OBJECTIVE MEASUREMENT OF SEDENTARY BEHAVIOUR AND PHYSICAL
ACTIVITY IN OLDER ADULTS AFTER HIP FRACTURE: RESULTS FROM A
RANDOMISED CONTROLLED TRIAL

by

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Abstract

Introduction: Hip fracture is a serious event with longstanding implications for older adults. These fractures frequently lead to reduced mobility, prolonged periods of sitting time, and consequently, a lack of physical activity.

Objectives: I aimed to test how a comprehensive geriatric management clinic affects sedentary behaviour and physical activity patterns over a 12-month period, and to characterise the recovery patterns of sedentary behaviour and physical activity for older adults after hip fracture.

Methods: This study collected prospective objective measurements (accelerometry) of sedentary behaviour and physical activity patterns from older adults with hip fracture. I described and tested sedentary behaviour and physical activity using accelerometry at baseline, 6 and 12 months from a parallel-group, 1:1 single-blinded randomised controlled trial for older adults 3-12 months after hip fracture. The usual care group received standard post-operative management; the intervention group received usual care plus a clinical management by health professionals.

Results: The study enrolled 53 participants [mean age (SD) 79(8) years], 3-12 months post-fracture. Forty-five participants had valid data (intervention (n=22) or usual care (n=23) group). Participants had a mean (SD) age of 79.2 (7.4) years, ranged 65-98 years, with a median (p10, p90) of 203 (143, 335) days since fracture. Participants from both groups spent approximately 10 hours/day in sedentary behaviour. There were no statistically significant differences between groups for sedentary behaviour or physical activity variables at midpoint and final assessment. Men engaged in significantly more sedentary time (47 minutes; p=0.049), and spent less time in
light physical activity (44 minutes; p=0.044) compared with women, across the study. Although men had more sedentary time at each time point, the difference was attenuated at final assessment and was no longer statistically significant.

**Conclusion:** Older adults after hip fracture spend prolonged periods of waking hours sedentary and without much activity. Decreasing and breaking up sedentary time and increasing physical activity is an important target for rehabilitation. Differences between sexes should be acknowledged and addressed by health professionals. Further, strategies should be developed and tested to reduce time spent in sedentary behaviour and increase physical activity for older adults after hip fracture.
Preface

Statement of co-authorship:

This dissertation is based on an analysis of a secondary outcome of a randomised controlled trial conducted on mobility recovery after hip fracture. None of the text in this dissertation is taken directly from previously published articles, but chapter 3 is a manuscript that I have written and is currently in preparation for publication. I developed the study questions, hypotheses and rationale presented in Chapter 1 and wrote the literature review presented in Chapter 2. The randomised controlled trial, including methods and results, is described in Chapter 3. The study was conducted by the principal investigator, but the data analysis and interpretation are my original work. I wrote the study conclusions described in Chapter 4. All tables, graphs and figured throughout this thesis are of my own design, except for the Consolidated Standards of Reporting Trials (CONSORT) 2010 Flow diagram, designed by the CONSORT group [1].

Abstracts:

This work was accepted as an abstract at several conferences. The abstracts are based on data presented in Chapter 2 and Chapter 3.


**Research ethics approval:**

The study was approved by the UBC Clinical Research Ethics Board (H09-01291) and was approved at the following sites: Vancouver Coastal Health (VCHRI/VCHA), Vancouver General Hospital, Vancouver Coastal Health (VCHRI/VCHA), Lions Gate Hospital, Providence Health
Care, St. Paul's Hospital and Vancouver Coastal Health (VCHRI/VCHA) Vancouver Community.
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<td>BMI</td>
<td>Body Mass Index</td>
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<tr>
<td>CDC</td>
<td>Centre for Disease Control</td>
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<td>CHHM</td>
<td>Centre for Hip Health and Mobility</td>
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<td>CI</td>
<td>Confidence Interval</td>
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<td>CONSORT 2010</td>
<td>CONsolidated Standards of Reporting Trials 2010</td>
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<td>MEMS</td>
<td>Micro-Electro Mechanical System</td>
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<td>MET</td>
<td>Metabolic Equivalents of Task</td>
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<td>NHANES</td>
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<td>PRISMA</td>
<td>Preferred Reporting Items for Systematic Reviews and Meta-Analyses</td>
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<td>SPPB</td>
<td>Short Physical Performance Battery</td>
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<td>TCPS</td>
<td>Tri-Council Policy Statement</td>
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<tr>
<td>UC</td>
<td>Usual Care</td>
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<tr>
<td>UBC</td>
<td>University of British Columbia</td>
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<tr>
<td>VCH</td>
<td>Vancouver Coastal Health</td>
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Glossary of Terms

- Allocation concealment: The process in which the person in charge of randomisation does not know what the following treatment allocation will be, in order to prevent selection bias affecting which patient will be in which allocation group.

- Baseline: Data collection time point at point of recruitment.

- Blinding: The process in which study group allocation is concealed from the individual, the research staff or both. An essential part of a randomised controlled trial.

- Clinical trial: Any research study that is prospectively conducting an intervention for one or more groups of human participants.

- Confidence interval: A result of a statistical analysis that manifests as a range of values that represents the probability that the true effect of the tested variable in the study population sample will be found within that range. If the coefficient includes zero within its values, it means that the result is not statistically significant.

- Data cleaning: The process in which inaccurate or corrupt data is corrected or removed from study analysis.

- Older adult: Adults from the age group of 65 and older.

- Eligibility criteria: Criteria that, if met, allow for the participants to be included in the study if they wish to.

- Epoch: A time sampling interval.

- Hypothesis: A theorised or suggested answer to the research question based on current knowledge.
- Informed consent: A process in which a participant gives their consent to participating in a study, after reading and understanding the terms of the study and when the agreement to participation is completed of their own free will.

- Intervention: A group in a randomised control trial that receives a certain treatment.

- Metabolic Equivalent of Task (MET): A measurement expressing the energy cost of an activity in reference to energy expenditure (measured by oxygen consumption) when resting.

- Outcome measure: The results of a test that is being carried out in a study. The test is done prior to intervention and the results are compared with those after the intervention.

- Participants: A group of people who are taking part in a study.

- Physical activity: Any bodily movement produced by skeletal muscles that requires energy expenditure [2, 3].

- Randomisation: A process in which the research participants are assigned to different study groups by the practice of using chance methods, such as a number generator or flipping a coin.

- Randomised controlled trial: A type of study design in which participants are randomly allocated into either an experimental group or control group.

- Research bias: A case in which a researcher influences the course of a study or its results. The researcher can intervene either in favor of or against an individual, or group of people, compared with another individual or a group.

- Sample size: The overall number of participants who takes part in a study.

- Sedentary behaviour: Activity of low energy expenditure (MET ≤ 1.5), usually referring to a sitting or reclining position [4].
- Sedentary break: A pause in the time that is spent in sedentary behaviour.
- Sedentary bout: A quota of time spent in sedentary behaviour.
- Selection bias: A bias that is the result of an unrepresentative population due to selection of individuals or groups to be included or excluded in the study.
- Simple linear regression: An approach for modeling the relationship between a dependent variable $y$ and one independent variable $X$. The core model equation is $Y=aX+b$. A simple linear regression deals with the case where there is one dependent variable and one independent variable.
- Usual care: The usual post-operative treatment offered in British Columbia for patients recovering from hip fracture.
Acknowledgements

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I would like to also thank my fellow lab mates and the faculty, staff and trainees of the Centre for Hip Health and Mobility for stimulating discussions, help and support and for making my time as a graduate student memorable and incredible.

Finally, I would like to thank my husband, Tal Shalev, who has been there for me every step of the way. I do not know how I could have done it without you. Thank you.
Dedication

I would like to dedicate this thesis to my son, Aidan who brought so much joy into my life. I love you more than words could say.
Chapter 1: Introduction

Sedentary behaviour is defined by the Sedentary Behaviour Research Network as time spent in activities which require low energy expenditure, and usually refers to time spent in a sitting or reclining position [4]. Recent studies have shown that prolonged sedentary behaviour can be linked to a variety of conditions, such as cancer [5], obesity [6], low physical function [7-9], metabolic diseases [10], cardiovascular diseases [11], reduced muscle mass [12] and type 2 diabetes [6]. Sedentary behaviour may have a negative effect on adults even if they meet physical activity guidelines and was previously seen as an independent factor to physical activity [4, 13, 14]. A recent harmonised meta-analysis, that included 13 studies (n> one million participants) and a follow up time of at least two years, reported no increase in early mortality risk for participants who self-reported being sedentary for > eight hours/day, if they engaged in 60-75 minutes of moderate-vigorous physical activity (MVPA) daily. There was no risk reduction conferred with similar patterns of TV watching and MVPA [15]. However, 60-75 minutes/day of MVPA is unrealistic for most (older) adults; thus, based on current knowledge, older adults who engage in prolonged sitting (and concurrently are inactive) are at risk for adverse health outcomes, as mentioned above. What remains to be determined is what amount of daily MVPA could offset deleterious health outcomes in older adults. One group at particular risk of prolonged sitting are older adults after hip fracture. Hip fracture is a serious common event for older adults with long term implications. Older adults after hip fracture often lose their mobility and many will never regain it [16]. Mobility disability may lead to prolonged time spent in sedentary behaviour [17] and lack of time spent in physical activity which in turn may have negative effects on overall health and recovery from the fracture [18, 19]. With the negative effect sedentary behaviour and physical activity have on health, it is important to understand how sedentary and how active older adults after hip fracture are during the
recovery process from hip fracture. Having this knowledge will contribute to the development of targeted strategies to decrease sitting time, increase activity and enhance recovery.

Aiming to summarise current data, I conducted a systematic search of the literature, following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [20], looking for studies that measured sedentary behaviour and/or physical activity using objective measurement tools in older adults after hip fracture. I identified research studies published in English with no time restrictions from the following databases: Cumulative Index to Nursing and Allied Health Literature (CINAHL); Embase; Google Scholar; Ovid MEDLINE; PsycINFO; Public Library of Science (PLoS); PubMed; SportDiscus and Web of Science. I only retrieved 15 studies that met these criteria; of these only two studies measured sedentary behaviour directly and all measured physical activity (in the forms of: time upright, time walking, time in activity, activity count and number of steps).

To date, there have been relatively few studies that evaluated sedentary behaviour and physical activity patterns in older adults, despite the fact that this age group is more likely to engage in very little physical activity [7]. Even fewer studies evaluated physical activity in older adults after hip fracture [18, 19] and only a handful have used objective measurement instruments [17, 21-24]. A recent Cochrane review evaluated the effect of different interventions on increasing mobility in older adults up to a year after hip fracture surgery [25]. They included 19 different randomised controlled trials, involving a total of 1589 participants, mostly women [25]. The interventions reported by the different studies included several aerobic muscle (e.g. weight-bearing exercises) and balance exercises. Studies were too diverse in intervention type and setting to pool the data, several of them had methodological flaws and they reported different and contradictory results. Successful interventions included a two-week weight-bearing program, a quadriceps muscle strengthening exercise program, an intensive 12 weeks of physical training and home-based physical therapy, and 6 months and one year of intensive physical
training. Unsuccessful interventions included a treadmill gait retraining program, 12 weeks of resistance training, 16 weeks of weight-bearing exercise, intensive physiotherapy and home-based resistance or aerobic training. In addition, two trials in hospital setting soon after hip fracture tested the effect of electrical stimulation of the quadriceps. While one reported no benefit and bad tolerance, the other reported increased mobility and good tolerance. This is what led researchers to conclude that there is not enough evidence from randomised trials to determine the effects of a specific mobilisation strategy, regardless of setting or rehabilitation stage [25].

