

# CERVICAL SPINAL CORD INJURY AND UPPER LIMB ROBOTIC THERAPY

## RESEARCH DISSERTATION

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## **Literature review**

As humans, how we interact with our environment is highly complex. We have an intricate system within our body which enables us to move, interpret information from our surroundings and perform interactions. Sustaining a spinal cord injury (SCI) impairs our capacity to execute such functions. This review of the literature surrounding SCI has been performed with the purpose of generating research using robotic devices for upper limb therapy among people who have sustained a SCI at the cervical level. Several data bases including Ebscohost, Medline, Cinahl and Scopus were searched using key words: spinal cord injury, cervical, upper limb, arm, therapy, rehabilitation, acute care. The following literature review will explore the functional implications of sustaining a cervical level SCI, current evidence surrounding the use of robotic devices in cervical SCI for upper limb therapy and the implications for occupational therapists working in this field.

### **Spinal cord injuries**

Sustaining a SCI is a debilitating and life-long injury. The spinal cord is a column of nerves which are responsible for communicating motor and sensory information between the persons brain and the rest of their body. This communication assists in determining how a person will interact with their environment. The spinal cord is surrounded by vertebra, which act as a protective mechanism to prevent damage to the collection of nerves in the spinal cord. At each level of vertebra, a branch of nerves leave the spinal cord which lead to a network of nerves which innervate the muscles and body systems in that area of the body. When the spinal cord is damaged, the muscles and body systems below that injury point are compromised, resulting in an impaired level of functioning. At the cervical level of the spinal cord, nerves are primarily innervating muscles of the shoulder and arm which make up the upper limb. Cervical nerves also innervate the diaphragm, therefore spinal cord injury at the cervical level, impairs function through a reduced capacity of the diaphragm, impacting breathing, and a reduced functional capacity of the upper limb (1).

A complete injury is a definite lesion of the spinal cord, resulting in no neural communication being carried below the lesion site, this type of injury is permanent and highly debilitating. Commonly the lower limbs are paralysed as a result of a complete injury, due to the nerves innervating the legs being located below the thoracic spine level resulting in the use of a wheelchair for mobilising (1). There is no cure for a complete SCI, therapy involves

compensatory techniques to overcome the loss of function. An incomplete injury is an indefinite lesion, where only a partial section of the spinal cord is damaged. Incomplete injuries have highly variable impacts on function which is dependent upon which section of the spinal cord is damaged, and how much of the cord is severed (1). Incomplete injuries have a greater recovery potential due to the remaining nerves which still have communication potential and a capacity to innervate muscle and bodily systems. For an incomplete injury, therapy aims to increase the capacity of the remaining neural pathways and innervated muscles through physical training, to compensate for the lost neural pathways.

The level of injury is assessed by a doctor using the American Spinal Injury Impairment (ASIA) scale which assists in categorising the level of function associated with the type of injury. There are five levels categorised by the scale (A-E) ranging from complete, incomplete sensory, incomplete motor and normal motor and sensory function (2). Having such a scale assists in determining the functional impacts and implications the SCI has on the patient, which can assist with focusing therapy towards the deficits and enhancing the remaining functions.

Cervical level SCI statistics in Australia demonstrate that the cervical region is the most common injury site, making up 64% of all traumatic SCI sustained. Males make up the majority of people experiencing a cervical level SCI (80%) and the greatest incidence rate is among people aged 15-24 years (3) (4). Injuries are commonly sustained through motor vehicle accidents, motorbike accidents, sports and water sport activities (5). The cost of SCI on the Australian economy has been estimated at 2 billion Australian dollars annually (5). This is as a result of the cost of acute care, surgery, extensive rehabilitation and ongoing medical and living expenses associated with having a disability. Furthermore, there is an indirect burden of cost associated with a loss of income for people who have sustained a SCI and reliance on the government for a disability pension. With the greatest incidence rate among youth, there is a lifetime ahead of them living with a disability in the community.

### **Impact on function**

Injury at the cervical level can be debilitating for everyday function with paralysis of lower limbs, trunk and has the potential to severely impair upper limb function. Loss of upper limb function has been reported as one of the most debilitating factors of sustaining a cervical level SCI due to the loss of independence and inability to interact with the environment that comes with upper limb use (6). With such debilitating effects as a result of impaired upper

limb function and often lower limb function, high levels of care and support are required for people to perform everyday tasks, resulting in a high reliance on carers and a loss of independence.

At the cervical level of the spinal cord, expected functions include innervating muscles move the upper limb, such as the shoulder and elbow joints. Finger and wrist function is also impacted by the cervical region of nerves (1). Low level cervical injuries (C7-8) impact fine motor skills of the fingers and wrist joint. Mid-level (C5-6)cervical injuries impair muscular function of the elbow and some of the muscles innervating the shoulder joint. High level cervical injuries(C3-4) impact shoulder function, breathing and movements of the head and neck. Cervical injuries at the first and second level are rare and are commonly fatal due to the autonomic regulation and functions impacted as a result of the injury (2).

Upper limb therapy is described in the literature as critical for an individual's wellbeing. Engaging in upper limb therapy results in an increased quality of life experienced by the patient as they have some capacity to interact with their physical and social environment. They also can experience increased independence to perform activities of daily living (ADLs), giving them a sense of control over their own life, as compared to depending on carers for support to meet their basic needs (7). These factors contribute to the increased importance of upper limb therapy forming a major component of rehabilitation for people who have sustained a SCI at the cervical level. With occupational therapy being focused towards performance of everyday tasks, therapy needs to be aimed towards building capacity to participate in everyday activities. The spinal cord does not have the capacity to repair itself after being damaged (8), therefore returning to everyday functioning is reliant upon occupational therapists performing functional skills training with people who have sustained a SCI. As previously discussed, the loss of upper limb function as a result of sustaining a cervical SCI is one of the most debilitating factors impacting quality of life. Increasing the level of knowledge pertaining to this issue can empower occupational therapists to advocate for more functional focused therapy, even in the acute phase.

