FACTORS ASSOCIATED WITH FALLS AMONG WHEELCHAIR USERS LIVING WITH SPINAL CORD INJURY

BY

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DISSERTATION

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ABSTRACT

Spinal Cord Injury (SCI) results in damage to the spinal cord that affects approximately 296,000 persons in the United States. As a result of damage to the spinal cord, more than half of those individuals affected by SCI are not able to ambulate and will use a wheelchair to support performance of their daily living activities. Falls are highly prevalent among non-ambulatory individuals with SCI and can result in detrimental consequences including physical injuries such as bone fractures and head concussions, fear of falling (FOF), functional limitations, and low quality of life. In worst cases, falls can lead to death. The first step essential to prevent falls and fall-related injuries is to assess risk factors, then identify individuals at risk of falls, before intervening with targeted fall prevention programs. Despite the evident importance of fall prevention in this population, few studies have specifically investigated the characteristics and predictors of falls and fall-related injuries. Consequently, there is a lack of clinical guidelines and evidenced-based fall prevention programs for non-ambulatory individuals with SCI. The overreaching purpose of this dissertation is to investigate factors associated with falls and fall-related injuries among non-ambulatory individuals with SCI.

The project was divided in three studies. Study 1 (Chapter 3) focused on investigating the feasibility and preliminary validity and reliability of remote sitting balance assessments among non-ambulatory individuals. This study was deemed necessary due to the restrictions placed on human research because of the COVID-19 pandemic. Study 2 (Chapter 4) investigated the characteristics of falls, fall-related injuries, and FOF among non-ambulatory individuals with SCI. Study 3 (Chapter 5) explored factors associated with falls and fall-related injuries among non-ambulatory individuals with SCI. The potential factors associated with falls and fall-related injuries were evaluated according to the International Classification of Functioning, Disability

and Health model. The potential risk factors investigated included variables of demographics information, sitting balance performance, psychological measures, environmental barriers, functional independence, wheelchair skills, quality of life, and community participation.

Results from study 1 indicate that remote assessment of sitting balance is feasible, valid, and reliable using the Function in Sitting Test, the Trunk Control Test, the modified Functional Reach Test, and the T-Shirt Test. The results from study 2 confirm that falls, fall-related injuries, and FOF are frequent among non-ambulatory individuals with SCI. Participants reported that falls occur mostly inside of the house, during transfer activities, and associated with environmental barriers or surface conditions. Injuries resulted from falls varied from minor injuries, such as cuts or bruising, to severe injuries, including fractures and head concussions. The study also reveals that FOF is highly related to reduced overall function. The results from study 3 indicate that clinicians should consider time since injury and level of mobility function in a wheelchair when identifying individuals at risk of falls and components of physical health when identifying individuals at risk of fall-related injuries.

This project provides evidence that remote monitoring of sitting balance critical for daily living activities of non-ambulatory individuals is feasible, valid, and reliable. These findings are important to provide targeted care and can guide home-based interventions through remote assessment. The results of this project also provide more information on characteristics of falls and fall-related injuries. This information can guide the development of targeted fall prevention programs specific for non-ambulatory individuals with SCI. Finally, the findings demonstrate that clinicians can identify non-ambulatory individuals with SCI at risk of falls and fall-related injuries. The identification of individuals at risk of falls is important to refer them to appropriate fall prevention programs. This information is also important to develop effective fall risk screening tools specific for this population. Future research is needed to develop fall risk screening tools and fall prevention programs specific for non-ambulatory individuals with SCI.

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“Veni, Vidi, Vici”

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CHAPTER 1. INTRODUCTION

1.1. Background

At the population level, approximately 60 to 76% of non-ambulatory individuals with spinal cord injury (SCI) experience at least one fall during a period of 6 to 12 months[1]. The consequences associated with falling are significant and can negatively influence the health, wellbeing, and quality of life of non-ambulatory individuals living with SCI[2]. Falls can lead to serious injuries including fractures, concussions, and dislocations. A non-ambulatory individual living with SCI may also develop a fear of falling (FOF) which is associated with a loss of confidence, decline in mental health, difficulty engaging in societal roles, and physiological deconditioning[3,4]. Thus, a vicious cycle of falling and FOF put individuals with SCI at an increased risk of falls, fall-related injury, and reduced self-efficacy. Compared with older adults[5,6], other neurologic populations[7], or ambulatory individuals[8-10], few studies have specifically investigated factors associated with falls from a wheelchair in this population.

The identification of fall risk factors is important as it guides the development of fall risk screening tools necessary to identify individuals at risk of falls. The identification of fall risk factors is also important as it guides clinicians and researchers to develop targeted and effective fall prevention programs. Clinicians and researchers have employed several methods to gather information on fall risk in older adults and other neurologic populations. Commonly, self-reported measures and performance-based assessments have been used to identify individuals at risk of falls. More recently, the use of technology for this purpose has also been receiving attention[11-14]. In people with multiple sclerosis, a recent study indicates that self-reported outcome measures of balance are more sensitive than performance-based measures in predicting falls[15]. However, the Area Under the Receiver Operating Characteristics statistics (AUC) of these self-reported measures varies between 0.89-0.92, indicating that the measures are not fully predictive[15]. In addition, self-reported assessments are subjective and may be influenced by recall bias. Due to the multifactorial nature of falls, a more sensitive approach might be to combine self-reported and performance-based measures to identify individuals at risk of falls.

Among non-ambulatory individuals with SCI, few risk predictors of falls and fall-related injuries have been reported[16-18]. High level of mobility, shorter time since injury, history of previous falls, and recent pain have been reported by Nelson *et al*. as the most important fall risk predictors in this population[17]. Briefly, the authors argued that most individuals with higher levels of mobility during their early stages of SCI are highly active and involved in several activities of daily living which may lead them to fall from their wheelchair[17]. Also, the authors argued that reporting a recent pain was associated with a decreased efficiency of movements and dysfunctional postures during wheelchair activities, including transfers, which might increase exposure to falls[17]. Furthermore, history of previous falls, recent pain, and high quality of life have been reported as predictors of fall-related injuries[17]. The ability to maintain balance in a wheelchair, which has been commonly reported by wheelchair users as one of the most important contributors of falls,[19] has not been investigated as a fall risk predictor in this population. A better understanding of falls and fall-related injuries risk predictors is necessary to identify individuals at risk and to develop suitable fall prevention interventions.

1.2. Specific Aims

The purpose of this study is to investigate factors associated with falls and fall-related injuries among non-ambulatory individuals with SCI using self-reported measures and remote performance-based outcome measures. The study is comprised of two phases. The first phase

(Chapter 3) investigates: (a) preliminary feasibility, validity, and reliability of remote sitting balance assessments among non-ambulatory individuals with various disabilities, including SCI. The authors hypothesize that remote sitting balance assessment will be feasible, and present with appropriate validity and reliability among non-ambulatory individuals with SCI. This hypothesis was established because the items of the selected sitting balance measures are clear and straightforward to score and do not require use of specialized equipment.

The second phase (Chapters 4 and 5) aims to: (b) investigate the frequency and characteristics surrounding falls and fall-related injuries, (c) gain an in-depth understanding of the relationship between education on fall prevention and FOF, occurrence of falls, injurious falls, and activity curtailment, (d) determine factors associated with falls and fall-related injuries, and (e) determine the combination of self-reported and performance-based outcome measures that present with the highest level of sensitivity and specificity to identify individuals at risk of falls and fall-related injuries in this population. The authors hypothesize that, a combination of participants' characteristics and performance-based measures, such as balance, transfer, and wheelchair skills will present with the highest accuracy to identify non-ambulatory individuals with SCI at risk of falls. This hypothesis was based on the results of previous studies that highlighted poor balance, transfer, and wheelchair skills, as factors highly associated with falls in this population[16,19,20].

The first phase (Chapter 3) of the study examined the feasibility and preliminary validity and reliability of remote sitting balance assessments through the comparison of data collected in-person and remotely. The need for this phase became evident as the COVID-19 pandemic imposed a lockdown that restricted in-person access to healthcare and research activities. In addition, a valid and reliable method to perform remote assessments is important for individuals with mobility limitations who are unable to travel to healthcare facilities and for individuals who live in inaccessible areas. The data collected for this phase were analyzed to respond the following questions: 1) Is remote assessment of sitting balance feasible for non-ambulatory individuals with SCI? and 2) Is remote assessment of balance outcome measures valid and reliable among non-ambulatory individuals with SCI? The results of the first phase were used to scientifically justify remote data collection for the second phase.

The second phase (Chapters 4 and 5) investigated the frequency, characteristics, and factors associated with falls and fall-related injuries among non-ambulatory individuals with SCI. Data was collected through an online survey followed by a remote sitting balance and transfer quality assessment. Participants who engaged in phase one were not invited to participate in phase two. The analysis of the data was performed to respond to the following questions: 1) What are the frequencies and characteristics of falls and fall-related injuries among non-ambulatory individuals with SCI? and 2) What factors can be used by clinicians and researchers to identify individuals at risk of falls and fall-related injuries? The results of this phase can inform future studies about specific components essential to develop fall prevention interventions and fall risk screening tools for non-ambulatory individuals with SCI.

1.3. Research Needs

Despite the evident need to better understand the characteristics of falls and fall-related injuries among non-ambulatory individuals with SCI, very few studies have explored the characteristics and the consequences of falls in this population[17,19,20]. Additionally, only a few studies have specifically investigated predictors of falls[16-18] and predictors of fall-related injuries in this population[16,17]. The investigation of characteristics and predictors of falls and fall-related injuries is particularly important in order to identify individuals at risk and refer them to fall prevention programs to avoid the consequences related to falls and fall-related injuries. Furthermore, the need to develop remote assessments, including remote balance evaluations, for populations at risk of falls became evident during the COVID-19 pandemic lockdown.

A better understanding of characteristics of falls will help to inform more effective fall prevention programs for non-ambulatory individuals with SCI. The benefits of fall prevention programs in reducing negative consequences of falls, including FOF, have been reported in older adults[21,22] and individuals with other neurologic diseases[3,23,24]. Fall prevention programs have also shown to be effective in improving quality of life and community participation[5,21,22]. However, the development of these programs and their influence is still yet to be fully investigated in non-ambulatory individuals with SCI.

The present study can help to gain an in-depth understanding of characteristics of falls and fall-related injuries. The study can also help to identify the main predictors of falls and fall-related injuries in order to target individuals at risk of falls. Finally, the results of this study can inform clinicians and researchers on factors to target to develop effective fall prevention programs in this population. The results of this study have the potential to enhance the clinical practice of physical and occupational therapists through improved evaluation techniques, ability to target individuals at high risk of falls, help with the development of fall prevention programs, guide high quality treatment, and provide targeted care. Preventing falls or reducing frequency of falls in non-ambulatory individuals with SCI will ultimately help to improve the quality of life and community participation in this population.

CHAPTER 2. LITERATURE REVIEW

2.1. Spinal Cord Injuries

Spinal cord injury (SCI) is a disabling neurological condition, affecting the spinal cord, leading to sensory, motor, autonomic, and/or bowel dysfunction[25]. The most recent estimate of the annual incidence of SCI is approximately 54 cases per one million people in the United Stated, which equals to 17,900 new SCI cases each year[26]. Also, it is estimated that the annual global incidence of traumatic SCI was 0.93 million persons with a range between 0.78 and 1.16 million[27] persons. In addition, the Global Burden of Disease Study estimated that the prevalence of SCI worldwide was 27.04 million (24.98 – 30.15 million) in 2016, which is expected to increase in view of population growth[27]. In the United States, it is estimated that the number of people living with SCI is approximately 296,000 persons with a range between 252,000 and 373,000 persons[26]. Although the incidence of SCI is relatively low, the resulting consequences have a significant impact on the individuals, their families, and healthcare systems. It was estimated in 2016 by the Global Burden of Disease Study that SCI caused 9.5 million (6.7 – 12.4 million) years of life lived with disability[27].

In recent years, the National Spinal Cord Injury Statistical Center (NSCIS) in the United States estimated that the average age at injury has increased to 43 years, when compared with the 1970s, when the average age at injury was estimated at 29 years[26]. Also, the NSCIS reported that about 78% of all new SCI cases affects males[26]. The causes of SCI vary according to the region where the individual lives and the level of injury. Worldwide, the main cause of SCI in most regions is falls, followed by conflict and terrorism, as well as motor vehicle road injuries[27]. In the United States, vehicle crashes account for approximately 38.2% of the total cases of SCI, while falls account for about 32.3%, followed by violence (primarily gunshot wounds) accounting for

14.3% of the cases[26]. Other common causes of SCI include injuries sustained from engagement in sports or recreation activities[26]. SCI can also result from medical or surgical procedures and other diseases such as tumors in the spine[26].

According to the segment of the spinal cord affected, SCI can be classified as cervical, thoracic, or lumbar. Cervical injuries generally lead to tetraplegia, while lower injuries (thoracic or lumbar) lead to paraplegia. In addition, according to the International Standards for Neurological Classification of SCI (ISNCSCI), the extent of lesion, determined through the American Spinal Injury Association-ASIA Impairment Scale (AIS), can lead to complete or incomplete injuries[28]. The AIS examination determines 5 types of SCI based on the extent of the motor or sensorial function affected, AIS A, B, C, D, or E[28]. The full description of the different types of SCI based on the AIS examination is presented in Table 1.

Table 1. Description of the different types of SCI based on AIS examination[28].

AIS	**Description**
A: Complete	No sensory or motor function is preserved in the sacral segments S4-5
B: Sensory Incomplete	Sensory but not motor function is preserved below the neurological level of injury including the sacral segments S4-5. Also, no motor function is preserved more than three levels below the motor level on either side of the body.
C: Motor Incomplete	Motor function is preserved at the most caudal sacral segments for voluntary anal contraction or sensory function preserved at the most caudal sacral segments S4-5. Also, there is some sparing of motor level on either side of the body. Less than half of key muscle functions below the single neurological level of injury have a muscle graded ≥ 3.
D: Motor Incomplete	Motor incomplete status as define for AIS C, with at least half of key muscle functions below the single the single neurological level of injury having a muscle graded ≥ 3.
E: Normal	Motor and sensory function tested with the ISNCSCI are graded as normal in all segments, and the individual had prior deficits. Someone without an initial SCI does not receive an AIS grade.

AIS: American Spinal Injury Association-ASIA Impairment Scale; ISNCSCI: International Standards for Neurological Classification of SCI

The combination of level of the spinal cord injury and the type of injury, according to AIS, leads to a variety of remaining functional abilities which determine the level of functionality, recovery, and independence of the individuals affected by SCI. Therefore, individuals with SCI may present with incomplete or complete tetraplegia, incomplete or complete paraplegia, or no residual deficits (individuals who recovered from initial motor and/or sensory deficits). The NSCIS estimates that 47.4% of SCI are incomplete tetraplegia, 19.7% are incomplete paraplegia, 19.9% are complete paraplegia, 12.4% are complete tetraplegia, and 0.6% present with no residual deficits[26]. The initial classification of the SCI may also determine the length of stay in the hospital after a SCI. Recently, it is estimated that the length of stay in the hospital acute care unit in the United States decreased from 24 days in the 1970s to 11 days. Inpatient rehabilitation length of stay has also declined from 98 days to 30 days recently[26]. The healthcare cost related to acute care and rehabilitation after a SCI is very high and vary according to healthcare systems. It is estimated that the lifetime direct costs of SCI in developing countries range from 2.1 million to 5.4 million per person[25]. In 2020 in the United States, the average yearly expense of an individual with high tetraplegia is estimated to be $1,163,425 during the first year of injury, and the indirect cost averaged $78,633[26]. Due to the chronicity of the injury, the average lifetime cost at 25 years of injury is estimated to be $5,162,152[26].

SCI results in significant physical, psychological, and economic burdens for individuals, their relatives, and the society in general. Limitations following a SCI include functional impairment of primary muscles responsible for postural control leading to diminished control over seated posture for wheelchair users and standing posture for ambulatory individuals with SCI[29]. In addition, spasticity, diminished sensorial function, and respiratory constraints may lead to reduced functionality in this population. The reduced ability to control several functions put individuals with SCI at risk of falls.

2.2. Theoretical Model for Research Design

The International Classification of Functioning, Disability and Health (ICF) model was used to guide this project (see Figure 1)[30]. Briefly, the model posits that a person's level of functioning is the result of a dynamic interaction between the health conditions, personal factors, and environmental factors. The ICF framework is an interactive and dynamic biopsychosocial model of disability where all components contribute to the expression of disability. In the proposed study, the health condition related to falls in non-ambulatory individuals with SCI is complex, interactive, and multidimensional, resulting in impairments of body functions and structures (i.e., trunk impairment, weakness of core muscles), limitation of activities (i.e., reaching for objects, transfer from wheelchair to car), participation restriction (i.e., family meetings, social encounters). The interactions between these components are highly influenced by personal factors (i.e., age, sex, associated comorbidities) and environmental factors (i.e., cluttered room, weather). The selection of the outcome measures used in this project was based on the different components of the ICF model. This selection will assure a comprehensive assessment of fall risk factors based on the individual's impairment of body functions, limitations in activities, restriction in participation, personal factors, and environmental factors. The inclusion of such a wide variety of outcome measures will help to better understand the different factors that can contribute to falls in this population. A broader study of fall risk factors will also be helpful to develop effective and accurate fall risk screening tools.

As for clinicians, identifying non-ambulatory individuals at risk of falls through a comprehensive assessment is the first step to plan further fall prevention strategies. These strategies include implementing therapeutic interventions, such as exercise and practice of functional activities (i.e., transfers) to target the individual's body functions and structures, and as well as improve activities performance, respectively. These are considered essential steps in rehabilitation to support an individual's general well-being, quality of life, and community participation.

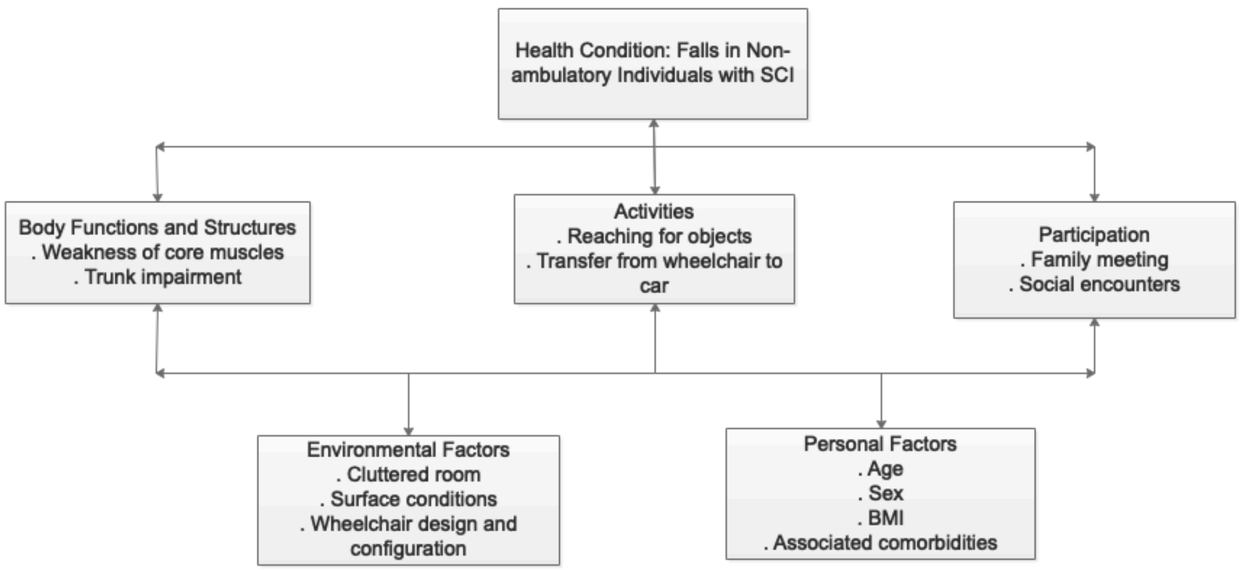

Figure 1. ICF model adapted to falls in non-ambulatory individuals with SCI

2.3. Sitting Balance

The ability to maintain a seated posture in humans has been a subject of high interest among researchers and clinicians. Seated posture can be defined as the ability to keep or restore the body's center of mass within the base of support in a seated position, or more generally, within the limits of stability[31,32]. Maintaining a seated posture is a complex process that involves the coordinated actions of biomechanical, sensory, motor, and central nervous system components[32]. Based on the internal organization of the body, the central nervous system interprets and elaborates a response according to the information received from the sensory systems, and the postural muscle synergies are activated to perform specific limb, trunk, eye, and/or head movements to maintain a seated posture[33-35]. Also, the motor coordination and the sensory organization act as a subsystem and use prior sensory information to predict and prepare an appropriate response for any upcoming perturbations[33]. The system also develops the ability to adapt postural coordination to changes, such as changes in the environment or changes in the task goal. Therefore, the ability to maintain a seated posture is regulated by a complex system responsible for the planning and execution of a flexible movement pattern, which enables a person to achieve many postural goals (See Figure 2).

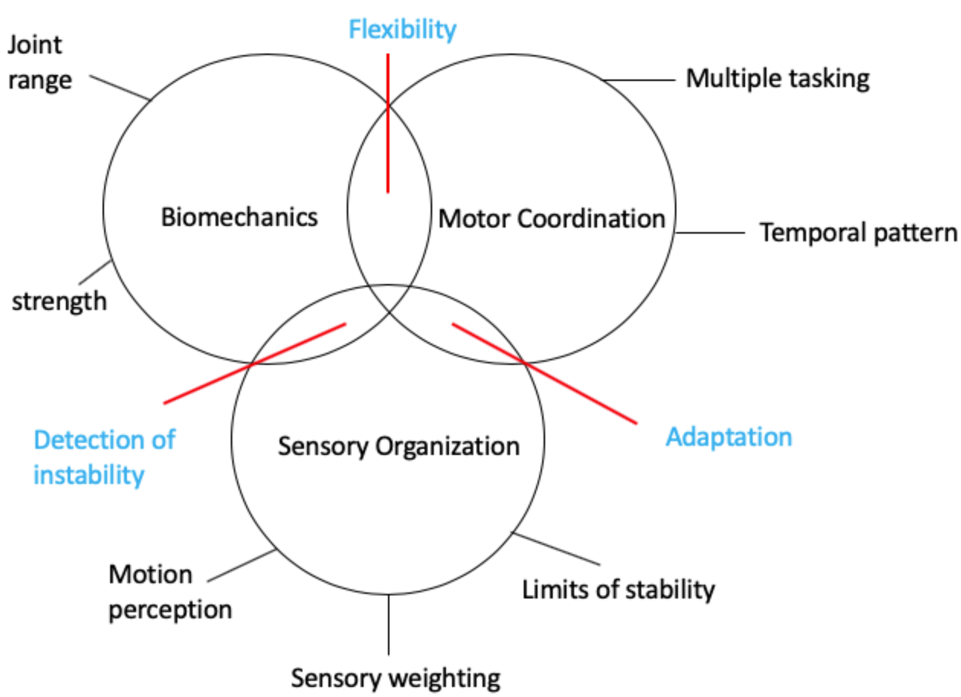

Figure 2. Examples of motor coordination, sensory organization, and biomechanical subcomponents underlying seated postural control (Adapted from F. B. Horak, 1997[33]).