Prior to the B4 study, no other study tested the effect of an intervention (of any kind) on reducing sedentary behaviour in older adults after hip fracture. In addition, no other study measured both sedentary behaviour and physical activity patterns prospectively, in the form of time spent sedentary or time spent active, for a period of one year in older adults after hip fracture.

Noting a knowledge gap, I aimed in this thesis to synthesise and contribute to the available evidence for sedentary behaviour and activity patterns for older adults after hip fracture. I characterised and examined differences in sedentary behaviour and physical activity patterns between the two groups of older adults with hip fracture who were enrolled in a one-year clinical trial. In this trial I tested the effect of a comprehensive geriatric management clinic versus usual care and characterised the recovery patterns of sedentary behaviour and physical activity for older adults after hip fracture. Men and women were previously shown to present different activity patterns [26]. Therefore, after a careful review of the literature I decided to evaluate sedentary behaviour and physical activity differences between sexes. This is important as understanding activity differences between men and women could help health professionals address sex-specific needs.

Thus, my research questions were: 1. Is there a difference between groups for sedentary behaviour and physical activity at 6 and 12 months after hip fracture? 2. Is there a difference in
sedentary behaviour and physical activity patterns between men and women? And 3. What percentage of their waking time do older adults after hip fracture spend in sedentary behaviour and physical activity?

Prior to analysing the data, I hypothesised that older adults who were allocated to the intervention group will show better activity patterns at the data collection time points. I hypothesised that a decrease in time spent sedentary will be seen in all participants over the 12-month course of the study. I also hypothesised that older adults who took part in the intervention group and completed a comprehensive program will spend statistically significantly less time in sedentary behaviour and more time in light and MVPA than the control (usual care) group; this would be consistent with current literature reporting an increase in activity status following an active physical activity intervention [27]. I also hypothesised that I will see a statistically significant difference in time spent in sedentary behaviour and physical activity patterns between men and women at all three time points and that women would be less sedentary and more active than men across the study. These results would be consistent with the current literature that suggests that women have a better overall sedentary profile, meaning they spend less time in sedentary behaviour than men, independent of age, physical functioning, cognitive functioning, depressive symptoms and accelerometer wear time [26] and less time in sedentary bouts than men [26, 28]. It has also been previously shown in the literature that men and women show different physical activity patterns at older ages, with women being more active [26]; I hypothesised that this trend will continue post-fracture. Finally, I hypothesised that study participants will spend more than 60% of their waking hours in sedentary behaviour. As healthy older adults spend approximately 60% of their waking hours sedentary [29], I hypothesised that after hip fracture, older adults will spend more time in sedentary behaviour.

There are four chapters in this thesis. Following this introductory chapter, chapter 2 presents a literature review of hip fractures, sedentary behaviour, physical activity and activity monitors. Chapter 3
is a manuscript of the randomised controlled trial in preparation for publication, presenting methods, results, discussion and conclusions. In chapter 4, I draw the conclusions of my thesis regarding the goals or hypotheses presented in this introduction, discuss the meaning of the results in light of current knowledge in the field and the significance and contribution of the research reported, comment on strengths and limitations of the research, discuss any potential applications of the research findings, and suggest future research directions. The bibliography will follow the concluding chapter.
Chapter 2: Literature Review

In the following chapter I provide an overview of literature related to hip fracture, sedentary behaviour and physical activity, study metrics used and their association with health outcomes. I also review studies that examined sedentary behaviour and activity patterns during the recovery from hip fracture. I begin this section by providing definitions of older adults and hip fracture and continue by discussing different aspects of sedentary behaviour and physical activity. I complete this chapter with a discussion on measurement of sedentary behaviour and physical activity.

2.1 Older Adults

Older adults are a growing population around the world [30], especially in post-industrial countries [31]. Beginning in the 20th century, mostly due to improvement in living conditions, diet and hygiene along with advancement in medicine, more people in developed countries have started living longer and reaching old age. This happened around the world and women were found to live longer than men, on average [32].

‘Older adult’ and ‘old age’ are often defined as adults 60-65 years of age and older [33]. As in most developed countries, Canada accepts the definition of elderly or older adult as an adult aged 65 years or older and sets the retirement age accordingly. Both the World Health Organization (WHO) [3] and the Center for Disease Control (CDC) [34] consider an older adult to be an adult aged 65 years or older.

In older adults, hip fracture is the most common serious injury; hip fractures are ranked as the most common type of fracture to occur in older adults aged 80 and older and the second most common type of fracture to occur in older adults age 65 and older [17].
2.2 Hip Fracture

Hip fractures are serious and costly incidents. It is estimated that around the world 1.26 million hip fracture cases are diagnosed every year [35]. This number is predicted to grow to between 7.3 and 21.3 million by 2050 [35]. In Canada, more than 25,000 Canadians are diagnosed each year, with an estimated cost of treatment of CAD$26,000 per person [36], posing a heavy burden on the Canadian public health care system.

Hip fracture occurs in the proximal end of the femur, near the hip joint. It is commonly diagnosed based on symptoms and positioning of the leg, with an X-ray being taken to confirm diagnosis and assess the fracture. Hip fractures are a life limiting event that often results in long-term functional impairment and morbidity and in some cases can even lead to death [16]: in the first year following a hip fracture, up to 20% of older adults diagnosed with a hip fracture will die [37] and up to half will have permanent functional disability [16] and will never regain their pre-fracture functional mobility [38-40]. This decreases their capacity to complete activities of daily living [41], and for some can lead to loss of independence (only half of older adults after hip fracture were reported by two separate studies to be walking independently outdoors [42, 43]), leading to a necessary transition into more supportive housing [44]. Symptoms of hip fracture frequently include inability to move the joint and/or bear weight on the hip, pain in the hip or groin, stiffness, pain and bruising around the hip area and a shorter leg on the side of the fractured hip [41].

Usual care after fracture includes surgery to repair the fractured bone, which involves a week long hospitalisation followed by a period of rehabilitation. This period may include administration of drugs, short-term nursing and physical therapy sessions, which are essential for regaining mobility and strength [41] in order to accomplish everyday activities. However, post-fracture complications may
include venous thromboembolism, development of pressure ulcers, urinary tract infection, cardiac and pulmonary complications and further loss of muscle and bone mass [45, 46].

More than 95% of all hip fractures are the result of a fall [47, 48]. Risk factors for a hip fracture include factors related to bone health and falls risk, such as: advancing age [49]; decreased bone density and bone mass (e.g., in osteoporosis [50]), decreased muscular strength; lack of physical activity; chronic medical conditions that can reduce bone strength (e.g., endocrine disorders); certain medications and impaired cognition, balance, perception and vision [41].

Older adults after hip fracture often lose their mobility and more than half of them will not regain their pre-fracture mobility in the year following the fracture [51]; reduced mobility may result in prolonged time sitting down, hence prolonged sedentary behaviour.

2.3 Sedentary Behaviour

2.3.1 Sedentary Behaviour and Health Outcomes

Sedentary behaviour is defined by the Sedentary Behaviour Research Network as “time spent in activities which require low energy expenditure, usually a sitting or reclining position” [4]. Previously, sedentary behaviour was seen merely as a way to evaluate low level of participation in physical activity [7]. However, this trend is starting to change as more research is focusing on sedentary behaviour and its potential health outcomes. Research examining long periods of sedentary time, while controlling for moderate-vigorous physical activity (MVPA), found that prolonged sedentary behaviour is associated with negative health outcomes regardless of activity status [13]. This suggests that sedentary behaviour should be looked at as an independent factor and should be further studied [7].

Recent studies in the adult population have suggested that prolonged periods of sedentary time can be negatively correlated with various health outcomes [52, 53], such as cancer [5], obesity [6], low
physical function [7-9], metabolic diseases [10], cardiovascular diseases [11], reduced muscle mass [12] and type 2 diabetes [6]. Sedentary behaviour was also associated with higher rates of all-cause mortality [54].

Based on the National Health and Nutrition Examination Survey (NHANES), Chastin and colleagues reported that prolonged sedentary behaviour was negatively associated with bone mass density of the femur and hip sub-region bones in women only, regardless of time spent in physical activity [28]. Other studies have found sedentary behaviour to be associated with an increased risk of muscle weakness, balance impairment and falls [55, 56]. These factors make sedentary behaviour a risk factor for bone health, falls and fractures, which in turn might lead to hip fracture. Sedentary behaviour was also found to be associated with an increased risk of mortality [53], regardless of physical activity status [57].

2.3.2 Sedentary Behaviour vs. Physical Inactivity

Sedentary behaviour and inactivity are two distinct concepts. While physical inactivity is defined by the CDC as “physical activity levels less than those required for optimal health and prevention of premature death”, meaning failing to achieve physical activity guidelines [58], sedentary behaviour is an independent concept that is evaluated from the amount of time spent in activities of low energy expenditure (usually a sitting or reclining position) [4]. As such, older adults can be considered to be sedentary even if they meet physical activity guidelines. For example, if after meeting their daily physical activity requirement older adults spend the rest of their waking hours sitting down and watching TV or reading the newspaper, they will still be considered sedentary. At the same time, older adults can be considered inactive for not meeting the minimum activity guidelines, but not be considered sedentary. For example, if they spend the vast majority of their waking hours in light physical activity,
such as cleaning the house or gardening, but do not meet the required minutes of MVPA, they will be considered inactive for not meeting the minimal physical activity guidelines, but not necessarily be sedentary.

2.3.3 Sedentary Behaviour Patterns in Older Adults

Very few studies have explored patterns of sedentary behaviour in healthy older adults under free living conditions [7]. Previous studies that explored sedentary behaviour using accelerometry have found that older adults aged 65 years and older are the most sedentary age group, spending between 60-66% of their waking hours sedentary [29, 59]. Studies have also found men to be more sedentary than women [54, 60] and older adults who were depressed, smokers, obese or had more chronic health conditions were more likely to be sedentary [54]. Although there are clear physical activity recommendations for adults, there are currently no sedentary behaviour recommendations for older adults.

In a systematic review the extent to which older adults are sedentary [61], older adults were found to spend an average of 9.4 hours per day in sedentary behaviour, which comprises between 65-80% of their waking hours. About a third of their sitting time is carried out in leisure activities and another third in watching TV. Time spent in sedentary behaviour was associated and consistent with an increase in age, and older men spent more time in sedentary behaviour than older women [61]. In another systematic review, age was found to be associated with prolonged sedentary behaviour. Older age was associated with more hours of TV viewing, screen viewing and general sitting [62].

2.3.4 Sedentary Behaviour After Hip Fracture in Older Adults

Very limited research has been done to explore the contribution of sedentary behaviour to physical recovery after hip fracture and studies that characterised daily activity during the recovery period
objectively using an accelerometer or pedometer are rare [17, 60]. Decreased mobility after a hip fracture can lead to further muscle weakness and thus increase the risk of falling. This may lead older adults to lower their physical activity and spend prolonged periods of their waking hours throughout the recovery period in sedentary behaviour (e.g. sitting) [19, 21, 23] which can lead to a spiral of mobility-disability [63].

I found only two studies that measured sedentary behaviour directly and both reported prolonged sedentary time (>10 h/day): the first one measured sedentary time in the first days following a fracture and reported that participants spent as much as 99% of their time sedentary [17], while the second one is the published baseline results of the B4 study, where our group reported that community dwelling older adults 3-12 months post fracture spent approximately 76% of their waking hours sedentary [60]. The latter reported age, gender, and time since fracture to be associated with sedentary behaviour.