Predicting recovery patterns for people who have sustained a cervical SCI is complex. The diagnosis of a complete or incomplete injury plays a large role in determining the functional outcomes, however incomplete injuries can be highly variable in how they impact motor and

sensory function. Generally for incomplete injuries, the greatest functional recovery in the upper limb occurs between one and twelve months post injury (9). For complete injuries, upper limb motor recovery shows the greatest improvement in the initial three months post injury (9), patients who demonstrate a small amount of muscular strength in baseline testing have greater outcomes with therapy. Through manual muscle testing, a baseline grade of 2/5 can progress to greater than 3/5 within two weeks of therapy, as compared with lower grades of zero or 1/5 which achieved the same results within three months of therapy (9).

Furthermore, Kirshblum & O'Connor emphasised that the greater recovery potential comes as a result of therapy commencing rapidly. Recently, the use of robotics has been emerging as a tool in upper limb therapy to increase muscular strength, achieved through the increased repetitions being performed in a shorter period of time. However, the efficacy of these devices is not certain within the SCI population. Furthermore, this therapy modality does not always correlate to everyday task performance.

### **Robotic devices as a therapy tool**

Robotic devices are emerging as a therapy modality due to their attributes which reduce therapist burden and provide an engaging component of therapy. Using robotic devices in therapy aims to prevent muscular atrophy, enhance coordination, develop motor patterns, and enhance function (10). Occupational therapists have been increasingly using robotics in their upper limb therapy due to their ability to produce a greater number of repetitions of movements in therapy sessions, as compared with traditional and human manipulation therapy (6). Increasing the volume of repetitions in therapy sessions targets increasing muscular strength and enhancing motor patterns, which can be achieved over short periods of time (11). This is a crucial factor in acute settings where robotics can be time efficient in delivering higher volumes of therapy in shorter time periods. Traditional therapy relies on the occupational therapist to manipulate the body to perform movements, and when performed intensely, creates a burden on the therapist. Without careful consideration, therapist fatigue may impact the accuracy and effectiveness of patient movements, which could be detrimental to therapy outcomes (7). The inclusion of robotic therapy in occupational therapy practice, reduces this burden and risk of ineffective therapy due to therapist related fatigue.

Robotics has also been explored as a more engaging therapy medium, particularly when coupled with a computer interface which allows the patient to play games. Providing therapy modalities where patients can interact and be an active participant in therapy, such as with

robotics where they are immersed in a game or activity, rather than therapist manipulation. This can provide the patient with a greater sense of control in their therapy and prove as more engaging therapy, in turn having greater outcomes due to the patient's active participation in physical therapy (12).

Feedback is a critical factor in learning. For task focused motor learning, feedback provides patients with an opportunity to recognise if the movement is successful in achieving the functional task, receiving such feedback reinforces movements which results in greater motor learning outcomes (12). Immediate feedback directed to the patient provides greater reinforcement and helps the patient understand what movements are required and successful to achieve the task. Furthermore, passive therapy with immediate and engaging feedback has been described as increasing motor learning for functional movements and consequently, improving upper limb use in everyday tasks. Therefore, robotic devices with a feedback system for the patient have the ability to enhance motor learning outcomes for functional tasks.

Research into robotic upper limb therapy is evident through neurological research, primarily pertaining to stroke rehabilitation. Literature has reported significant improvements in upper limb function in these populations as a result of robotic therapy (13). A case study in an acute rehabilitation setting for stroke patients concluded that robotic devices used in a high dose upper limb therapy program with occupational therapists, produced meaningful functional outcomes as per the Fugl-Meyer Assessment and Functional Independence Measure for patients which promoted their independence (14). The use of robotics in neuromotor-rehabilitation has been discussed in the literature as a positive form of therapy due to multisensory and sensorimotor modalities which have been described as potentially more engaging and motivating as compared with traditional therapist manipulated therapy (15). This potentially enhances patients attitude to participate in therapy as it is highly engaging, motivating and rewarding, resulting in greater therapy outcomes as patients increase their engagement in therapy.

### **Robotic devices in spinal cord injury therapy**

Looking at SCI as a single morbidity, the brain is still functioning in a capacity to plan movements, therefore aims of upper limb therapy relate to retraining the remaining neural pathways to complete motor patterns (1). As compared with stroke rehabilitation, SCI

therapy has a reduced focus on cognitive retraining of the brain. However, similarities can be seen through upper limb therapy adapting neural pathways and motor patterns in impaired upper limb function, with the aim of enhancing upper limb capacity and functional outcomes (16). Therefore, questions have been raised about the feasibility of robotic therapy in SCI populations to assist in retraining upper limb movement and subsequently, improve associated functional outcomes. Currently, there is limited literature determining the outcomes of using robotic devices with patients who have sustained a SCI, particularly cervical level injuries.

A single case-study exploring a patient's journey through rehabilitation after sustaining an incomplete C4 SCI, used a combination of traditional upper limb therapy and robotic therapy with an occupational therapist (17). The patient completed a 20 day rehabilitation program which commenced 26 days post-surgical intervention for the SCI. The patient participated in two hours of occupational therapy Monday-Friday, which was evenly split into an hour of ADL training and one hour using the robotic device. The robot used was a unilateral device, which supported and promoted movements for everyday function; such as elbow and shoulder flexion and extension. The device also featured five levels of resistance to support movement, ranging from full passive movement to full active movement of the patient. Primary outcome measures used were active range of motion, perceived upper limb function using the Capabilities of Upper Extremity Instrument, and the Functional Independence Measure. Secondary outcome measures included were muscular strength and sensation. The results showed an improvement in active range of motion of both the elbow and shoulder, improved independence in completing self-care tasks identified by the Functional Independence Measure, increased perceived improvement in upper limb function and improved muscular strength. Sensory function did not demonstrate any consistent changes as a result of the therapy. It was suggested that the combination of ADL training and robotic therapy, improved active range of motion and strength contributed to the increase in independence in completing ADLs. Such studies give promise to more robotic devices to assist in upper limb rehabilitation and support function in everyday tasks, however it is noted that a single case study has limitations relating to generalisation. More rigorous studies need to be completed in order to determine an appropriate therapy protocol for using robotics with traditional occupational therapy for SCI patients (17).