Seated posture is affected when there is a deficit in the function of any of its regulator components. In people with SCI, motor performance may be impaired by muscular weakness and disruption in somatosensorial input, resulting in impairment of seated postural stability[36].

Therefore, people with SCI face significant challenges to maintain seated posture. In general, people with SCI develop new muscle synergies through a reorganization of postural motor control to maintain seated posture and perform their daily activities[37,38]. Trunk instability in people with SCI may lead to a posterior pelvic tilt and an increased thoracolumbar kyphosis[39]. Therefore, in order to maintain a stable seated posture, people with SCI adopt compensatory strategies[40]. These compensatory strategies increase the base of support resulting in the improvement of many functions, such as reaching[41]. Depending on the injury level (cervical, thoracic, or lumbar) and type of injury (complete or incomplete injury), the level of muscular weakness and somatosensorial disruption vary[42] and therefore, a difference exists in seated postures according to the degree of disruption. In general, greater seated postural stability has been reported in individuals with lower thoracic SCI when compared with those with higher thoracic SCI[43,44]. For an appropriate stabilization of the trunk, anticipatory movement of the erector spinae and abdominal muscles is needed prior to the initiation of upper limb activities in a seated posture[45]. For example, prior to a reaching activity, a coordinated action of the core and abdominal muscles is essential to maintain trunk stability[45]. The inability to effectively recruit the abdominal muscles such as rectus abdominis, transverse abdominis, external and internal obliques and the erector spinae in people with high thoracic and cervical injuries may lead to compensatory strategies using non-postural muscles including latissimus dorsi, trapezius, neck, upper and lower extremity muscles to maintain seated posture[37,46]. People with SCI with low thoracic lesions present with more residual sensorimotor functions and therefore, have the capacities to adopt more complex strategies in maintaining and restoring a seated posture[38]. Meanwhile, people with SCI with high thoracic lesions seem to rely on less complex strategies using more passive postural support[38]. In people with cervical SCI who present with impairment in the upper limb, trunk, and lower limb muscles, seated posture is more unstable due to a greater inability to recruit postural muscles compared to those with thoracic injuries[47]. The extent of preserved sensation and motor control according to the level of injury in people with SCI plays a significant role in their ability to maintain a seated posture.

In summary, people with SCI adopt different compensatory strategies to maintain a seated posture when compared to able-bodied people[29,47]. Based on the residual functions according to the level and type of injury, simpler or more complex compensatory strategies are used by people with SCI to maintain a seated posture. People with higher SCI adopt simpler compensatory strategies while people with lower SCI (i.e., people with more residual functions) adopt more complex compensatory strategies to maintain a seated posture. Despite the compensatory methods that people with SCI may adopt and use, their seated posture remains suboptimal compared to individuals without neurological deficits. Therefore, improving seated posture should be a priority for clinicians aiming to improve the performance of daily living activities (ADLs) among people with SCI.

2.4. Assessment of Sitting Balance

The assessment of seated postural control is of high importance to plan and monitor rehabilitation programs, for discharge planning, for diagnostic purposes, and to propose solutions for falls among non-ambulatory people with SCI. The appropriate assessment of seated postural control involves the assessment of the functional goals of the balance system: 1) static, maintenance of a specific postural alignment in a seated posture; 2) proactive, facilitation of voluntary movement between postures; 3) reactive, reactions that recover from equilibrium to external disturbances; and 4) sensorimotor integration. Several approaches have been used in laboratory and clinical settings to assess a seated postural control.

In laboratory settings, several biomechanical techniques have been used to assess seated postural control in people with SCI. Standard measures of the center of pressure (COP) motion, for example, sway area, anterior-posterior and medial-lateral COP displacements, COP velocity, mean COP length have been widely used[29,36,47-49]. An advantage of the COP measures is that they provide a good reflection of the system's neuromuscular response to the perturbations of the body's center of gravity. However, measures of COP do not provide a direct measure of postural stability[50].

Posturography measures[51,52], smartphone application[13], video-based measurements[53], and standalone accelerometry[54] have also been used to assess seated postural control. An example of a posturography measure is the virtual time to contact (VTC). The VTC has been used as a direct measure of seated postural instability in people with SCI[51,55]. The VTC considers the acceleration, velocity, and position of the COP trajectory to estimate the temporal margin to the stability boundary[56] and therefore, presents with the advantage of not requiring loss of stability[51]. Other measures, including motion capture analysis systems, have also been explored to assess seated posture in people with SCI[57,58]. Even though motion capture systems provide accurate and objective quantification of movement underlying seated postural control, the equipment used in a laboratory setting is relatively costly and requires expertise to analyze and interpret the results. Most clinicians, such as physical therapists, lack of such expertise, and therefore, the application of the motion analysis systems to assess seated posture in clinical settings is limited. More recently, technology-based measurement, including smartphones, has also been explored to assess seated posture[11-14,59]. Given the wide use of smartphones in the society and the ease to obtain seated postural measures with the smartphone, this new approach seems promising[11-13]. However, more research is needed to explore and validate the use of such technology to assess seated posture in people with SCI[13].

In clinical settings, several outcome measures have been used to investigate seated postural control measures. A systematic review summarized the most appropriate clinical seated postural measures among non-ambulatory people with SCI based on their development and their clinical utility[60]. The review indicates that the modified functional reach test (mFRT) is one of the most common seated postural control measures used in clinical settings[61]. The mFRT assesses how far a person can reach forward in a seated position without losing balance[61]. This test is simple, quick to administer, and does not require expensive equipment to be performed. This test was recommended by Boswell-Ruys *et al.* as one of the minimum sets of clinical balance measures to adequately assess seated postural control among non-ambulatory individuals with SCI[62]. In addition, the predictive ability of the functional reach to differentiate fallers and non-fallers has been reported in ambulatory people with SCI[63]. Several studies have confirmed the use of the mFRT through the validation of its psychometric properties, test-retest reliability (ICC = 0.85 – 0.94) and validity with the COP ($r = 0.71$)[61,62,64,65]. However, the test only assesses the proactive component of seated posture[60]. Therefore, the mFRT does not provide any insight into the system's neuromuscular response to perturbations of the body's center of gravity. In addition, it is difficult for clinicians to quantify the amount of compensatory strategies used by people with SCI to reach especially, at the scapular-shoulder complex[66].

The trunk control test (TCT)[67], the function in sitting test (FIST)[55,68], T-shirt Test[44,62], sitting balance measure (SBM)[69] have also been used to assess seated postural control among non-ambulatory people with SCI. Similar to the mFRT, these seated postural outcome measures are simple to administer, quick, and do not require expensive equipment to be performed in clinical settings. In addition, the SBM, the FIST, the TCT, and the T-shirt test, assess more than one component of seated posture and, therefore, provide more information on which components of seated posture needs to be improved.

The SBM, was developed mainly based on assessment of common ADLs associated with seated balance, such as static and dynamic short sitting balance items. The SBM was specifically developed to meet the need of sitting balance assessment among people with SCI. However, some items of the measure are redundant, which results in an inconsistent internal consistency of the measure[69]. More research is needed on the SBM before it can be used to assess seated postural control among non-ambulatory people with SCI.

The FIST assesses the static, proactive, reactive, and sensorial components of a seated posture through the performance of 14 daily living activities such as: sitting eyes closed and open, trunk rotation, pick up an object, and multidirectional nudges[55,68]. The FIST has been reported to be a reliable (ICC = 0.95 for test-retest; Cronbach's coefficient-α = 0.81 for internal consistency) and valid (correlation with the mFRT, $r = 0.64$) seated postural test among non-ambulatory people with SCI[55,70]. The FIST evaluates all the components of clinical seated posture among non-ambulatory individuals with SCI and presents with appropriate psychometric properties. However, its ability to predict falls has not been investigated in this population.

The TCT was also developed based on assessment of common ADLs associated with seated posture among non-ambulatory people with SCI[67]. The test assesses the proactive, static, and sensory components of seated posture and includes reaching, touching the feet using trunk muscles, and rolling on both sides. Although the TCT does not evaluate the reactive component of seated posture, the test was shown to be reliable ($K_w = 0.99$ for test-retest, and $K_w = 0.98$ for inter-rater reliability) and valid (correlation with the spinal cord independence measure, r = 0.87)[67]. The TCT has been recommended as an appropriate measure to assess unsupported seated posture in this population[60]. In addition, exploring the ability of the TCT to predict falls among non-ambulatory with SCI has been suggested[67].

The T-shirt test measures the time taken by the participants to don and doff a t-shirt[44,62]. A shorter time indicates a better performance. This test is suitable for clinical practice since it encompasses a routine activity that non-ambulatory people with SCI perform daily. The t-shirt test was found to be reliable (test-retest ICC = 0.89) and valid (correlation with ASIA, r = 0.61 – 0.71)[62] among non-ambulatory people with SCI. The most significant limitation of the T-shirt test is that it only evaluates the proactive component of sitting balance. Also, the T-shirt Test cannot specify what component of balance system is affected in order to direct balance impairment treatment. However, it can be easily used to monitor the progress of a seated posture rehabilitation program[60].

Despite the advantages of the clinical seated postural outcome measures, they present several limitations. The most important limitation is the subjectivity of the scoring. Even though the subjectivity of the scoring is evaluated through the reliability of the measures such as test-retest, intra and inter-rater, this remains a significant disadvantage when compared with biomechanical approaches. Another disadvantage is that most of the clinical seated postural measures do not distinguish different types of seated postural deficits. They only determine whether or not a person has a seated postural instability[34]. However, the TCT, the FIST, the T-shirt test, and the mFRT selected for this project showed the best psychometric properties and their combination provides clinically relevant information.

2.5. Lessons Learnt from Fall Prevention in Older Adults

Falls are a major health concern among older adults and the second leading cause of unintentional injury deaths worldwide, after road traffic injuries[71]. Adults older than 65 years of age experience the highest number of fatal falls[71]. In 2015, the total healthcare cost of falls for older adults in the United States was estimated to be approximately 50 billion dollars[72]. For decades, falls among older adults have been of high interest among researchers and clinicians. The data gathered on falls in geriatric populations provide insight into the consequences and predictors of falls, and more importantly, to develop fall prevention programs in this population. The lessons learned from the geriatric population lay out the foundation for fall prevention studies in other populations including people with multiple sclerosis[23,24], Parkinson's disease[73], and SCI[74]. The first step toward effective fall prevention involves the understanding of the factors that can contribute to those falls. This process has been important because it has helped to develop valid and reliable outcome measures and screening tools in order to identify older adults at risk for future falls[75]. Also, it provides the necessary information that can be used to develop targeted fall prevention programs.

Several consequences of falls among older adults have been reported in the literature. It is estimated that between 20 – 30% of older adults who fall in the United States sustain moderate to severe physical injuries such as bruises, hip fractures, or head trauma[71]. Physical injuries have been reported as the principal factors that can lead to hospitalization, reduced functional ability, and increased dependency for ADLs[76]. In addition to physical injuries, falls can lead to fear of falling (FOF), social isolation, decreased quality of life, and mortality among older adults[3,77].

Studies among older adults have highlighted numerous fall risk predictors. Those studies have reported more than 400 intrinsic and extrinsic potential fall risk predictors in this population[78]. The most predominant intrinsic factors include previous history of falls, impaired cognition, functional impairment, old age (80 and above), poor vision, poor standing balance, arthritis of knees, comorbidities associated, motor weakness, and gait impairment[79,80]. In addition to the intrinsic predictors, extrinsic predictors of falls among older adults are mostly related to environmental factors, including home hazards and surface conditions[81]. Based on those reported fall predictors, several fall prevention programs or interventions to reduce fall frequency have been developed for older adults[82,83]. Most of these fall interventions entail the assessment of the known and modifiable risk predictors of falls[5].

In general, fall prevention interventions are principally designed to address the predictors for falls, such as poor mobility and balance, impaired vision, polypharmacy[84], and cognitive impairment[85]. Individually tailored interventions have also been developed to address fall concerns among older adults[82]. Several systematic reviews have reported the effectiveness of multifactorial fall interventions that include exercise programs that address balance and strength, and home hazard modifications to prevent future falls and reduce the frequency of falls among older adults[21,22].

Moreover, further studies are suggested to determine the characteristics of older adults who are likely to benefit from established fall prevention programs[6]. The multifactorial interventions proposed for older adults are individualized or specific for a group, for example, a group of older adults with dementia. The diversity of fall prevention interventions makes it difficult to generalize the findings for the entire community of older adults[6]. In a recent systematic review, Lee & Yu[5] suggested that exercise and environmental modification are key components of effective multifactorial fall prevention programs. Overall, exercise and environmental modification components should be included when designing multifactorial fall prevention interventions to reduce falls in geriatric populations[5].

Several lessons can be learned from research and the steps underlying fall prevention among older adults, which can be used to guide fall prevention studies among people with SCI. It is noteworthy to highlight that although the literature on older adults provides insights on falls in this population, there are important differences in fall predictors between people with SCI and healthy older adults. For instance, the mechanisms leading to falls in ambulatory people are different from the mechanisms leading to falls in non-ambulatory people[16,17,63,86]. Nonetheless, like the studies in older adults, the first step towards effective fall prevention studies in people with SCI is to characterize falls, identify the predictors of those falls, and further develop fall prevention programs specifically designed to target the identified fall predictors.

In comparison with falls in healthy older adults, much less is known about fall risk predictors in people with SCI. Around 50 specific risk factors have been investigated in people with SCI compared to over 400 fall risk predictors reported in healthy older adults[1,87,88]. A recent systematic review summarized the common fall risk predictors among individuals with SCI[1]. The result of this review indicates that similar primary fall risk predictors exist between ambulatory and non-ambulatory individuals living with SCI, including loss of balance, muscular weakness, spasticity, trunk weakness, FOF, history of previous falls, safety issues with the wheelchair or walking aid, and hazards within the environment[1]. There is a paucity of studies analyzing the effect of fall prevention targeting specific fall risk predictors among individuals with SCI[89]. There are reports of only two studies that analyzed the feasibility of a structured intervention that aims to reduce fall incidence and concerns about falling in non-ambulatory[90] and ambulatory[91] individuals with SCI. The results indicate that structured fall prevention education has the potential to reduce fall incidence and improve quality of life among both ambulatory and non-ambulatory individuals with SCI[90,91]. The results of these interventions suggest a need to continue exploring tailored multifactorial fall prevention programs to specifically target fall predictors among individuals with SCI. In addition, there is a need to develop or validate specific outcome measures with the ability to identify individuals at future risk of falls[8]. This would be important as validating outcome measures to identify individuals at risk of falls can guide the development of fall prevention programs. Validated outcome measures would also help to refer individuals at risk of falls to appropriate fall prevention programs.

The lessons learned from research among older adults can be applied to people with SCI, taking into consideration the specificity of this population. Further studies are warranted to continue identifying predictors of falls among people with SCI, identify the characteristics of specific groups of people who need fall prevention, and develop targeted fall prevention programs.

2.6. Falls in Individuals with Spinal Cord Injuries

Falls are one of the most common secondary complications for individuals with SCI leading to re-hospitalization[27]. Depending on the level of injury and type of injury, fall mechanisms differ greatly between ambulatory and non-ambulatory individuals with SCI.

2.6.1. *Falls and Fall-related Injuries in Ambulatory Individuals with SCI*

The incidence of falls is high among non-ambulatory individuals with SCI. Khan *et al.*[1] estimated that approximately 78% of ambulators experience at least one fall between 6 to 12 months. Most falls in this population occur at home (75%), during the morning or afternoon (81%), and while walking (47%)[92]. The consequences of those falls include physical injuries, development of FOF, vulnerability, frustrations, decline in overall functionality, and reduced quality of life[3,7,93]. A variety of factors have been identified as contributors of falls among ambulatory individuals with SCI. Biological factors including muscle weakness, spasticity, and balance impairment have been reported as factors leading to falls in this population, as well as behavioral factors such as inattention, FOF, and risk taking[1]. In addition, environmental factors including slippery surface, uneven ground, and low lighting have been reported as contributors of falls among ambulatory individuals with SCI[1].

Because of the detrimental consequences of falls in ambulatory individuals with SCI, several studies have focused on the identification of individuals at risk for falls and fall-related injuries using performance-based or self-reported measures[8,18,86,92]. These studies are important as they lead to the development of fall risk screening tools, which is an essential step in fall prevention. A recent systematic review and meta-analysis indicated that the Berg Balance Scale presented with moderate ability to discriminate ambulatory fallers and non-fallers with SCI[8]. Other laboratory-based and clinical measures, such as measures of lower extremity strength, cutaneous pressure sensitivity, walking speed, velocity in the mediolateral direction of center of pressure, cognitive-motor interference have been reported as fall risk predictors in this population[92,94]. Moreover, self-reported measures such as previous history of falls, FOF, and low general quality of life have been reported to discriminate ambulatory recurrent fallers and non-recurrent fallers[18,86].

Several predictors of fall-related injuries have also been reported among ambulatory individuals with SCI. Saunders *et al.*[95] reported perceived poor balance (OR 4.3, 95% CI 1.3 -

14), less exercise (OR 2.77, 95% CI 1.51 – 5.09), and pain medication misuse (OR 2.53, 95% CI 1.29 – 4.97) as strong predictors of fall-related injuries in this population. Also, Jørgensen *et al.*[86] reported FOF (OR 4.3, 95% CI 1.3 – 14) and history of recurrent falls in the previous year (OR 4.2, 95% CI 1.2 to 14) as predictors of fall-related injuries among ambulatory individuals with SCI. More recently, Cao *et al.*[96] indicated that the use of an assistive device is highly associated with fall-related injuries. The authors reported that ambulatory individuals with SCI who used one walking device had 194% greater number of injuries compared with those who used no device[96]. Also, ambulatory individuals with SCI who used multiple devices had 730% greater number of fall-related injuries when compared with those who used no device[96]. Furthermore, Cao *et al.*[96] found that walking and use of cane were associated with 214% and 160% greater number of fall-related injuries, respectively. As such, the use of walking device should be considered while developing fall risk screening for ambulatory individuals with SCI.

The next step towards effective fall prevention initiative is the development of targeted fall prevention programs for ambulatory individuals with SCI. There is a lack of evidence regarding interventions to reduce fall incidence or prevent falls in this populations. Amatachaya *et al.*[91] recently investigated the effect of a 4-week, 30 min per day, 5 days a week, walking training on fall incidence among ambulatory individuals with SCI. The authors evaluated the effect of walking training on a walking track with different surfaces including artificial grass, soft surfaces, and pebbles, compared to overground walking training on hard, flat, and smooth surfaces[91]. The authors reported a significant reduction of fall incidence after a 6-month follow-up among those individuals who underwent walking training on different surfaces compared to those who underwent overground walking training[91]. However, to date, this is the only study found in the literature specifically targeting fall incidence among ambulatory individuals with SCI. More research on the topic is therefore warranted.

2.6.2. *Falls and Fall-related Injuries in Non-Ambulatory Individuals with SCI*

Compared with research among older adults and ambulatory individuals with SCI, little is known about falls among non-ambulatory individuals with SCI. In the recent years, few studies have evaluated the incidence, circumstances, and characteristics of falls and fall-related injuries specifically among non-ambulatory individuals with SCI[16,19,20]. The studies that were conducted indicated that falls are frequent in this population and mostly occur inside of the house, during transfer activities, and are associated with environmental barriers[16,19,20]. Also, little is known about fall-related injuries among non-ambulatory individuals with SCI. Forslund *et al*.[16] and Nelson *et al*.[17] indicated that falls lead to minor injuries, such as cuts and bruising, to more severe injuries such as fractures and head concussions. However, the exploration of fall-related injuries among non-ambulatory individuals with SCI is still not exhaustive and deserves further consideration.

Few studies have specifically investigated predictors of falls in non-ambulatory individuals living with SCI[16-18]. Predictors of falls previously reported include pain in the previous two months, positive for alcohol use, greater motor function, previous falls, number of SCI years, shorter length of wheelchair, age, and sex[16-18]. Nelson *et al.* argued that most non-ambulatory individuals with SCI are males and generally active adults who are highly engaged in ADLs[17]. Those individuals with greater motor function, highly engaged in ADLs, and participating in sport activities may be at an increased exposure to falls[17]. The authors also highlighted pain reported in the previous two months as a significant fall risk predictor[17]. Pain may lead to a dysfunctional sitting posture in a wheelchair, resulting in decreased efficiency in movements during wheelchair activities such as transfers or reaching for an object. Nelson *et al.* also argued that alcohol use may result in impaired cognitive functions and behavior, which may increase exposure to falls[17]. Also, shorter length of the wheelchair, which allows for a more maneuverability, may make the wheelchair unstable and more prone to falls[17]. Nelson *et al.* provided comprehensive fall risk predictors in non-ambulatory individuals with SCI[17]. However, the study was conducted in 2010 and since then, the characteristics of individuals with SCI may have changed. For example, the mean age of individuals with SCI in the United States has changed from approximately 29 during the 1970s to 43 years old since 2015[26]. A more recent study investigating the predictors of falls is therefore necessary.