Reducing time spent in sedentary behaviour and increasing time spent in different levels of physical activity are essential for the rehabilitation process and restoration of functional mobility after hip fracture [23]. And yet, many older adults after hip fracture spend the majority of their waking hour sedentary, in either sitting or lying position throughout their rehabilitation period [60] and especially in the acute setting [17]. Reasons why older adults are sedentary after fracture may include pain, fatigue and factors related to fracture type or rehabilitation management (such as the accessibility to physiotherapy) [17]. Ways to reduce sedentary time may include factors that address both the older adult’s physical state by increasing number of physiotherapy sessions and improving the older adult’s emotional state by addressing their mood and motivation [23].
2.3.5 Breaks in Sedentary Behaviour

The consequences sedentary behaviour may have on health depends not only on the total amount of time older adults spend in sedentary behaviour, but also on the patterns of activity. Improvement in overall health status was seen in cases where sedentary time was fragmented into smaller segments or was interrupted by physical activity of any level [64-66].

In a cross-sectional study involving 1566 participants that evaluated breaks in sedentary behaviour in older men using an accelerometer [54]. Breaks in sedentary time were reported to occur regularly, with an average of seven breaks per sedentary hour. Most sedentary periods lasted less than 30 minutes and the number of sedentary periods per day that lasted 1 hour or more was very low [54]. In addition, the number of breaks seen in men was lower and their duration was longer than those seen in women [54]. Sedentary bouts were longer and active bouts were shorter in older adults with mobility-disability than in older adults without mobility-disability [67]. Breaks in sedentary behaviour were also associated with a lower waist circumference, lower body mass index and a low fasting blood glucose [64], as well as lower level of C-reactive protein (a marker of inflammation) [68].

The NHANES study, which was discussed earlier in this thesis, also examined the association between sedentary behaviour and physical activity and bone mineral density in a cohort of American adults. They found the duration of sedentary behaviour to be negatively associated with bone mineral density for both the femur and the hip sub-regions, but the number of sedentary behaviour periods throughout the day had no effect [28].

Taken together, these findings suggest that it is both the amount of time older adults spend in sedentary behaviour and the pattern accumulated throughout the day that are associated with the physiological differences between older adults that in turn could affect fracture recovery.
2.4 Physical Activity

2.4.1 Physical Activity in Older Adults

Physical activity is defined as any bodily activity that is a result of skeletal muscle movement and requires energy expenditure that is higher than the resting metabolic rate [2, 3]. The Canadian Physical Activity Guidelines for older adults aged 65 years or older recommend a minimum of 150 minutes per week of MVPA and two resistance training sessions per week [69]. Older adults with limited mobility should also engage in physical activity in order to augment balance and prevent falls [69].

There is a linear relation between physical activity and health status. That is, the more active a person is, the better the health benefit [70] and people who exceed activity guidelines are believed to gain further health benefits [70]. Studies have found that maintaining an active lifestyle, at all ages, can contributes to the prevention of several chronic diseases, such as cardiovascular disease, diabetes, cancer, hypertension, obesity, depression and osteoporosis and is also associated with a reduced risk of premature death [70, 71]. For older adults, living an active lifestyle helps maintain strength, balance and endurance and may allow them to continue living independently in the community [72].

Older adults spend a significant amount of time in low intensity activities. Older adults were previously reported to spend approximately 20% of their daily waking hours in low intensity level activities and less than 1% in MVPA [73]. Women were reported to spend more time in low-light activity than men, while men were reported to spend more time in MVPA than women [73].

Aerobic physical activity in older adults was reported to improve mobility impairment, functional status, bone density, cardiometabolic health and mental health [74], while resistance training was reported to build strength and muscle mass, which are important for older adults’ aerobic capability (the maximal amount of activity one can do) [74]. Balance training was found to be important as it can reduce fear of falling and improve mobility and balance in older adults who are at high risk of falling.
However, despite the potential health benefits of maintaining an active lifestyle, many older adults do not meet activity guidelines and the percentage of adults who meet activity guidelines decreases with age [74]. The CDC found that only approximately 20% of American older adults meet physical activity guidelines [34]. Accordingly, inactivity is seen to increase consistently with age [74].

2.4.2 Physical Activity and Its Role in Preventing Hip Fracture in the General Older Adult Population

Physical activity plays a significant role in both prevention and recovery from hip fracture [75]. However, this is beyond the scope of my thesis. In short, exercise and physical therapy can reduce the risk for falling by developing strength, muscle mass flexibility, and balance which are requisite abilities for basic activities such as standing and walking [76, 77]. In a Cochrane review that looked at interventions for preventing falls in older people living in the community it was found that exercise is effective in reducing rate of falls, risk of falling and the risk of sustaining a fracture [78]. Another systematic review reached a similar conclusion: physical activity and exercise can prevent falls in older adults [79]. The overall rate of falling was reduced by 17% based on the results of 44 studies encompassing 9,603 participants. Balance training, amount of exercise and lack of a walking program were found to be associated with the efficacy of exercise programs [79]. One of the reasons why the absence of a walking program can reduce falls is that many falls occur while walking and increasing walking time can increase the chances of a fall. Another potential explanation is that time walking comes at the expense of time spent in balance training in time-limited programs. Interestingly, despite the importance of muscle strength, they did not find moderate or high-intensity strength training to be associated with a greater effect of exercise on falls.
Depending on the type of activity, muscle involvement and intensity, physical activity improves cardiovascular, respiratory, musculoskeletal, and neuromuscular abilities [80]. Stronger musculoskeletal and neuromuscular systems can increase strength, balance, postural stability gait, mobility [81-84] and even bone mass density [85-87]. In both men and women, prolonged inactivity might lead to up to 40% reduction in bone mass [86], while maintaining an active lifestyle might lead to bone hypertrophy of up to 40%. In addition, physical activity can alter the body’s metabolism and hormonal mechanisms which in turn affect the body’s calcium balance, positively influencing bone density [86]. In this way physical activity can protect from bone loss and increase bone mass and density. All of these factors have a positive effect on both risk of fall and bone strength: improvement in physical activity status and switching to an active lifestyle were found to be associated with a 20–40% reduced risk of hip fracture relative to sedentary individuals [80], who spent most of their awake time in sitting or reclining positions [7]. Therefore, physical activity is recommended to prevent falls in community-dwelling adults aged 65 years or older [88].

2.4.3 Activity during the Recovery Process After Hip Fracture

Very little research has focused on measuring physical activity in older adults at different stages of recovery from hip fracture. Recovery from hip fracture is very difficult for older adults, and might manifest itself, among other things, in low activity levels [42] and reduced mobility relative to healthy, community dwelling older adults [89]. These are often the result of short term and long term pain [90], fear of falling [91], multimorbidity [92], frailty and loss of independence [93], all of which have been reported at different stages of recovery and might reduce mobility in different ways. Engagement in physical activity is often limited in older adults after hip fracture, regardless of stage of recovery, and
they often do not meet the recommended activity guidelines for physical activity for older adults for time spent in MVPA or number of recommended daily steps [17, 21, 22, 60, 89, 94].

While engagement in physical activity is reported to be low across studies, time spent in physical activity (represented by activity counts, upright time or standing time, time in activity, time walking and number of steps) increased over time [89, 94, 95]. When looking at different studies that used different methods and different study cohorts, an increase was seen both within studies and across studies. Studies that measured physical activity at the hospital ward, within the first week post fracture, reported less than an hour in upright position and about a minute of stepping [17, 94, 96]. In addition, they reported a gradual increase in upright time over the course of hospitalisation [94], with more upright time at discharge associated with lower fear of falling and increased gait speed [91]. Different studies that measured physical activity in rehabilitation centres reported more encouraging results with approximately 100 minutes in upright position, 16 minutes of walk time and a mean of about 2 minutes in MVPA in the first three months post-fracture [21, 95]. Several studies that measured physical activity in community dwelling older adults after hip fracture reported the highest activity level with more than 200 minutes in upright position [24, 42] a median of 186 minutes [60] in light physical activity and a median of 2 minutes in MVPA within the first year post fracture [60]. It is important to mention that while the accumulated active time has gone up over time, each activity bout remained short. The maximum tolerated dose of walking by adults admitted for inpatient rehabilitation after hip fracture was 6 minutes [97] and even a year post-fracture the mean length of upright events was just below five minutes with a variability of almost five minutes [42]. Number of steps also increased from a mean of 35.7 daily steps in the acute hospitalisation [17] period reported by one study and a mean of 507 daily steps in rehabilitation centre [97] by a second study to 4,060 daily steps in the community a year post-fracture [22], as was reported by another study. As expected, older adults after hip fracture residing in
the community were significantly less active than their healthy community dwelling peers, who spent almost twice the amount of time active [89]. Currently, there are no recommended guidelines for minimal physical activity for older adults undergoing rehabilitation [89, 98], which makes it difficult to assess how active or inactive older adults after hip fracture actually are. Regardless, the low activity levels reported are not ideal and should be a cause for concern.

Reasons for limited physical activity vary. The fracture, the surgery and hospitalisation period that follow often lead to lower limb pain, a decline in muscle power on the side of the fractured hip and a decrease in muscle mass and strength [99], which can restrict activity [21]. Following hip fracture, up to half of older adults will not regain their previous level of mobility [38, 40] and many will report difficulty performing basic activities, such as walking, climbing stairs and performing self-care tasks for up to two years following the fracture [100, 101].

As higher levels of physical activity post-fracture is a mark of recovery [89] and plays a significant role in recovery and rehabilitation from the fracture [23, 38, 102] and the prevention of future falls and injuries [63, 100, 103], low activity levels are concerning. Physical activity improves functional balance, mobility [104], overall strength [27] and muscle strength, and increases confidence and perceived health. It was also shown to decrease mobility impairments, functional limitations and fear of falling; all of which improve functional ability, recovery and rehabilitation from the fracture [105-108] with better functional outcome at three and six months post-fracture [23]. Early functional use, mobilisation and weight bearing on the fractured leg in the days following the surgery were shown to support healing and recovery of personal functioning [109], as well as reduce or prevent functional decline [106, 110].

Physical activity improves functional outcome, strength, gait speed and endurance, and physical performance even if started months after the fracture [27, 111]. Maintaining physical activity during the
rehabilitation period from hip fracture is believed to support and improve functional recovery [23]. Age, gender, gait speed, time since fracture, physical capacity and number of comorbidities were found by different studies to be associated with physical activity findings [21, 60, 95]. In addition, physical activity was found to be associated with a greater functional recovery 3 and 6 months post-fracture and number of daily steps was found to be associated with improved walking, mobility and better balance scores [23, 27]. Race, education, marital status, BMI and resilience were not associated with any physical activity parameters studied [21]. In addition, physical activity was not associated with length of hospital stay or discharge destination [17].

The National Institute for Health and Clinical Excellence guidance from December 2015 recommends health professionals to “offer patients a physiotherapy assessment and, unless medically or surgically contraindicated, mobilisation on the day after surgery” [112]. They do not provide any other activity recommendations or guidelines. In June 2009, the Scottish Intercollegiate Guidelines Network (SIGN) posted guidelines for early mobility. They suggest that if the older adult’s overall medical condition allows, mobilisation and multidisciplinary rehabilitation should begin within 24 hours post-surgery [113]. In addition, they also suggest that older adults take weight on the fractured leg soon after surgery, unless there are medical concerns that restrict this [113].