A pilot study explored the use of the ARMEO robotic device in upper limb therapy in a sub-acute context for cervical level SCI patients over a six week period. The device was described as an interactive and motivating tool, however it was a unilateral device and had limited the planes of motion in which the arm could be moved (18). Results demonstrated no significant findings, however it was concluded that using robotic devices is feasible in this population and context due to the increased range of exercises which could be performed by the patient and the reduced burden on the therapist. It was noted that the small sample size of 12 participants, may have impacted the outcomes and impacts the generalisability of the findings. Furthermore, more rigorous studies need to be performed to conclude the clinical utility of robotic devices in this population and context.

A recent scoping review analysed 12 studies on the use of robotic devices in upper limb therapy for cervical level SCI. The study included articles published from acute and rehabilitation settings, with a variety of inpatient and outpatient cases being included from the rehabilitation setting. One thing noted from the review was the consistent volumes of robotic therapy delivered; most articles highlighted a consistent therapy pattern where patients participated in therapy for a minimum of one hour per day on most days of the week, with a range between two and six weeks for the intervention. The majority of the studies did not report any other allied health interventions at the same time as the robotic therapy, whilst only two of the studies reported combining the robotic therapy with an occupational therapy program (19).

The review contained articles which were mainly case studies, however one randomised control trial was included, highlighting a gap in rigorous studies in the field. The results presented one or more of the studies illustrated increased range of motion of the upper limb and increased muscular strength as a result of robotic therapy. There was also a noted improvements in functional independence in two or more of the studies. Furthermore, the greatest improvements in upper limb function were noted among individuals with mild-moderately impaired hand function at baseline, suggesting that low level cervical SCI and incomplete injuries have a greater capacity to regain upper limb functions. Whilst these results are promising, none of the findings were statistically significant and with the majority being case studies, there is a limited capacity to generalise the findings to the greater population. Two of the studies included were based in an acute hospital setting, whilst the

rest were rehabilitation based. This demonstrates there is greater research occurring in the rehabilitation field for robotics in cervical level SCI therapy, and a major gap in acute therapy in the literature. The review concluded that more rigorous studies are required to establish the effectiveness of robotics for patients who have sustained a cervical SCI in relation to upper limb function, in both the acute and rehabilitation contexts.

### **Acute care context**

Patients can often have an extensive hospital stay in the acute phase after sustaining a SCI. Reports from the state SCI service, indicate that the average length of stay in the acute hospital context is 44 days (20). Complications commonly arise during the acute stage relating to the medical stability of the patient, infection and co-morbidities as a result of the accident leading to the injury. The literature demonstrates that performing surgery as early as possible, to stabilise the patient's vertebral column to prevent damage to the spinal cord, is associated with shorter admissions in the acute context (21). However, often medical stability is easier to achieve as compared with regaining function. Due to the dramatic changes in function and reduced independence in completing ADLs, patients remain in acute care where they can receive high levels of support (15). The process of introducing therapy in the acute phase can pose a risk, as patients are often still experiencing pain, fatigue and emotional trauma, however several positive benefits have been suggested as a result of commencing therapy as early as possible. Data from inpatient rehabilitation reports from the state SCI service indicate that the average time spent in rehabilitation is 124 days (22). Whilst the focus of rehabilitation is to deliver high amounts of therapy to increase functional status, commencing therapy in the acute stage has the potential to enhance outcomes achieved in rehabilitation.

Sustaining a SCI at the cervical level is often a traumatic experience and people commonly experience psychosocial symptoms related to anxiety and depression as a result (23). Commencing therapy as soon as possible after sustaining such an injury has been reported to reduce emotional health conditions such as anxiety and depression. This has been attributable to therapy focusing on individuals strengths and what they can do, whilst enhancing their capacity to regain a level of independence. It has also been noted that having a functional focus is vital for psychosocial wellbeing due to the positive effects of meaningful engagement in everyday tasks (24). Promoting this therapy in the acute stage may enhance patients sense of control over their life, after sustaining a devastating injury.

Engaging in functional therapy programs in the acute phase after sustaining a SCI has also been noted in the literature to be beneficial for retaining the strength and function of the upper limbs. Performing such therapy acutely has the greatest neural plasticity potential to regenerate motor patterns in completing functional movements, and maintaining a level of functioning to prevent muscular atrophy from prolonged disuse of the musculoskeletal system (6). Furthermore, retraining motor patterns for functional tasks has been associated with greater outcomes in the acute phase due to practicing executing multiple motor patterns, which helps develop overall upper limb movement capacity (6).

It has been queried whether the use of robotics in acute therapy can reduce the number of days in hospital due to their ability to produce greater volumes of therapy in a shorter period, coupled with the increased engagement in therapy for the patient (15). With this in mind, acute therapy has been deliberated as a positive influence to reduce days in hospital and assist in developing independence to complete ADLs. Furthermore, majority of the literature is focused in a rehabilitation context, where the therapy is commenced in a non-acute stage of healthcare. While this is a common path for many patients, there is a gap in the literature addressing the impact of therapy in an acute context. Maintaining a small level of muscular activity has been argued as beneficial to maintaining neural pathways and preventing detrimental muscular atrophy (6), therefore maintaining some activity in the acute phase can prevent muscular atrophy.

### **Diego by Tyromotion**

Tyromotion robotics have produced a computer assisted robotic device, known as the Diego. This device has been designed to improve upper limb function, with a particular focus on enhancing movement in relation to everyday functioning (25). The patient engages with the device through four straps attached to the patients arms via suspended cables from the top of the device. The device allows unilateral or bilateral training, with the bilateral training increasingly translatable to performing functional tasks used in everyday life.

The Diego also has the capacity to perform range of motion testing, in active and passive capacities, providing more accurate measurements for the occupational therapist .

The robot device has inbuilt intelligent gravity, allowing the support from the cables to be adjusted between zero gravity elimination and complete gravity elimination, which supports active and passive ranges of movement. The benefit of this feature allows the patients

physical capacity to be supported to allow them to participate in therapy. The robot interfaces with a built in computer, whereby the patient can interact in therapy by playing games controlled by their arm movements, providing interactive and motivational therapy. The games are targeted at producing arm movements which are used frequently in everyday life, with the aim that upper limb functional capacity is enhanced. The Diego can also be set up so the patient does not interact with the computer; instead patients can interact with the environment around them in seated functional tasks. Furthermore the gravity assisted feature can be used in this position which assists in promoting re- learning of muscular motor patterns which are used frequently in everyday life. This particular feature allows the movements practiced during therapy playing the games, to be used in practicing functional tasks. This benefits the patient's physical ability to practice functional tasks in a supported environment, enhances the motor patterns developed to execute the functional skills while increase their confidence to perform the tasks in a supported manner. This device may be applicable to people who have sustained a cervical level SCI due to the functional gravity support feature which can be adjusted by the therapist, as per the functional status associated with the injury sustained. Therefore, making therapy tailored to individual functional capacities to support participation in therapy.