More recently, Forslund *et al.* reported falls in the previous year as the only significant predictor of recurrent falls among non-ambulatory individuals with SCI[16]. In another study conducted by the same research group, Jørgensen *et al.,* described age, sex, and greater mobility function as significant predictors of recurrent falls in this population[18]. The differences in the predictors of falls reported in both studies indicates that further investigation is warranted to identify as many as possible fall risk predictors in this population. An exhaustive list of fall risk predictors is necessary to develop effective fall screening tools to identify individuals at risk of falls.

Only two studies previously examined fall-related injuries in this population[16,17]. Predictors of fall-related injuries include general quality of life, pain in the previous two months, greater motor function, previous falls, and home entrance inaccessibility[16,17]. Nelson *et al.* argued that home entrance inaccessibility, for example, having steps at entrance could be highly related to more impactful falls resulting in injuries[17]. However, the authors did not specifically investigate whether the injurious falls occurred at the home entrance and did not discard home entrance inaccessibility as a spurious finding in their study[17]. Therefore, the authors recommended further investigation on characteristics and predictors of fall-related injuries in this population[17]. Forslund *et al.* reported general quality of life as the only significant predictor of fall-related injuries[16]. The authors argued that this may be because non-ambulatory individuals who experienced many falls have a lower quality of life[16]. The interpretation of this predictor is limited as quality of life is broad and encompasses several domains such as physical health, social relationships, psychological, and environmental. These results highlight the importance of further studies to explore predictors of fall-related injuries among non-ambulatory individuals with SCI. The validation of those predictors will contribute to the development of fall-related injuries screening tool specific for non-ambulatory individuals with SCI.

As a result of the few numbers of studies exploring incidence, characteristics, and predictors of falls and fall-related injuries among non-ambulatory individuals with SCI, there is a lack of interventions targeting prevention of falls and fall-related injuries in this population. Rice *et al.*[90] recently investigated a one time, 1:1, 45 minute fall management program focusing on transfer education and exercise to increase upper extremity strength and core stability among non-ambulatory individuals with SCI. After the initial education, participants were asked to integrate the education at home[90]. The authors reported a significant decrease in fall incidence and improved sitting balance 12 weeks after exposure to the intervention[90]. The study, designed as a pre-post pilot, provided important preliminary data but, larger randomized clinical trials are necessary to confirm the results.

In summary, few studies have explored the characteristics and predictors of falls and fall-related injuries among non-ambulatory individuals with SCI. To reduce incidence of falls and fall-related injuries in this population, research efforts should be made to better understand the characteristics surrounding those falls. Then, further studies should identify and report predictors of falls and fall-related injuries. The next step should involve the development of effective fall risk screening tools to identify individuals at high risk of falls. Lasty, further studies should develop targeted fall prevention programs based on the factors and predictors associated with falls and fall-related injuries. My research proposal was developed with the purpose of characterizing falls and fall-related injuries. This study also aims to explore outcome measures with the ability to effectively identify non-ambulatory individuals with SCI at high risk of falls. The results of this study will serve to develop effective fall risk screening tools. In the future, this research will be important to inform the development of tailored, multifactorial fall prevention programs, for individuals with a high risk of falls.

CHAPTER 3. PRELIMINARY RELIABILITY AND VALIDITY OF REMOTE SITTING BALANCE ASSESSMENTS AMONG WHEELCHAIR USERS[1]

3.1 Introduction

Impaired seated posture is a common limitation and an intrinsic fall risk among wheelchair users living with spinal cord injury (SCI) or multiple sclerosis (MS)[19,89]. Approximately, 60% of individuals with SCI rated recovery of seated posture as a high priority function to regain functional independence and improve quality of life [97]. The ability to maintain a seated posture is essential to perform daily living activities in a wheelchair including transfers and reaching activities[98,99]. Thus, for wheelchair users with a chronic and non-progressive disease, maintenance and recovery of seated posture is important for performance of common activities of daily living and a common goal. As a result, proper evaluation is important in clinical settings.

The appropriate assessment of seated posture is essential to guide rehabilitation goals and development of effective interventions[100]. Recently, efforts have been made by researchers to improve the evaluation of seated posture among wheelchair users through technology including motion sensors embedded within mobile smartphone[13], force plate based posturography[51], three-dimensional motion capture[52], and clinical balance outcome measures, including but not limited to, the Trunk Control Test (TCT), Function in Sitting Test (FIST), Sitting Balance Measure, and the T-shirt Test[55,60,62]. Technology based seated postural control assessment are objective and sensitive to impairment but require expertise and might be difficult to be implemented in clinical settings. Meanwhile, clinical balance outcome measures are easy to administer in clinical settings but they are subjective and sometimes lack sensitivity[101]. Both technology based and clinical

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seated postural control assessments have been developed to be performed face-to-face between clinicians and wheelchair users.

Unfortunately, many individuals with mobility limitations, including individuals who use a wheelchair on a full-time basis, are unable to travel to healthcare facilities, especially those who are required to travel long distances[102]. Additionally, during a health crisis, like the COVID-19 pandemic, face-to-face visits in clinical settings and research laboratories are significantly reduced[103]. Individuals at high risk of contracting infectious disease, including wheelchair users living with SCI and MS, are advised to practice social isolation and social distance during a pandemic. These circumstances reduce clinicians and researchers' opportunities to perform face-to-face evaluations. A potential solution to overcome the aforementioned barriers may be the implementation of telerehabilitation and telehealth through the use of remote video-based research visits. Indeed, with the COVID-19 pandemic, the value of telerehabilitation has become clear[104,105].

Outcome measures completed during in-person assessments can be modified to be conducted during remote assessments. Previous studies have demonstrated the feasibility and utility of telerehabilitation among wheelchair users with SCI[106] and MS[107]. However, the studies have focused solely on patient-reported outcome measures and phone or videocall follow-up consultations to check on participant's satisfaction about rehabilitation service, and not on physical assessment such as balance assessments[106,107]. To the best of our knowledge, no published studies have yet compared the level of agreement between in-person and remote sitting balance assessments among individuals who use a wheelchair on a full-time basis. This represents a gap in knowledge that needs to be established prior to implementing telerehabilitation into standard clinical practice.

Therefore, the purpose of this preliminary study was to investigate the feasibility and preliminary concurrent validity of remote sitting balance assessment and to determine the level of agreement between in-person and remote sitting balance assessments among wheelchair users. The authors hypothesize that remote assessment of sitting balance will present with a good level of agreement with an in-person assessment. This hypothesis was established because the items of the selected sitting balance measures are clear and straightforward to score and do not require use of specialized equipment.

3.2. Methods

3.2.1. *Participants*

Eleven non-ambulatory adults recruited from the local community who participated in a previous in-person seated posture assessment study were contacted and invited to participate in this remote assessment[13]. To be eligible, participants were required to be at least 18 years old, use a wheeled mobility device for their main form of mobility, able to sit unsupported for at least 30s, and able to communicate with the research group through a video conference software (e.g., Zoom or FaceTime). Participants unable to sit upright for at least 30 min and participants unable to lift their arm above their shoulder were excluded from the study. This study was approved by the local Institutional Review Board of the University (Reference #19387) and all participants provided informed consent before engaging in the remote research activities.

3.2.2. *Feasibility*

A feasibility study was conducted to analyze whether remote assessment is appropriate to evaluate sitting balance among wheelchair users with SCI and MS using the FIST, the TCT, and the T-shirt test. Six feasibility indicators previously used to assess feasibility of remote basic wheelchair skills among wheelchair users were analyzed [108]. These indicators include recruitment rate, retention rate, internet access, data collection burden, adherence, and study protocol. Definitions and parameters of success of the feasibility indicators are described in Appendix A.

3.2.3. *Research protocol*

The procedures for the in-person seated posture assessment are fully described elsewhere[13]. For this remote assessment, after participants signed the online informed consent document, a research assistant reached out to them to schedule a time to conduct the remote assessment using the participant's preferred video conference platform. On the assessment day, a video conference call was set up. Each participant had their own, unique meeting code and were required to enter a password to enter the meeting. In addition, the screen sharing option was disabled. At the start of the meeting, the participant first entered a waiting room and then was admitted by the host to assure that only the host and the participant have access to the meeting. After the participant entered the meeting, the meeting was locked so that no one else could join. Only the participant, the researcher, and any additional researcher were allowed to participate in the remote assessment. After the video call was set, participants were asked to show a surface such as a bed, sofa, or bench without a backrest where they could sit and perform the sitting balance assessments. According to the position of the bed, sofa, or bench, general instructions were given to the participants on how to position their web camera for the remote assessment. Then, participants were asked to transfer from their wheelchair to the assessment surface. After, participants sat on the assessment surface and maintained their hips and knees flexed at approximately 90°. A step/stool was used for positioning and foot support when needed. The trained research assistant provided feedback on the positioning of the camera and adjustments so that the participant full body was in frame. Participants were asked to position their web camera lateral to their sitting position for the remote sitting balance assessments. After sitting with their best posture and the web camera adjusted, general instructions were given to the participants about the safety procedures of the remote sitting balance assessment. To maximize safety and minimize the risk of falling, participants were instructed that if they did not feel secure doing any of the sitting balance activities, they could decline to perform the assessment.

After instructions were given to the participants, a research assistant who assessed participants' seated posture during the in-person assessment conducted all the procedures for the remote seated posture assessment. The seated posture assessment includes the assessment of the clinical sitting balance outcome measures described below:

Function in Sitting Test (FIST)

The FIST assesses static and dynamic balance control while performing 14 common activities of daily living such as sitting with eyes closed and open, reaching for an object, and scooting[68]. The FIST was validated for use among non-ambulatory individuals with SCI[55] and MS[109]. Each of the 14 items on the FIST is scored on a scale of 0 to 4. Scores range from 0 to 56, 0 indicates an inability to perform any of the sitting tasks, and 56 indicates a full ability to perform all the tasks[110]. Higher scores indicate better balance performance. To perform the remote assessment, participants were asked to provide a small object such as a set of keys or a pen. Specific modifications were needed to complete this test remotely. Anterior, posterior, and lateral nudges could not be performed remotely. Instead, trunk sudden displacement and recovery assessed during the nudges in forward, posterior, and lateral directions were observed and scored during the performance of the forward reach, lateral reach and pick-up object from behind items, respectively. In addition, participants were asked to purposefully put an object (set of keys or pen) behind their back and drop the same object on the floor before performing the 'pick-up object from behind 'and 'pick- up object from the floor' items, respectively.

Trunk Control Test (TCT)

This test measures static and dynamic balance control while performing 13 tasks including maintaining a sitting position for 10 seconds, touching the feet, rolling, and reaching activities[67]. Each of the 13 items on the TCT is scored on a scale of 0 to 2 except for the rolling items which are scored on a scale of 0 to 1. A total score ranging from 0 to 24 is obtained, with higher scores indicating better balance performance. No equipment was needed to perform the remote assessment of the TCT. However, participants were asked to reach in different directions as far as possible without losing balance for the reaching tasks. This modification replaced the use of a cardboard target for the reaching tasks in the TCT.

T-shirt Test (TST)

This test measures the time taken by the participants to put on and take off a t-shirt[62]. Participants wore their regular clothing for the duration of the test and were asked to put a t-shirt on over their clothing. Participants were asked to spread out a t-shirt flat on their laps. A chronometer was used to time the test. Timing started when participants were told to put-on the t-shirt and ended when participants pulled down the t-shirt and adjusted it. The time required to take-off the shirt and regain a stable position was also measured. The test was repeated 3 times.

The average time was calculated for each component (don and doff) and the total time. Participants were requested to use a t-shirt one size larger than their normal size. Shorter time indicated better performance. To perform the remote assessment, participants were asked to provide a t-shirt one size larger than they normally wear. No specific modifications were required to complete the t-shirt test.

3.2.4. *Statistical Analysis*

Descriptive statistics were calculated to characterize the sample. The pairwise t-test was performed to calculate the mean difference (MD) and 95% confidence interval (CI) between in-person and remote assessments to investigate concurrent validity of the remote sitting balance assessment using the FIST, TCT, and T-shirt Test[111]. Intraclass coefficient correlation (ICC) was calculated to investigate the agreement between the sitting balance outcome measures' scores obtained by in-person and remote assessments. The magnitude of the ICC was interpreted as follows: very high (ICC ≥ 0.90), high (0.7 ≤ ICC ≤ 0.89), moderate (0.5 ≤ ICC ≤ 0.69), low (0.26 ≤ ICC ≤ 0.49), and very low (ICC ≤ 0.25)[112]. In addition, a Bland-Altman graph analysis was performed, and limits of agreement (2 SD above and below of the MD) were calculated[113]. All analysis were performed using SPSS software version 25 (IBM, Chicago, USA) with a significance level of $\alpha = 0.05$.

3.3. Results

From the eleven non-ambulatory individuals who performed the in-person assessment and were contacted and invited, seven participants (mean age: 42.7 ± 19.74 years; gender: 2 males, 5 females) agreed to participate in the remote assessment and repeated the seated posture assessment. One participant declined participation in the remote assessment without providing a specific reason and 3 participants did not respond to repeated contact via multiple modalities phone calls, texts, and emails. From the 7 included participants, three were diagnosed with multiple sclerosis and 4 participants had a spinal cord injury. Description of participants' data is presented in Table 2.

Table 2. Descriptive characteristics of the participants

ID	Sex	Age (years)	Injury/Disease	Level of injury	Type of WC
P1	F	61	Multiple sclerosis	N/A	Power
P2	F	23	Spinal cord injury	T10	Manual
P3	M	47	Spinal cord injury	N/R	Manual
P4	M	74	Multiple sclerosis	N/A	Power
P5	F	43	Multiple sclerosis	N/A	Power
P6	F	29	Spinal cord injury	T12	Manual
P7	F	22	Spinal cord injury	T4	Manual
Total (Mean ± SD)	-	42.7 ± 19.74	-	-	-

F: female, M: male, n/a: not applicable, n/r: not reported, P: participant, SD: standard deviation, WC: wheelchair

3.3.1. *Feasibility indicators*

The definitions, parameters of success, and results of the feasibility indicators are presented in Table 1. Six of the 6 (100%) feasibility indicators analyzed (recruitment rate, retention rate, internet access, data collection burden, adherence, and study protocol) were achieved. Based on a previous study on remote wheelchair skills, success is achieved for a feasibility study when 77% or more feasibility indicators are met [108]. The 100% success based on the 6 feasibility indicators analyzed in our study indicates the remote sitting balance assessment among wheelchair users is feasible.

3.3.2. *Validity and reliability*

A summary of the concurrent validity and reliability between in-person and remote sitting balance assessments are presented in Table 3. No significant differences were observed between the mean scores obtained by in-person and remote assessments of the FIST (MD = 0.71; 95% CI, -1.26 to 2.7, $p = 0.41$), TCT (MD = 0; 95% CI, -0.92 to 0.92, $p = 1$), and the T-shirt Test (MD = 4.76; 95% CI, -1.39 to 10.91, $p = 0.11$). In addition, very high agreement was found between in-person and remote assessments using the FIST (ICC = 0.98; 95% CI, 0.88 to 0.99, $p < 0.001$), TCT (ICC = 0.982; 95% CI, 0.9 to 0.99, $p < 0.001$), and high agreement between both in-person and remote T-shirt Test assessments (ICC = 0.88; 95% CI, 0.3 to 0.98, $p = 0.01$).

Table 3. Results of the concurrent validity and reliability between in-person and remote assessments

Outcome measure	In-person assessment *(mean ± SD)*	Remote assessment *(mean ± SD)*	Pairwise t-test *MD (95% CI)*	Intraclass coefficient correlation *ICC (95% CI)*
FIST	47.14 ± 1.7	46.43 ± 7.7	0.71 (-1.26, 2.7)$^{\Delta}$	0.98 (0.88, 0.99)**
TCT	18.71 ± 3.55	18.71 ± 3.95	0 (-0.92, 0.92)$^{\Delta}$	0.982 (0.9, 0.99)**
T-shirt Test	20.73 ± 11.28	15.97 ± 8.86	4.76 (-1.39, 10.91)$^{\Delta}$	0.88 (0.3, 0.98)*

CI: confidence interval, FIST: function in sitting test, ICC: Intraclass coeficient correlation, MD: mean difference, SD: standard deviation, TCT: trunk control test
$^{\Delta}$ $p > 0.05$
* $p = 0.01$
** $p < 0.001$

Furthermore, the Bland-Altman analysis of the FIST, TCT, and the T-shirt Test revealed that 95% of the difference scores between both in-person and remote assessments would fall within the 95% limits of agreement. Figure 3 shows the Bland-Altman graph between both in-person and remote FIST assessments. The results revealed that the difference between both assessments can be expected to vary between 0.71 ± 4.1 points, or between -3.4 and 4.8 points, a range of approximately 8 points. The sample differences did not exceed 5 points in the FIST score, and we are 95% confident that differences between both FIST assessment methods will not exceed 8 points in this population.

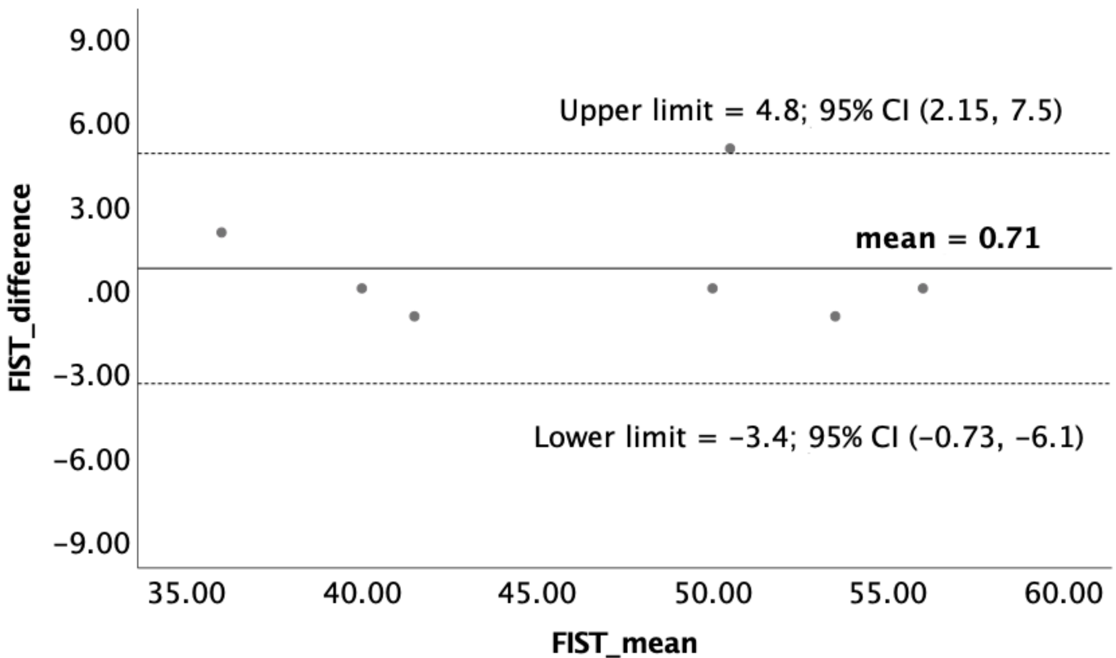

Figure 3. Bland-Altman for in-person and remote assessments of the FIST

Figure 4 shows the Bland-Altman graph between both in-person and remote TCT assessments. The results revealed that the difference between both assessments can be expected to vary between 0 ± 1.96 points, or between -1.96 and 1.96 points, a range of approximately 4 points. The sample differences did not exceed 2 points in the TCT score, and we are 95% confident that differences between both TCT assessment methods will not exceed 3 points in this population.

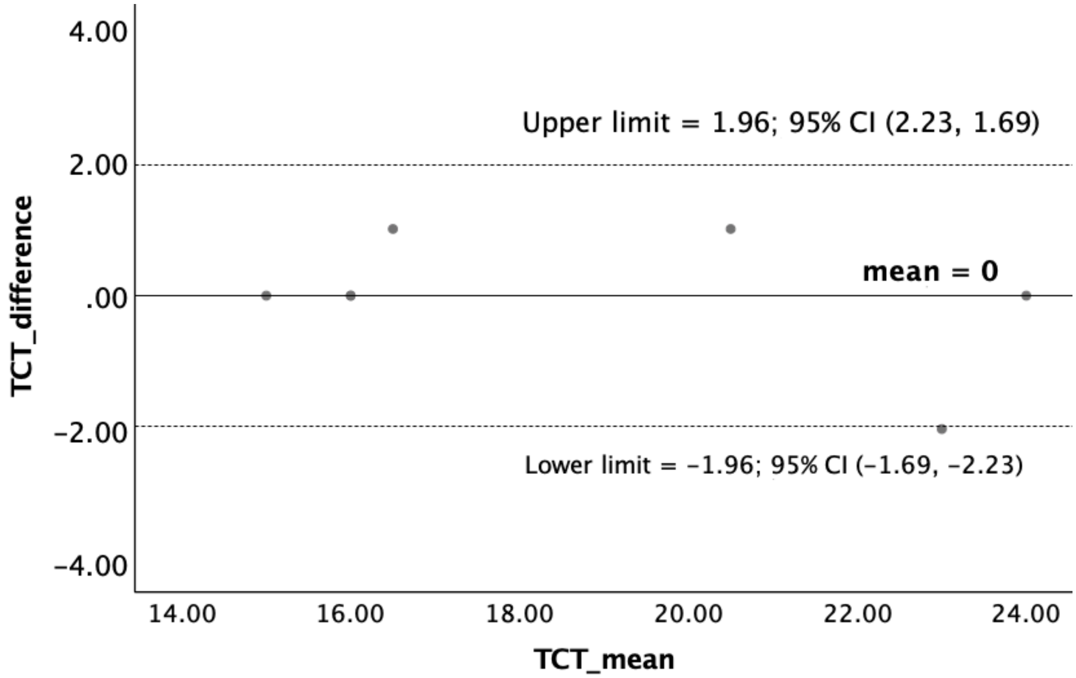

Figure 4. Bland-Altman for in-person and remote assessments of the TCT

Figure 5 shows the Bland-Altman graph between the in-person and the remote T-shirt Test assessments. The results revealed that the difference between both assessments can be expected to vary between 4.76 ± 11.70 s, or between -8.8 s and 17.8 s, a range of approximately 26 s. The sample differences did not exceed 18 s in the T-shirt Test score and we 95% confident that differences between both TCT assessment methods will not exceed 26 s in the population.