2.5 Mobility Interventions After Hip Fracture

Noting the importance of physical activity to older adults, especially after hip fracture, but also noting their minimal participation in physical activity along with prolonged sedentary behaviour and inactivity led some researchers to test potential interventions in addressing this problem.
### 2.5.1 Effect of Mobility Interventions After Hip Fracture

A Cochrane review from 2012 aimed to evaluate the effects of different interventions for improving mobility after hip fracture surgery in adults [25]. They included 19 trials, involving 1589 participants overall, that tested different interventions beginning at different stages of recovery. They reported methodological problems with these studies and no data were pooled, as the studies were significantly different. The studies tested a variety of interventions; e.g.: weight-bearing programs, quadriceps muscle strengthening exercise programs, treadmill gait retraining programs and intensive physiotherapy regimens. The different studies showed contradictory results: some reported improved mobility while others reported no effect, which led the authors to conclude that there is currently not enough evidence to decide which is the best intervention strategy to help older adults walk and continue walking after hip fracture surgery [25].

### 2.5.2 Objective Measurements of Physical Activity After Mobility Intervention

I conducted a systematic search of the literature, looking for intervention studies that measured the effect of the intervention on physical activity objectively using activity monitors, similarly to what we did in the B4 study. I have found only three studies that previously tested mobility interventions for older adults after hip fracture, at any stage of recovery. A recent study involving 397 participants compared daily physical activity at four and 12 months post hip fracture repair surgery for patients managed with comprehensive geriatric care in a geriatric ward and those managed with orthopaedic care in an orthopaedic ward [42, 43]. While the orthopaedic care participants received the conventional care, which included traditional in-hospital physiotherapy, the comprehensive geriatric care intervention included interdisciplinary assessment of health, function, disease and social situation, and a mobilisation plan was carried out in collaboration between the physiotherapist and nursing staff, who were instructed to
encourage mobilisation as early as the first day post-fracture with progression according to individual ability [96]. They found that participants treated with comprehensive geriatric care during their hospital stay spent an average of 33.6 more minutes upright than the orthopaedic care participants at the four-month time point and 26.1 more minutes at the 12-month time point. These results suggest that an early intervention is important for improving mobility and can provide long-term results.

A different study tested the effect of a community exercise program, which included functional stepping and lower extremity strengthening exercises, compared with standard outpatient therapy in a group of community dwelling older adults two and a half months post-fracture [27]. They measured functional mobility, balance confidence, falls efficacy, lower extremity strength and daily physical activity at baseline and 16 weeks later. Their results showed that the community exercise program participants increased their physical activity levels and improved mobility, balance, and quadriceps strength more than the standard outpatient therapy group [27]. This suggests that the potential for activity and mobility improvement is not lost and can be initiated even months after the fracture.

An additional study tested the impact of an exercise intervention, by using an exercise intervention, exercise plus motivation, motivation only and routine care [22]. They followed a cohort of 209 women three weeks post-fracture for a period of one year. Their results suggested that participating in activity only or motivation only interventions can lead to an increase in activity compared with routine care. Participants in both of these groups walked approximately 3000 more daily steps [22]. Interestingly, there was no statistical difference between the exercise plus motivation and the routine care group. The researchers suggested that this might be due to the division of time between the two methods, leading to participants not receiving enough exercise or enough motivation.

In conclusion, all three studies reported an increase in activity compared with a control group, suggesting that there is a benefit to developing and administering an activity intervention in order to
increase physical activity in older adults recovering from hip fracture [22, 27, 43]. However, considering the Cochrane review mentioned in section 2.5.1 [25], I suggest repeating these studies in large populations to validate results.

2.6 Measurement of Activity Patterns

In order to evaluate the effect of sedentary behaviour and physical activity on health outcomes it is important to objectively quantify the amount of time spend in each activity category. There are many ways to measure activity levels in older adults, each with advantages and disadvantages [114]. The three types of physical activity measures are direct observation, self-reporting questionnaires and/or objective measuring monitors [114]. The criterion standard for measuring energy expenditure is using the doubly labeled water method [115]. In this method, two isotopes in water (one of oxygen and one of hydrogen) are injected into the subject, equilibrated with total body water and then eliminated differentially from the body. The labeled hydrogen will be eliminated from the body as water, while the labeled oxygen can be eliminated as either water or carbon dioxide; the carbon dioxide can then be calculated. The carbon dioxide loss tells us the energy produced, as the amount of oxygen that left the body as carbon dioxide equals the amount that was produced by the body’s metabolism. This model has been previously validated [115].

2.6.1 Self-Reporting Methods

Self-reporting methods include questionnaires, surveys, diaries and logs that are designed for assessing activity completed in a specific period of time and are specific and tailored for a defined group of people [66]. Self-reporting methods are easy to administer and participant burden is low [66]. The importance of these measurement methods is that they provide researchers with information on specific activities,
and the context and location for the activity (e.g., indoors vs. outdoors). Self-reporting questionnaires can provide more details on the type of activity [116]. Information regarding sedentary time can be achieved by specific targeted questionnaires and the use of activity diaries and logs. Self-reporting questionnaires are relatively inexpensive and can therefore be used in larger and long-term studies. However, self-reporting questionnaires that report time spent in physical activity or sedentary behaviour are the most inaccurate measuring method as they are often influenced by participants’ interpretation and are subject to memory and recall bias [117, 118].

2.6.2 Objective Methods

Objective methods of assessing sedentary time and physical activity include monitors, such as accelerometers and pedometers. Direct observation of participants’ activity is limited to small and short-term studies, as using these methods for large studies or for a long period of time can be invasive and costly [114]. Activity monitors provide an objective, reliable and unbiased measurement of the time spent in each physical activity category and time spent in sedentary behaviour [116]. Therefore, the use of activity monitors is usually the preferred objective measurement method [114].

Since the 1980’s researchers have used accelerometers as activity monitors to assess and quantify activity levels [119], with early activity monitors containing piezoelectric ceramic sensors [120]. Accelerometry technology has come a long way since then, and current monitors are based on both piezoelectric sensors and piezoresistive and capacitive technology, such as Micro-Electro Mechanical System (MEMS) [119]. In 2009 ActiGraph released the ActiGraph GT3X+ activity monitor, a 4 × 4 × 1.45 mm triaxial sensor with a full range of ± 3g that can measure both dynamic and static acceleration [119]. ActiGraph GT3X+ accelerometers are a type of MEMS accelerometer and are comprised of a free middle polysilicon plate that serves as a bridge between two fixed plates. The
middle plate forms a capacitor with each of the fixed plates. In response to movement and acceleration, the middle plate moves, causing a change in the capacitance of the two capacitors and thus a voltage change which the device interprets as acceleration. The data is then stored digitally in the device’s memory. The acceleration data is filtered at a bandwidth of 0.25 to 2.5 Hz, the frequency of most human movements, and therefore background vibrations are excluded. Activity monitors can be worn on the waist, thigh, chest and wrist. Cleland et al. aimed to determine the ideal location of placement accelerometers on the body in order to accurately detect physical activity. In their study, they placed six wireless tri-axial accelerometers at six different locations: chest, wrist, lower back, hip, thigh and foot on eight healthy males. Activities tested included walking, running on a motorised treadmill, sitting, lying, standing and walking up and down stairs. They reported that hip worn accelerometers are the most accurate in detecting activity, and the rest of the accelerometers have similar levels of accuracy. They also recommended to test activity when several accelerometers are placed in more than one position to improve accuracy [121].

Activity monitors can provide researchers with information regarding time spent in activity, and the intensity of the activity by calculating raw acceleration over time (epochs) and converting this into activity counts [122, 123]. Activity counts summarise epoch data in a way that simplifies data management, analysis and interpretation. However, when transforming the raw data, researchers lose data that can be used for further analysis, such as walking speed and posture transition [123]. As sedentary behaviour involves resting for a prolonged period of time, distinguishing between time spent sedentary and non-wear time can be quite a challenge. Therefore, in objective measurement monitors, sedentary time is not measured directly but is estimated from time spent in activities of low counts [29].

Objective measurements are reliable measurement tools that provide us with accurate information about the time spent active and when in the day the activity was carried out. Also, since they
do not rely on participant self-reporting, they eliminate the risk of recall bias. However, they are not free of disadvantages. They do not always catch small and slow movements that are often present in older adults and their function can be impaired by the way a person is wearing them [124]. Objective measurements indicate that an activity occurred but not type or context of the activity [116]. Thus, information that is provided by self-reporting questionnaires can still be very valuable: they can provide the context and type of activity, reasoning and explanations for prolonged sedentary time as well as self-perception of activity. Finally, activity monitors are expensive and produce large quantities of data, which can create a bottleneck of data processing and analysis [116].

Besides the ActiGraph monitor, there are several other accelerometers that are in use in research settings, among them activPAL (PAL Technologies Limited, Glasgow, UK) StepWatch (Orthocare Innovations, Mountlake Terrace, WA) and Actical ((Mini Mitter Co., Inc.,Bend, OR). Pedometers, such as Yamax (YAMAX SW-200) and Fitbit (Fitbit Inc, San Francisco, CA) are often in use as well. ActiGraph and activPal are the two most commonly used. Both ActiGraph and activPAL are small and light self-worn monitoring devices that have the ability to measure both the frequency and the magnitude of acceleration that is the result of ambulatory motion for up to one week. Both provide output in the forms of tables, graphs and charts that can be further analysed [125]. However, the two accelerometers use different activity count thresholds and different processing algorithms to assess activity levels [125], which may lead to differences in classification of activity [126]. For example, ActiGraph, which serves as an energy-expenditure classification device, uses the Freedson 1998 [126] threshold count to assess activity level, and identifies sedentary behaviour as less than 100 counts per minute. The activPAL, on the other hand, acts as a postural classification triaxial accelerometer that uses an inbuilt inclinometer to collect postural data, such as whether the person wearing it is sitting/lying (and is therefore in sedentary behaviour) or standing and walking (and is therefore in physical activity)
and is placed on the thigh using a layer of hydrogel or a sleeve and a sheet of medical dressing, if waterproof properties are required [127]. As the inclinometer property provides important data to researchers, researchers that used the ActiGraph without the inclinometer property often needed to make assumptions about body posture that may not be accurate. ActiGraph came out with an improved accelerometer, the ActiGraph GT3X+ which is equipped with an inbuilt inclinometer, that can assess movement on three axes: vertical, antero-posterior, and medio-lateral [125]. When the ActiGraph GT3X+ is worn properly and is completely vertical, it can assess posture in addition to METs.

There is a debate around which accelerometer is the most suited for research purposes to assess sedentary time. A recent study examined the validity of both the ActiGraph and the activPAL and concluded that activPAL is the most accurate and precise accelerometer to assess sedentary behaviour in free living conditions [125]. It was concluded that the calculation of sedentary time in the current Actigraph GT3X+ is based on thresholds from the different axes and that the inclinometer embedded inside is not sensitive enough to detect postural information accurately, which may lead to misclassification of sedentary time [125]. The activPAL calculates acceleration and posture in the thigh axis and can assess sedentary pattern and limb position (sitting/lying, standing and stepping) based on the inclination of the thigh using advanced dynamic acceleration and inclination logging technology [127, 128]. The activPAL classifies activity using the Intelligent Activity Classification™ algorithm. However, it is important to mention that the validity of data collected from a postural accelerometer has not yet been determined [129].

2.6.3 Recording Sedentary Behaviour and Physical Activity Post Hip Fracture

With advancement in technology, including the development of activity monitors, researchers started to assess activity levels in different populations. One of the populations that was of interest to some
researchers was older adults after hip fracture [21]. Objective monitoring of older adults after hip fracture is similar to that of other populations and is accomplished mainly by placing an activity monitor on either the thigh, chest or waist for different periods of time, which can vary from a few hours to a few days [17, 21, 95]. This allows researchers to assess and follow-up the activity patterns of older adults after hip fracture in different settings (e.g. hospitals, rehabilitation centres, community), for different periods of time (weekdays, weekends, seasons) and for a varying length of follow-up, which will provide researchers with a comprehensive overview of the older adult physical activity pattern throughout the day. The main challenge in this population is sensitive skin and skin irritation that might be caused by a direct placement of the monitor on the skin as well as slow gait speed that might not be picked up by the activity monitor and will result in missed activity [130].

