The Effect of Using Robotic Lower Limb to Improve Endurance in Spinal Cord Injury: Literature Review

Aditya Denny Pratama[1], Aulya Sabilla[2], Mita Noviana[3], Iman Santoso[4]

[1-4]Physiotherapy Study Program, Vocational Education Program, Universitas Indonesia
pratama.aditya@ui.ac.id

Abstract. The incidence of spinal cord injury is 90% due to traumatic causes, with traffic accidents being the leading cause, and falls being the second most common cause. Spinal cord injury occurs due to external physical trauma that damages the spinal cord or non-traumatic due to disease processes. Complications that occur are total or partial loss of locomotor function which can result in decreased endurance. One of the rehabilitation programs to restore endurance and walking function is by using robotic lower limb or exoskeleton robot. The purpose of this study was to explain the effect of using robotic lower limb to increase endurance in spinal cord injury cases. This research is a literature review study in narrative form, where 5 articles were reviewed after searching and selecting four databases. The review found a total of 83 subjects with a diagnosis of spinal cord injury aged 15 - 75 years were given intervention using robotic lower limb with a frequency of 5 times per week with a duration of 30 - 60 minutes. After the intervention was carried out for 2 - 8 weeks, analysis of evaluation data found an increase in the ability to walk distance, and walking speed through assessment with 6MWT and 10MWT, so that it can be concluded that the provision of lower limb robotics is effective in increasing endurance in SCI patients..

Keywords: endurance, spinal cord injury, robotic lower limb

1 Introduction

Traffic accidents, falls, and acts of violence are the most common causes of spinal cord injury [1]. Spinal Cord Injury (SCI) is an injury to the spinal cord due to trauma or non-trauma that results in neurological disorders including motor, sensory, and autonomic functions [2]. Spinal cord injury can occur due to external physical trauma that damages the spinal cord. Total or partial loss of locomotor function is one of the main consequences of spinal cord injury. Therefore, restoring walking function is one of the goals in rehabilitating patients with spinal cord injuries [3].

Every year it is estimated that 40-80 cases per one million population, around 250,000 to 500,000 people have experienced spinal cord injury. 90% of the highest incidence of SCI is caused by traumatic caused. Men are most at risk between 20-29 years of age and over 70 years, while women are most at risk between 15-19 years and over 60 years old [4].

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To achieve functional walking, patients not only muscle strength and innervation but also good endurance and minimal fatigue [5]. One of the rehabilitation programs to increase endurance and restore walking function is using a robotic lower limb or exoskeleton robot. Along with the times, technological developments also affect the health sector. One of them is the development of robotic lower limb technology for SCI patients. The lower limb exoskeleton robot is a rehabilitation tool for paraplegia sufferers by allowing sufferers to walk. This robotics can increase independence, mobility, and quality of life. In addition, it can reduce complications of prolonged wheelchair use (such as pain, decubitus wounds, and decreased bone density) [6]. Providing lower limb robot intervention is expected to increase endurance for people with spinal cord injuries.

Based on the above background, on this occasion the author will discuss a literature review entitled "The Effect of Using Robotic Lower Limb to Improve Endurance in Spinal Cord Injury". The purpose of this study is to explain the effect of using robotic lower limb to increase endurance in cases of spinal cord injury.

2 Literature Review

Spinal Cord Injury (SCI) is an injury to the spinal cord due to trauma or non-trauma that results in neurological disorders including motor, sensory, and autonomic functions [2]. Traumatic injury is the most common cause of SCI, namely due to traffic accidents, falls, and acts of violence, while non-traumatic injuries can be caused by pathologies such as stenosis of the spine, inflammation of the spine, or suppression by abscesses [1]. SCI sufferers will experience changes in physical, psychological, social interactions, and inhibited daily activities [7].

Endurance is the physical capacity to do a job for a long time. Endurance has two different types [8]:

1. Cardiorespiratory endurance
   Cardiorespiratory endurance or aerobic endurance is the ability of the heart, lungs, and blood vessels to effectively work continuously to deliver oxygen involving contractions of large muscle groups for a long time while doing physical activity [9][10].
2. Muscular endurance
   Muscular endurance is the ability of a single muscle or muscle group to contract continuously for a long time [8][9].

