]. Available: https://www.uofmhealth.org/health-library/ug2762.

[11] Terry J. EllapenHenriette V. HammillMariette SwanepoelGert L. Strydom, "The benefits of hydrotherapy to patients with spinal cord injuries," *African Journal of Disability*, vol. 7, no. 0, 2018. DOI: 10.4102/ajod.v7i0.450.

[12] L. van de Venis, B. P. C. van de Warrenburg, V. Weerdesteyn, B. J. H. van Lith, A. C. H. Geurts, and J. Nonnekes, "Improving gait adaptability in patients with hereditary spastic paraplegia," *Trials*, vol. 22, no. 32, 2021.