2.6.3.1 Objective Evaluation of Sedentary Behaviour and Physical Activity in Older Adults after Hip Fracture

There are currently no specific guidelines for sedentary behaviour and physical activity for older adults after hip fracture [98]. Research in this field has looked at physical activity after hip fracture in the form of absolute time (min/day) spent in light or MVPA, number of steps taken, time on feet and time walking [17, 21-24, 42, 43, 60, 89, 95, 96]. Activity monitors can assess both the length and intensity of the activity and the numbers of steps taken [17].

Older adults after hip fracture spend most of their time sedentary [17, 60]. As mentioned earlier, this is a relatively new research topic that has been studied by very few researchers. A recent study at a hospital orthopaedic ward aimed to determine physical activity levels during an acute inpatient admission following surgery for hip fracture. They found that during the acute hospitalisation period, older adults spend up to 99% of their day in sedentary behaviour and ~ 1% (approximately 16 minutes)
standing or walking each day [17]. Sedentary time is reduced during the rehabilitation period, but the numbers are still high. For example, patients in rehabilitation centres spend an average of 23 hours per day in sitting or lying positions [19]- that is, only 1 hour/day engaging in activity. However, those numbers include time spent sleeping, so the actual time spent in sedentary behaviour cannot be calculated from the study results provided.

During the hospitalisation post-hip fracture surgery, older adults were found to spend only about 1.1 ± 1.0% of their day standing, and 0.05 ± 0.09% of their day stepping, which represents less than 1 min per day [17]. Another study that measured physical activity during the first postoperative days for hip fracture found that the mean time spent upright in older adults post-hip fracture surgery is 52 minutes per day [96]. During the rehabilitation period, older adults after hip fracture slowly begin to be more active within the first three months. Older adults in an inpatient rehabilitation centre within three weeks after hip fracture were reported to spend a median of 102.6 minutes per day on feet and a median of 16.3 minutes per day of walk time [95], and older adults two months post-fracture were reported to spend a mean of only 1.8 minutes per day in MVPA [21]. After the first three months and within the first year post-fracture activity increases: community dwelling older adults three months post-fracture were reported to spend a mean (SD) of 260.9 minutes per day in an upright position [24], while community dwelling older adults 3-12 months post fracture were reported to spend a median of 186.6 minutes per day in light physical activity and 2 minutes per day in MVPA [60].

The number of steps participants take with the progression of their recovery period increases as well. While in the hospital post-surgery, older adults stepped a mean of 35.7 steps per day [17]; during the first year post-fracture they stepped up to 2889 steps per day [27], not meeting the current recommended guidelines of 10,000 steps per day [131]. However, Tudor-Locke and Bassett suggest that
the current recommendation of 10,000 steps per day is not suitable and inappropriate for older adults who typically average between 5000-7500 steps per day [131].

2.6 Summary

Hip fracture is a common occurrence in older adults. Lower levels of sedentary behaviour and higher levels of physical activity are important for healthy aging and may contribute to the recovery process after hip fracture. And yet, older adults after hip fracture spend a large proportion of their waking hours in sedentary behaviour, which might have a negative effect on their overall health and recovery.

Studying the short and long term implications of sedentary behaviour is an emerging field and there are limited studies that put their focus on older adults after hip fracture, despite the fact that this group is the most sedentary and could benefit greatly from these kinds of studies. There is little known about sedentary behaviour patterns in older adults after hip fracture and the way it affects their health and recovery process.

Studies have found sedentary behaviour and physical activity to be key factors in recovering from a hip fracture and reducing complications [96]. Considering how important physical activity is and the negative effect prolonged sedentary behaviour might have, understanding the patterns of activity during the recovery period and addressing it will be of great value. Successful interventions should address these patterns and offer options and solutions to encourage and motivate older adults after a hip fracture to reduce sedentary time and to take part in physical activities that have great potential to improve the recovery process and their overall quality of life.

As sedentary behaviour is a separate and independent factor from physical activity and can have serious health implications when prolonged regardless of whether or not an older adult is meeting
physical activity guidelines, recommendations should be made to minimise time spent in sedentary behaviour in addition to encouraging the older adult to take part in MVPA.

There are different ways to measure sedentary behaviour and physical activity, each with advantages and disadvantages, but it is believed that measuring activity using objective measurement devices such as an accelerometer or pedometer will provide the most accurate estimation of activity, as it eliminates participant bias.

Reducing sedentary time and increasing physical activity has the potential to help improve the recovery process from hip fracture, with exercise interventions shown to support this goal by increasing measured physical activity [22, 27, 43]. Not much is known and very little research has been done to assess how sedentary or how active older adults are and how physical activity interventions increase overall activity.

2.7 Research Rationale

Aging population and its associated complications is one of the challenges that Canada is facing in the 21st century [30]. Hip fractures are serious events that have long term implications on older adults’ mobility, health and well-being. In spite of improvement in health care provided, mobility among patients after hip fracture has not changed significantly over the past two decades and remains low [39, 132]. There are many variables that are associated with mobility, but sedentary behaviour has previously been overlooked and I believe it may contribute significantly to a number of adverse health outcomes.

Very few studies have objectively characterised daily activity in older adults after hip fracture. Nonetheless, it is important to synthesise the available evidence and to conduct research in this important clinical area for older adults. Collectively, this information provides insight into the trajectory
of mobility recovery in this population, and supports future effective interventions to reduce the risk of mobility-disability following hip fracture.

Our RCT aimed to explore how a comprehensive approach to treatment of hip fracture affects time spent in either sedentary behaviour or physical activity over a 12 months period. I hope that my analysis of this study will add to the limited body of knowledge and provide better insight into mobility-recovery patterns in older adults after hip fracture.
Chapter 3: Study Manuscript

In the following chapter I present a manuscript of this randomised controlled trial. When writing it I followed the CONsolidated Standards of Reporting Trials (CONSORT) 2010 guidelines for reporting of parallel-group randomised-controlled trials¹.

3.1 Introduction

Decreasing sedentary time (low energy expenditure in a sitting or reclining position [4]) and increasing physical activity (skeletal muscle movement requiring energy expenditure [3]) are important factors in maintaining older adults’ mobility and contribute to healthy aging [133]. Engaging in regular physical activity reduces the risk of falls and injuries [63, 100, 103] and plays an important role in recovery from hip fracture [23, 38, 102] - a serious and significant event for older adults.

Despite the benefits of physical activity, older adults after hip fracture often report walking restrictions, reduced ability to climb stairs, and difficulty with activities of daily living throughout formal rehabilitation, and up to two years following fracture [23, 100, 101]. These mobility challenges reinforce a sedentary lifestyle with a subsequent reduction in physical activity. Previous work from our group [60] observed this trend: older adults after hip fracture spend the majority of their time sedentary and partake in minimal physical activity. Many older adults struggle with maintaining an active lifestyle after hip fracture; yet the more active they are, the better chance for recovery in the months after fracture [23].

Sedentary behaviour is defined by the Sedentary Behaviour Research Network as time spent in activities which require low energy expenditure, and usually refers to time in a sitting or reclining position [4]. It is associated with a variety of health conditions, such as low physical function [7-9], reduced bone mass density, muscle weakness and reduced muscle mass [12], balance impairment and
falls [55, 56] and higher rates of all-cause mortality [54]. These factors are of great interest for older adults, and specifically older adults after hip fracture who are at particular risk for sedentary behaviours. Sedentary behaviour is also thought to be associated with negative health outcomes independent of activity patterns [7, 13]. More recent literature suggests that high doses of moderate to vigorous physical activity (MVPA; 60-75 minutes/day) may offset prolonged sitting time [15]. However for older adults with hip fracture this may not be attainable. To illustrate, in general older adults aged 65 years+ are the most sedentary age group, spending between 60-66% of their waking hours sedentary [29, 59]. Older adults also engage in very little physical activity: only approximately 20% of American older adults meet physical activity guidelines [34] and the percentage decreases with age [74].

The daily pattern of accumulation is an important component to the assessment of sedentary behaviour. Jefferies and colleagues, in a cross-sectional study (n=1566) objectively (using accelerometry) described sedentary behaviour patterns in community-dwelling older men [54]. They found a regular pattern of seven breaks each hour, with sedentary bouts lasting < 30 minutes and few prolonged sedentary bouts [54]. In addition, men with a higher self-reported health fragmented their sitting time with shorter bouts (and thus more breaks) [64-66]. Although, in general, older men may accumulate more sedentary behaviour compared with women [54, 60] independent of age, physical functioning, cognitive functioning, depressive symptoms and accelerometer wear time [26]. They tended to have higher sitting time and participate in less physical activity than women, spending approximately half an hour more in sedentary behaviour and 25 minutes less in leisure physical activity [28, 61].

For older adults with hip fracture, few studies characterise daily activity objectively with accelerometry [23, 24, 28, 60]. To my knowledge, there are currently no published studies that tested the effect of a mobility intervention on daily sedentary behaviour and physical activity patterns. Further, no studies have described the differences between men and women throughout the recovery period.
Knowledge of sitting time patterns during the hip fracture recovery period (noting differences between men and women) can provide insight into the effect of mobility interventions, provide trajectory of mobility enacted during recovery and help tailor an appropriate treatment plan accordingly. Thus, I tested the effect of a hip fracture follow-up clinic on older adults’ sedentary behaviour and physical activity patterns as they recover from hip fracture.

3.2 Methods
This was an analysis of a secondary outcome for a randomised controlled trial (RCT). Detailed information on the study protocol was published previously [134]. Briefly, the B4 study was a parallel-group, single-blinded RCT comparing two different hip fracture management methods: usual care and a specialised follow-up clinic. The study took place at the Centre for Hip Health and Mobility in Vancouver, BC, Canada (ClinicalTrials.gov Identifier: NCT01254942) [134]. The primary focus of the study was on mobility, and this current investigation focused on a secondary outcome, sedentary behaviour and physical activity patterns. The B4 study included community-dwelling older adults with recent hip fracture (within 3-12 months) and excluded older adults who (i) before the injury could not walk 10 meters, (ii) were diagnosed with dementia and/or (iii) did not return to community living after hospital discharge. An independent statistical company randomised participants using a computerised program to remotely allocate participants into intervention and control groups, with randomisation stratified by sex and recruitment site. The B4 study was approved by the university and hospital internal review board (IRB) and all participants provided written informed consent.

The main study was designed to test the effect of the clinic on mobility (operationalised as the Short Physical Performance Battery (SPPB) [135]). Participants in the usual care group (UC) received standard post-operative management given after hip fracture; participants in the intervention group (B4)
received usual care and attended a specialised interdisciplinary clinic that included a geriatrician, a physiotherapist and other allied health professionals as required, based on participant health needs. All research assistants, data analysts and investigators were blinded to group allocation. However, due to the nature of the intervention, participants were aware if they were (or were not) randomised to receive the intervention. The study staff collected basic demographic and body composition variables from study participants, recorded age and time since fracture and measured average gait speed. For this secondary outcome, our participants wore accelerometers in order to characterise sitting and activity patterns at baseline and over the course of the trial; these methods are described in more detail below.

3.2.1 Intervention

3.2.1.1 Usual care
All participants randomised to the UC group received the usual orthopaedic post-operative treatment for their hip fracture given to older adults after hip fracture surgery in British Columbia. This included, in some cases, the prescription of calcium and vitamin D and administration of home rehabilitation services, such as physiotherapy, nursing, and occupational therapy.