The Diego is an end-effector device meaning it has an increased degrees of freedom in the movements it allows. End-effector devices are described as more simplistic in their structure, however they allow more complex movements to be performed (7). With the high degree of freedom in upper limb movements, there are multiple planes of motion in which the Diego allows movements, thus promoting more naturalistic movement patterns to occur.

Furthermore, the device is set up to be used for bilateral training which is highly translatable to functional movements. Some robotic devices used in rehabilitation do not allow the person to produce natural movement patterns as they only focus on one or two movements, or are unilateral training devices, making it increasingly difficult to transfer therapy into everyday functional movement. This gives the Diego a point of difference as compared with other robotic devices available in upper limb therapy.

### **The role of occupational therapy**

Occupational therapy philosophy is based on assisting individuals to engage in their occupations which are valued in everyday life contributing to survival and fulfillment.

Occupational therapy also prides itself on promoting people to be independent and strive to achieve goals which are important to the person to function in their everyday life. During the

acute and rehabilitation phases after sustaining a SCI at the cervical level, occupational therapy plays a significant role in enhancing a person's capacity to engage in their occupations of everyday life. Particularly, occupational therapy has an emphasis on skill retraining for functional tasks, based upon the type of injury and associated functional deficits the person is experiencing.

The literature notes that when therapy is focused upon retraining motor patterns for the purpose of completing functional tasks, patients have been increasingly engaged in therapy, as compared with therapy modalities which focus on isolated movements (12). Furthermore, having a goal oriented focus on the execution of functional skills can be highly rewarding for patients. This allowing them to be motivated towards achieving goals, and having a purposeful goal to achieve (12). Such evidence supports occupational therapy theory of promoting meaningful and functional goals in our practice.

Occupational therapy has a great capacity to promote the use of robotics in SCI therapy due to occupational therapist's ability to set goals and focus on functional tasks which promote independence. This can be coupled with the potential benefits of robotics to enhance functional outcomes. The proposed use of the Diego to promote everyday function of the upper limb aligns with occupational therapy core values to enhance functional outcomes so people can engage in their occupations. Therefore we can explore how the Diego device may provide meaningful outcomes for people who have sustained a cervical SCI, through acute care upper limb therapy. The literature has indicated positive impacts from therapy commencing in the acute stage for physical and psychological reasons, however there is still a gap in protocols for therapy commencing in the acute stage to assist in guiding therapists to practice in this period. Furthermore, there is a noted gap in the literature for the use of robotic devices in acute care, with a majority of the literature developed in the rehabilitation setting. There is limited literature exploring the use of robotics in SCI, particularly cervical region injuries, therefore there is limited guidance on how to implement such devices in therapy and the associated outcomes, posing as problematic for therapists wishing to use these devices in therapy. Such gaps in the literature demonstrate a lack of clinical utility evidence to support the use of these devices in therapy, however they are still being increasingly used (19).

The international classification of functioning, disability and health (ICF) is a commonly used framework in healthcare settings to explore and explain the relationships between the

environment, participation in activities, body structures and disease (26). Given the context of the present study taking place in an acute hospital setting and working in a multidisciplinary team with several health professions involved with patient care, the ICF is appropriate for communication between multiple disciplines. Taking these factors into account, the ICF has been selected as the model to assist in guiding the study.

The assumption of the model is that the variables interact and therefore have impacts on each other. In relation to the given project, the variable of focus is body structures and function, pertaining to the use of upper limbs, as an outcome. The main question giving rise to this outcome is if participation in upper limb therapy using the Diego device, changes upper limb structure and function. Through using the ICF in this project we are able to explore the interrelationships between sustaining a cervical SCI and associated body structure and function of the upper limb, after participating in a upper limb program using the Diego robotic device, with a focus on ADL activities, within the acute hospital environment.

Therefore, by exploring acute upper limb therapy with meaningful engagement and outcomes, there will be increased resources to inform occupational therapists to guide their practice in this population. The proposed study aims to explore the use of the Diego robotic device in an acute hospital setting for patients who have recently sustained a cervical level SCI. The focus will be using the Diego for upper limb therapy and assessing associated upper limb kinematic and functional outcomes as a result of using the device in conjunction with a standard occupational therapy program in the acute setting. Results will assist in developing the body of literature surrounding the use of robotic devices as an upper limb therapy modality for people who have sustained a SCI in the cervical region. Such literature can assist occupational therapists in designing therapy plans and the timing of interventions for the best possible outcomes for their patients. With occupational therapy being a profession based on evidence guiding their practice, conducting such research is critical to ensuring that we are using interventions which are supported in the literature.

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Manuscript.

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Robotics and acute upper limb therapy in cervical  
spinal cord injury:  
A quantitative case study.

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**Abstract.**

A major debilitating factor of sustaining a cervical level spinal cord injury is the loss of independence in completing activities of daily living as a result of impaired upper limb function. Early intervention has been hypothesised to preserve upper limb function in this population and enhance capacity to perform functional tasks. The use of robotics as an upper limb therapy modality is increasing in the neurorehabilitation field, however there is limited evidence to support their use in the cervical spinal cord injury population. Despite this, occupational therapists are using them as part of a therapy program.

**Aim:** This study aimed to explore the upper limb outcomes of using a computer assisted robotic device in acute therapy for people who have sustained a cervical spinal cord injury.

**Methods:** A single case pre-post study design was performed with one middle aged male who had who was an inpatient at a public metropolitan hospital in Australia. They undertook a three week therapy program using the Diego by Tyromotion in conjunction with standard occupational therapy interventions. Range of motion, muscular strength, pain, fatigue the Spinal Cord Independence Measure, and the Canadian Occupational Performance Measure were used as outcome measures.

**Results:** Increases were seen in range of motion and muscular strength and functional status; objective and subjectively.