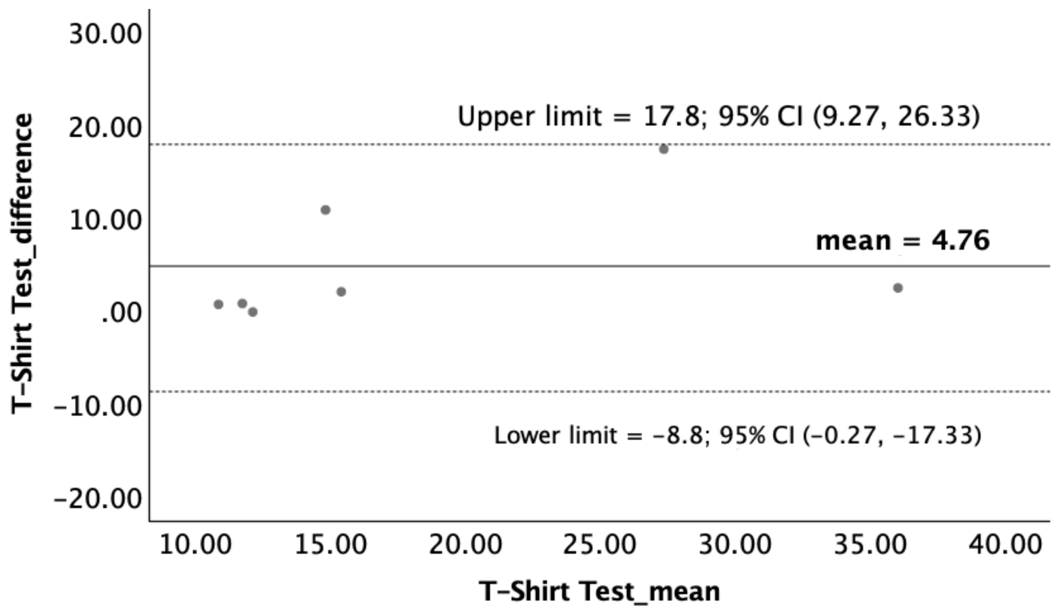

Figure 5. Bland-Altman for in-person and remote assessments of the T-shirt Test

3.4. Discussion

Remote assessments have benefits for reducing the burden on clients and research participants with SCI and MS who use a wheelchair. The results of this study indicated that remote assessment with the FIST, TCT, and T-shirt Test is feasible, valid, and a reliable method to assess sitting balance assessments among full time wheelchair users living with MS and SCI. The 100% success of the 6 feasibility indicators analyzed in this study confirms the feasibility of remote sitting balance assessment. In addition, no difference was found between in-person and remote sitting balance assessments, and the agreement between both methods ranged from high to very high for the balance outcome measures used. Preliminary results indicate that remote use of the FIST, TCT, and T-shirt Test have the potential to accurately assess sitting balance among full time wheelchair users living with MS and SCI. Remote assessment could be a valuable method for assessing sitting balance among wheelchair users. This approach is important to the practice of telehealth and telerehabilitation during a pandemic, such as the 2020 COVID-19 pandemic, when in-person contact should be limited. In addition, such an approach has value for people living in rural areas and people with a lack of transportation.

The validity of the remote sitting balance assessment was assessed through concurrent validity. Our results indicate that the FIST, TCT, and T-shirt Test present with appropriate concurrent validity to remotely assess sitting balance among wheelchair users. We found no significant difference in the mean scores of in-person and remote assessments. A previous study has validated tele-assessment of the Berg Balance Scale among individuals with motor function limitations including standing balance limitations by reporting a negligible difference between in-person and tele-assessment[114]. However, to the best of our knowledge, this is the first study to validate a remote assessment of sitting balance among wheelchair users.

In addition, the reliability of the remote sitting balance measures was assessed through agreement analysis between both in-person and remote assessments. Our results show that in-person and remote sitting balance assessments using the FIST have excellent agreement (ICC = 0.98). The sample differences between in-person and remote assessments did not exceed 5 points in the FIST score. This score of 5 points is similar to the minimal detectable change (MDC) of the FIST established for individuals with stroke ($MDC_{stroke} = 5.5$)[115]. and close to the MDC established for individuals with SCI ($MDC_{SCI} = 4$)[55]. A difference of up to 5 points is still acceptable within the limits of true changes that the FIST is able to detect. This confirms the agreement between the in-person and remote sitting balance assessments among wheelchair users using the FIST. However, more research is needed to establish the minimal clinical important difference (MCID) of the FIST in a variety of wheelchair users before it can be recommended for a remote seated postural assessment among wheelchair users.

Additionally, the sample differences between both in-person and remote assessments using the TCT did not exceed 3 points. The MDC and MCID have not been established for the TCT; therefore, it is not possible to verify the true measurement error of the test based on the sample mean difference of 3 points between the in-person and the remote assessments. However, the agreement between in-person and remote sitting balance assessment using the TCT was excellent (ICC = 0.982). In addition, there was no difference between in-person and remote sitting balance assessment using the TCT (MD = 0). This result confirms the agreement between the in-person and remote sitting balance assessments among wheelchair users using the TCT.

Finally, the sample differences between in-person and remote assessments using the T-shirt test did not exceed 18s. A difference of 18s between in-person and remote assessments might appear to be high, however, an MDC and MCID are still yet to be established for the T-shirt Test to verify the true measurement error of the test. Nevertheless, the T-shirt Test shows a good agreement between both in-person and remote assessments (ICC = 0.88). Based on this high agreement level between in-person and remote assessments, the T-shirt Test presents with potential to be considered a reliable remote sitting balance assessment among wheelchair users. However, additional more research is warranted to establish the true measurement error of this measure before it can be recommended to assess remote seated postural control among wheelchair users.

The major strength of the present study relies on its effort to validate a remote assessment of sitting balance outcome measures among wheelchair users. The FIST, TCT, and T-shirt Test are simple, easy, and quick to administer sitting balance measures that have been validated for clinical use among wheelchair users with SCI and MS[55,62,109]. In both clinical and research contexts, in-person assessments are at times not possible because of limited availability of accessible transportation, time requirements and involved expenses, such as fuel and parking fees[102]. Remote assessment could also minimize challenges related to inaccessible environments and unstable medical conditions. In addition, given the likely ongoing nature of the COVID-19 pandemic and associated social distance requirements for vulnerable individuals, remote assessments could be an excellent alternative for monitoring patients and participants status.

3.5. Limitations

This study presents with several limitations. First, the small sample of participants recruited limits the generalizability of the findings. This is because the remote assessment was based on an initial in-person study of a small sample size of 11 participants[13]. The need for this preliminary investigation surged because of the COVID-19 pandemic. Therefore, this study suggests future studies to evaluate the psychometric properties of remote seated postural control assessment among a broader sample of wheelchair users. Future studies should also have the participant's assistant or caregiver apply the nudges during the remote FIST assessment. Another limitation of this study was the fact that participants were remotely assessed approximately 32 weeks after the in-person assessment. This reduces the homogeneity of the assessments. During this period of time, several participants might have improved their sitting balance through trainings, or their balance abilities might have worsened, especially those with multiple sclerosis. Ideally, a period of 14 days is recommended between the initial assessment and the re-assessment in attempt to replicate the same conditions as the initial assessment[116]. However, the high level of agreement between both assessments after approximately 32 weeks indicates an excellent reliability of the remote sitting balance assessment with the FIST, TCT, and T-shirt Test. Also, the 32 weeks' time frame assessment indicates that these sitting outcome measures can be used for a long-term follow-up. It was also challenging to standardize the placement of the camera during the remote assessment. The placement of the camera varied according to the space available in participant's homes. Finally, it was challenging to standardize the surface where the sitting balance assessments were performed. Some participants performed the assessments in their sofa while others performed the assessments in their beds. The difference in the stability on a bed compared to a sofa may influence the results presented in this study. Further studies should work to standardize the placement of the camera and the surface on which the assessments are performed remotely.

3.6. Conclusions

Preliminary results found the remote assessment of clinical balance measures to be feasible. The results also showed preliminary evidence of validity and reliability of remote seated postural control assessment among wheelchair users with SCI and MS. This preliminary study indicates that remote assessment is feasible to perform and could be a viable and valuable telehealth approach for monitoring sitting balance in this population. The FIST, TCT, and T-shirt Test have the potential to be used for monitoring wheelchair users, screening potential participants in research studies, and assessing the effectiveness of clinical and research interventions. Remote assessment also provides clinicians with the opportunity to continue therapeutic treatments when an in-person assessment is not possible. Future work should continue to evaluate remote assessments in broader wheelchair populations. This is valuable to maintain telehealth and telerehabilitation during a pandemic such as the current COVID-19 pandemic.

CHAPTER 4. FREQUENCY AND CHARACTERISTICS OF FALLS, FALL-RELATED INJURIES, AND FEAR OF FALLING AMONG WHEELCHAIR USERS WITH SPINAL CORD INJURY

4.1. Introduction

Recent estimates indicate that the number of individuals living with spinal cord injury (SCI) in the United States is approximately 296,000 persons, ranging from 252,000 to 373,000 persons[26]. Among them, 47.4% present with incomplete tetraplegia, 20.3% with incomplete paraplegia, 19.9% with complete paraplegia, and 12.4% with complete tetraplegia[26]. Most of these individuals who are non-ambulatory will use a wheelchair to support their mobility. Non-ambulatory individuals are commonly defined as individuals unable functionally to ambulate and self-report as full-time power or manual wheelchair users[55,117].

Falls are a major health concern in this population. It is estimated that approximately 69% (95% CI 60% - 76%) of non-ambulatory individuals with SCI experience at least one fall over a period of 6 to 12-month[1]. Falls may result in physical injuries, including minor injuries such as bruising or more serious injuries such as fractures or head concussions. For example, in an individual with SCI, a fall might result in a 4 to 8-week hospital stay with significant time on bed rest which often leads to immobilization, loss of strength, and blood clots[118]. In addition to physical injuries, falls may lead to fear of falling (FOF) that can affect the performance of activities of daily living (ADLs), quality of life, and restrict the social participation of non-ambulatory individuals with SCI[2,3].

Thus, it is important to identify and document risk factors of falls and fall-related injuries in order to develop effective fall prevention programs for this population. Compared to older adults[5,6], ambulatory individuals with SCI[8,86], or other neurologic populations[7,119,120], limited research exists on predictors of falls in non-ambulatory individuals with SCI[16-18]. In addition, fall-related injuries in this population have not been thoroughly described in the literature[16]. Previous research has reported that most falls experienced by non-ambulatory individuals with SCI occur inside of the house, during transfers, and are associated with environmental hazards encountered in the domestic environment[16,19,20]. Despite the increased interest in the field of fall prevention in this population, further studies have been recommended to better understand the full spectrum of falls and fall-related injuries[1,16].

Furthermore, the consequences of FOF among non-ambulatory individuals with SCI have not been fully described in the literature[3,19]. Sung *et al.*[2] recently reported associations between FOF, quality of life, and social participation of wheelchair users with various health conditions resulting in disability including individuals with SCI. The authors indicated significant differences in quality of life and social participation between non-ambulatory individuals who reported FOF and those who did not[2]. Among non-ambulatory individuals living with multiple sclerosis, there is evidence that FOF is highly associated with activity curtailment, leading to dependence, and reduced quality of life[3,4,7]. However, no research has been conducted to examine the influence of FOF on the performance of ADLs, specifically among non-ambulatory individuals with SCI. Furthermore, there is a gap in the literature on the development of fall prevention programs and on the effectiveness of interventions to reduce FOF among non-ambulatory individuals with SCI.

The objective of this study is to provide insights on frequency and characteristics of falls, injurious falls, fall-related injuries, FOF, and activity limitations due to FOF among non-ambulatory individuals with SCI. As a secondary aim, we sought to investigate the relationship between education on fall prevention, FOF, frequency of falls, injurious falls, and activity curtailment in this population. Based on the findings from previous studies[16,19,20], the authors hypothesized that falls, fall-related injuries, FOF, and activities limited due to FOF will be commonly reported by the participants of the study.

4.2. Methods

4.2.1. *Study design and setting*

This observational, cross-sectional study is part of the Prediction of Falls among non-ambulatory individuals living with SCI (Predi Falls-SCI) study. Predi Falls-SCI aims to identify factors related to falls among non-ambulatory individuals living with SCI. An online survey was conducted between January 2021 and July 2021 in the U.S. The study was reviewed and approved by the Office for the Protection of Research Subjects at the University of Illinois at Urbana-Champaign (#20718). All participants provided written informed consent before taking part in the study.

4.2.2. *Participants*

Participants were invited to take part in the study if they met the following inclusion criteria: (1) 18 years old or over; (2) self-reported SCI, (3) at least 12 months after onset of injury; (4) motor complete injury classified as AIS A or B; (5) level of injury between C5 and above L5; (6) self-report use of a wheelchair for at least 75% of mobility, (7) able to communicate with the research team through smartphone or laptop video conferencing software, and (8) able to understand English. Participants were excluded if they were classified as AIS E or present with additional medical conditions that might affect their ability to appropriately read and understand instructions. Athletes participating in sports leading to frequent falls, such as wheelchair basketball, were also excluded.

4.2.3. *Study protocol*

Recruitment strategies included sending emails to SCI support groups across the US, Facebook posts, personal communication with administrators of SCI rehabilitation centers, and magazine/newsletter advertisements. SCI advocacy groups were also asked to assist with recruitment by posting information about the study on their social media channels and websites. Individuals interested in participating called, texted, or emailed the research team to indicate their interest. Potential participants were screened over the phone using a specific phone screening script developed by the research team (Appendix B). Participants were asked to self-report their age, SCI level, type of SCI, and if use of a wheelchair is their primary source of mobility (self-reported use of a wheelchair for at least 40 hours per week). If the potential participant was found to be eligible for the study, the research procedures were explained, along with potential risks. An opportunity was provided for the participants to ask questions to the research staff. After completion of the initial phone call, an online consent form was sent to the potential participants. The informed consent, along with other study related assessments, were completed using the platform REDCap. REDCap is a web-based, secure, HIPAA compliant, data capture and management application. Participants were asked to review the consent and encouraged to follow up with the research team regarding any additional questions or concerns. Once all questions were addressed, participants wishing to participate in the study were given the opportunity to electronically sign the informed consent document. Next, participants were asked to confirm eligibility criteria and complete the main survey which included sociodemographic and fall-related questionnaires.

Sociodemographic questions included sex, age, race, height, weight, type of mobility aid (manual or power wheelchair), etiology of SCI (traumatic or non-traumatic), time since SCI, and level of SCI. The fall-related questionnaires included customized questions related to falls, fall-related injuries and FOF.

First, participants self-reported the number of falls experienced in the previous 6 months (if any). A fall was operationally defined as an unintentional event in which one comes to rest on the ground, floor, or other lower level[121]. Participants were then asked to report on the specific locations where their most recent fall occurred. Participants were also asked to describe the actions they were doing, and the circumstances associated with the most recent fall that they could remember in the previous 6 months.

In addition, participants were asked to report on their most recent fall-related injuries experienced in the previous 6 months, if any, and the nature of the injury (e.g., bruising, fracture, etc.). Based on the description, fall-related injuries were classified as minor, moderate, or severe as previously suggested and defined by Schwenk et al[122]. Examples of minor injuries included bruises, scratches, or minor abrasions; moderate injuries included abrasions, lacerations, or sprains; and severe injuries included fractures or head concussions[122].

Finally, participants were asked to respond to two questions related to FOF and associated activity curtailment: 1- “Are you afraid or concerned about falling?” 2- “Do you think your fear of falling has made you cut down on any activities you used to do?”. Participants were also asked to report if they ever received education on fall prevention from a professional, such as therapist or physician.

4.2.4. *Data analysis*

All statistical analyses were performed using IBM-SPSS for Macintosh (Version 25, SPSS Inc, Chicago, IL, USA). The Kolmogorov-Smirnov test was used to assess data distribution. The data was found to be non-normally distributed, therefore, non-parametric statistics, median and interquartile range, were used to characterize continuous variables. Categorical variables were presented as count and frequency. Previously described codes by Sung *et al*.[19] and Singh *et al*.[20] were used to classify specific locations and contributors of falls based on the description of the falls provided by our study participants. Examples of specific locations of falls included bedroom, bathroom, or garage and contributors of falls included surface conditions, no use of seat belt, or obstacle in the way[19,20]. Participants were classified as "fallers" if they reported experiencing at least one fall in the period of 6-month and "non-fallers" if they did not report any falls in the 6-months prior to data collection. Differences between fallers and non-fallers participants were explored using the Mann-Whitney U test for continuous variables and Chi-square tests for categorical variables. Fisher's exact test was used to analyze differences between groups of categorical variables with few persons (< 5). Bivariate logistic regression analyses were used to explore the relationship between FOF (Yes/No), education about fall prevention (Yes/No), activity curtailed due to FOF (Yes/No), fall-related injury (Yes/No), and falls (Yes/No). Individual missing data were excluded on a case-by-case basis from the analysis. Crude falls rate was calculated using the following formula:[123]

Crude falls rate = total number of falls/total number of participants.

Falls rate per person-year was calculated using the following equation:[123]

Falls rate per person year = (total number of falls/total number of person- days) multiplied by 365.

Statistical level of significance was set at $p < 0.05$ for all the analyses.

4.3. Results

4.3.1. *Participants*

A total of 145 individuals showed interest in participating in the study and contacted the research team. After initial screening, 70 individuals met the eligibility criteria, agreed to participate, and signed the online informed consent. Eleven (15.7%) participants did not complete the survey and were therefore removed from the final analyses through listwise deletion. A total of 59 participants provided complete answers to the survey and were included in the study. Figure 6 illustrates the flow of study participants. The sociodemographic and SCI clinical characteristics of these 59 participants categorized as fallers and non-fallers are summarized in Table 4. In addition, the sociodemographic and SCI clinical characteristics of the participants who have experienced at least one fall, categorized based on injury status, are summarized in Table 5. No statistically significant differences were found regarding the sociodemographic and SCI clinical characteristics between fallers VS non-fallers, and between injured VS not injured (See Tables 4 and 5). A trend in the data ($p = 0.06$) was found between sex and time since injury between fallers and non-fallers (Table 4).

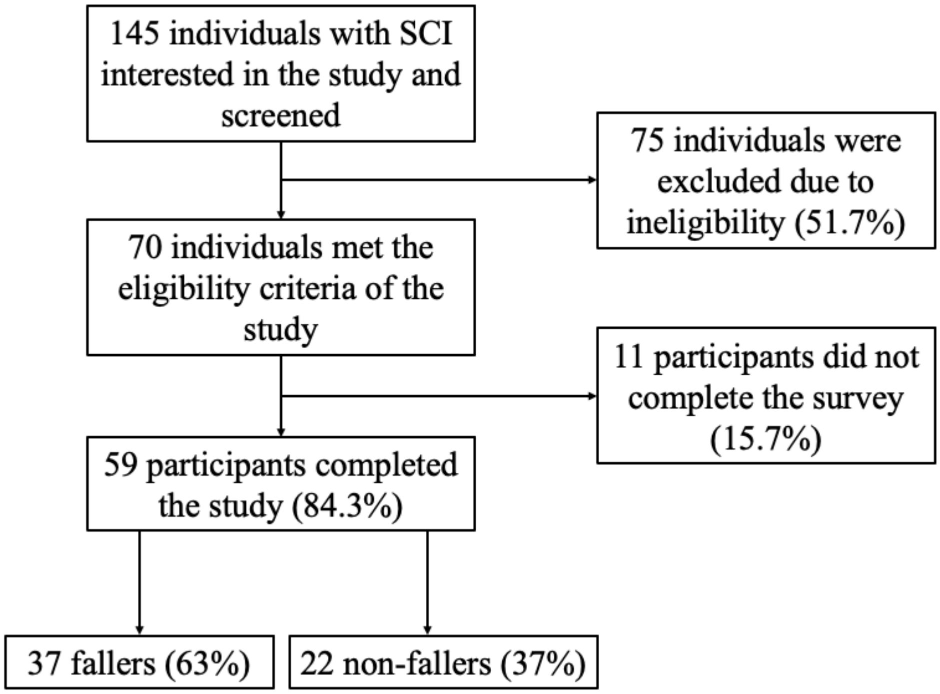

Figure 6. Flowchart of study participants

Table 4. Characteristics of study participants (fallers and non-fallers): results are expressed as frequencies and percentages for categorical variables and Median (IQR) for continuous variables.

Characteristics	Total sample (n = 59)	Fallers (n = 37, 63%)	Non fallers (n = 22, 37%)	*p*-value
Sex, n (%)				
Male	28 (47.5)	21 (56.8)	7 (31.8)	0.06
Female	31 (52.5)	16 (43.2)	15 (68.2)	
Age, y				
Median (IQR)	52.5 (21)	51 (22)	53 (17)	0.23
Min-max	19 - 72	19 - 69	26 - 72	
Race, n (%)				
Asian	3 (5.1)	3 (8.1)	0 (0)	0.56
African American	6 (10.2)	4 (10.8)	2 (9.1)	
Caucasian	48 (81.4)	29 (78.4)	19 (86.4)	
Hispanic	2 (3.4)	1 (2.7)	1 (4.5)	
Height (cm)				
Median (SD)	171.5 (17.1)	173 (19)	170.2 (19)	0.77
Min-max	137.2 - 190.5	137.2 - 190.5	147.3 - 188	
Weight (Kg)				
Median (IQR)	75 (27)	71.4 (29)	78 (26)	
Min-max	42 - 125	42 - 120	55 - 125	0.33

Table 4 (cont.)