Anatomy and Physiology

1. Spine
   The spine has an important role in the anatomy of the human body. The spine plays a role in protecting the spinal cord and spinal nerves, supporting body weight, maintaining upright posture, attaching the ribs, and supporting body movement [11]. There are 33 vertebrae that extend from the base of the skull to the tailbone which are divided into 5 segments, namely 7 cervical bones, 12 thoracic bones, 5

lumbar bones, 5 sacrum bones, and 4 vertebrae that merge to 1 small bone called the coccygeal / tailbone [11][12].

In the spine there is cartilage tissue called intervertebral discs located between the vertebrae which function to maintain the flexibility of the spine and as a shock absorber. In the middle of the intervertebral disc there is a nucleus pulposus and around it there is anulus fibrosus, a structure like a ring consisting of collagen fibers and fibrocartilage. Each vertebrae has a gap that functions as a pathway for nerves to enter or exit to or from the spinal cord called the intervertebral foramen [11].

Figure 1. Spine Structure

2. Spinal Cord
   The medulla spinalis or spinal cord and brain is part of the central nervous system. This structure has a length of 45 cm (18 inches) and a centerline of 2 cm which starts from the inferior medulla of the brain stem above the C1 vertebra and ends at the L1-L2 vertebrae, where it will taper called the conus terminale or conus medullaris. Underneath the conus medullaris is connective tissue called the filum terminale. The spinal cord exits an opening at the base of the skull called the foramen magnum. Delivering sensory, motor, and autonomic messages between the brain and the rest of the body is the main function of the spinal cord [13][14]. The spinal cord is protected by meningen; from the deepest layer to the outermost layer is the pia mater, arachnoid, and duramater because it contains nerves that if damaged cannot be replaced [15].

Humans have 31 pairs of spinal nerves that leave the vertebral column through a gap called the intervertebral foramen. The spinal nerves consist of 8 pairs of cervical nerves, 12 pairs of thoracic nerves, 5 pairs of lumbar nerves, 5 pairs of sacrum nerves, and 1 pair of coxisegal nerves. Lumbar and sacrum nerves will be gathered called cauda equina.[16] Each spinal nerve carries sensory fibers from certain parts of the body surface called dermatomes. Dermatomes can help clinicians determine the lesion level involving sensation in the nervous system [13].

The structure of the spinal cord consists of 2 different areas, namely the inner gray matter and the white matter area that surrounds it. Gray matter is shaped like the letter "H" or butterfly containing nerve cell bodies, glia, dendrites, unmyelinated axons, and terminal axons of neurons. The gray matter is divided into the dorsal (posterior) cornu which is where afferent neurons end, the ventral (anterior) cornu contains cell bodies of efferent motor neurons that innervate skeletal muscles, and the lateral cornu is autonomic nerve fibers that innervate cardiac muscle and smooth muscle [14]. White matter is structured to form tracts, which are nerve fibers along the cord carrying different types of information. The tractus ascendens carry sensory information from the spinal cord to the brain (afferent), while the descending tract conveys motor information from the brain to the spinal cord (efferent) [14].

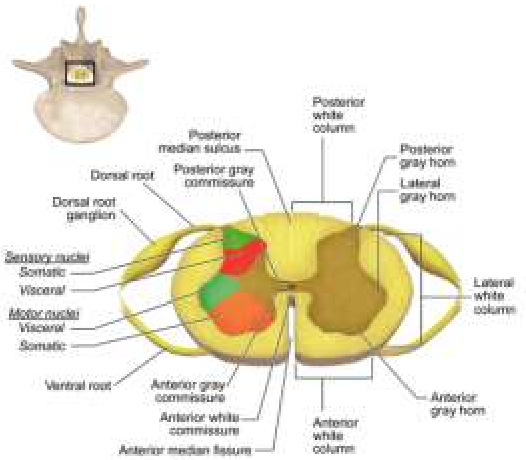

Figure 2. Spinal Cord Structure

Epidemiology

According to WHO (2013), approximately 40-80 cases per one million population, or around 250,000 to 500,000 patients has experienced spinal cord injury. The incidence of SCI is mostly caused by traumatic causes, which is 90%, although the proportion of non-traumatic causes continues to increase [4].