**Conclusion:** Preliminary findings suggest that the Diego may be a useful tool for improving upper limb outcomes when combined with occupational therapy in this population, however greater research and participants are required for definitive data.

## Background

Our ability to interact with our environment comes as a result of a complex sensory and motor system. The spinal cord plays a major role in this as it contains nerves which communicate motor and sensory information between the person's brain and their body, and assists in determining how a person will interact with their environment. A spinal cord injury (SCI) disrupts this communication, resulting in a debilitating injury which is lifelong. At the cervical level of the spinal cord, nerves are primarily innervating muscles of the upper limb (UL). Therefore a cervical spinal cord injury (CSCI), reduces a person's ability to utilise their UL, severely impacting a person's functional capacity (1). There are two main types of SCI, complete and incomplete. A complete injury is a definite lesion of the SCI with no neural messages passing the lesion site. An incomplete injury is an indefinite lesion of the spinal cord, where some neural messages can be carried past the lesion site, where the spinal cord is still intact. Incomplete lesions are highly variable in how they present functionally which is dependent upon the site of the lesion and the severity. The American Spinal Association Impairment (ASIA) scale has been developed to classify injuries in relation to complete and incomplete, and the functional implications of varying incomplete injuries (2).

In Australia, everyday one person will sustain a SCI. Cervical level SCI make up 64% of all traumatic spinal cord injuries, with 80% of injuries occurring in males and the greatest incidence being people aged 15-24 years (4) (3). According to the state SCI service, in 2016 74% of all SCI recorded were traumatic, 51% of injuries were at the cervical level, 66% were incomplete injuries and 79% of injuries sustained were in males (20). Such data demonstrates that traumatic incomplete cervical level injuries are most common in males, within this part of Australia.

Injury at the cervical level can be debilitating for everyday function with paralysis of lower limbs, trunk and has the potential to severely impair UL function. Often, high levels of support and care are required as a result of the reduced independence experienced through impaired function, particularly of the UL to perform basic everyday tasks. Loss of UL function has been reported as one of the most debilitating factors of sustaining a CSCI due to the loss of independence and inability to interact with the environment that comes with being unable to use their UL (6).

## **Robotic upper limb therapy**

The use of robotics is increasing as an UL therapy tool due to their ability to produce a greater number of repetitions of movements in therapy sessions, as compared with traditional occupational therapy using therapist manipulation (6). Furthermore, therapist-related fatigue can occur as a result of manipulation therapy, resulting in less-accurate movements performed, hindering therapy outcomes (7). It has been proposed that the use of robotics may decrease the length of stay in the acute hospital ward, due to the ability of it to deliver high volumes of therapy in a short period of time (15). This factor could be crucial for patients who have sustained a CSCI, whom often experience an extended acute hospital admission due to the dramatic reduction in independence as a result of the injury.

Feedback is a critical component of learning. An opportunity to recognise if movements are successful has been identified as crucial in learning motor tasks and enhances outcomes, particularly when practicing functional movement patterns relating to everyday tasks (12). Robotic therapy with feedback mechanisms therefore can reinforce learning outcomes, as patients can understand what movements are successful for achieving tasks. There are also theories that robotic devices provide greater engagement in therapy. It is proposed that multisensory and sensorimotor factors in using robots are more engaging and motivating as compared with traditional therapy practices (15). In conjunction with the higher volumes of repetitions, feedback capacities, and motivational factors, robotics could potentially enhance outcomes of therapy.

Tyromotion robotics have produced a computer assisted robot, known as the Diego, designed to improve UL function in neuro-rehabilitation, in relation to everyday functioning (25). The Diego is a bilateral end-effector device. The patient has two straps on each arm, above and below the elbow, attached to suspended cables from the top of the device above the patient. The robot device has inbuilt intelligent gravity, so the cables can be adjusted between zero gravity elimination and complete gravity elimination to support active and passive ranges of movement to match the individuals' capacity. The robot interfaces with a built in computer, which allows the patient to interact with a variety of games during therapy. The games are controlled by arm movements, which are targeted at producing movements which are used frequently in everyday life, with the aim that UL functional capacity is enhanced. The Diego can also be set up so the patient does not interact with the computer; instead patients can interact with the environment around them in seated functional tasks. The gravity assist

feature can be used in this set-up, promoting re-learning of muscular motor patterns which are used frequently in everyday life.

The end-effector nature of the Diego means the degrees of freedom is increased, allowing a greater number of movements to be performed. This allows the individual to practice performing movements as per their functional capacity, in multiple planes of motion, which is easily translatable to everyday tasks (7). Other robotic devices being used in the field only allow unilateral training, or support movements in one plane of motion, as only one aspect of the movement required has been practiced. Such therapy makes it increasingly difficult to translate these movements to functional tasks. Currently, no literature has been located exploring the use of the Diego in neurological rehabilitation, including SCI therapy.

### **Robotics in spinal cord injury**

The majority of the literature exploring the use of robotics in UL therapy relates to stroke rehabilitation as compared with SCI rehabilitation, demonstrating a gap in this field.

However, the small amounts of literature located have shown promise to the use of robotics in therapy for SCI. A single case-study with a patient who had sustained an incomplete C4 SCI, concluded that the combination of traditional UL therapy and the use of a robotic device had positive impacts on UL function. An increase in range of motion (ROM), improved functional outcomes as assessed by occupational therapy assessments and an increased sense of independence were highlighted in the results (17). Furthermore, a scoping review of 12 studies exploring the use of robotics for UL therapy in CSCI patients highlighted an increased ROM and UL strength as a result of the therapy, in addition to improved functional independence (19). However, both of these studies did not report any statistically significant findings, making generalisability of findings difficult.

### **Acute care**

The state SCI service reports that the average length of stay in an acute hospital ward after sustaining a SCI is 44 days (20). The number of days spent on the acute ward is decreasing due to medical advances which are assisting in the initial medical treatment and surgery for the injury (10). The increases in access to allied health services in the acute phase has also contributed to the reduction in days spent on the acute ward and the increase in transition to rehabilitation. Reports have also highlighted that the duration spent in inpatient rehabilitation is on average 124 days, demonstrating increased amounts of therapy delivered during this

period (22). Despite rehabilitation being greater in duration with a greater focus on regaining function, commencing therapy in the acute stage has the potential to enhance outcomes achieved in rehabilitation.