Mobility aid, n (%) Power WC Manual WC	 17 (28.8) 42 (71.2)	 8 (21.6) 29 (78.4)	 9 (40.9) 13 (59.1)	 0.11
Cause of SCI, n (%) Traumatic Non-traumatic	 43 (72.9) 16 (27.1)	 25 (67.6) 12 (32.4)	 18 (81.8) 4 (18.2)	 0.23
Time since injury, y Median (IQR) Min-max	 16.5 (27.25) 0.5 - 57	 11 (27.75) 1 - 54	 23.5 (27.25) 0.5 - 57	 0.06
Level of injury, n (%) Cervical High thoracic Low thoracic Lumbar Unknown	 13 (22) 15 (25.4) 22 (37.3) 5 (8.5) 4 (6.8)	 5 (13.5) 12 (32.4) 14 (37.8) 3 (8.1) 3 (8.1)	 8 (36.4) 3 (13.6) 8 (36.4) 2 (9.1) 1 (4.5)	 0.24

IQR: interquartile range, SCI: spinal cord injury, WC: wheelchair, y: years

Table 5. Characteristics of study participants who have experienced at least one fall based on injury status: results are expressed as frequencies and percentages for categorical variables and Median (IQR) for continuous variables.

Characteristics	Total sample (n = 30)	Injured (n = 14, 46.7%)	Not injured (n = 16, 53.3%)	*p*-value
Sex, n (%) Male Female	 16 (53.3) 14 (46.7)	 6 (42.9) 8 (57.1)	 10 (62.5) 6 (37.5)	 0.28
Age, y Median (IQR) Min-max	 51 (22) 19 - 69	 54 (13) 39 - 69	 46.5 (24) 19 - 67	 0.33
Race, n (%) Asian African American Caucasian Hispanic	 2 (6.7) 4 (13.3) 23 (76.7) 1 (3.3)	 1 (7.1) 4 (28.6) 9 (64.3) 0 (0)	 1 (6.3) 0 (0) 14 (87.4) 1 (6.3)	 0.11
Height (cm) Median (SD) Min-max	 173 (19) 137.2 - 190.5	 170.2 (21.6) 137.2 - 190.5	 173 (21) 152.4 - 188	 0.17
Weight (Kg) Median (IQR) Min-max	 73 (28) 45.4 - 120	 68 (26) 51 - 120	 71 (43.3) 45.4 - 118	 1.00
Mobility aid, n (%) Power WC Manual WC	 7 (23.3) 23 (76.7)	 5 (35.7) 9 (64.3)	 2 (12.5) 14 (87.5)	 0.13

Table 5 (cont.)

Cause of SCI, n (%)				
Traumatic	21 (70)	9 (64.3)	12 (75)	0.52
Non-traumatic	9 (30)	5 (35.7)	4 (25)	
Time since injury, y				
Median (IQR)	12 (27.5)	15 (26.75)	13.5 (27.75)	1.00
Min-max	1 - 54	1 -54	1 - 37	
Level of injury, n (%)				
Cervical	4 (13.3)	2 (14.3)	2 (12.5)	0.21
High thoracic	11 (36.7)	6 (42.9)	5 (31.3)	
Low thoracic	10 (33.3)	2 (14.3)	8 (50)	
Lumbar	2 (6.7)	2 (14.3)	0 (0)	
Unknown	3 (10)	2 (14.3)	1 (6.3)	

IQR: interquartile range, SCI: spinal cord injury, WC: wheelchair, y: years

4.3.2. *Frequency of falls and fall-related injury*

Overall, 63% of participants reported falling at least once during the previous 6 months, and 48.6% of those reported recurrent falls (> 2 falls). A total of 152 falls (range: 0 - 45) were reported by the participants. The crude falls rate and falls rate per person-year were 2.58 falls/person and 5.22 falls/person-year, respectively. Figure 7 displays the distribution of falls reported by participants.

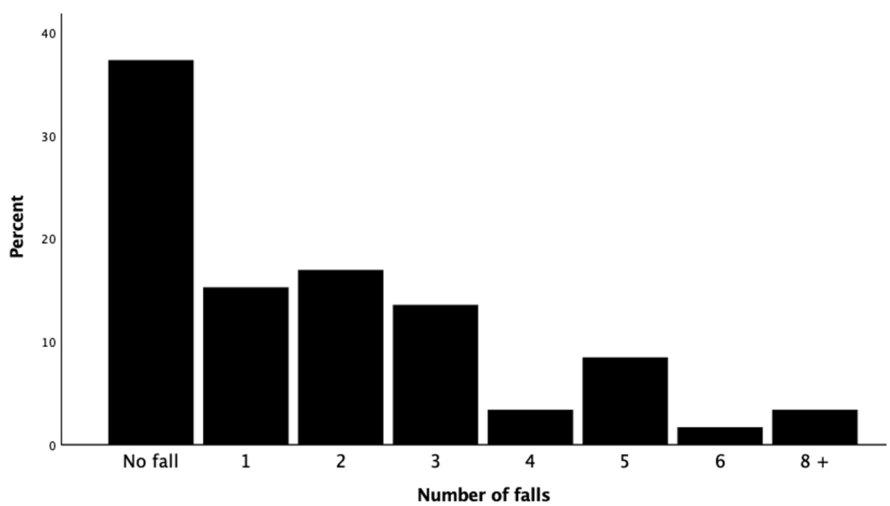

Figure 7. Distribution of falls

From the 37 participants who experienced at least one fall, data on fall-related injuries were missing for 7 participants. Therefore, from the 30 participants whose data were available, 46.7% reported injuries after falls. Participants who reported fall-related injuries experienced a total of 74 falls over a period of 6 months. The crude fall-related injuries rate and fall-related injuries rate per person-year were 0.47 fall-related injury/person and 0.95 fall-related injury/person-year, respectively.

4.3.3. *Characteristics of falls and fall-related injuries*

The characteristics of falls and fall-related injuries experienced by the participants are summarized in Table 6. Participants reported transferring (n = 25, 43.2%) from their wheelchair to another surface such as a bed, couch, car, and toilet or bathtub as the most common activity being performed during a fall. The results also revealed that wheelchair propulsion (n = 13, 22.4%) and reaching for an object (n = 7, 12%) were commonly being performed when a fall occurred. In addition, transporting heavy objects (n = 5, 8.6%), engagement in leisure activities (n = 4, 6.9%) such as dancing, hunting, and other activities (n = 4, 6.9%) such as gardening or trimming vines were reported by the study participants.

Regarding the location of falls, participants who experienced at least one fall reported falling at home as the most common location (n = 50, 74.6%). Among those falls, falls occurred in the bedroom (n = 19, 28.4%), living room (n = 14, 20.9%), bathroom (n = 10, 15%), and garage (n = 7, 10.3%). Participants also reported falling outside of the house, in the street (n = 17, 25.4%). Fall attributions (n = 11) were extracted from the reported falls. The most frequently reported attributions included obstacles (n = 6, 54.5%), surface conditions (n = 4, 36.4%), and no use of seat belt (n = 1, 9.1%).

A total of 14 fall-related injuries were reported. Among the injuries reported, 6 (42.8%) resulted in minor injuries including bruises, swelling, and scratches, and 2 (14.2%) resulted in moderate injuries including a deep facial laceration and a deep laceration (body part not specified). Six (42.8%) falls resulted in severe injuries including hip, tibia, and ankle fractures.

Table 6. Characteristics of falls, fall-related injuries, and fear of falling among full-time wheelchair users with SCI, n = 59 unless otherwise stated.

Fall Data	Number (Percentage)
Fall occurrence	
• Yes	37 (63)
• No	22 (37)
Education on fall prevention (n = 52)	
• Yes	30 (57.7)
• No	22 (42.3)
Fall related actions	
• Transfers	25 (43.2)
• Manual wheelchair propulsion	13 (22.4)
• Reaching	7 (12)
• Transporting heavy objects	5 (8.6)
• Leisure	4 (6.9)
• Others	4 (6.9)
Locations of falls	
- Home	
• Bedroom	19 (28.4)
• Bathroom	10 (15)
• Living room	14 (20.9)
• Garage	7 (10.3)
- Outside	
• Street	17 (25.4)
Fall attributions	
• Surface conditions	4 (36.4)
• No use of seat belt	1 (9.1)
• Obstacle	6 (54.5)
Fall-related injury	
• Yes	14 (46.7)
• No	16 (53.3)
Type of injury	
• Minor	6 (42.8)
• Moderate	2 (14.2)
• Severe	6 (42.8)

Table 6 (cont.)

Fall Data	Number (Percentage)
FOF • No • Yes - Somewhat - Fairly Very	16 (27) 43 (73) - 29 (67.4) - 8 (18.6) - 6 (14)
Activity curtailment due to FOF • Yes • No • Unknown	 17 (28.8) 39 (66.1) 3 (5.1)
Activities curtailed due to FOF • Exercise • Independent transfer • ADLs • Leisure • Everything • Others	 6 (20.7) 7 (24.1) 6 (20.7) 6 (20.7) 2 (6.9) 2 (6.9)

ADLs: activities of daily living, FOF: fear of falling

4.3.4. *Fear of falling and education on fall prevention*

Table 6 presents detailed information about frequency of FOF, activity curtailment due to FOF, and education on fall prevention. Across all study participants, 43 (73%) reported having FOF. Seventeen (28.8%) participants reported activity curtailment due to FOF. Performance of independent transfers (n = 7, 24.1%), exercise (n = 6, 20.7%), performing activities of daily living (n = 6, 20.7%), and engagement in leisure activities (n = 6, 20.7%) were the most common activities curtailed by study participants due to FOF. In addition, 2 (6.9%) participants reported not being able to perform any activity due to FOF and 2 (6.9%) reported that they avoided going outside of the house or traversing irregular surfaces due to FOF. Twenty-two (42.3%) of 52 participants who provided information on fall prevention education reported that they have never received education on fall prevention from a health professional.

Table 7 summarizes the relationship between FOF, education about fall prevention, activity curtailment due to FOF, fall-related injury, and falls. The results from the logistic regression showed no significant relationship between receiving education on fall prevention, falls occurrence, fall-related injuries, and FOF. Only having FOF was significantly associated with activity curtailment due to FOF (OR = 10, 95% CI 1.2 – 83.4, $p = 0.03$). The finding indicates that among non-ambulatory individuals with SCI who report FOF, the odds of limiting their activities increases by 10 when compared to those who do not report FOF.

Table 7. Association between fall occurrence, number of falls, fall-related injuries, education on fall prevention, fear of falling, and activity curtailment among wheelchair users with SCI.

Association between variables	B	SE	Wald	df	*p*-value	OR	OR (95% CI)
EFP X Fall occurrence (n = 52)	0.43	0.58	0.55	1	0.46	1.53	0.5 – 4.72
EFP X Number of falls (n = 31)	-0.09	0.12	0.58	1	0.45	0.91	0.71 – 1.16
EFP X Fall-related injury (n = 30)	-0.29	0.74	0.15	1	0.7	0.75	0.18 – 3.17
EFP X FOF (n = 52)	- 0.62	0.65	0.93	1	0.33	0.54	0.15 – 1.9
FOF X Fall occurrence (n = 59)	1.23	0.71	3.01	1	0.08	3.43	0.85 – 13.8
FOF X Fall-related injury (n = 30)	-1. 05	0.82	1.62	1	0.2	0.35	0.07 – 1.76
FOF X Activity curtailment (n = 59)	2.3	1.08	4.53	1	0.03*	10	1.2 – 83.4
Fall history X Activity curtailment (n = 59)	- 0.7	0.6	1.35	1	0.25	0.5	0.16 – 1.61
EFP X Activity curtailment (n = 52)	-0.05	0.62	0.01	1	0.93	0.95	0.28 – 3.16

EFP: education on fall prevention, FOF: fear of falling, n: number of participants, df: degree of freedom
* $p < 0.05$

4.4. Discussion

This cross-sectional study aimed to explore the characteristics and frequency of falls, fall-related injuries, and FOF among non-ambulatory individuals living with SCI. In addition, this is the first study to explore the association between education on fall prevention, fall occurrence, number of falls, fall-related injuries, FOF, and activity curtailment due to FOF in this population. The results indicated that during a period of 6-months, approximately two-thirds (63%) of the study participants fell at least once and almost half of them (48.6%) fell recurrently. In addition, our results revealed that 46.7% of those who fell at least once reported an injury due to their falls. Study participants present with fall rates of 5.22 and 0.95 for falls/person-year and fall-related injury/person-year, respectively. Most falls occurred at home (74.6%), during transfer activities (43.2%), and associated with surface conditions (36.4%) or obstacles in the way (54.5%). Moreover, approximately three-fourths (73%) of the study participants reported FOF and 28.8% of them limited engagement in activities due to FOF. The study also revealed that receiving education on fall prevention from a health professional (57.7% of the study participants) was not associated with the occurrence of falls, number of falls, falls frequency, falls-related injuries, FOF, or activity curtailment due to FOF.

Unsurprisingly, our study revealed that non-ambulatory individuals living with SCI are at a high risk of falling. The findings align with the pooled frequency of falls of 69% (95% CI 60% - 76%) among non-ambulatory individuals with SCI for a period between 6 to 12 months reported in a recent systematic review[1]. Also, the frequency of falls identified in our study (63%) is consistent with the frequency of falls (64%) reported by Forslund *et al*.[16] in a study where the authors prospectively monitored falls for a period of 12-month. In contrast to our results, other studies reported much lower frequency of falls in this population. Amatachaya *et al*.,[124] Nelson *et* *al.*,[17] and Matsuda *et al.*[125] reported 33%, 31%, and 31% of frequency of falls among non-ambulatory individuals with SCI, respectively. These low frequencies of falls compared to the frequency of falls reported in our study maybe due to differences in sample characteristics and social context. These previous studies were conducted between 2010 and 2015. Since then, research and clinical practice in SCI rehabilitation have advanced and characteristics of individuals with SCI, functional independence, and the social context in which individuals with SCI live have changed. However, despite the differences in study designs (retrospective vs prospective) and fall monitoring periods (6-month vs 12-month), the alignment between the frequency of falls revealed by our study and the most recent finding by Forslund *et al.*[16] and Khan *et al.*[1] suggests two out of three non-ambulatory individuals with SCI experience at least one fall in a period of 6-12 months.

Our results also revealed that among those individuals who experienced at least one fall during a period of 6-month, almost half (46.7%) of them report a fall-related injury. Our results align with the frequency of fall-related injuries reported by Kirby *et al.*[126] (47.1%) and Nelson *et al.* (46.7%)[17] for noninstitutionalized manual wheelchair users and community-dwelling Veterans living with SCI, respectively. Conversely, these frequencies of fall-related injuries reported in our study and in the previous studies by Kirby *et al.*[126] (47.1%) and Nelson *et al.* (46.7%)[17] are much higher than the frequency of fall-related injuries presented by Forslund *et al.*[16] (23%). These differences might be explained by the difference in the study designs. Forslund et al.[16] asked participants to prospectively monitor falls to reduce recall bias. In contrast, our study used a retrospective study design which may be compromised with recall bias. Our results revealed that most fall-related injuries led to minor and moderate injuries such as bruising, cuts, or swelling. These findings are consistent with those reported by Singh *et al.,*[20] Nelson *et al*.,[17] Forslund *et al*.,[16] and Kirby *et al*.[126]. Moreover, our study found that 42.8% of our participants reported experiencing severe injuries after falls, mostly lower extremity factures. Nelson *et al*.[127] also reported lower extremity fractures as the most common severe fall-related injuries in this population. Therefore, these investigations indicate that fall-related injuries are common and may result in minor injuries such as bruising, swelling, or cuts, and more severe injuries, such as fractures. Since falls resulting even in minor injuries can have a significant psychological impact on non-ambulatory individuals with SCI[93], we recommend that clinicians and researchers dedicate more attention to prevention of fall-related injuries in this population.

The characteristics of falls reported by our study participants confirm the complex nature of falls from a wheelchair among non-ambulatory individuals with SCI. The majority of the participants reported falling at home (76.4%) and during transfers (43.2%). Surface conditions (36.4%) or environmental barriers (54.5%) were common attributes reported to be associated with falls. These findings are consistent with the percentages of falls at home, 72% and 65%, reported respectively by Sung *et al*.[19] and Forslund *et al*.[16] indicating that falling at home is more common in this population when compared to falls outside of the home. Moreover, most of these falls occurred in the bathroom, bedroom, and the living room, highlighting the need to make home environments accessible and safer for non-ambulatory individuals with SCI. This can be achieved with modifications in home environments such as the addition of ramps, grab bars, and the use of assistive technology to facilitate performance of ADLs in the home. Also, transferring from a wheelchair to other surfaces, such as beds, cars, a toilet, or a bath chair, was found to be the most frequent activity leading to falls in this population. This result is consistent with previous studies where researchers highlighted transfers as the most common fall contributors in non-ambulatory individuals with SCI[16,19,20,127]. The finding points out the importance of including transfers training in fall prevention interventions for non-ambulatory individuals with SCI. Finally, environmental barriers, such as cluttered rooms, and surface conditions, such as slippery or wet floors, have been reported by our study participants as the most common fall attributions. These factors should also be taken into consideration and included into education about falls for this population.

Our study also indicates that FOF is a common concern among this population. The results revealed that almost three-fourths (73%) of the study participants reported FOF. The finding align with the study by Sung *et al.*[19] where the authors also highlighted that 65% of non-ambulatory individuals with SCI reported FOF. Among those individuals, 28.8% limited their performance of activities due to FOF. Furthermore, the bivariate logistic regression analysis revealed a strong relationship between FOF (yes/no) and activity curtailment (yes/no) due to FOF (OR = 10, 95% CI 1.2 – 83.4, $p = 0.03$). Non-ambulatory individuals with SCI who report a FOF increase their odds of limiting their performance of activities by 10. This result deserves notable attention by clinicians and researchers as activity curtailment leads to functional dependence, reduced quality of life, and restriction in social participation exposing the individual to physical deconditioning and future risk of falls[2,3]. Furthermore, receiving education on fall prevention from health professionals was not associated with a reduction of occurrence of falls, fall-related injuries, FOF, or activity curtailment due to FOF. This may suggest that the current strategies of education on fall prevention are not effective for this population. Indeed, to the best of our knowledge, only one evidenced-based fall prevention intervention for manual wheelchair users with SCI has been described in the literature[90]. Even though the authors presented a significant reduction of incidence of falls after the intervention, the results require further investigation[90]. The borderline p-value ($p = 0.047$) of the difference between pre- and post-intervention and the medium effect size ($d_z = 0.507$) reported by the authors[90] indicates that future studies with stronger study designs, such as randomized clinical trials, are needed on this topic. Similar results on the inconclusiveness of fall prevention strategies to reduce fall-related outcomes have been highlighted among people with multiple sclerosis[24,128]. However, in our study, we did not inquire about the specific components, length of the program, and which professional provided the education on fall prevention received by the participants which limits the interpretation and generalization of our results.

4.5. Study limitations

It is important to highlight that there are some limitations to this study. First, our results are based on a cross-sectional design of self-reported retrospective data. This study design is subject to recall bias [129]. For example, participants may not have precisely reported the number of falls and the minor injuries experienced. To minimize the recall bias, the time frame in which participants had to recall the frequency of falls was limited to only six months. In addition, characteristics of falls and fall related injuries examined on the most recent fall experienced. Also, the information collected was limited to the questions asked. Based on this point, we were not able to provide detailed information on the characteristics of falls and fall-related injuries experienced by participants, such as time of day when falls occurred. Another limitation to this study is that due to the relatively small sample size analyzed, the sub-group analysis of fall-related injuries was not exhaustive. We were not able to provide detailed information about the location or activity-related to fall-related injuries in this population. This information is important to better understand fall-related injuries and help mitigate these falls among non-ambulatory individuals with SCI. We recommend that future studies focus on determining the characteristics of fall-related injuries in this population. Finally, as noted above, we did not inquire about the specific components, length of the program, and which professional provided the education on fall prevention received by the participants. This information will be important to help clinicians and researchers to customize or modify existing fall prevention programs to better target fall-related outcomes among non-ambulatory individuals with SCI.

4.6. Conclusion

This cross-sectional study revealed that falls and fall-related injuries are common among non-ambulatory individuals with SCI. Falls mostly occurred inside of the house, during transfer activities, and due to environmental barriers or surface conditions. This highlights the importance of developing individualized fall prevention programs that include transfer and wheelchair skill trainings. Also, our study revealed that FOF is an important factor to be considered since it is highly related to limitations of several activities including performance of ADLs, exercise, independent transfers, or leisure. This ultimately leads to a vicious cycle of functional dependence, reduced quality of life, restriction in social participation, and physical deconditioning, leading to more risks of falls. Healthcare providers should also include education on FOF into fall prevention programs for non-ambulatory individuals with SCI. These fall prevention programs should be accessible to this population at every stage of their rehabilitation process.

CHAPTER 5. FACTORS ASSOCIATED WITH FALLS AND FALL-RELATED INJURIES AMONG WHEELCHAIR USERS WITH SPINAL CORD INJURY

5.1. Introduction

Falls are common among individuals living with spinal cord injury (SCI). A recent review estimated that approximately 78% of ambulators and 69% of non-ambulatory individuals with SCI experience at least one fall in a period of 6 to 12 months[1]. Overall, the consequences of falls are far reaching, resulting in individual and societal burdens. Those consequences include physical injuries, fear of falling (FOF), and associated activity curtailment[2-4]. Muscle paralysis and impaired sensation below the level of injury may exacerbate the severity of falls leading to fall-related injuries. Falls resulting in injury among individuals with SCI might lead to immobility and bed-dependency which in turn may result in secondary complications, such as pressure ulcers[130]. Falls are therefore associated with an increased need for healthcare utilization contributing to a high socio-economic cost[2-4]. For example, among older adults, the cost of healthcare related to injuries after falls, which may include fractures and head injuries, is estimated at approximately one billion dollars[131]. Therefore, among healthcare providers, policymakers, and researchers, falls are considered a public health crisis that need to be addressed urgently and efficiently[132,133].

The effectiveness of fall prevention programs depends on, among other factors, the appropriate identification of the risk predictors for both falls and fall-related injuries. For this purpose, reliable screening tools are essential to allow early identification of individuals with SCI at risk of falls and refer them for appropriate fall preventions programs. Among non-ambulatory individuals with SCI, few studies have been specifically investigated potential fall risk predictors[16-18]. Among those predictors, Nelson *et al.*[17] reported pain in the previous two months, positive for alcohol abuse, greater motor function, previous falls, number of SCI years, and shorter length of wheelchair as significant fall risk predictors in non-ambulatory individuals with SCI. Forslund *et al.*[16] reported previous recurrent falls as fall risk predictors for future recurrent falls. Meanwhile, Jørgensen *et al.*[18] highlighted greater mobility function, age, and sex, as fall risk predictors for future recurrent falls.