The prevalence of SCI cases is highest at 906 per one million in the United States and lowest at 250 per one million in Rhone-Alpes, France [17]. Spinal cord injury affects 8 million people in Indonesia, with 46.2% due to traffic injuries causing 25% of deaths, 45% of permanent disabilities, and up to 10% of emotional disorders such as depression [18]. Men are most at risk at ages 20-29 years and over 70 years, while women are most at risk at ages 15-19 years and over 60 years [4].

Etiology

Spinal Cord Injury can be differentiated by traumatic and non-traumatic.

1. Traumatic
   Traumatic SCI occurs when there is external physical trauma that damages the spinal cord. Traffic accidents are the most common traumatic case, and falls are the second most common cause [19]. Falls from height are the most common traumatic event. This is because in developed countries the elderly population is increasing so it usually occurs in low falls (falls with a height of < 1 meter) and in developing countries it is caused by falls from heights or high falls which reflect the uneven safety standards. Other traumatic causes are accidents due to work and recreation, sports, and violence [2].
2. Non traumatic
   The causes of non-traumatic SCI can be categorized into congenital (spinal dysraphism, and bone malformations), genetic disorders (hereditary spastic paraparesis, spinocerebellar ataxia, adrenomyeloneuropathy, leukodystrophy, and spinal muscular atrophy), degenerative disorders of the spine, metabolic disorders, vascular disorders, inflammatory/autoimmune diseases [20].

Classification

Based on severity, SCI can be divided into complete and incomplete injuries. A complete injury is a neurological function disorder where the patient loses sensation and motor function below the level of the lesion. Meanwhile, incomplete injury is a decrease in neurological function both motor and sensory below the level of the lesion so that it still functions but cannot perform optimally [2].

Classification according to the American Spinal Injury Association (ASIA), which is currently used as the international standard for SCI severity assessment [2][21]:

1. ASIA A (Complete): Loss of motor and sensory function in sacral segments S4-S5.
2. ASIA B (incomplete): Impaired motor function below the lesion (including the S4-S5 segment), but still has sensory function.
3. ASIA C (incomplete): Motor function below the neurological level is still functional and has a muscle score of less than 3.
4. ASIA D (incomplete): Motor function below the neurological level is functional and at least half of the major muscle function below the level of injury has a muscle score ≥ 3
5. ASIA E (incomplete): Normal motor and sensory function

Injury level symptoms

Symptoms that arise based on the level of injury [22]:

1. Level C2 – C3: Damage to diaphragmatic breathing
2. Level C4: Quadriplegia with impaired innervation of the diaphragm and chest wall muscles leading to difficulty in breathing
3. Level C5: Quadriplegia with some function in the shoulder and elbow. Difficulty breathing due to impaired innervation of the diaphragm and chest wall muscles.
4. Level C6: Quadriplegia with some function in the shoulder, elbow, and wrist. Difficulty breathing due to impaired innervation of the chest wall muscles.
5. Level C7: Quadriplegia with some function in the shoulder, elbow, and wrist, but poor hand function (usually only finger extension).
6. Level C8: Quadriplegia with normal arm function but weakness in the hand
7. Level T1 – T6: Paraplegia with loss of function starting from the center of the chest but still able to control the arm
8. Level T7 – T12: Paraplegia with loss of function from the hip and little control of the trunk.
9. Level L1 – L5: Paraplegia of the legs

Pathophysiology

The mechanism of spinal cord injury consists of primary injury and secondary injury.

1. Primary injury

   Primary injury is an initial injury due to sudden trauma resulting in failure of the biomechanical structure of the spine [2]. The injury causes deep wounds, strains or tears in the nervous tissue and blood vessels due to compression, flexion, extension, dislocation or distraction of the bones. In addition, the bone structure due to compression causes hematoma in the spinal cord [16].