Psychosocial symptoms such as anxiety and depression often present in people who have sustained a traumatic CSCI (23). Commencing therapy rapidly can assist in reducing these symptoms due to engaging the person in everyday task practice, reducing their feelings of a loss of independence. Furthermore, having a functional focus to therapy has been noted to enhance psychosocial wellbeing attributable to emphasising strengths of the patient and what they can do in everyday tasks (24). In addition to the psychosocial aspects of engaging in early therapy, physical benefits of engaging in therapy in the acute stage relate to preventing muscular atrophy and maintaining muscle integrity through movement. Performing movement therapy acutely also has the greatest neural plasticity potential to regenerate motor patterns in completing functional movements (6). With such evidence supporting acute therapy, greater research is required to present appropriate interventions for UL function in this stage after sustaining a CSCI.

Predicting recovery patterns is difficult for CSCI is complex. Generally, incomplete injuries have a greater capacity for recovery due to the remaining neural pathways, and greatest functional recovery patterns are seen between one and twelve months after sustaining the injury (9). As compared with complete injuries, where motor recovery is seen in the initial three months post injury. The literature also notes that a regained muscular strength, as assessed through manual muscle testing, has greater outcomes from therapy. Within two weeks of therapy, a baseline grade of 2/5 can progress to a 3/5 (9).

The International Classification of Disability, functioning and Health (ICF) is a commonly used framework in healthcare settings to explore and explain the relationships between the environment, participation in activities, body structures and disease (26). Given the context of the present study taking place in an acute hospital setting and working in a multidisciplinary team with several health professions involved with patient care, the ICF is appropriate. The assumption of the model is that these variables interact and impact outcomes of each other. In relation to the given project, the variable of focus is body structures and function, pertaining to the use of upper limbs, as an outcome. The main question giving rise to this outcome is if participation in UL therapy using the Diego device, changes UL structure and

function. Through using the ICF in this project we are able to explore the interrelationships between sustaining a CSCI and associated body structure and function of the UL, after participating in a UL program using the Diego robotic device, with a focus on activities of daily living (ADLs), within the acute hospital environment.

The main focus of occupational therapy is to assist people in engaging in occupations which they require and value in everyday life, while promoting functional capacity and independence. The proposed use of the Diego to promote everyday function of the UL aligns with occupational therapy core values to enhance functional outcomes. Therefore we can explore how this device may provide meaningful outcomes for people who have sustained a CSCI. There is limited literature exploring the use of robotics in SCI, particularly CSCI, therefore there is limited guidance on how to implement such devices in therapy and the associated outcomes. Furthermore, to date, no literature has been located regarding the utility of the Diego device. Conducting such research provides significance on a world-wide scale as there has been no research located on the clinical utility of the Diego, meaning there will be evidence to identify its clinical utility. The research objective is to assess the feasibility of using the Diego robotic device in an acute setting for a patient who has a cervical level SCI in relation to UL kinematics and associated function.

Through conducting the study we hope to answer the following questions:

- What are the upper limb kinematic functions from using the Diego for an UL occupational therapy rehabilitation program in an acute setting for an individual who has sustained an incomplete cervical level SCI?
- Will early intervention provide greater upper limb function through preservation of upper limb use?
- Does the Diego device compliment a structured occupational therapy UL program?

## **Methods**

A single case study method was followed for this project, following a pre and post design. Ethics approval was obtained by the local health district and the site to conduct the research prior to contact with the participant. The study was also registered as a clinical trial.

To be included in the study participants were required to have newly sustained a cervical level SCI, a diagnosis of a complete or incomplete injury as per the ASIA impairment scale (A-D) from their treating consultant and associated approval in the study, to be over the age

of 18 years, provide informed consent, and have a tolerance of sitting in a wheelchair upward of 90 minutes. Not meeting these criteria or withdrawal of consent would remove the participant from the study. The occupational therapist discussed participation in the study with the patient, the proposed therapy program, the device and consent procedures. The patient was also provided with written information on participation in the study. Approval was obtained by the treating consultant, based on the patient being medically stable. The patient gave informed consent and was informed of the withdrawal processes.

The study followed a pre and post design, with baseline measurements taken prior to partaking in the therapy program. The measurements were taken again at the end of the therapy program.

All therapy sessions were recorded by the occupational therapist, as per standard documentation protocol, detailing activities undertaken such as the games performed on the Diego and the functional tasks practiced in standard therapy sessions. Subjective data from the participant on their experiences of the therapy sessions were also documented.

I certify that all applicable institutional and governmental regulations concerning the ethical use of human volunteers were followed during the course of this research.

### **The case**

For the purpose of the study, the subject will be referred to under a pseudonym John.

John is a 51 year old male from a metropolitan capital city in Australia. John has been an active member of sport for the majority of his life, and sustained his injury playing field sport as a result of colliding with another player on the field. John was admitted to a metropolitan hospital which specialises in SCI, where he was diagnosed with a C3 spinous process fracture, C4-5 stenosis and spinal cord oedema. John underwent immediate surgery to stabilise the vertebra and prevent further spinal cord damage; a C3-5 posterior laminectomy and lateral mass fusion was performed. Later, he was formally diagnosed with an incomplete C4 spinal cord injury, level C as per the ASIA impairment scale. This diagnosis indicated that there is still some innervated muscle able to move, below the site of the injury, however half of the muscles below the injury site cannot actively move against gravity (2). John then spent six days in the intensive care unit (ICU) before being transferred to the spinal ward within the hospital. John was an inpatient in the hospital for a total of 39 days, six days in ICU and 33 on the acute ward before being transferred to the rehabilitation facility. John requires a power wheelchair as his mode of getting around as a result of the injury. John had no issues relating to respiration, he used an indwelling urinary catheter and over the course of the admission,



started regaining sensation in his bowels. There were no recorded issues with joint proprioception or muscle spasticity in John's case. Prior to commencing in the trial, John had engaged in four sessions with an occupational therapist. He was fitted with resting hand splints in ICU, had his power wheelchair prescribed and received small amounts of fine motor skill therapy prior to commencing in the program.