Moreover, for fall-related injuries, Nelson *et al.*[17] identified pain in the previous two months, greater motor score, previous falls, and home entrance inaccessibility as predictors while Forslund *et al.*[16] identified general quality of life (QOL) as the only predictor in this population. As evidenced above, only three studies[16-18] have specifically investigated fall predictors and only two have examined predictors of injury among non-ambulatory individuals with SCI. Thus, more studies are warranted to develop a reliable fall screening tool to identify individuals at risk of falls.

In recent years, effort has been made by researchers and clinicians to design and improve fall prevention programs for non-ambulatory individuals with SCI[90,134]. For example, Rice *et al.*[90] showed in a pilot, pre-post study that education on fall prevention was able to reduce incidence of falls among manual wheelchair users with SCI. This preliminary finding is promising, indicating individuals with SCI can benefit from such programs. However, it is not known whether receiving education on fall prevention from a health professional is a predictor of fall-related outcomes among non-ambulatory individuals with SCI.

Thus, the purpose of this study is to determine factors associated with falls and fall-related injuries among non-ambulatory individuals with SCI. In addition, the study aimed to determine which combination of self-reported and performance-based outcome measures presents with the highest level of discriminant ability to identify individuals at risk of falls and fall-related injuries in this population. The authors hypothesized that, a combination of participants' characteristics and performance-based measures, such as balance, wheelchair transfer quality, and wheelchair skills, would present with the highest accuracy to identify non-ambulatory individuals with SCI at risk of falls. This hypothesis was based on the results of previous studies that highlighted poor balance, transfer, and wheelchair skills, as factors highly associated with falls in this population[16,19,20].

5.2. Methods

5.2.1. ***Study design***

This cross-sectional observational study is part of the Prediction of Falls among non-ambulatory individuals with SCI (Predi_Falls-SCI) study which aimed to identify factors related to falls in this population. An online survey was conducted between January 2021 and July 2021 in the U.S using the Research Electronic Data Capture (REDCap)[135] survey platform. REDCap is a secure, web-based data management application. In addition, physical assessments, including balance and transfer abilities, were assessed remotely. The Transparent Reporting of a multivariable prediction model for Individual Prognosis or Diagnosis (TRIPOD) was followed to conduct and report the study[136]. The TRIPOD checklist is presented in Appendix C. The study was reviewed and approved by the Office for the Protection of Research Subjects at the University of Illinois, Urbana-Champaign (#20718). All participants provided informed consent before taking part in the study.

5.2.2. *Participants*

A convenience sample of individuals with SCI were recruited to participate in the study. Participants were recruited from SCI support groups across the US, Facebook posts, personal communication, and magazine/newsletter advertisements. Participants were invited to take part in the study if they met the following inclusion criteria: (1) 18 years old or over with a chronic SCI for at least 12 months after injury; (2) motor complete injury classified as American Spinal Injury Association Impairment Scale (AIS) A or B; (3) level of injury between C5 and above L5; (4) self-report use of a wheelchair for at least 75% of mobility, (5) able to communicate with the research team through smartphone or laptop video conferencing software, (6) ability to maintain sitting balance for at least 30 seconds to perform the balance assessments, and (7) able to understand English. Participants were excluded if they were classified as AIS E or presented with any additional medical conditions that might affect their ability to perform the tests. Athletes participating in sports leading to frequent falls, such as wheelchair basketball, were also excluded.

5.2.3. *Data collection procedure*

Due to the restrictions placed on human subject research because of the COVID-19 pandemic, all testing procedures were performed virtually. Figure 8 illustrates the steps for the study procedures. Following screening for eligibility criteria, a researcher sent a link to participants through email to complete a demographic survey and surveys on falls, fall-related injuries, FOF, education on falls, quality of life, wheelchair skills, psychological measures, community participation, functional independence, and environmental barriers. After completion of the online surveys, a researcher hand delivered or mailed the assessment package which included: a paper goniometer, a paper ruler, fall tracking calendars for 6 months, and stamped return envelopes to all participants. The assessment package was mailed through the United Parcel Service (UPS) to ensure timely delivery and tracking. When delivered by the researcher, the package was dropped off at the participant's front porch.

After delivering the assessment package, participants and a researcher met over a video call. Participants performed sitting balance and transfer testing with the assistance of a family member, caregiver, or friend. After participants provided informed verbal and electronic consent to record the assessments, a researcher initiated the recording of the assessments.

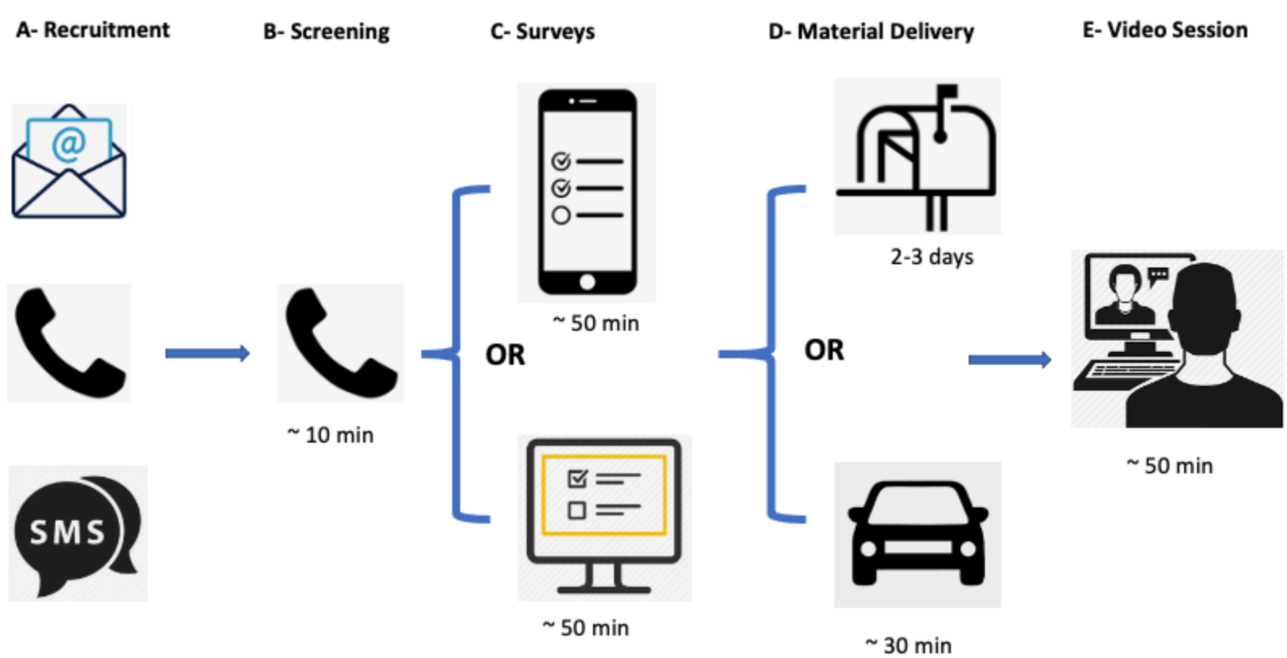

Figure 8. (A) Potential participants contacted the research group and manifested their interest in participating in the study. (B) Potential participants were screened over the phone for eligibility criteria by a researcher. (C) Eligible participants were provided with a link to complete demographics and surveys. (D) A researcher delivered assessment packages to study participants who completed the surveys through drop off or mail. (E) Participants met with the researcher to perform remote sitting balance and transfer assessments.

5.2.4. ***Outcome measures***

The outcome measures used in this study were selected based on the International Classification of Functioning, Disability and Health (ICF) Model developed by the World Health Organization (WHO)[30]. All the components of the ICF model including body functions and structure, activities, participation, personal factors, and environmental factors were included to assure a comprehensive assessment of fall risk factors. Prior to the completion of the physical assessments, participants completed the following self-reported outcome measures:

1) Demographics, characteristics of SCI, and a survey to collect information on the frequency of falls and fall-related injuries experienced by the participants in the previous 6-months. A fall was defined as an unintentional event in which one comes to rest on the ground, floor, or other lower level[121]. Participants were asked to report the specific location where their most recent fall occurred, the actions they were doing, and the circumstances associated with the most recent fall in the previous 6 months that they could remember. Participants were also asked to describe the most recent injury they experienced any as a result of a fall and the nature of the injury. Finally, participants responded to a question about whether they ever received education on fall prevention from a healthcare professional.
2) *Fear of falling and associated activity curtailment*: Participants responded "Yes" or "No" to two questions developed to assess FOF and associated activity curtailment[137]: 1- "Are you worried or concerned that you might fall?" and 2- "Do you think your fear of falling has made you cut down on any activities you used to do?". In addition, participants completed the SCI Falls Concern Scale (SCI-FCS) questionnaire. The SCI-FCS is a questionnaire of 16 activities of daily life assessing concern about falling in non-

ambulatory individuals with SCI[138]. The questionnaire has been validated for this population and showed excellent internal and test-retest reliability, and good construct validity[138]. Higher scores indicate greater fall concerns.

3) *Psychological measures*: The Hospital Anxiety and Depression Scale (HADS) was used to assess symptoms of depression and anxiety[139]. HADS evaluates how the individual felt during the last week. A subscale score > 8 denotes anxiety or depression.
4) *Functional independence*: The Spinal Cord Independence Measure (SCIM) III, specifically developed for individuals living with SCI, was used to evaluate functional independence[140]. The 17 items of the SCIM III assesses domains related to self-care, respiration and sphincter control, and mobility. Higher scores indicate greater functional independence.
5) *Environmental barriers*: The 25 items of the Craig Hospital Inventory of Environmental Factors-short form (CHIEF-SF) was used to quantify environmental barriers experienced within 5 domains including: policies, physical and structural, work and school, attitudes and support, and services and assistance[141]. Higher scores indicate greater frequency and/or magnitude of environmental barriers.
6) *Wheelchair skills*: Participants' wheelchair skills were assessed using the Wheelchair Skills Test 5.0 (WST)[142]. The WST for power or manual wheelchair users evaluates the capacity, confidence, and performance of participants' wheelchair skills. Higher percentages indicate greater capacity, confidence, and/or performance of wheelchair skills.
7) *Quality of life*: The 26-item World Health Organization Quality of Life- Brief version (WHOQOL-BREF) was used to quantify QOL[143]. The WHOQOL-BREF is a reliable and

valid self-reported outcome measure that evaluates domains of physical health, psychological health, social relationships, and environment. Higher scores indicate a greater perceived QOL.

8) *Community participation*: The Community Participation Indicator (CPI) was used to assess participants' community participation[144]. The 48 items questionnaire evaluates the domains: 1) importance of participation in activities (importance) and 2) control over participation (control). Raw CPI scores are converted to a percentage score varying from 0 to 100%. Higher percentages indicate higher levels of participation for each domain.

During the physical assessment, participants' balance performance was evaluated remotely using the Function in Sitting Test (FIST)[55,70], Trunk Control Test (TCT)[60,67], T-shirt Test[44,62], and modified Functional Reach Test (mFRT)[60,61]. A paper ruler was sent to the participants to estimate reaching distance during the mFRT. The remote assessment of sitting balance measures using the FIST, TCT, mFRT, and the T-shirt Test has been fully described elsewhere[145]. These outcomes have been found to be valid and reliable for use among non-ambulatory individuals[145]. An assessment of transfer quality was performed using the Transfer Assessment Instrument (TAI)[146,147]. The procedures for the remote TAI assessment are fully described elsewhere[146,147]. Remote transfer assessment has been shown to be reliable in this population[147]. A paper goniometer sent to the participants was used during the TAI evaluation. Finally, participants completed a self-assessment of their transfer assessment using the self-TAI[148].

5.2.5. *Statistical analysis*

Data were coded, entered, and analyzed using IBM-SPSS Statistics for Macintosh version 25 (SPSS Inc., Chicago, IL, USA). Counts and frequencies were used to describe categorical variables and normality of data was assessed using the Kolmogorov-Smirnov test. The data was found to be non-normally distributed. Due to the non-normal distribution, Mann-Whitney U tests were used to examine differences in continuous variables. The association between categorical variables was tested using Chi-square or Fisher exact tests.

A logistic regression analysis was conducted to examine the factors associated with falls and fall-related injuries among non-ambulatory individuals with SCI. Number of falls reported by participants was regarded as the dependent variable of the study, dichotomized as 0 fall (non-faller) or ≥ 1 (faller). Furthermore, fall related injuries were used as a dependent variable, and dichotomized as 0 injury (no injury) or ≥ 1 injury (injury). Individual missing data were excluded on a case-by-case basis from the analysis.

Independent variables were selected based on the results of previous studies[16,17]. Correlation between variables was examined using Spearman's rank correlation (ρ). To avoid collinearity in the multivariate logistic regression models and to reduce the number of independent variables, variables with correlation less than 0.4 were selected and entered in the bivariate analysis. Also, for variables assessing similar constructs, such as different measures of balance or environmental barriers, even if the correlation was less than 0.4, only the one with lowest p-value was included in the initial multivariate logistic model. All variables with a p-value of ≤ 0.15 from the bivariate analysis were considered for inclusion in the multivariate logistic regression analysis. This value of ≤ 0.15 was chosen as it is recommended when using regression analysis in smaller cohorts and to ensure no relevant variable was left out of the model[149].

Two logistic regression models (initial and final) were built for each dependent variable (falls and fall-related injuries). The logistic regression models were analyzed using backwards enter mode with final predictor variables assessed at a p-value < 0.05. Model building was iterative and guided with interpretability, parsimony, and the evaluation of the Wald statistic for each variable at each step. Goodness-of-fit of the final reduced model was assessed using the Hosmer and Lemeshow test and the Nagelkerke R^2 value. Odds ratios (OR) and 95% confidence intervals (CI) are reported for factors associated with falls and fall-related injuries. Receiver operating characteristics (ROC) curve analysis was carried out to select the optimal cut-off point to dichotomize the composite measure of the logistic regression model and the continuous variables. The area under the ROC curve (AUC) statistic value was estimated. The AUC statistic can have any value between 0 and 1 which indicates the strength of the prediction. An AUC value ≤ 0.5 represents a non-useful test, between 0.5 and 0.6 represents bad prediction, and between 0.6 and 0.7 represents sufficient prediction. Good, very good, and excellent prediction correspond to AUC values between 0.7 and 0.8, 0.8 and 0.9, and 0.9 and 1, respectively [150,151]. For the composite measure of the logistic regression model, the sensitivity and specificity were calculated and the optimal cut-off score was determined based on Youden's index.

5.3. Results

5.3.1. *Participants*

A total of 70 eligible individuals agreed to participate in the study and signed the electronic informed consent. Of the 70 participants, 11 did not provide any data and were excluded from the analysis. Fifty-nine individuals completed the online surveys. Of the 59 participants, 20 individuals completed the remote physical assessments. The demographics and clinical information of the participants are presented in Appendix D and E, respectively.

Briefly, a total of 152 falls were reported, 22 (37%) did not experience a fall during the previous 6-month and were categorized as non-fallers, and 37 (63%) experienced at least one fall during that period and were categorized as fallers. Also, from the 37 participants who experienced at least one fall, data on the most recent injuries associated with a fall were available for 30 participants. From those 30, 14 (46.7%) reported fall-related injuries and 16 (53.3%) did not report any fall-related injuries after the fall. Further description of the characteristics of falls and fall-related injuries experienced by the participants is available in Chapter 4.

5.3.2. *Regression analysis for falls*

A total of 34 independent variables were initially considered. After bivariate logistic analysis, there were eight potential predictor variables that presented with a *p*-value ≤ 0.15 and were deemed suitable for further multivariable logistic analysis (Table 8): Gender, time since injury, recurrent fallers (> 2 falls), SCIM III self-care, SCIM III mobility, SCIM III total score. In addition, age was added as a confounder predictor and education on fall prevention was included as the study aimed to specifically examine the effect of education on fall prevention. After analysis for multicollinearity, SCIM III self-care and SCIM III total score were excluded because they were highly correlated with SCIM III mobility. Gender was also excluded from the initial multivariate logistic regression analysis because it was highly correlated with SCIM III mobility score and presented with the highest *p*-value. Even if gender can be regarded as a confounder, it did not show any predictive ability of falls previously in this population[16,17].

Therefore, five variables (age, time since injury, recurrent falls, SCIM III mobility score, and education on falls) were deemed suitable and included in the initial multivariate logistic regression analysis. Table 9 shows the full model of the initial multivariate logistic regression analysis with all five variables included.

Table 10 shows the final multivariate logistic regression model with three predictor variables including time since injury, SCIM III mobility score, and education on fall prevention. The results indicate that participants with fewer SCI years had approximately 1-time higher odds of being fallers than those with longer SCI years. Also, participants with greater mobility function in the SCIM III had 1.16 higher odds of being fallers than those with lower mobility function in the SCIM III. Moreover, the AUC statistic (Figure 9) of the final model was 0.73 (95% CI, 0.60 – 0.86, $p = 0.003$). This is higher than the AUC values of the included variables in isolation (Table 10). The model's sensitivity and specificity at an optimal cut-off of 0.53 were estimated at 81% and 55%, respectively. The model had a good fit (Hosmer and Lemeshow test, $p = 0.30$, Nagelkerke $R^2 = 0.22$). The 2 X 2 table used to calculate the AUC statistics, sensitivity, and specificity is presented in Appendix F.

The estimates of the parameters in the model in Table 10 can be used to determine the probability of falling for an individual using the following equation:

Probability of falling $= \frac{1}{1 + e - X}$

Where X = (-0.05*Time since injury) + (0.15*SCIM III Mobility score) + (0.92*Education on Fall Prevention)

Table 8. Bivariate logistic regression analysis of factors associated with frequency of falls. Potential predictors were variables with a p-value ≤ 0.15 after bivariate analysis.

Potential Predictor	**β**	**OR**	**95% CI**	***p*-value**
Demographic				
Age	-0.03	0.97	0.93 – 1.01	0.18
Gender: Female	1.03	2.81	0.93 – 8.52	**0.07**
Height	0.01	1.01	0.94 – 1.08	0.85
Weight	-0.01	0.99	0.98 – 1.01	0.36
Time since injury	-0.03	0.97	0.94 – 1.01	**0.09**
Injury level: Cervical				
- High thoracic	-1.57	0.21	0.02 – 2.60	0.22
- Low thoracic	0.29	1.33	0.10 – 17.82	0.83
- Lumbar	-0.54	0.58	0.05 – 6.59	0.66
- Unknown	-0.69	0.50	0.03 – 8.95	0.64
Fall Information				
Number of falls	0.08	1.08	0.95 – 1.23	0.23
Recurrent fallers: Yes	- 0.95	2.59	0.79 – 8.52	**0.12**
Fear of Falling				
SCI-FCS	0.02	1.03	0.97 – 1.09	0.41
Afraid of falling: No				
- Somewhat	1.47	4.33	0.57 – 33.13	0.16
- Fairly	0.21	1.23	0.21 – 7.15	0.82
- Very	0.51	1.67	0.20 – 14.27	0.64
Activity curtailment: Yes				
- No	0.81	2.25	0.17 – 29.77	0.54
- Don't know	1.50	4.50	0.37 – 54.54	0.24
Intervention				
Education on falls: Yes	0.51	1.66	0.56 – 4.89	0.36
Balance Measures				
FIST	0.03	1.03	0.83 – 1.27	0.81
TCT	0.09	1.09	0.75 – 1.59	0.66
T-shirt Test	0.69	1.99	0.44 – 8.97	0.37
mFRT	0.25	1.29	0.85 – 1.95	0.24
Self-TAI	-0.15	0.85	0.18 – 4.09	0.85
TAI	-0.39	0.68	0.16 – 2.94	0.60
Psychological Measures				
HADS-D	0.003	1.00	0.87 – 1.16	0.97
HADS-A	0.03	1.03	0.91 – 1.16	0.66
Community Participation				
CPI-Importance	-0.03	0.97	0.92 – 1.03	0.36
CPI-Control	0.01	1.00	0.94 – 1.08	0.83
Environmental Barriers				
CHIEF-SF	-0.003	1.00	0.96 – 1.03	0.84

Table 8 (cont.)

Potential Predictor	**β**	**OR**	**95% CI**	***p*-value**
Functional Independence				
SCIM III Self-care	0.08	1.08	0.97 – 1.21	**0.14**
SCIM III Respiration	0.03	1.03	0.96 – 1.10	0.41
SCIM III Mobility	0.13	1.14	1.00 – 1.29	**0.05**
SCIM III Total	0.03	1.03	0.99 – 1.07	**0.11**
Wheelchair Skills				
WST-Capacity	0.01	1.00	0.98 – 1.04	0.69
WST-Confidence	0.01	1.00	0.98 – 1.04	0.63
WST-Performance	0.01	1.00	0.98 – 1.04	0.67
Quality of Life				
WHOQOL-Physical Health	-0.03	0.98	0.93 – 1.02	0.26
WHOQOL-Psychological	-0.002	1.00	0.97 – 1.03	0.88
WHOQOL-Social relationships	-0.02	0.98	0.96 – 1.00	0.20
WHOQOL-Environment	-0.01	0.99	0.96 – 1.02	0.45

CHIEF-SF: Craig Hospital Inventory of Environmental factors- Short Form; CPI: Community Participation Indicators; FIST: Function in Sitting Test; HADS-A: Hospital Anxiety and Depression Scale- Anxiety; HADS-D: Hospital Anxiety and Depression Scale- Depression; mFRT: Modified Functional Reach Test; SCI-FCS: Spinal Cord Injury- Falls Concern Scale; SCIM III: Spinal Cord Injury Measures III; TAI: Transfer Assessment Instrument; TCT: Trunk Control Test; WHOQOL: World Health Organization Quality of Life; WST: Wheelchair Skills test

Table 9. Full model for multivariate logistic regression analysis (n = 59) to identify individuals with SCI at risk of falls.