3.2.1.2 Intervention as delivered
In addition to receiving usual care, all participants in the intervention group received an assessment by the geriatrician, physiotherapist and occupational therapist. Additional appointments and referrals to specialists and other health professionals were on a needs basis. A detailed description of the intervention delivered is published elsewhere [134].
3.2.2 Accelerometry Data Acquisition and Analyses

Study staff collected physical activity and sedentary behaviour data using accelerometry at three data collection time points. Our participants wore a waist-mounted ActiGraph GTX3+ (LLC, Fort Walton Beach, FL) tri-axial accelerometer continuously (for non-water-based activity) during all waking hours for seven consecutive days.

The study coordinator provided the initialised accelerometer to participants at the end of the in-person assessment at baseline, midpoint (6 months) and final (12 months) time points; a courier service then picked up the accelerometer at the end of the seven days. Following receipt of the accelerometer, trained research assistants downloaded the data and immediately checked to ensure data were present. After obtaining data from all participants for each time point, I inspected it to identify any spurious findings. In my analysis, I included data from participants who had at least three days of data with a minimum of 8 hours/day of wear time [136] and I considered > 90 minutes of continuous zeros as non-wear time, with allowance of 1-2 minutes of counts between 1-100 [137]; this strategy was consistent with the findings from a previous systematic review [134]. I used the following cut points to determine activity intensity for my accelerometry analyses: sedentary time ≤100 counts/minute [29], light physical activity 101–1951 counts/minute and MVPA ≥1952 counts/minute [138].

I used ActiLife software v6.11.2 (ActiGraph LLC, Pensacola, FL, USA) to process accelerometer data. Following data processing, the study coordinator standardised variables to a 13-hour day to account for differences in wear time over the three time points: baseline (recruitment), 6 months (end of intervention) and 12 months (the end of the study). My variables of interest included: sedentary time (minutes/13 hour-day); duration of average sedentary bout (minutes/13 hour day); duration of average sedentary break (minutes/13 hour day); light physical activity (minutes/13 hour day); MVPA
(minutes/13 hour day); and step count (steps/day). Our group previously published the baseline values for this cohort of participants and separately for men and women [60].

3.2.3 Statistical Analysis

I provide participant flow through the study in Figure 3.1. The data were cleaned by one researcher and individually checked by two independent research assistants. For the accelerometry data I excluded from the analysis participants with: 1. two or more time points of missing data; and 2. data missing not at random (MNAR), meaning cases in which the reason for missing data is related and could have affected sedentary behaviour or physical activity measurements. For participants with accelerometry data missing at random (MAR) I imputed the median of the observed values for that variable.

I summarised participants’ data using counts and proportions for categorical data and median (p10, p90) for continuous data. For the outcomes of interest (sedentary behaviour and physical activity), I explored the data graphically and created correlational matrices (Table 3.1) between activity at the different time point and different demographic variables. For each of the outcomes, I estimated the treatment effect using a normal linear regression model with allocation group and baseline measurement of the outcome treatment effect as covariates. To mitigate the influence of outliers I employed a robust regression estimation procedure. In secondary analyses I expanded the models to include additional covariates based on biological plausibility (gait speed) or because they were associated with the outcome at baseline (time since fracture and age). I graphically assessed the adequacy of the models I developed using residual plots (residuals versus predicted values and versus each covariate). I compared between men and women using a mixed regression model that collapsed participants data from the three time points. In order to compare number of daily steps between men and women, I accounted for step length
(height as a surrogate variable [139]). In my analysis I used Stata Version 13.1 (StataCorp, College Station, TX).

### 3.3 Results

Over an 18-month period, research staff recruited 53 community dwelling older adults: 26 participants were randomly allocated to the B4 group and 27 to the UC group. Three individuals were excluded as they were missing more than two data collection time points and five individuals were excluded as their data were missing not at random (they were too ill or weak to participate in accelerometry collection). I imputed accelerometry values for two participants whose data were missing at random due to accelerometer malfunction. The cohort (n=45, 22 participants from the B4 group and 23 from the UC group) had a mean (SD) age of 79.2 (7.4) years, range 65-98 years, with a median (p10, p90) of 203 (143, 335) days since fracture and a median (p10, p90) gait speed of 0.84 (0.41, 1.09) m/s at baseline (Table 3.2). The majority of participants were women (60%), married (53.3%) and well educated (91% completed high school). In the analysis I included three participants who were more than 12 months post fracture. These participants were recruited to the study within the time frame; however, there was a delay in conducting baseline assessments due to logistic reasons. There were no adverse events adjudicated to the intervention.

#### 3.3.1 Sedentary Behaviour and Physical Activity

Overall, study participants spent the majority of their waking hours not moving (>10 hours in a 13-hour day), very little time in light physical activity, barely any time in MVPA and took a very low number of daily steps (Table 3.3). I also found men to be more sedentary and spent less time in light physical activity than women at all three time points (Figure 3.2, Figure 3.3 & Table 3.4).
In the basic robust regression I saw no clinically or statistically significant differences between the two groups at midpoint or final for any sedentary or physical activity variable (Table 3.5). Similarly, in the robust multivariable regression model (Table 3.6). I also saw no clinically or statistically significant differences between groups at midpoint or final, for any sedentary or physical activity variable. Both groups showed similar activity patterns over time: physical activity increased at midpoint and decreased at final assessment. The median (p10, p90) length of sedentary bout for the B4 group was 26.35 (22, 35) and 28.2 (20.6, 38.1) minutes at baseline and final assessment, respectively and for the UC group 27.2 (21, 51.3) and 29.6 (21.7, 51.1) at baseline and final assessment, respectively.

### 3.3.2 Men and Women

Despite a higher gait speed, men engaged in significantly more sedentary behaviour and spent less time in light physical activity compared with women across the study time period (Table 3.7). In addition, the median length of their sedentary bout was slight longer than women (up to six minutes), but these differences were not statistically or clinically significant. As per our previous publication [60], at baseline men engaged in statistically significant more sedentary behaviour and less light physical activity compared with women. However, I did not observe a statistically significant difference between men and women at final assessment for either sedentary behaviour (p=0.894) or light physical activity (p=0.911). They also accumulated less steps/day (adjusted for height), although at baseline the difference was statistically significant (-2182 steps/day; p=0.028), the effect was attenuated at final assessment (-1833 steps/day; p=0.132).
3.3.3 Percentage of Time Spent in Sedentary Behaviour and Physical Activity

As a cohort, our participants spent 75.8%, 75.7% and 78.1% of their day sedentary at baseline, midpoint and final assessment, respectively. They therefore spent 24.2%, 24.3% and 21.9% of their day in physical activity. These results are alarming and higher than values reported in healthy older adults that were previously shown to spend approximately 60% of their waking hours sedentary [29].

Our intervention group showed a slightly less sedentary profile than the control group with 73.5% vs. 78.3% at baseline, 74.5% vs. 81.4% at midpoint and 77.7% vs. 79.3% of their day spent in sedentary behaviour at final assessment. These results were not significant at baseline (p=0.24), midpoint (p= 0.55) or final assessment (p=0.49).

Men showed a more sedentary profile than women with 81.4% vs. 72.8% at baseline, 78.9% vs. 73.5% at midpoint and 81.5% vs. 75.9% of their day spent in sedentary behaviour at final assessment. These results were significant at baseline (p= 0.04), but not at midpoint (p= 0.83) or final assessment (p=0.67).

3.4 Discussion

To my knowledge, this is the first study to describe and test the effect of a mobility intervention on sedentary behaviour and physical activity in older adults after hip fracture. Overall, participants spent prolonged periods of time in sedentary behaviour, although I did not observe statistically or clinically significant differences between groups. Further, the entire sample increased sedentary time and decreased physical activity over time. At baseline, men had significantly more sedentary behaviour and spent less time in light physical activity compared with women. However, at final assessment, the
differences between men and women were no longer statistically significant. These data highlight the importance of addressing prolonged sitting time in older adults after hip fracture.

There are several plausible explanations for these findings. First, the activity variables were a secondary objective of the B4 study, and thus, physiotherapy sessions were not specifically targeted to reduce sedentary time or increase physical activity. As the field of sedentary behaviour is relatively early in its development, rehabilitation does not consistently emphasise decreasing sedentary behaviour as a therapeutic goal [140]. Second, as noted by Handoll and colleagues, there is currently not enough evidence to determine which strategies are the best for recovery after hip fracture surgery [25]. The intervention may not have been intense enough, or of long enough duration to see changes over the 12 months. Third, although the study did not provide geriatric management to the UC group, all participants had access to physicians and allied health professionals in the community setting. Finally, as part of the protocol study staff collected data monthly via phone calls to all participants. The phone call and social interaction may have served as a form of co-intervention [141] to the UC group and inadvertently encouraged them to be more active.

Overall, participants spent most of their waking hours sedentary, spending more than 75% of their waking hours in sedentary behaviour over the 12 months. Reasons why older adults are sedentary after fracture may include pain [142], fear of falling [143], fatigue [97] and factors related to fracture type or rehabilitation management (such as the accessibility to physiotherapy) [17]. It is important to note prolonged periods of sedentary behaviour in this population can lead to further muscle weakness and thus increase the risk of falling and a second hip fracture and can lead to a spiral of mobility-disability[63] which would impact fracture recovery.

Physical activity is said to be a good mark of recovery [89], however, participants spent very little time in light physical activity, barely any time in MVPA and walked a low number of daily steps.
Tudor-Locke and Bassett suggested that the current recommendation for older adults of 10,000 daily steps is not suitable for older adults who take an average of 5000-7500 steps per day [131]. The study participants were far from reaching those values (<3000 steps/day). Although these values are low, they are consistent with other similar studies. For example, Resnick and colleagues measured physical activity (using accelerometry) in 117 community dwelling older adults two months post-fracture; participants achieved an average of 2 minutes of MVPA and about 1000 steps per day [21]. In another study by Resnick and colleagues, they measured average daily steps in older adults who were 12 months post hip fracture (n=208); on average, they only achieved about 4000 steps/day [22]. Thus, these data extend the literature by drawing attention to the low physical activity levels adopted by older adults after hip fracture.

Our group previously published the baseline data of sedentary behaviour [60], where men accumulated statistically more sedentary behaviour and spent less time in light physical activity compared with women. However, at final assessment the differences between sexes were no longer significant. That is, sedentary time difference (adjusted) between men and women decreased from 58 minutes (baseline) to 23 minutes at final assessment (Figure 3.2). Further, the difference in light physical activity (adjusted), decreased from 54 minutes (baseline) to 32 minutes at final assessment (Figure 3.3). I observed a similar pattern for step counts. Although, overall these results are consistent with the literature (with older men engaging in more sedentary behaviour and less light activity) [28, 29, 61, 93]. I cannot explain, based on current results, why men improved over time relative to women and the difference was no longer significant. Regardless, my results show that men closed the gap over time for their sedentary behaviour and physical activity patterns.

I note several limitations within our study. First, this was a relatively small, select sample of older adults with hip fracture. Regardless, the study retained 85% of participants at final assessment and
provides a comprehensive view of the recovery period. In addition, study participants were at different stages of their recovery process, as participants were recruited within 3 and 12 months post fracture. However, I was able to control for this in my analyses. The study had missing data from 10 participants for which data were imputed for two whose data were missing at random and dropped from participants whose data were missing not at random. However, since the data are missing at random, the estimate of the median remains unbiased. I believe that due to the low number of imputed data points, the risk of underestimating standard error and the risk of “pulling” estimates of the correlation toward zero (to affect variable relation) is not a major concern in this model [144]. Finally, although the study was not powered to address sex differences in sedentary behaviour and physical activity, findings emerged regardless within the data.