### **Outcome measures**

The assessments used gave a profile of the UL kinematic functions which could be used to infer functional capacities in addition to objective and subjective functional measures. Manual muscle testing (MMT) was performed by the occupational therapist to assess UL strength. Active ROM was performed by John and recorded by the occupational therapist using a goniometer. The visual analogue pain and fatigue scales were used respectively to assess levels of pain and fatigue experienced by the participant. The Canadian Occupational Performance Measure (COPM) was used to assess self-perceived performance and satisfaction of the patient performing tasks which were identified as important to them. The Spinal Cord Independence Measure (SCIM) was used as a standardised assessment to assess performing activities of daily living. The SCIM has been identified as more sensitive to change than the Functional Independence Measure (FIM), and assesses tasks which are more likely to be influenced by a SCI (27). Pre-therapy assessments were performed over three one hour sessions in the first week of the trial, this was purposefully executed to prevent fatigue impacting the patient's performance. Post-therapy assessments were performed in one occupational therapy session at the end of the trial due to John being discharged to rehabilitation, therefore assessments were required to be performed promptly.

### **Intervention**

John commenced his participation in the study 16 days after sustaining his injury. The therapy block involved a three week trial period, on a Monday-Friday basis, with no formal therapy taking place on weekends. One to one occupational therapy sessions during the trial ran for one hour in duration. Initial assessments were performed over three occupational therapy sessions in the first week of the trial. The post-therapy assessments were completed in one occupational therapy session at the end of the trial period.

During the trial period a total of six sessions were spent using the Diego with the occupational therapist, these sessions were scattered however there were three sessions conducted on three consecutive days. Games were played in all of the sessions, using virtual

reality and cognition as motivations, and movements were focused on working in the sagittal plane. Functional tasks were performed using the Diego as support three sessions which involved: One session practicing brushing teeth with assistance from a palmar band and combing his hair with his fingers. The second functional session trialled upper body dressing which involved putting a t-shirt over his head. The third functional session practiced hanging clothes out on a make-shift line above head level. Sessions using the Diego were one hour in duration, with the sessions incorporating functional training evenly split between engaging in game therapy and functional tasks.

An additional four sessions were spent working on ADLs and UL therapy with the occupational therapist, with a particular focus on feeding and drinking independently.

Adaptive equipment was used to aid in independent feeding. John also had three community visits facilitated by the occupational therapist during this period, with a focus on independently managing his power wheelchair.

## **Results**

John displayed improvements in a number of the assessments taken. Specifically, ROM in the shoulder demonstrated improvements in all of the movements, except extension which maintained a full ROM from baseline to post-intervention (refer to table 1). In the elbow, ROM of flexion and from pronation showed increase from baseline to post-intervention measurements, extension maintained a full ROM from baseline to post-therapy measurements (refer to table 2).

Muscular strength was tested through MMT and demonstrated that the right elbow extensor improved from a poor (2) to a fair (3) grade, left extensor and both flexors maintained their normal (5) grade. MMT of the shoulder did not change from baseline measurements and post-therapy measurements, all movements remained graded at a 5.

Pain remained stable at 2 from pre and post measurements, demonstrating no change in pain experienced. However, fatigue reduced from a 4 to 2 in the post-measurement.

Self-perceived performance of activities assessed through the COPM showed improvements in both total and average self-rated performance and satisfaction scores. John identified computer use, mobile phone use, cleaning his teeth, performing bowel care and showering as his occupational performance goals. Cleaning his teeth was the only activity which improved

from a score of 1 for both performance and satisfaction, to a 3 for performance and 4 for satisfaction respectively post-therapy.

There was an improved overall SCIM score, demonstrating some improvements; baseline 18 out of 100 compared to post-therapy 22 out of 100. Specifically small improvements were noted in feeding from total assistance (0) to eating independently with aid (2), dressing upper body improved from total assistance (0) to partial assistance (1) and grooming from total assistance (0) to partial assistance (1) (see table 3).

Table 1: ROM of shoulder

	<b>Baseline</b>		<b>Post-therapy</b>	
	Left	Right	Left	Right
<b>Horizontal flexion</b>	64	79	85	96
<b>Flexion</b>	76	81	145	112
<b>Extension</b>	Full	Full	Full	Full
<b>Internal rotation</b>	54	54	66	66
<b>External rotation</b>	40	25	56	49
<b>Abduction</b>	83	120	131	130

Table 2: ROM of elbow.

	<b>Baseline</b>		<b>Post-therapy</b>	
	Left	Right	Left	Right
<b>Flexion</b>	131	140	150	146
<b>Flexion in full pronation</b>	131	60	140	125
<b>Extension</b>	Full	Full	Full	Full

Table 3: Self-care SCIM

	<b>Baseline</b>	<b>Post-therapy</b>
<b>Self-care:</b>		
<b>Feeding</b>	0	2
<b>Bathing upper body (A)</b>	0	0
<b>Bathing lower body (B)</b>	0	0

<b>Dressing upper body (A)</b>	0	1
<b>Dressing lower body (B)</b>	0	0
<b>Grooming</b>	0	1

### **Documentation**

Subjective data recorded by the occupational therapist highlighted John's perspective of participating in the therapy sessions using the Diego. John reported in the initial session using the device that it was enjoyable and he could feel the muscles in his shoulders working as he played the games. In the third session, John's family were present. John reported that he was challenged by the movements performed, with an emphasis on the muscles in his shoulders working hard when playing the games. His family provided extrinsic motivation, encouraging his performance in the games. For the fourth session, John had reportedly felt unwell in the morning however he reported that he got out of bed to attend therapy due to his motivation to play games on the Diego. Similarly, John reported he felt his shoulder muscles working hard during the Diego session. In the fifth session, John's competitive nature had him wanting to achieve the three out of three star mark rating from playing the games. This reportedly motivated him to continue engaging in the games. The occupational therapist also reported that John was extremely focused when engaging with the games on the Diego.

### **Discussion**

This study has provided an insight into UL function after sustaining an incomplete CSCI and participating in a robotic therapy program guided by an occupational therapist. A number of interesting results have been presented as a result of the study, providing some promise that robotics may be a beneficial tool in UL therapy for this population. Overall the combination of standard UL therapy and UL therapy using the Diego demonstrated small improvements in the UL assessments and ADL task performance for John.