   In the initial phase, there will be bleeding and in the next phase in the blood vessels there will be a disturbance of blood flow. This results in hypoxia and infraction in the surrounding area and damage to the substantia grisea [16]. Neuron cells will be damaged and disruption of intracellular processes results in reduced thickness of the myelin sheath so that nerve transmission is disrupted. Another factor causing decreased nerve transmission is the emergence of edema and macrophages due to the inflammatory process [16][23].

2. Secondary injury

   Secondary injury is triggered by the primary injury resulting in further chemical and mechanical damage to the spinal tissue causing excitotoxicity of the nerves due to calcium accumulation in the cells, as well as increasing reactive oxygen concentrations and glutamate levels. This damages the nucleic acids, proteins and phospholipids of the cells resulting in neurological dysfunction [24].

Risk Factors

The risk factors for someone getting a spinal cord injury include [25]:

1. Age and Gender
   Men are at higher risk of SCI compared to women. Men aged between 16 to 30 years and over 65 years are more at risk of SCI. Those aged 16 to 30 years are more likely to suffer SCI due to motor vehicle accidents. While in the age group above 65 years, falls are the main cause.
2. Risky actions
   Not using the right equipment for a particular activity is a dangerous action that can lead to injury. Examples of such actions are driving without a seat belt, and cycling or motorcycling without a helmet. Acts of violence account for 15% of SCIs.

Clinical Manifestations

The severity and location of the injury is a factor in the emergence of different spinal cord injury symptoms characterized by partial or complete loss of sensory function or motor control of the arms, legs, and/or body.

Patients with SCI may experience one or more symptoms. Symptoms that can occur include [26]:

1. Numbness, tingling, or changes in sensation in the hands and feet
2. Pain in the head, neck, or back
3. Weakness or loss of ability to function in body movements
4. Dysfunction of bladder control, bowel control, and sexual function
5. Walking impairment
6. Difficulty breathing

Prognosis

The prognosis of spinal cord injury varies depending on the neurologic level of injury, severity (complete or incomplete injury, ASIA scale), and patient-specific factors (age, past medical history/comorbidity, secondary complications, motivation and psychosocial well-being) [27]. Complete spinal cord injury generally has a poor prognosis. Patients will have persistent neurologic deficits and/or disability if there is no improvement within the first 72 hours. It is likely that >50% of incomplete spinal cord injury patients can return to walking if sensory function below the lesion is not impaired [2]. Ambulation or the ability to walk independently in the community, with or without the use of tools and supports is one of the goals of patient recovery after experiencing SCI. The level of injury and the ASIA scale are factors that determine the prognosis of functional recovery [28].

ASIA A has a very low possibility of achieving functional walking ability [29]. ASIA A patients in cervical lesions are unable to return to walking, whereas, in thoracic and lumbar lesions, 8% of patients can ambulate with assistive devices but with slow average speed and large energy expenditure [28][29]. ASIA B patients show some motor recovery and may transition to ASIA C or ASIA D. In ASIA C patients, age is a factor in walking recovery. Patients with age <50 years have a chance of achieving functional walking of 80-90%, and the percentage at age >50 years decreases to 30-40%. The prognosis for ambulation in ASIA D is good at 1 year post-injury [29].

Physiotherapy Diagnosis

The diagnosis of SCI is made with a complete anamnesis, neurological physical examination, and supporting examination. Physical examination includes motor function based on the Medical Research Council scale, sensory function, and tendon reflexes [16].
Physiotherapy diagnosis in cases of spinal cord injury consists of:

1. Impairment: spasticity, muscle weakness, abnormal posture, and abnormal gait.
2. Functional Limitation: difficulty in functional activities such as transfer and ambulation.
3. Participation Restriction: difficulty socializing and working.
4. Environmental Factor: getting support and family, the use of assistive devices to support functional activities.
5. Personal Factors: age

Diagnostic Imaging Test

Trauma patients are considered to have a spinal cord injury if there are complaints of pain in the vertebral region, radicular pain, paralysis, numbness, and or impaired urinary function until the diagnosis has been made [30]. Diagnostic imaging test include Magnetic Resonance Imaging (MRI) is used to determine the severity of the injury by producing details of tissues, organs, bones, and nerves, Computerized Tomography (CT) provides images of organs, bones, and tissues and can detect bleeding, fractures, and spinal stenosis, and X-rays which are rapid screening tools to see obvious spinal fractures or dislocations [22][26].