Predictor	**β**	**S.E.**	**Wald**	**df**	***p*-value**	**Odds ratio (95% CI)**
Age	-0.01	0.03	0.19	1	0.65	0.94 – 1.04
Time since injury	-0.04	0.02	2.90	1	0.08	0.92 – 1.01
Recurrent fallers: Yes	-0.92	0.67	1.90	1	0.16	0.11 – 1.47
SCIM III Mobility	0.16	0.08	4.25	1	0.03	1.01 – 1.36
Education on falls: Yes	0.81	0.66	1.51	1	0.22	0.62 – 8.11

SCIM III: Spinal Cord Injury Measures III

Table 10. Final model for multivariate logistic regression analysis (n = 59) to identify individuals with SCI at risk of falls.

Predictor	β	S.E.	Wald	df	p-value	Odds ratio (95% CI)	AUC value (95% CI)
Constant	-1.06	1.07	0.98	1	0.32	0.35	
Time since injury	-0.05	0.02	4.21	1	**0.04**	0.96 (0.92 – 0.99)	0.35 (0.21 – 0.50)
SCIM III Mobility	0.15	0.07	4.40	1	**0.03**	1.16 (1.01 – 1.33)	0.63 (0.48 – 0.78)
Education on falls: Yes	0.92	0.64	2.06	1	0.15	2.52 (0.71 – 8.88)	0.44 (0.28 – 0.59)

SCIM III: Spinal Cord Injury Measures III

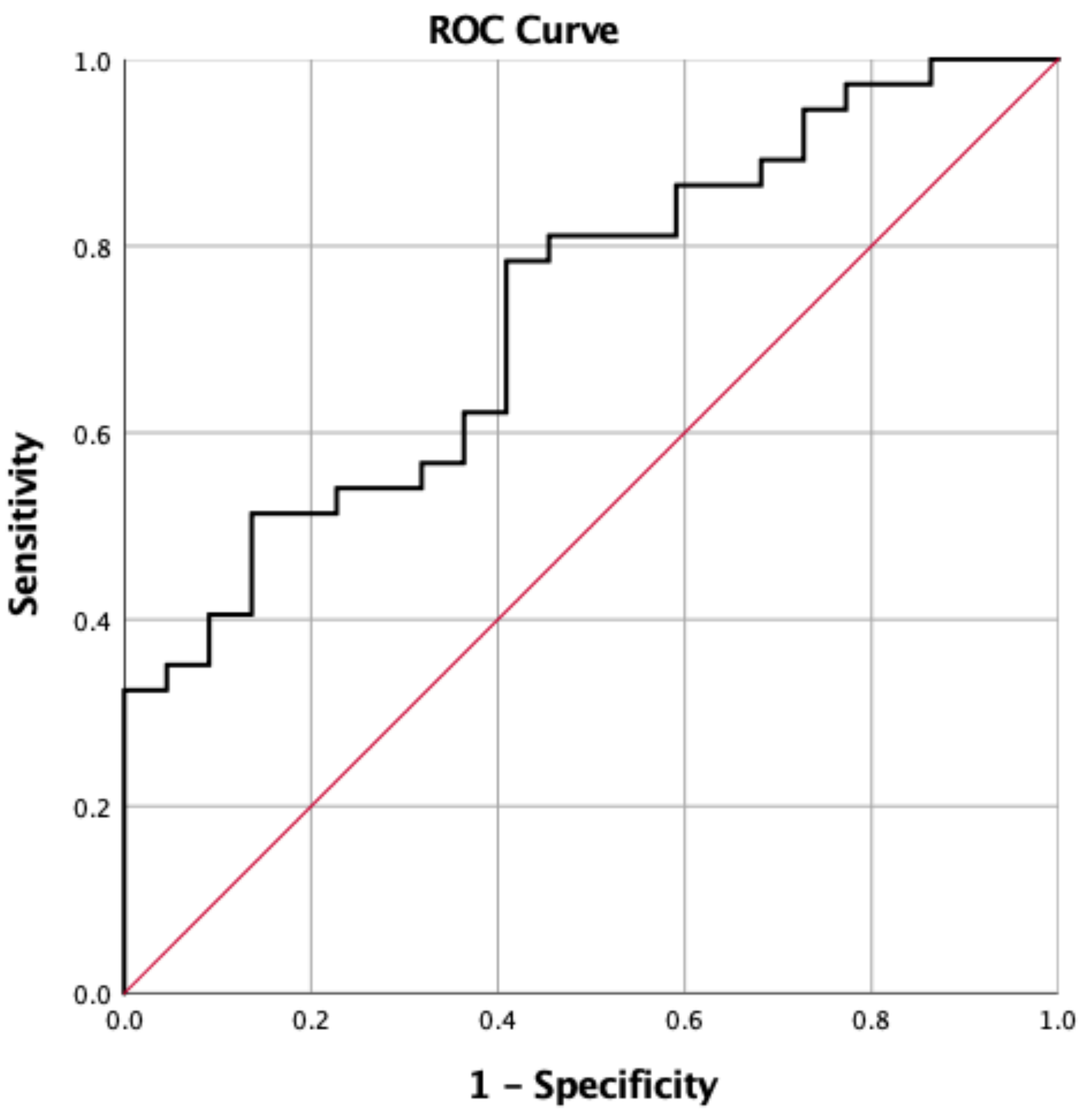

Figure 9. ROC analysis of the final model, AUC = 0.73 (95% CI, 0.60 – 0.86), p = 0.003

5.3.3. *Regression analysis for fall-related injuries*

A total of 34 variables were also initially considered for fall-related injuries. After bivariate logistic analysis, there were five potential predictor variables with a *p*-value ≤ 0.15 that were deemed suitable for further multivariable logistic regression analysis (Table 11). These predictors included age, gender, WHOQOL physical health, CHIEF-SF, and education on fall prevention. Gender was included because it was regarded as a confounder. Also, education on fall prevention was included as our analysis aimed to examine the influence of this variable on fall-related injuries. Table 12 shows the full model for initial multivariate logistic regression analysis with all five variables included.

Table 13 shows the final multivariate logistic regression model with four predictor variables including age, gender, WHOQOL physical health, and education on falls. The results indicate that for each unit increase in WHOQOL physical health (higher score on physical health domain of quality of life), the OR of experiencing a fall-related injury group decreases by 8% points (OR = 0.92, $p = 0.04$). Moreover, the AUC statistic (Figure 10) of the final model was 0.77 (95% CI, 0.59 – 0.96, $p = 0.01$). This is higher than the AUC values of the included variables in isolation (Table 13). The model's sensitivity and specificity at an optimal cut-off of 0.37 were estimated at 79% and 75%, respectively. The model had an adequate fit (Hosmer and Lemeshow test, $p = 0.05$, Nagelkerke $R^2 = 0.39$). The 2 X 2 table used to calculate the AUC statistics, sensitivity, and specificity is presented in Appendix G.

The estimates of the parameters in the model in Table 13 can be used to determine the probability of having a fall-related injuries for an individual using the following equation:

Probability of fall-related injuries = $\frac{1}{1+ e-X}$

Where X = (-1.61*Gender) + (0.08*Age) + (-0.10*Education on Fall Prevention) + (-0.08*WHOQOL Physical Health)

Table 11. Bivariate logistic regression analysis of factors associated with fall-related injury. Potential predictors were variables with a p-value ≤ 0.15 after bivariate analysis.

Potential Predictor	β	OR	95% CI	*p*-value
Demographic				
Age	0.06	1.06	0.99 – 1.13	**0.10**
Gender: Female	-0.80	0.45	0.10 – 1.95	0.29
Height	-0.01	0.99	0.91 – 1.08	0.83
Weight	-0.01	0.99	0.98 – 1.01	0.43
Time since injury	-0.002	1.00	0.95 – 1.05	0.94
Injury level: Cervical				
- High thoracic	-0.69	0.50	0.02 – 11.09	0.66
- Low thoracic	-0.51	0.60	0.04 – 8.73	0.70
- Lumbar	-2.08	0.13	0.01 – 2.72	0.15
- Unknown	20.51	-	-	0.99
Fall Information				
Number of falls	0.07	1.07	0.97 – 1.17	0.17
Recurrent fallers: Yes	-0.51	0.60	0.14 – 2.58	0.49
Fear of Falling				
SCI-FCS	0.05	1.05	0.97 – 1.14	0.22
Afraid of falling: No				
- Somewhat	-22.05	-	-	0.99
- Fairly	-21.05	-	-	0.99
- Very	-21.61	-	-	0.99
Activity curtailment: Yes				
- No	-20.10	-	-	1.00
- Don't know	-21.90	-	-	1.00
Intervention				
Education on falls: Yes	-0.29	0.75	0.18 – 3.17	0.70
Balance Measures				
FIST	0.23	1.26	0.92 – 1.72	0.15
TCT	0.13	1.14	0.80 – 1.63	0.48
mFRT	0.23	1.26	0.85 – 1.85	0.25
T-shirt Test	-0.96	0.26	0.07 – 2.03	0.26
Self-TAI	-0.34	0.71	0.15 – 3.49	0.67
TAI	0.07	1.07	0.37 – 3.14	0.90
Psychological Measures				
HADS-D	0.03	1.03	0.83 – 1.28	0.77
HADS-A	0.10	1.10	0.92 – 1.33	0.30

Table 11 (cont.)

Community Participation				
CPI-Importance	0.05	1.05	0.97 – 1.13	0.24
CPI-Control	0.06	1.06	0.96 – 1.16	0.25
Environmental Barriers				
CHIEF-SF	-0.06	0.94	0.88 – 1.01	**0.10**
Functional Independence				
SCIM III Self-care	-0.10	0.91	0.75 – 1.09	0.30
SCIM III Respiration	-0.004	0.99	0.90 – 1.09	0.93
SCIM III Mobility	-0.15	0.86	0.69 – 1.07	0.18
SCIM III Total	-0.03	0.97	0.91 – 1.03	0.39
Wheelchair Skills				
WST-Capacity	-0.03	0.97	0.93 – 1.01	0.18
WST-Confidence	0.01	1.01	0.97 – 1.05	0.75
WST-Performance	-0.01	0.99	0.96 – 1.03	0.74
Quality of Life				
WHOQOL-Physical Health	-0.05	0.95	0.90 – 1.01	**0.10**
WHOQOL-Psychological	0.00	1.00	0.95 – 1.05	0.99
WHOQOL-Social relationships	-0.004	0.99	0.97 – 1.02	0.77
WHOQOL-Environment	-0.04	0.97	0.92 – 1.02	0.17

CHIEF-SF: Craig Hospital Inventory of Environmental factors- Short Form; CPI: Community Participation Indicators; FIST: Function in Sitting Test; HADS-A: Hospital Anxiety and Depression- Anxiety; HADS-D: Hospital Anxiety and Depression- Depression; mFRT: Modified Functional Reach Test; SCI-FCS: Spinal Cord Injury- Falls Concern Scale; SCIM III: Spinal Cord Injury Measures III; TAI: Transfer Assessment Instrument; TCT: Trunk Control Test; WHOQOL: World Health Organization Quality of Life; WST: Wheelchair Skills test

Table 12. Full model for multivariate logistic regression analysis (n = 59) to identify individuals with SCI at risk of falls.

Predictor	β	S.E.	Wald	df	*p*-value	Odds ratio (95% CI)
Age	0.09	0.05	3.02	1	0.08	0.99 – 1.21
Gender: Female	-2.21	1.14	3.79	1	0.05	0.01 – 1.02
WHOQOL physical Health	-0.07	0.04	2.83	1	0.09	0.86 – 1.01
CHIEF-SF	-0.08	0.05	2.77	1	0.10	0.85 – 1.01
Education on falls: Yes	-1.08	0.97	0.01	1	0.91	0.13 – 6.03

CHIEF-SF: Craig Hospital Inventory of Environmental factors- Short Form; WHOQOL: World Health Organization Quality of Life

Table 13. Final model for multivariate logistic regression analysis (n = 59) to identify individuals with SCI at risk of falls.

Predictor	β	S.E.	Wald	df	p-value	Odds ratio (95% CI)	AUC value (95% CI)
Constant	1.46	2.77	0.28	1	0.60	0.92	
Gender: Female	-1.61	1.03	2.47	1	0.12	0.20 (0.03 – 1.49)	0.60 (0.40 – 0.81)
Age	0.08	0.04	3.31	1	0.07	1.08 (0.99 – 1.18)	0.64 (0.43 – 0.85)
WHOQOL Physical Health	-0.08	0.04	4.15	1	**0.04**	0.92 (0.85 – 0.99)	0.34 (0.14 – 0.54)
Education on falls: Yes	-0.10	0.96	0.01	1	0.92	0.91 (0.14 – 5.91)	0.54 (0.33 – 0.75)

WHOQOL: world health organization quality of life

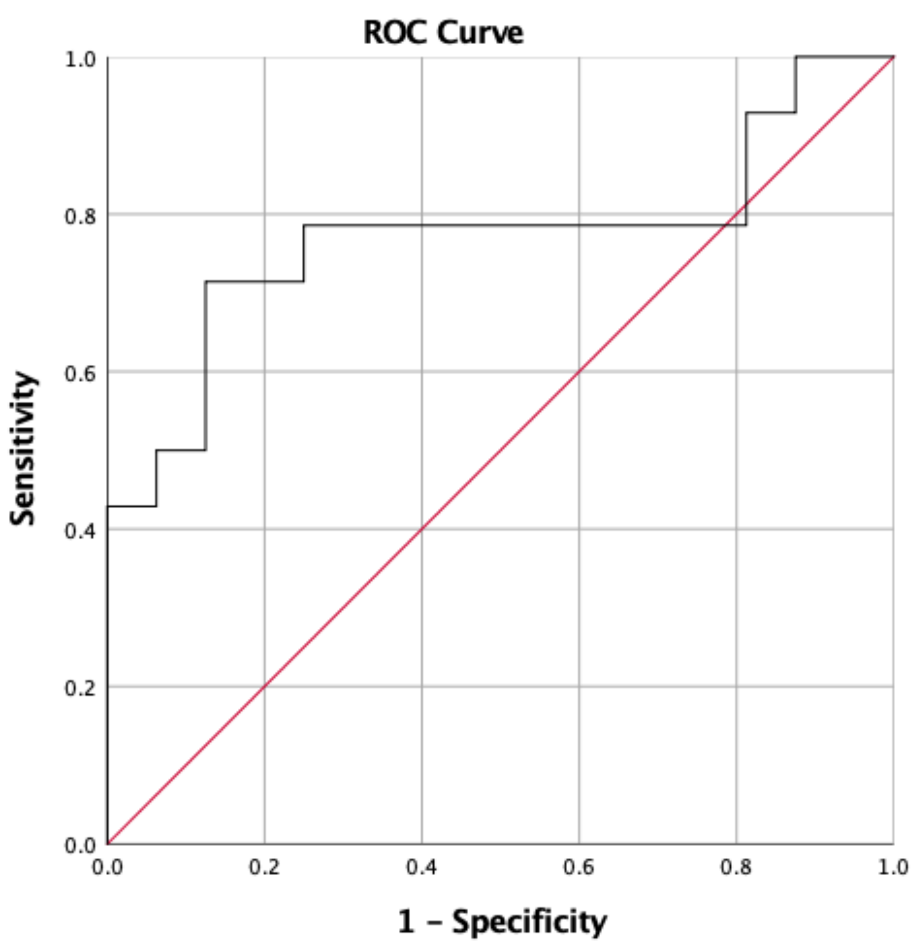

Figure 10. ROC analysis of the final model, AUC = 0.77 (95% CI, 0.59 – 0.96), p = 0.01

5.4. Discussion

This research investigated factors associated with falls and fall-related injuries among non-ambulatory individuals with SCI according to the ICF model proposed by the WHO[30]. The ICF model was adopted to assure a comprehensive assessment of fall risk factors. This cross-sectional study indicated that approximately two-thirds (63%) of the participants reported at least one fall in the previous 6-months. Also, 46.7% of those who reported at least one fall, reported a fall-related injury. While a few previous studies[16-18] specifically examined the strength of associations between falls and risk factors among non-ambulatory individuals with SCI, there is a need to continue exploring these relationships. This exploration will provide insight on factors associated with falls in this population to improve the ability of clinicians to identify individuals at risk for falling and develop fall risk screening tools for this population. In addition, the identification of factors associated with falls may be used to inform the development of effective fall prevention programs. After analyzing a broader range of variables in multivariate logistic regression models compared to previous studies[16-18], time since injury and SCIM III mobility score were found to be significant risk indicators for falls in this population. The model containing these indicators presented with a sensitivity of 81%, specificity of 55%, and an AUC statistic value of 0.73 (95% CI, 0.60 – 0.86). In addition, the physical health domain of WHOQOL was found to be the only significant risk indicator for fall-related injuries. The model containing the WHOQOL- physical health presented with a sensitivity of 79%, specificity of 71%, and an AUC statistic value of 0.77 (95% CI, 0.59 – 0.96).

Notably, fewer years since SCI and greater mobility function (SCIM III mobility score) reported in our study as predictors for falls aligned with the predictors highlighted by Nelson *et al.*[17] in this population. Individuals with more recent onset of SCI are often adults who are highly active, engaging in both basic and instrumental activities of daily living (ADLs). Engaging in ADLs with few experiences using a wheelchair might lead to an increase exposure to falls. Also, individuals with greater mobility function are generally more independent and more engaged in their ADLs, which might lead to falls. Other studies have also highlighted greater mobility function (SCIM III mobility score)[152], higher level of ability[153], and higher levels of physical activity[125] as predictors of falls in individuals with SCI. Other fall predictors, such as pain in the previous two months, alcohol abuse, and a shorter length of wheelchair previously reported by Nelson *et al.*[17] were not examined in our study. However, the model presented in our study, with only two predictors, achieved a sensitivity of 81% and an AUC of 0.73. Our model was as predictive as the model proposed by Nelson *et al.*[17] in which the authors needed six predictors to explain 81% of the variance in fall risk. While our model presented with good discriminant ability and sensitivity, the relatively low specificity (55%) indicates that some non-fallers may be incorrectly identified as fallers and referred to fall prevention programs that might not be needed. This incorrect referral to fall prevention programs is likely not harmful to those individuals and might help to improve their general well-being and functional independence[24,90]. Nonetheless, our model would allow clinicians to identify most individuals at risk of falls before a fall occurs, communicate the probability of falling to individuals with SCI, and refer them to appropriate fall prevention programs.

The sub-analysis of those who experienced at least one fall indicates that WHOQOL-physical health was the only predictor of fall-related injuries among non-ambulatory individuals with SCI. This finding suggests that increased scores on the physical health domain of the WHOQOL questionnaire was associated with decreasing odds of having a fall-related injury. The physical health domain of the WHOQOL questionnaire evaluates components related to energy and fatigue, mobility, physical pain and discomfort, sleep and rest, work capacity, performance of ADLs, and medication[143]. For example, pain and discomfort may lead to a dysfunctional seated posture in a wheelchair, resulting in decreased efficiency in movements during transfers or reaching for an object, which could contribute to an increased risk of sustaining an injury after a fall. Considering the components evaluated by the physical health domain of the WHOQOL during fall risk screenings is important to appropriately identify individuals at risk of fall-related injuries.

Interestingly, none of the significant predictors for falls reported in this study sample were found to be significant predictors for fall-related injuries. Our results align with the report by Forslund *et al*.[16] who indicated general QOL as the only predictor of fall-related injury in non-ambulatory individuals with SCI. Because QOL is broad, our results add to knowledge about the specific domain (physical health) associated with fall-related injuries in this population. In contrast, the fall-related injury predictors, including greater motor function, lack of accessibility of home entrance, and history of previous falls identified by Nelson *et al.,*[17] were not found to be significant predictors in our model. With exception to pain in the two previous months and lack of accessibility of home entrance not explored in our study, greater motor function and history of previous falls were not found to be significant after bivariate analysis in our study. This difference in the results may be due to variations in participant populations. The study by Nelson *et al.*[17] was conducted between April 2004 and March 2007. Since that time, SCI trends and characteristics have changed. For example, the mean age of individuals with SCI in the United States has changed from approximately 29 during the 1970s to 43 years old since 2015[26]. Moreover, our findings presented with a sensitivity and specificity of 79% and 75%, respectively and an AUC of 0.77, indicating good discriminant ability of our model. The alignment between our results and the findings by Forslund *et al*.[16] indicates that clinicians might use the physical health domain of WHOQOL-BREF to identify non-ambulatory individuals at risk of falls and refer them to appropriate fall prevention programs.

Surprisingly, receiving education on fall prevention was not found as a fall risk predictor. Although, this is the first study to analyze this variable as a potential risk predictor, the findings suggest that the current education on fall prevention for individuals with SCI may not be affecting fall-related outcomes. The interpretation of this finding is somewhat limited because the specific components, length of the educational programs, and which professional provided the education on fall prevention received by the participants in this study was not investigated and detailed information on those programs was lacking. However, further examination of the influence of fall prevention programs on fall-related outcomes is needed to inform clinicians whether improvement of those programs is necessary.

Compared to ambulatory individuals with SCI among whom performance-based measures have shown ability to differentiate between fallers and non-fallers[8,92], performance-based measures such as balance measures including the FIST, TCT, or TAI were not found to be associated with falls and fall-related injuries among non-ambulatory individuals with SCI. This might be due to the lack of sensitivity of clinical performance-based measures used for non-ambulatory individuals[101]. Efforts should be made by clinicians and researchers to improve the sensitivity of those outcome measures to facilitate their inclusion in research and clinical settings. Also, the complexity of falls from a wheelchair might explain the absence of associations between clinical performance-based measures and falls among non-ambulatory individuals. Although the performance-based measures evaluated in this study were not found to be significant to identify individuals at risk of falls, findings from qualitative research highlight the importance of these measures. Participants often report poor balance, transfers, and reaching for items to be associated with falls[16,19,20]. Accurate prediction of falls from a wheelchair likely requires the integration of the predictors of falls described in this study and the integration of findings from qualitative research described in previous studies[16-18].