John's ROM showed improvements in both the shoulder and elbow joints in several movements. Similar results have been highlighted in a robotic UL program, however they did not record any changes in right shoulder flexion and abduction, unlike in John's case (17). Interestingly, John commenced his therapy block 16 days after sustaining his injury, as compared with commencing 26 days post injury in a rehabilitation facility. Without

significant results conclusions cannot be made, however it is interesting that greater ROM outcomes were noted in John's case where therapy commenced in the acute stage. Increased levels of pain are commonly experienced in the acute phase after sustaining a SCI. Reports in the literature have identified that increased levels of pain are associated with a decreased ROM in the UL (28). Results from the present study demonstrated that John's low level of pain did not change between pre and post therapy assessments. The decreased levels of pain experienced may have enhanced John's engagement in therapy, therefore enhancing ROM outcomes.

There was a slight improvement in the right elbow extensor muscle group, demonstrated through MMT. It was highlighted in the literature that a muscle graded as a two could progress to a grade three in two weeks of therapy, which is what John has experienced (9). With John experiencing an incomplete injury and regaining some muscle strength, engaging in therapy in the acute stage has enhanced some of the lost muscular strength. Furthermore, it had been concluded that incomplete injuries have a greater chance of regaining motor function in the initial month after sustaining the injury, when engaged in therapy (29). John continually reported throughout engaging with the Diego that he could feel his shoulder muscles working, providing an interesting insight that he did feel he was being physically challenged. The literature highlights an importance in preserving muscular function during the acute phase to prevent muscular atrophy, therefore by engaging in physically challenging UL therapy, John has been able to preserve some of his muscular strength, and improve the strength in his elbow extension (6). Engaging in such therapy has potentially prevented his muscular strength deteriorating any further.

Results from the SCIM demonstrated small improvements in John's performance of self-care tasks. This finding implies that the combination of practicing self-care tasks using the Diego in addition to standard UL therapy, did change John's ability to perform self-care ADLs. The changes were too small to imply that the patient had regained independence, however in the given time-frame it is not normally predicted that someone would achieve independence. A similar case study also reported changes in ADL performance after partaking in a robot UL therapy program, the FIM results demonstrated improvements in upper body dressing and eating, aligning with our results (17).

John reported that his satisfaction and performance had improved after participating in the therapy program, particularly relating to the self-care task of brushing teeth. Interestingly, this was one of the functional tasks John practiced using the gravity assistance feature of the Diego raising questions about the benefits of assistance against gravity to practice executing motor patterns. Similar results have been published with a patients perceived performance of ADLs improving after completing a robotic UL therapy program (17). Whilst the COPM may not be a true reflection of a person's objective performance of tasks, including the patient's values has been depicted as important to empowering the individuals to have a sense of control over their therapy (30). It is also noted that people should be satisfied with their own ability to perform tasks, rather than be externally told about their performance.

Fatigue was noted to have decreased after participating in the therapy program. No further information was obtained to determine if the reduced fatigue was felt in general day to day wellbeing, or at the end of therapy sessions. Assumptions could be made that the decreased levels of fatigue experienced may have been attributable to the increased fitness experienced from participating in therapy. Pain did not increase as a result of participating in the therapy program, which provides a positive insight into commencing therapy using the Diego in the acute phase may not exacerbate pain experienced by patients.

It was reported by John that participating in therapy using the Diego was highly engaging, motivating and rewarding. The grading of performance, out of three stars, was a motivator to continue to improve on the previous grade, or maintain the top grade. When a lower score was given, the patient reportedly wanted to play the game again in order to achieve the highest score. As discussed in the literature, robotic therapy has been hypothesised as being increasingly engaging for patients, which may enhance outcomes due to greater participation in therapy (12). With the combination of results, it could be inferred that we observed increases in UL assessments because John continually engaged in Diego therapy.

In comparing the present study to a similar study executed overseas, the case study ran over a four week therapy program with two hours of occupational therapy on weekdays. Therapy commenced 26 days after sustaining the injury in an acute-rehabilitation setting. Sessions were split evenly into ADL training and robotic therapy, an overall intensive therapy block. The present study commenced a shorter duration after sustaining the injury and involved a less intensive therapy block and interestingly similar outcomes were seen between the

studies. This raises questions of whether an acute program is more efficient at achieving upper limb functional outcomes.

Through completing the study we were able to answer the study aims and objectives: We discovered that ROM and muscular strength increase as a result of using the Diego in conjunction with an occupational therapy UL program for an incomplete C4 injury. The results from the SCIM and COPM identify a small increase in function, with the combination of increased ROM and muscular strength it could be suggested that UL use was preserved through engaging in the therapy program. As a result, small increases in function were recorded. The combination of a standard UL occupational therapy program and using the Diego, provided an indication that UL kinematics and associated function. Therefore, the Diego did compliment the occupational therapy program in the acute setting for this patient with an incomplete C4 injury.

Overall, we observed changes in UL kinematics as a result of participating in an UL therapy program using the Diego computer assisted robot and standard occupational therapy. The changes in UL kinematics may have supported the small changes in functional capacity recorded, however more rigorous studies are required to confirm any correlations.

### **Limitations**

However, it is noted that with only one participant, the data cannot be inferred as significant, nor can it be generalised to the specific population group. We are unable to draw conclusions on the use of the Diego device, however this study has created a foundation for future research to build upon. Further research is required to further explore the outcomes of using the Diego robotic device in patients who have sustained a CSCI to determine UL function.

### **Conclusion**

This pilot study has explored the use of the Diego as an acute UL therapy tool for a patient who has experienced a CSCI. There are positive findings from the results which demonstrate some improvement in UL capacity and associated function in ADLs. However, greater studies are required to determine the feasibility of this device in an acute setting for this population. As a result of the study we were unable to establish a therapy protocol for occupational therapists to use the Diego in conjunction with standard therapy, due to the limitation of participants.

**Conflicts of interest**

There are no conflicts of interest to report from conducting this study, with no financial incentives or competing interests to come of completing the study.

**Funding**

The study ran as part of the acute care within the hospital, with no extra funding going towards the occupational therapists and research assistants involved in the project.

The Diego computer assisted robotic device was provided by Cantley Medical, in conjunction with Tyromotion robotics.



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