Outcome Measure

The parameters used to assess endurance and walking ability were the Six Minute Walk Test (6MWT) and the Ten Meter Walk Test (10mWT). The Six Minute Walk Test (6MWT) is a test used to assess walking endurance and aerobic capacity. In this test the patient will be assessed for the ability to walk for 6 minutes on a flat and hard surface. The patient is allowed to rest for a moment if any discomfort arises, but the time will continue to run and the examiner records the number of breaks taken as well as the total rest time. In addition, the patient is allowed to use a walking assist device and the type of assist device must be documented [31][32].

During the test, the examiner is not allowed to walk in front of or beside the patient as it may affect the patient's walking speed. The examiner should walk at least half a step behind the patient. Before and after the test, the examiner should record the patient's vital signs such as heart rate, blood pressure, oxygen level, and borg scale [31]. The absolute contraindications of 6MWT recommended by the American Thoracic Society are a history of unstable angina and myocardial infarction in the past month and relative contraindications include blood pressure ≥180/100 mmHg and resting heart rate >120x/min [32]. The scoring in this test is the distance walked by the patient in 6 minutes, measured in meters and can be rounded to the nearest decimal [31].

Ten Meter Walk Test is a test to assess walking speed in meters per second (m/s) on a flat surface [33]. The test measurement is taken on a flat road at a normal walking speed or fast walking, then walking time and the number of steps taken will be measured [34]. This test can be used as an indicator to determine changes in the endurance of the patient's walking ability after receiving rehabilitation and estimate the patient's mobility in the community [35][36].

The patient is instructed to walk on a 14-meter track. Before the test was performed, the examiner marked the 2-meter and 12-meter distance track to eliminate the effects of acceleration and deceleration. The time will start when the participant starts the step at the 2-meter marker and ends when the foot passes the 12-meter marker.[36] The test was conducted twice and the walking speed results were calculated by dividing the average distance walked in meters (m) by the average time (s) [37].

Intervention

The lower limb exoskeleton robot is a rehabilitation tool for paraplegia patients with allowing the sufferer to walk. Generally operated by a trained physiotherapist or trained patient [38]. The benefits of using this robotics include increasing muscle strength, increasing walking speed and efficiency, increasing independence, mobility, and improving mood and mental conditions which will have an impact on quality of life. In addition, it can reduce the complications of prolonged wheelchair use and secondary complications such as spasticity, pain, pressure sores, decreased bone density, cardiovascular changes and bladder function [6].

In general, there are several conditions for patients who can use this device, such as [39][40]:

1. Have a healthy bone density
2. No fractures
3. Hands and shoulders can support crutches
4. Able to stand using a device such as a walker
5. In good general health
6. Weight not more than 113 kg

The exoskeleton device uses a battery supply, as well as a brace that is placed on the paralyzed or weak limbs to facilitate standing, walking, climbing stairs and performing daily activities [6]. The recommended exercise dose in this robotic use for energy improvement is 150 minutes per week of moderate effort or 75 minutes per week of intense effort [41]. There are currently many exoskeleton devices on the market, but only 3 devices have been approved by the U.S. Food and Drug Administration and tested in different environments and according to the criteria for SCI. However, some devices are currently being developed and used in trials. The following robotic exoskeletons are approved for rehabilitation by the Food and Drug Administration [42]:

1. Indego, can be used in the community with injury levels T3 - L5, and in rehabilitation facilities with injury levels C7 - L5
2. Ekso, can be used in rehabilitation facilities with injury level T4 - L5 ASIA A - D
3. ReWalk, can be used in communities with injury levels T7 - L5, and in rehabilitation facilities with injury levels T4 - L5.