5.5. Limitations

There are several limitations that should be considered in this study. First, we included a relatively small sample size in our study. Specifically, the sub-analysis of fall-related injuries was performed with a small number of fallers. However, our results corroborate with the findings presented by Forslund *et al*.,[16] in which the fall frequency of 149 participants was prospectively tracked. Also, the bivariate analysis with the balance measures and the TAI was conducted with only 20 individuals which might hinder the power of the analysis. When comparing the literature on fall predictors among non-ambulatory individuals with SCI to the existing literature on ambulatory individuals[8,92], older adults[79,154], or individuals with other neurologic diseases[7,119], it becomes evident that further research with a bigger sample size is required to provide more robust findings. Another limitation is that our analyses were based on self-reported and retrospective fall data. Compared to prospective fall tracking, retrospective fall data may be influenced by recall bias, therefore limiting the interpretation of our results. However, a recent review indicates that there was no difference between the results of retrospective and prospective fall tracking procedures among individuals with SCI[1]. In addition, our study is important as it comprehensively evaluates the ability of performance-based and self-reported measures to identify non-ambulatory individuals with SCI at risk of falls and fall-related injuries. The results presented in this study can help to develop fall risk screening tool specific for this population.

Also, we suspect that most participants underreported minor fall-related injuries. Future studies using emerging fall detection devices that will automatically and accurately detect and provide an objective report of fall frequency might also help to provide more robust findings. The validity of the use of these devices among non-ambulatory individuals also deserves further attention[13,155]. Furthermore, the lack of details on the specific components of fall prevention programs, lengths of the educational programs, and which health professional provided the education on fall prevention might hinder the interpretation of our results. Lastly, the proportion of variance in our final model suggests that other factors not analyzed in our study might limit our ability to accurately identify individuals at risk of falls. However, this is the first study that included such large number of potential predictors (34) of falls in this population.

5.6. Conclusion

This study focused on identification of fall risk predictors among non-ambulatory individuals with SCI. From a clinical standpoint, findings confirm the need to increase awareness about falls and fall-related injuries in this population. During fall risk screenings, clinicians should consider time since injury and level of mobility function, as well as components included in the physical health domain of the quality of life questionnaire, such as level of energy and reports of fatigue and physical pain. Carefully considering these findings and reports are important as they have been found to be associated with falls and fall-related injury, respectively. Identifying non-ambulatory individuals with SCI at risk of falls will improve referrals to rehabilitation professionals for enrolment in fall prevention programs in a timely manner. Education on wheelchair-related falls should be incorporated in early stages of SCI rehabilitation process.

For future directions, the influence of current fall prevention programs on fall incidence and fall-related injuries should be further investigated. Acknowledging the limitations on the lack of information about the specific components of fall prevention programs, length of the programs, and which professionals provided the education on falls, our findings suggest the current education on fall prevention are not effective in reducing fall-related outcomes. Fall prevention programs might require, in addition to education on fall prevention, training of transfers or wheelchair skills. Even if poor transfer quality, poor balance, and wheelchair skills were not found to be associated with falls in our study, they have been reported by participants as factors commonly associated with falls. Targeted training might improve overall functional mobility skills of non-ambulatory individuals with SCI and better prepare them to prevent falls. Also, clinicians and researchers should further investigate fall risk predictors to externally validate the multivariate logistic regression models presented in this study. Consequently, rehabilitation professionals should prioritize the development of a fall risk screening tool specific for non-ambulatory individuals with SCI.

CHAPTER 6. CONCLUSIONS

Spinal cord injury (SCI), damage to the spinal cord, can result in significant physical and psychological burdens for individuals and their relatives[25]. Approximately, two in three non-ambulatory individuals with SCI experience at least one fall in a 6 to 12-month period[1], and approximately half of those falls lead to injuries[17,126]. The injuries range from minor impairments, such as bruising and cuts, to major impairments, such as fractures or head concussions[16,17]. The identification of risk factors of falls and fall-related injuries is important to guide the development of fall risk screening tools and fall prevention programs. Moreover, the identification of individuals at risk of falls is essential in order to refer those individuals to appropriate fall prevention programs. However, non-ambulatory individuals with SCI seldom receive fall and fall-related injury risk screenings due to the lack of evidenced based guidelines on the topic in this population. In addition, the COVID-19 pandemic brought to light the importance of remote assessment in this population[145].

Overall, the purpose of this project was to investigate the frequency and characteristics of falls, fall-related injuries, and predictors of falls in non-ambulatory individuals with SCI. In addition, the study investigated the feasibility and preliminary psychometric properties of remote assessments of sitting balance in this population. Determining predictors of falls and fall-related injuries for non-ambulatory individuals with SCI is a critical step towards the development of effective fall risk screening tools to identify individuals at risk of falls and to inform the development of effective fall prevention programs. Overall, this research will work to improve overall function, quality of life, and community participation of non-ambulatory individuals living with SCI.

Three studies, divided in two phases, were performed to provide information on factors that can guide clinicians to identify individuals at risk of falls. The first phase was performed to adjust the original design of the study from in-person data collection to a remote assessment due to the COVID-19 pandemic[145]. The results of this phase indicated that remote sitting balance assessments, using the Function in Sitting Test, the Trunk Control Test, the modified Functional Reach Test, and the T-shirt Test, is feasible and present with appropriate reliability and validity when compared with in-person assessments[145]. Reliable and valid remote assessment of seated balance provides clinicians with the opportunity to continue therapeutic care when in-person assessments are not possible. Often, in both clinical and research contexts, in-person assessments are not possible because of limited availability of accessible transportation, time requirements, and involved expenses such as parking and fuel fees. Reliable and valid remote assessments could also help minimize the challenges related to inaccessible environments that limit an individual's ability to have a face-to-face interaction with a healthcare professional. In addition, valid and reliable remote assessments could be an excellent alternative for monitoring vulnerable individuals during a healthcare crisis, such as the COVID-19 pandemic. This first phase of the study was essential to establish alternative assessment strategies to maintain overall health and well-being, especially for those with limited access to healthcare.

The second phase investigated the frequency and characteristics, as well as predictors of falls and fall-related injuries, among non-ambulatory individuals with SCI. The results indicated that falls and fall-related injuries are frequent in this population and deserve special attention from clinicians and researchers. Understanding the characteristics surrounding falls and fall-related injuries is essential to guide the development of fall prevention programs in this population. In addition, the results indicated that higher levels of mobility and fewer years since

SCI are predictors of falls, and the physical health domain of the World Health Organization quality of life is a strong predictor of fall-related injuries in this population. These findings can help with the development of fall risk screening tools to identify individuals at risk of falls. The ability to appropriately identify individuals at risk of falls will help clinicians to refer them to fall prevention programs. This will ultimately reduce the occurrence of falls and fall-related injuries, improve overall functions, enhance the quality of life and community participation.

This project fills a gap in the research of prediction of falls and fall-related injuries among non-ambulatory individuals with SCI. Compared with other populations[5-7] and ambulatory individuals with SCI[8,9,92], more information is needed to better understand the characteristics and predictors of falls and fall-related injuries among non-ambulatory individuals with SCI[16,17]. Our results corroborate the findings from previous studies suggesting that falls occur mostly inside the house, during transfer activities, and are associated with environmental barriers. These findings provide important information to develop valid and accurate fall risk screening tools to identify non-ambulatory individuals with SCI at risk of falls.

There are limitations to this project that need to be considered. The analysis of the data was based on retrospective fall data. This study design presents with recall bias which might hinder the clinical interpretation of the results. However, the results align with studies using prospective fall tracking among non-ambulatory individuals with SCI. Also, the relatively small sample included in our study may hinder the power of the results presented. Specifically, because of the small number of fall-related injuries assessed in this study, we were not able to provide more information on the circumstances and characteristics surrounding falls leading to injury.

Moving forwards, more studies are warranted to specifically investigate risk factors and predictors of falls and fall-related injuries among non-ambulatory individuals with SCI. This will provide more information on the characteristics of falls and fall-related injuries and factors to be targeted in fall prevention programs. More accurate data on characteristics of falls may be obtained in future studies using emerging fall detection devices that will automatically provide an objective report of fall frequency. Further studies should also investigate the specific components of fall prevention programs, length of the programs, and which professionals provided the education on falls. In addition, future studies should aim to develop a fall risk screening tool based on the factors associated with falls and fall-related injuries uncovered in this research. This fall risk screening tool should be widely available in clinical settings to identify individuals at risk of falls and refer them to appropriate fall prevention programs. Finally, clinicians and researchers should develop fall prevention programs based on the characteristics of falls and fall-related injuries. Home-based exercise programs and/or modifications of home environments, in addition to education on fall prevention, can be included in treatment plans.

In conclusion, falls and fall-related injuries are frequent among non-ambulatory individuals with SCI and deserve attention from clinicians and researchers. Falls mostly occur inside of the house, during transfers, and are associated with environment constraints, such as poor surface conditions. These falls may also lead to minor injuries or more severe injuries including lower extremities fractures or head concussions. Clinicians may identify individuals at risk of falls and fall-related injuries according to the individual's time since injury and level of mobility, and physical health, respectively. The study also provides important evidence for remote monitoring of sitting balance in this population. These findings are important to provide targeted care and guide home-based interventions through remote assessments. In addition, the findings suggest that clinicians can identify non-ambulatory individuals with SCI at risk of falls and fall-related injuries and refer them to appropriate fall prevention programs. These results will ultimately help prevent falls and fall-related injuries, maximize overall function, and enhance the quality of life of non-ambulatory individuals with SCI.

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APPENDIX A. DESCRIPTION FEASIBILITY INDICATORS, PARAMETERS OF SUCCESS, AND RESULTS

Indicator	Parameter of success	Results	Feasible
Recruitment rate	# participants/protocol	7/11 (63%) recruited for remote assessment	Yes
Retention rate	Complete remote assessment with > 80% of participants	100% completed remote assessment	Yes
Internet access	A minimum of 256 kBps	7/7 completed remote assessment	Yes
Data collection burden	Time spent for in-person and remote assessments	In-person: ~ 20 min Remote: ~ 25 min	Yes
Adherence	Minimal modifications are needed	Minimal change	Yes
Study protocol	Minimal modifications are needed	Minimal change	Yes

APPENDIX B. FALL PREDICTION RECRUITING SCRIPT AND PRE-SCREENING QUESTIONS

Hello! This is _______ from the Disability Participation and Quality of Life Lab at the University of Illinois. Is ________ available?

I'm calling because we received an e-mail/phone call indicating your interest in participating in our study examining methods to predict falls using balance measures among non-ambulatory individuals with spinal cord injury. I was wondering if you had a few minutes to talk about it.

If yes, move on. If no, is there another time we could talk? *Record date and time:*

____

Great! As I mentioned before, the aim of this study is to predict falls using balance measures among non-ambulatory individuals with spinal cord injury. This study will be important to better determine who is at risk of falls and may help clinicians to implement fall prevention strategies to avoid the consequences of falls.

If you choose to participate, you will be asked to attend two online study assessments. The first study assessment will last approximately 90 min including 50 minutes of completing a series of online questionnaires and the second study assessment will last approximately 30 minutes. During these assessments, you will first complete a screening that will take ~2 minutes. Researchers will ask your gender, age, level of injury, type of injury, history of past falls and question about wheelchair use.

If you pass the screening, you will be asked to respond a series of online questionnaires about fear of falling, transfer ability, wheelchair skills, social participation, and quality of life. These questionnaires will take you approximately 50 minutes to complete. Then, you will proceed to the online physical testing. During the online testing, setting up the calls and answering any questions may take 20 minutes and then, you will be asked to perform four clinical balance tests that will take you approximately 20 minutes. The sitting balance tests evaluate how well you maintain your seated posture while doing daily activities such as reaching, scooting, or putting on a t-shirt. After the first online study assessment, you will be asked to track your falls for a period of 6 months. You will track your falls using a paper fall calendar that will be provided to you. You will be asked to mark on the calendar whenever you experience a fall, the time and the activities that you were doing at the moment of the fall. You will receive phone calls every 2 weeks to remind you to track your falls and report if you have experienced any falls. After a period of 6 months, you will be asked to participate in a second online assessment to perform the same clinical balance tests you performed during the initial online study assessment once again.

You will not benefit directly from this research, but this data may help our research team to identify individuals at greater risk of falling and gather data to predict falls.

For your time, you will be compensated $30 for the completion of the study. You will receive $20 after your first online assessment and additional $10 after completion of the second online assessment.

Please note that video-recordings will be taken for research purposes during the online assessment. All the assessment will be led and monitored by a trained research assistant.

The study assessment will be held online using your preferred video conference platform (example include zoom, facetime, google hangout).

Do you have any questions? Are you interested?

If not, Ok! Thank you so much for your time. Would you mind if we kept your information and called about future studies?

If interested, GREAT! We are happy to have you come visit us. First, though, we need to ask you a few pre-screening questions. Is that, ok?

Screening Questionnaire			
Question		Response (please circle one)	
1.	How old are you? (Between 18 and 30 years old)		
2	Do you have a SCI or spina bifida?		
3	What is the level of your injury? (C5-L5)		
4	What is the type of your injury? (AIS A, B, C, D)		
5	Do you use of a wheelchair as your primary mobility source?	Yes	No
6	Are you able to communicate with the research team through video conference software?		
7	Do you have a care partner or family member who can provide assistance during the online assessment?		

Does the participant qualify for the study?

Yes No

- If the participant does not meet the inclusion criteria, please read the following information. "I am very sorry, but it does not look like you meet the inclusion criteria to participate in this research study. We appreciate your interest in the study. Would you like me to keep your information on file and notify you about other research studies we might have going on?"

Yes No

If yes, please collect the following information:

Name	
Address	
Email	

Please also document the reason the participant could not participate in the recruitment log.

- If the participant meets the inclusion criteria, please continue with the information below.

"It looks like you meet the inclusion criteria. If you don't mind, I would like to collect some additional information from you, and I can get you scheduled for your first study visit."

Name	
Address	
Email	

Let's find a time for your online assessment.

Write assessment day and time here: ____

Which video conference platform do you prefer? ________________

Thank you again for participating! ________________ will email soon with a welcome letter that goes over the study, gives you directions, and has a reminder of your assessment day and time. Have a great day!

APPENDIX C. TRIPOD CHECKLIST

Section/Topic	Item	Checklist Item	Page
Title and abstract			
Title	1	Identify the study as developing and/or validating a multivariable prediction model, the target population, and the outcome to be predicted.	64
Abstract	2	Provide a summary of objectives, study design, setting, participants, sample size, predictors, outcome, statistical analysis, results, and conclusions.	NA
Introduction			
Background and objectives	3a	Explain the medical context (including whether diagnostic or prognostic) and rationale for developing or validating the multivariable prediction model, including references to existing models.	65
	3b	Specify the objectives, including whether the study describes the development or validation of the model or both.	65
Methods			
Source of data	4a	Describe the study design or source of data (e.g., randomized trial, cohort, or registry data), separately for the development and validation data sets, if applicable.	66
	4b	Specify the key study dates, including start of accrual; end of accrual; and, if applicable, end of follow-up.	66
Participants	5a	Specify key elements of the study setting (e.g., primary care, secondary care, general population) including number and location of centres.	67
	5b	Describe eligibility criteria for participants.	67
	5c	Give details of treatments received, if relevant.	NA
Outcome	6a	Clearly define the outcome that is predicted by the prediction model, including how and when assessed.	69
	6b	Report any actions to blind assessment of the outcome to be predicted.	NA
Predictors	7a	Clearly define all predictors used in developing or validating the multivariable prediction model, including how and when they were measured.	69-71
	7b	Report any actions to blind assessment of predictors for the outcome and other predictors.	NA
Sample size	8	Explain how the study size was arrived at.	67
Missing data	9	Describe how missing data were handled (e.g., complete-case analysis, single imputation, multiple imputation) with details of any imputation method.	71
Statistical analysis methods	10a	Describe how predictors were handled in the analyses.	72-73
	10b	Specify type of model, all model-building procedures (including any predictor selection), and method for internal validation.	72-73
	10d	Specify all measures used to assess model performance and, if relevant, to compare multiple models.	73
Risk groups	11	Provide details on how risk groups were created, if done.	NA
Results			
Participants	13a	Describe the flow of participants through the study, including the number of participants with and without the outcome and, if applicable, a summary of the follow-up time. A diagram may be helpful.	74
	13b	Describe the characteristics of the participants (basic demographics, clinical features, available predictors), including the number of participants with missing data for predictors and outcome.	74
Model development	14a	Specify the number of participants and outcome events in each analysis.	74
	14b	If done, report the unadjusted association between each candidate predictor and outcome.	NA
Model specification	15a	Present the full prediction model to allow predictions for individuals (i.e., all regression coefficients, and model intercept or baseline survival at a given time point).	75-82
	15b	Explain how to the use the prediction model.	75-82
Model performance	16	Report performance measures (with CIs) for the prediction model.	75-82
Discussion			
Limitations	18	Discuss any limitations of the study (such as nonrepresentative sample, few events per predictor, missing data).	87-88
Interpretation	19b	Give an overall interpretation of the results, considering objectives, limitations, and results from similar studies, and other relevant evidence.	83-86

Appendix C (cont.)

Implications	20	Discuss the potential clinical use of the model and implications for future research.	88-89
Other information			
Supplementary information	21	Provide information about the availability of supplementary resources, such as study protocol, Web calculator, and data sets.	111-115
Funding	22	Give the source of funding and the role of the funders for the present study.	NA

APPENDIX D. CHARACTERISTICS OF STUDY PARTICIPANTS

Results are expressed as frequencies and percentages for categorical variables and mean (SD) or Median (IQR) for continuous variables.

Characteristics	**Total sample** (n = 59)
Sex, n (%)	
Male	28 (47.5)
Female	31 (52.5)
Age, y	
Median (IQR)	52.5 (21)
Min-max	19 - 72
Race, n (%)	
Asian	3 (5.1)
African American	6 (10.2)
Caucasian	48 (81.4)
Hispanic	2 (3.4)
Height (cm)	
Median (SD)	171.5 (17.1)
Min-max	137.2 - 190.5
Weight (Kg)	
Median (IQR)	75 (27)
Min-max	42 - 125
Mobility aid, n (%)	
Power WC	17 (28.8)
Manual WC	42 (71.2)
Cause of SCI, n (%)	
Traumatic	43 (72.9)
Non-traumatic	16 (27.1)
Time since injury, y	
Median (IQR)	16.5 (27.25)
Min-max	0.5 - 57
Level of injury, n (%)	
Cervical	13 (22)
High thoracic	15 (25.4)
Low thoracic	22 (37.3)
Lumbar	5 (8.5)
Unknown	4 (6.8)

IQR: interquartile range, SCI: spinal cord injury, WC: wheelchair, y: years

APPENDIX E. CLINICAL INFORMATION OF STUDY PARTICIPANTS

Results are expressed as frequencies and percentages for categorical variables and median (IQR) for continuous variables. N = 59 unless otherwise stated.

Characteristics	**Total sample**
Fall incidence	
• Yes	37 (63)
• No	22 (37)
Education on fall prevention	
• Yes	30 (57.7)
• No	22 (42.3)
Fall-related injury	
• Yes	14 (46.7)
• No	16 (53.3)
FOF	
• No	16 (27)
• Yes	43 (73)
SCI-FCS	28 (14)
HADS	
- Depression	5 (5)
- Anxiety	5 (6)
Balance measures (n = 21)	
- FIST	44 (12)
- TCT	22 (7)
- T-shirt test (s)	4.83 (2.66)
- mFRT (cm)	10.75 (7.75)
- Self-TAI	6.95 (1.65)
- TAI	8.15 (1.10)
Community participation	
- CPI-Importance	50 (15)
- CPI-Control	55 (8)
CHIEF-SF	21 (16)
SCIM III	
- Self-care	18 (3)
- Respiration and sphincter control	28 (13)
- Mobility	16 (6)
- Total	62 (16)
WST - Capacity	83 (22)
- Confidence	82 (21)
- Performance	65 (31)

Appendix E (Cont.)

Characteristics	**Total sample**
WHOQOL	
- Physical health	65 (11)
- Psychological health	69 (12)
- Social relationships	65 (31)
- Environment	88 (25)

IQR: interquartile range, CHIEF-SF: Craig Hospital Inventory of Environmental factors- Short Form; CPI: Community Participation Indicators; FIST: Function in Sitting Test; HADS: Hospital Anxiety and Depression Scale; mFRT: Modified Functional Reach Test; SCI-FCS: Spinal Cord Injury- Falls Concern Scale; SCIM III: Spinal Cord Injury Measures III; TAI: Transfer Assessment Instrument; TCT: Trunk Control Test; WHOQOL: World Health Organization Quality of Life; WST: Wheelchair Skills test

APPENDIX F. THE 2 X 2 TABLE FOR THE FINAL MULTIVARIATE LOGISTIC ANALYSIS FOR FALLERS' CLASSIFICATION

Composite	Faller	*N*	Non-faller	*N*	Total
Positive	True positive	31	False positive	13	44
Negative	False negative	6	True negative	9	15
Total		37		22	59

APPENDIX G. THE 2 X 2 TABLE FOR THE FINAL MULTIVARIATE LOGISTIC ANALYSIS FOR FALL-RELATED INJURIES CLASSIFICATION

Composite	Injured	*N*	Not injured	*N*	Total
Positive	True positive	10	False positive	2	12
Negative	False negative	4	True negative	14	18
Total		14		16	30

APPENDIX H. IRB APPROVAL LETTER

ILLINOIS

OFFICE OF THE VICE CHANCELLOR
FOR RESEARCH & INNOVATION

Office for the Protection of Research Subjects
805 W. Pennsylvania Ave., MC-095
Urbana. IL 61801-4822

Notice of Approval: New Submission

May 4, 2020

Principal Investigator	Laura Rice
CC	Amelia Woods Libak Abou
Protocol Title	Prediction of falls using clinical balance measures among non-ambulatory individuals with spinal cord injury: A prospective cohort study
Protocol Number	20718
Funding Source	Illinois Physical Therapy Foundation
Review Type	Full Board
Status	Active
Risk Determination	No more than minimal risk
Approval Date	May 4, 2020
Closure Date	May 3, 2025

This letter authorizes the use of human subjects in the above protocol. The University of Illinois at Urbana- Champaign Institutional Review Board (IRB) has reviewed and approved the research study as described.

The Principal Investigator of this study is responsible for:

- Conducting research in a manner consistent with the requirements of the University and federal regulations found at 45 CFR 46.
- Using the approved consent documents, with the footer, from this approved package.
- Requesting approval from the IRB prior to implementing modifications.
- Notifying OPRS of any problems involving human subjects, including unanticipated events, participant complaints, or protocol deviations.
- Notifying OPRS of the completion of the study.

UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

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