To my knowledge, this was the first study to test the effect of an intervention (of any kind) on reducing sedentary behaviour in older adults after hip fracture. In addition, this was the first study to prospectively describe patterns of sedentary behaviour and physical activity (across the activity spectrum) in older adults during their recovery from hip fracture. Although I did not note differences in activity patterns between the two groups, I recognised the persistently prolonged sedentary time and low levels of activity in this group of community dwelling older adults. Most of the study participants spent the majority of their waking hours in sedentary behaviour, and only took infrequent, short breaks from sitting. Further, they accumulated almost no higher intensity physical activity, with the remaining time engaged in light physical activity. Thus, this secondary analysis of the B4 study provides a novel and insightful perspective on the patterns of sedentary behaviour and physical activity in older adults recovering from hip fracture.

In summary, older adults after hip fracture spend most of their waking hours sedentary and engage in very low levels of physical activity. This is a stark reminder to older adults and health
professionals that reducing sitting time and encouraging the spectrum of physical activity (light, moderate, etc.) in addition to strength and balance exercises is vital for recovery and secondary prevention of future falls and fractures. I emphasise the critical need to develop concrete interventions to decrease sedentary behaviour and incrementally increase physical activity, and that the interventions are encouraged over the long term.
Table 3.1: Pearson Correlation Matrix for sedentary behaviour and physical activity variables at the different time points, time since fracture, age and gait speed at baseline.

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<th>MVPA T=0</th>
<th>SC T=0</th>
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<th>LPA T=6</th>
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GS = gait speed, LPA= light physical activity, MVPA=moderate-vigorous physical activity, SB= sedentary behaviour, SC= steps count, TSF=time since fracture. T=0 is baseline, T=6 is midpoint and T=12 is final assessment. Top number represents correlation value; bottom number represents p-value. A start represents statistical significance.
Table 3.2: Participants’ descriptive characteristics by group allocation and sex.

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<th>Men N=18</th>
<th>Women N=27</th>
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<td>Age, y mean (SD)</td>
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<td>79.7 (8.25)</td>
<td>79.8 (6.9)</td>
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<td>182 (142, 300)</td>
<td>211.5 (140, 339)</td>
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<td></td>
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</tr>
<tr>
<td>Living alone</td>
<td>8</td>
<td>11</td>
<td>4</td>
<td>15</td>
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<tr>
<td>Living with someone</td>
<td>15</td>
<td>11</td>
<td>14</td>
<td>12</td>
</tr>
<tr>
<td>Highest level of education, n</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Some/completed secondary/trade/technical school</td>
<td>11</td>
<td>9</td>
<td>4</td>
<td>17</td>
</tr>
<tr>
<td>Completed/some university/graduate school</td>
<td>16</td>
<td>14</td>
<td>14</td>
<td>10</td>
</tr>
<tr>
<td>Gait speed at baseline m/s median (10, 90)</td>
<td>0.80 (0.30, 1.06)</td>
<td>0.84 (0.41, 1.06)</td>
<td>0.87 (0.31, 1.12)</td>
<td>0.77 (0.41, 1.06)</td>
</tr>
</tbody>
</table>
Table 3.3: Participant sedentary behaviour and physical activity variables for three time points by group allocation. All variables are expressed as median and 10th and 90th percentiles (p10, 90).

<table>
<thead>
<tr>
<th></th>
<th>Control N=23</th>
<th></th>
<th></th>
<th>Intervention N=22</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline</td>
<td>Midpoint</td>
<td>Final</td>
<td>Baseline</td>
</tr>
<tr>
<td>Sedentary time, min/13 hr day</td>
<td>610.5</td>
<td>634.8</td>
<td>618</td>
<td>573.5</td>
</tr>
<tr>
<td></td>
<td>(496.8, 716.6)</td>
<td>(442.2, 725.1)</td>
<td>(481.2, 711.6)</td>
<td>(491.9, 670.1)</td>
</tr>
<tr>
<td>LPA, min/13 hr day</td>
<td>168.8</td>
<td>144.0</td>
<td>160.3</td>
<td>192.2</td>
</tr>
<tr>
<td></td>
<td>(63.2, 266.6)</td>
<td>(54.2, 282.9)</td>
<td>(68.4, 284.1)</td>
<td>(109.1, 278.7)</td>
</tr>
<tr>
<td>MVPA, min/13 hr day</td>
<td>1.1</td>
<td>1.4</td>
<td>1</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>(0.1, 23.7)</td>
<td>(0.3, 27.1)</td>
<td>(0, 30.6)</td>
<td>(0.6, 16.7)</td>
</tr>
<tr>
<td>Step Count, steps/day</td>
<td>2427</td>
<td>1926</td>
<td>2596</td>
<td>2780</td>
</tr>
<tr>
<td></td>
<td>(516, 5881)</td>
<td>(894, 8326)</td>
<td>(760,6886)</td>
<td>(1036, 6740)</td>
</tr>
</tbody>
</table>

13 hours = 780 minutes. LPA=light physical activity; MVPA=moderate-vigorous physical activity
Table 3.4: Participant sedentary behaviour and physical activity variables for three time points by sex. All variables are expressed as median and 10th and 90th percentiles (p10, 90).

<table>
<thead>
<tr>
<th></th>
<th>Men</th>
<th></th>
<th></th>
<th>Women</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N= 18</td>
<td>Baseline</td>
<td>Midpoint</td>
<td>Final</td>
<td>Baseline</td>
<td>Midpoint</td>
</tr>
<tr>
<td>Sedentary time, min/13 hr day</td>
<td>635.2</td>
<td>615.6</td>
<td>636.0</td>
<td>568.0</td>
<td>573.7</td>
<td>592.2</td>
</tr>
<tr>
<td></td>
<td>(542.9, 737.7)</td>
<td>(464.5, 728.4)</td>
<td>(484.7, 712.3)</td>
<td>463.5 (698.6)</td>
<td>(442.2, 676.3)</td>
<td>(444.8, 706.6)</td>
</tr>
<tr>
<td>LPA, min/13 hr day</td>
<td>139.2</td>
<td>161.5</td>
<td>141.3</td>
<td>196.1</td>
<td>202.3</td>
<td>178.8</td>
</tr>
<tr>
<td></td>
<td>(41.3, 220.0)</td>
<td>(50.9, 307.1)</td>
<td>(67.1, 283.9)</td>
<td>(80.9, 315.9)</td>
<td>(103.4, 283.7)</td>
<td>(73.3, 287.4)</td>
</tr>
<tr>
<td>MVPA, min/13 hr day</td>
<td>2.1</td>
<td>2.4</td>
<td>1.7</td>
<td>2.0</td>
<td>1.8</td>
<td>2.3</td>
</tr>
<tr>
<td></td>
<td>(0.1, 16.7)</td>
<td>(0.1, 27.1)</td>
<td>(0, 27.6)</td>
<td>(0.17, 38.1)</td>
<td>(0.3, 29.8)</td>
<td>(0.14, 46.9)</td>
</tr>
<tr>
<td>Step Count, steps/day</td>
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<td>2231</td>
<td>2576</td>
<td>3009</td>
<td>2848</td>
<td>2596</td>
</tr>
<tr>
<td></td>
<td>(489, 5154)</td>
<td>(446, 6957)</td>
<td>(654, 6038)</td>
<td>(1009, 9551)</td>
<td>(902, 9156)</td>
<td>(1037, 9453)</td>
</tr>
</tbody>
</table>