Figure 3. Robotic Lower Limb

Some of the types of lower limb exoskeleton robots that are used are:

1. AIDER (AssItive DEvice for paRalyzed patient)
   AIDER (AssItive DEvice for paRalyzed patient) is an exoskeleton developed by the Center for Robotics, University of Electronic Science and Technology of China in 2015 [43]. This device consists of batteries, crutches, and components of the hip, thigh, calf, and sole parts [35]. This device consists of batteries, crutches, and components of the hip, thigh, calf, and sole parts [35]. To control movement, the user uses buttons on the crutches and body posture. The right button controls walking or stopping, and the left button controls walking speed. Pressing both buttons for more than two seconds for sitting or standing position. To change the speed, press the left button once to slow down and twice to speed up. If the user stands in front of the stairs and leans the upper body forward, the frame will rise upwards. When there is an obstacle, lean forward to pass it, and lean right to pass it from the right [43].
2. Indego
   Indego consists of five components, which are, the hip segment, the right and left upper leg segments, and the right and left lower leg segments. The device features a carbon fiber Ankle-Foot Orthosis (AFO) that provides ankle stability. This tool weighs about 12 kg and is used in connection with an Apple iPod Touch via Bluetooth connection for data access. It uses sensors that are received through changes in the user's posture. Lean forward to start standing or walking, and lean back to stop or sit. Users also use a walker or crutches for stability when standing and walking [44].
3. Ekso
   Ekso is an exoskeleton to improve the ability to stand and walk in individuals with neurological disorders using battery power. To control Ekso using a remote control controlled by the therapist. The remote control is used to choose

between bilateral or unilateral assistance and to determine how each leg is moved and controlled [3].

3 Research Methods

This article uses the literature review method with a search period from February 2023 - May 2023. To expand and specify the search for articles or journals using keywords and Boolean operators (AND, OR NOT or AND NOT) to make it easier to determine the articles or journals used. The inclusion criteria in this study are: (1) Patients with a diagnosed spinal cord injury, (2) Intervention with robotic lower limb, (3) Endurance-related improvements, (4) Study design experimental study, cohort study, randomized controlled trial, (5) Articles or journals published after 2018, (6) Articles using English or Indonesian. Exclusion criteria include: (1) Patients who are not diagnosed with spinal cord injury, (2) Not using robotic lower limb as intervention, (3) Not evaluating endurance, (4) Expert opinion study design, systematic review, meta-analysis, literature review, (5) Articles or journals published below 2018, (6) Articles using languages other than English and Indonesian. The PICO framework is used as keywords in searching for articles, with the following details:

1. **Population**: spinal cord injury;
2. **Intervention**: robotic lower limb;
3. **Comparison**: none;
4. **Outcome**: endurance dan walking ability

In this literature review, a simplified approach was used to summarize and conclude articles to answer the literature review research questions. Stages that need to be done in the simplified approach method are: (1) summarize the journal or article, (2) identifying themes, (3) developing themes, (4) close supervision of themes, and (5) setting themes that do not support.

4 Result

Based on the results of a literature search through the online databases PubMed, ProQuest, Google Scholar, and Science Directde using the keywords "Spinal Cord injury OR Spinal Cord Injuries" AND "Lower Extremity Robot OR Robotic Lower Limb OR Exoskeleton Robot" AND "Endurance OR Walking Ability" the researcher obtained a total of 4,737 articles. After reading the titles and abstracts, 23 inclusion articles were obtained. Of the 23 articles found, further selection was carried out and 7 articles were found that matched the inclusion characteristics. Then, of the 7 articles further selected, 2 articles were excluded because they had weak strength for literature review and used undesirable outcomes. Then a critical appraisal is carried out on seven published journals so that the results of five journals will be synthesized. The article selection process is illustrated using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) flow chart. PRISMA Chart can be seen in Chart 1.

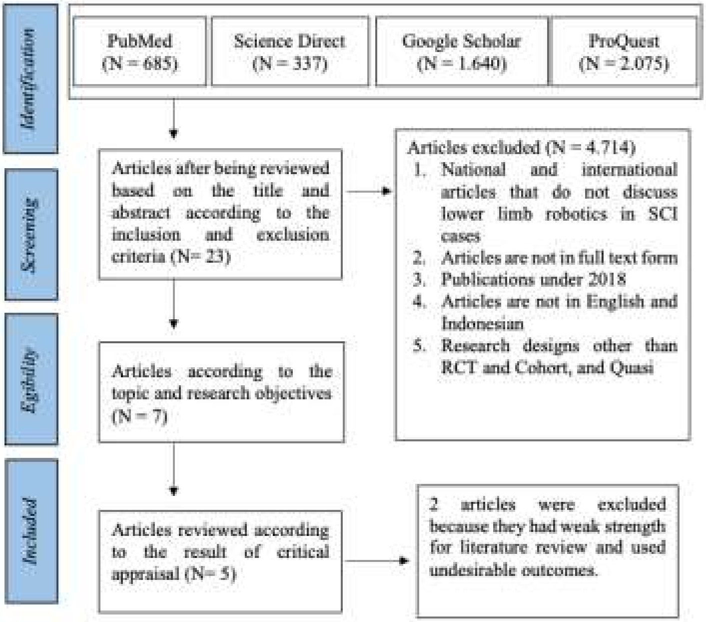

Chart 1. PRISMA Chart

The results of the article searches performed on the five studies in the experimental group and the control group can be seen in Table 1.

Table 1. Article Search Results

Author	Age	Experimental Group	Control Group	Research Results
Xiang et al	15 – 75 years old	Intervention with lower extremity exoskeleton robot. Exercise was given 5 times per week for 2 weeks at 30 minutes per day.	No intervention	Walking distance covered on the 6-min walking test (6MWT) during week 1 (13.0 ± 5.3 m) and week 2 (16.2 ± 5.3 m). Walking speed obtained from the 10-m walking test increased from 0.039 ± 0.016 to 0.045 ± 0.016 m/s.
Tefertiller et al	18 – 64 years old	Intervention with lower extremity exoskeleton robot. Exercise 3 times per week for 8 weeks.	No intervention	There was an increase in average walking speed from 0.31 m/s to 0.37 m/s. The average distance completed during 6MWT increased from 92.0 m to 107.5 m.
Bellitto et al	31 – 71 years old	Intervention with lower extremity exoskeleton robot. The exercises were given for 10 and 13 sessions.	No intervention	The results obtained in 6MWT in S1 from 86 m to 116 m, S2 from 66 m to 70 m, and S3 from 60 m to 112 m. There was a decrease in the time taken at 10MWT. S1 took time from 39 to 31 seconds, S2 from 53 to 44 seconds, S3 from 42 to 31 seconds.

Author	Age	Experimental Group	Control Group	Research Results
Bai et al	15 – 75 years old	Intervention with lower extremity exoskeleton robot. Exercise was given 5 times for 2 weeks with 30 minutes per session.	No intervention	Results showed an increase in walking distance at 6MWT, and a decrease in walking time at 10MWT after 2 weeks of training compared to after 1 week of training.
Gil-Agudo et al	16 – 70 years old	Intervention with lower extremity exoskeleton robot. The exercise consisted of 15 ambulation training sessions, 3 times each week for 5 weeks. The total duration was 1 hour, including 20 minutes to put on and take off the device, 30 minutes for gait training, 5 minutes of rest and 5 minutes to record the assessed variables.	Exercises with traditional gait training are mobilization, lower limb strengthening exercises and walking exercises using parallel bars. The training consisted of 15 sessions, 3 times per week for 5 weeks and 30 minutes per session,	Walking speed increased by 0.2 m/s in the experimental group and 0.1 m/s in the control group. At 6MWT, the experimental group had a higher increase in walking distance than the control group.

5 Discussion

Effect of Using Robotic Lower Limb to Increase Endurance in Spinal Cord Injury Cases

Based on the five articles reviewed, it can be seen that the application of robotic lower limb has an effect in increasing the endurance of spinal cord injury patients. In Xiang et al.'s research, 28 SCI patients who were given exercises using robotics found an increase in endurance as measured by 6MWT and 10MWT. The intervention was given for 2 weeks, 5 times per week with a duration of 30 minutes per day, and each session consisted of sitting, standing, and walking exercises with short rest periods. After two weeks of training, patients were able to walk more consistent distances than the first week and there was also an increase in walking speed [45].

The effect of robotic lower limbs on increasing endurance was also found in a study conducted by Tefertiller et al., on 32 SCI subjects. Exercises are given 24 sessions which are carried out 3 times per week for 8 weeks. All participants experienced an increase in walking speed at 10MWT and an increase in the distance traveled for 6MWT from the start of the evaluation to the end of the evaluation. The results of walking speed both indoors and outdoors were not significantly different. This suggests that participants walked as confidently in the community as they did in the rehabilitation room [44].

Another article researched by A. Bellitto et al. on 3 SCI subjects found an increase in walking time, the total number of steps, and distance walked. The training began with a 1-hour familiarization phase where subjects learned to shift their weight correctly in preparation for the initial robotic walking steps. After the familiarization phase, subjects were trained for 10 and 13 sessions (10 sessions in subject 1, 13 sessions in subject 2 and subject 3). The duration of training depended on the subject's fatigue and endurance. With this intervention, all subjects showed improved walking ability and endurance using the robotic device [3].

Similarly in the study of X. Bai et al., to 8 SCI patients. Exercise was given 5 times a meeting for 2 weeks with 30 minutes per session. There was an increase in walking distance at 6MWT, and a decrease in walking time at 10MWT after 2 weeks of training compared to after 1 week of training. Five patients were able to walk further on the 6MWT, and shorter walking time on the 10MWT after 2 weeks of training. Two patients had no significant change and one patient had a 6-minute decrease in walking distance and longer time when completing the 10MWT at week two compared to week one [35].

Another study was done by Gil-Agudo et al., on 23 SCI patients with 12 patients in the experimental group with robotic intervention and 11 patients in the control group who were given traditional gait training intervention. Both the experimental and control groups were given the same training duration consisting of 15 ambulation training sessions, 3 times each week for 5 weeks. After 5 weeks of training, there was an increase in endurance on the 6MWT. The experimental group had a higher improvement than the control group [46].

Increased endurance in the lower limb is measured by assessing walking ability, and walking speed. Loss of walking function is one of the consequences of spinal cord injury which results in decreased muscle strength, endurance, and functional ability. After SCI, factors that inhibit walking ability include muscle weakness, spasticity. In operating the robotic lower limb, the individual must shift their body weight in the direction they want and simultaneous movement of both crutches. Sensors on the device will then facilitate the movement of the legs. The use of robotics will make the user support their body weight on their lower limbs and active movement of both arms when using crtuches. During exercise, the weight-bearing lower limbs and the active contribution of the upper limbs including the trunk for weight transfer and dynamic balance control during robotic walking as well as the simultaneous movement of both crutches performed with elbow flexion movements will result in an increase in muscle strength as well as an increase in heart rate and oxygen consumption. With muscle activation and increased muscle strength, the adaptation of the cardiopulmonary system increases. The muscles use oxygen to keep working causing them to breathe harder so that the lungs can supply more oxygen. The heart beats faster to pump oxygen-rich blood to the muscles. The muscles use oxygen to generate the energy needed to keep moving. In addition, robot-assisted walking training has been shown to achieve moderate to severe levels of exercise intensity for individuals with spinal cord injuries. These submaximal training sessions can increase endurance. This will increase the cardiorespiratory endurance of people with spinal cord injury.

6 Conclusion

Based on a literature review of 5 research articles with a diagnosis of spinal cord injury aged 15 - 75 years given an intervention using robotic lower limb with a duration of 30 - 60 minutes for 2 - 8 weeks, it can be concluded that the provision of robotic lower limb is effective in increasing endurance in spinal cord injury patients measured by 6MWT and 10MWT parameters.

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