LPA=light physical activity; MVPA=moderate-vigorous physical activity
Table 3.5: Robust linear regression results for differences between allocation groups at midpoint and final assessment.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>R²</th>
<th>Variable</th>
<th>Coefficient</th>
<th>Standard Error</th>
<th>95% CI</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Intercept</td>
<td>36.31</td>
<td>55.32</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Time spent in sedentary at</td>
<td>0.71</td>
<td>Group allocation</td>
<td>-9.16</td>
<td>15.08</td>
<td>-39.60 to 21.28</td>
<td>0.55</td>
</tr>
<tr>
<td>midpoint</td>
<td></td>
<td>Sedentary</td>
<td>0.95</td>
<td>0.09</td>
<td>0.77 to 1.13</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>behaviour at baseline</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time spent in sedentary at</td>
<td>0.53</td>
<td>Group allocation</td>
<td>-13.47</td>
<td>19.57</td>
<td>-52.96 to 26.02</td>
<td>0.49</td>
</tr>
<tr>
<td>final assessment</td>
<td></td>
<td>Sedentary</td>
<td>0.84</td>
<td>0.12</td>
<td>0.61 to 1.08</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>behaviour at baseline</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Intercept</td>
<td>8.67</td>
<td>31.44</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Parameter</td>
<td>R²</td>
<td>Variable</td>
<td>Coefficient</td>
<td>Standard Error</td>
<td>95% CI</td>
<td>P</td>
</tr>
<tr>
<td>---------------------------------</td>
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<td>-----------------------</td>
<td>-------------</td>
<td>----------------</td>
<td>---------------</td>
<td>----</td>
</tr>
<tr>
<td>Time spent in light physical</td>
<td>0.67</td>
<td>Group allocation</td>
<td>6.29</td>
<td>15.02</td>
<td>-24.02 to 36.62</td>
<td>0.67</td>
</tr>
<tr>
<td>activity at midpoint</td>
<td>0.67</td>
<td>Time spent in light physical activity at baseline</td>
<td>0.91</td>
<td>0.09</td>
<td>0.72 to 1.1</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Time spent in light physical</td>
<td>0.48</td>
<td>Group allocation</td>
<td>13.43</td>
<td>18.21</td>
<td>-23.32 to 50.18</td>
<td>0.46</td>
</tr>
<tr>
<td>activity at final assessment</td>
<td>0.48</td>
<td>Time spent in light physical activity at baseline</td>
<td>0.76</td>
<td>0.11</td>
<td>0.52 to 0.99</td>
<td>0.00</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Intercept</td>
<td>-88.32</td>
<td>450.62</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Parameter</td>
<td>$R^2$</td>
<td>Variable</td>
<td>Coefficient</td>
<td>Standard Error</td>
<td>95% CI</td>
<td>P</td>
</tr>
<tr>
<td>------------------------</td>
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<td>-----------</td>
<td>-------------</td>
<td>----------------</td>
<td>-----------------</td>
<td>-----</td>
</tr>
</tbody>
</table>
| Number of steps taken at midpoint | 0.91  | Group     | 58.52       | 256.66         | -459.45 to 576.49 | 0.82
|                        |       | allocation| 0.05        | 576.49         |                 |     |
| Number of steps taken at baseline |       | Number of | 1.06        | 0.05           | 0.96 to 1.16    | 0.00
|                        |       | allocation| 0.05        | 0.00           | 0.85 to 1.10    | 0.00
| Number of steps taken at final | 0.84  | Group     | 166.63      | 316.29         | -471.68 to 804.95 | 0.60
|                        |       | allocation| 0.06        | 804.95         |                 |     |
| Number of steps taken at baseline |       | Number of | 0.98        | 0.85 to 1.10   |                 | 0.00
Table 3.6: Robust multivariable linear regression results for differences between allocation groups at midpoint and final assessment with covariate.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>R²</th>
<th>Variable</th>
<th>Coefficient</th>
<th>Standard Error</th>
<th>95% CI</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
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<td>39.68</td>
<td>118.43</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Time spent in sedentary</td>
<td>0.68</td>
<td>Group</td>
<td>-10.18</td>
<td>16.62</td>
<td>-43.79 to 23.42</td>
<td>0.54</td>
</tr>
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<td></td>
<td>allocation</td>
<td></td>
<td>23.42</td>
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<td></td>
</tr>
<tr>
<td>behaviour at midpoint</td>
<td>0.68</td>
<td>Sedentary</td>
<td>0.89</td>
<td>0.11</td>
<td>0.68 to 1.11</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
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<td></td>
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</tr>
<tr>
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<td>Time since fracture</td>
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<td>1.24</td>
<td>-0.12 to 0.33</td>
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<td>32.40</td>
<td>-2.27 to 2.76</td>
<td>0.85</td>
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<tr>
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<td>Average gait speed at baseline</td>
<td>-12.66</td>
<td>16.61</td>
<td>-78.20 to 52.87</td>
<td>0.70</td>
</tr>
<tr>
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<td>Intercept</td>
<td>145.55</td>
<td>136.48</td>
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</tr>
<tr>
<td>Parameter</td>
<td>R²</td>
<td>Variable</td>
<td>Coefficient</td>
<td>Standard Error</td>
<td>95% CI</td>
<td>P</td>
</tr>
<tr>
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<td>------------------------</td>
<td>-------------</td>
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<td>-------</td>
</tr>
<tr>
<td>Time spent in sedentary behaviour at final assessment</td>
<td>0.56</td>
<td>Group allocation</td>
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<td>-51.84 to 25.61</td>
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<td>0.71</td>
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<td>0.46 to 0.96</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Time since fracture</td>
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<td>0.13</td>
<td>-0.09 to 0.43</td>
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<tr>
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<td>Time spent in light physical</td>
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<td>Interception</td>
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<td>117.13</td>
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<td>-</td>
</tr>
<tr>
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<td></td>
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<td>16.10</td>
<td>-25.48 to 30.56</td>
<td>0.66</td>
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</tr>
<tr>
<td>Parameter</td>
<td>R²</td>
<td>Variable</td>
<td>Coefficient</td>
<td>Standard Error</td>
<td>95% CI</td>
<td>P</td>
</tr>
<tr>
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<td>-------------</td>
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</tr>
<tr>
<td>activity at midpoint</td>
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<td>Time spent in light physical activity at baseline</td>
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<td>0.63 to 1.06</td>
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<td>-0.32 to 0.12</td>
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<td>-2.73 to 2.10</td>
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</tr>
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<td>Time spent in light physical activity at baseline</td>
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<td>0.40 to 0.89</td>
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<td>R²</td>
<td>Variable</td>
<td>Coefficient</td>
<td>Standard Error</td>
<td>95% CI</td>
<td>P</td>
</tr>
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<td>-------------------------------</td>
<td>-------------</td>
<td>----------------</td>
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</tr>
<tr>
<td>final assessment</td>
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<td>activity at baseline</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Time since fracture</td>
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<td>0.12</td>
<td>-0.42 to 0.07</td>
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<td>Average gait</td>
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<td>34.84</td>
<td>-24.10 to 116.84</td>
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<tr>
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<td>0.07</td>
<td>0.91 to 1.18</td>
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<tr>
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<td></td>
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</tr>
<tr>
<td>Parameter</td>
<td>$R^2$</td>
<td>Variable</td>
<td>Coefficient</td>
<td>Standard Error</td>
<td>95% CI</td>
<td>P</td>
</tr>
<tr>
<td>-----------------------------</td>
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<td>--------------------------------</td>
<td>-------------</td>
<td>----------------</td>
<td>--------------------</td>
<td>------</td>
</tr>
<tr>
<td>Time since fracture</td>
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<td>-2.87</td>
<td>1.91</td>
<td>-6.73 to 0.98</td>
<td>0.14</td>
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</tr>
<tr>
<td>Age</td>
<td>-6.77</td>
<td>21.53</td>
<td>-50.34 to 36.79</td>
<td>0.75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average gait speed at baseline</td>
<td>-151.79</td>
<td>591.86</td>
<td>-1348.96 to 1045.37</td>
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<td></td>
</tr>
<tr>
<td>Number of steps taken at final assessment</td>
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<td>Intercept</td>
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<td>2508.75</td>
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<td>-</td>
</tr>
<tr>
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<td>Group</td>
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<td>348.86</td>
<td>-534.15 to 877.11</td>
<td>0.62</td>
</tr>
<tr>
<td>Time since fracture</td>
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<td>2.38</td>
<td>-8.98 to 0.66</td>
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</tr>
<tr>
<td>Parameter</td>
<td>R²</td>
<td>Variable</td>
<td>Coefficient</td>
<td>Standard Error</td>
<td>95% CI</td>
<td>P</td>
</tr>
<tr>
<td>-----------</td>
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</tr>
<tr>
<td>Age</td>
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<td>26.91</td>
<td>-1.00</td>
<td>26.91</td>
<td>55.44 to 53.44</td>
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</tbody>
</table>

Intercept= a mathematical constant, no clinical interpretation; Variables= explanatory variables: sedentary behaviour or physical activity at baseline, time since fracture, age, average gait speed at baseline, and group; 95% CI= 95% confidence interval;
Table 3.7: Mixed model results for differences between men and women at midpoint and final assessment.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Variable</th>
<th>Coefficient</th>
<th>Standard Error</th>
<th>95% CI</th>
<th>z</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sedentary behaviour</td>
<td>Intercept</td>
<td>626.69</td>
<td>19.15</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Sex</td>
<td>-47.29</td>
<td>24.05</td>
<td>-94.43 to -</td>
<td>-1.97</td>
<td>0.049</td>
</tr>
<tr>
<td></td>
<td>Midpoint</td>
<td>-5.08</td>
<td>7.71</td>
<td>-20.19 to -</td>
<td>-0.66</td>
<td>0.510</td>
</tr>
<tr>
<td></td>
<td>Final</td>
<td>-1.02</td>
<td>7.71</td>
<td>-16.14 to -</td>
<td>-0.13</td>
<td>0.894</td>
</tr>
<tr>
<td>Light physical activity</td>
<td>Intercept</td>
<td>148.05</td>
<td>17.58</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Sex</td>
<td>44.22</td>
<td>21.97</td>
<td>1.16 to 0</td>
<td>2.01</td>
<td>0.044</td>
</tr>
<tr>
<td></td>
<td>Midpoint</td>
<td>3.97</td>
<td>7.64</td>
<td>-11.00 to 0</td>
<td>0.52</td>
<td>0.603</td>
</tr>
<tr>
<td></td>
<td>Final</td>
<td>-0.85</td>
<td>7.64</td>
<td>-15.83 to 0</td>
<td>-0.11</td>
<td>0.911</td>
</tr>
</tbody>
</table>

Note: 95% CI refers to the 95% confidence interval.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Variable</th>
<th>Coefficient</th>
<th>Standard Error</th>
<th>95% CI</th>
<th>z</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Error</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td></td>
<td>2700.38</td>
<td>636.40</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Step count</td>
<td><strong>Sex</strong></td>
<td>905.67</td>
<td>807.83</td>
<td>-677.4 to 1.12</td>
<td>0.262</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Midpoint</strong></td>
<td>309.85</td>
<td>201.67</td>
<td>-85.4 to 1.54</td>
<td>0.124</td>
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</tr>
<tr>
<td></td>
<td><strong>Final</strong></td>
<td>269.32</td>
<td>201.67</td>
<td>-125.9 to 1.34</td>
<td>0.182</td>
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<tr>
<td></td>
<td><strong>assessment</strong></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Intercept = a mathematical constant, no clinical interpretation; Variables = explanatory variables: sedentary behaviour or physical activity at baseline, time since fracture, age, average gait speed at baseline, and group; 95% CI = 95% confidence intervals.
Figure 3.1: CONSORT 2010 Flow Diagram showing participants randomised into each group, number of participants receiving intervention and follow-up and participants analysed.
Figure 3.2: Time spent in sedentary behaviour in men and women at the different data collection time points.
Figure 3.3: Time spent in light physical activity in men and women at the different data collection time points.
Chapter 4: Conclusion

In the following chapter I discuss the conclusions of my thesis regarding the goals or hypotheses presented in the introduction, the meaning of the results in light of current knowledge in the field and the significance and contribution of the research reported. I also comment on strengths and limitations of the research, discuss any potential applications of the research findings, and suggest future research directions.

Hip fracture often leads to prolonged sitting, which leads to extended sedentary behaviour [17, 60]. I found that this cohort of older adults after hip fracture spent most of their waking hours sedentary and participated in very little physical activity, mostly in the form of light physical activity, and very little, if any, moderate-vigorous physical activity. Older adults after hip fracture also take very few steps throughout the day and do not meet physical activity guidelines for either overall activity per day or for number of daily steps as recommended for older adults by the Canadian Society for Exercise Physiology [69].

Prior to data analysis, I hypothesised that older adults who were allocated to the intervention group would show better activity patterns, as activity increase was seen in several previous studies which tested physical activity interventions and measured activity objectively using accelerometry [22, 27, 43], and that a decrease in time spent sedentary would be seen in all participants over the 12-month course of the study; I observed neither. There are several potential explanations for these findings. First, this was a secondary outcome of a randomised controlled trial and therefore the intervention was not specifically targeted to reduce sedentary time or increase physical activity and may not have been long or intense enough. In addition, while the study did not provide health services to the UC group, they had access to such services through their medical services plan. A potential reason that could explain why sedentary time did
not significantly decrease over the course of the study across all participants is that this cohort grew older over the year in which the trial took place. As I hypothesized, and as is seen in the literature [26], women were less sedentary and more active than men at all three time points. However, this was significant at baseline but not at midpoint or final assessment, which might suggest that men benefitted more from the study follow up than women and that different intervention strategies might affect men and women differently. Finally, as I hypothesised, the cohort of participants spent approximately 76% of their waking hours sedentary, about 30% more than healthy older adults [29], which emphasises the severity of this problem and the need to address their prolonged sitting time and lack of physical activity.

Our results are consistent with previous literature which also reported prolonged sedentary time and minimal engagement in physical activity in this population in different stages of recovery, from the first days and up to a year post-fracture [17, 21-24, 42, 43, 89-96]. My analysis adds to the body of knowledge in that this is the first randomised controlled trial to assess the effectiveness of a comprehensive geriatric intervention to objectively measure sedentary behaviour and physical activity using direct measurement tools in community dwelling older adults within the first year after hip fracture and follow them up for a period of one year. The intervention results and the fact that there were no differences between the groups along with the significant differences between men and women are important to note and consider when developing new intervention strategies and treatment plans.

There are many strengths to this study. The follow-up time was long and had multiple testing points: staff recorded physical activity and sedentary behaviour for a period of one week at three time points throughout the year. The study had reliable data from almost all participants at the different time points with very few missing data. However, the B4 study has some
limitations. Unfortunately, the study did not achieve the estimated sample size of 130 participants and therefore lacked power to detect significant differences between the two allocation groups. In addition, the ActiGraph accelerometer was previously found to perform poorly and failed to detect activity at low gait speed, which may have affected the results [122]. Despite this limitation, sufficient data were collected to provide information regarding participants’ activity levels to suggest that this cohort of participants was very sedentary.

As the contribution of physical activity to the healthy recovery process and its potential to decrease fear of falling and risk of falling is well established [74], and given the high level of sedentary behaviour and inactivity along with low levels of physical activity at all stages of recovery [17, 21, 22, 89], I would like to emphasise the critical need to develop concrete interventions to increase the time older adults after hip fracture spend in physical activity and lower time spent in sedentary behaviour, already at the hospital and until full recovery. Health professionals should be aware of the prolonged sitting time and minimal engagement in physical activity and also be aware of sedentary behaviour and physical activity differences between men and women and address them when writing a treatment plan that aims to reduce overall sedentary time, fragment it throughout the day and increase time spent in physical activity. Health professionals should also consider targeted gender-specific intervention strategies that will suit the older adult better and hopefully lead to better recovery results.

Based on the study results, I recommend that sedentary behaviour and physical activity guidelines be developed specifically for older adults after hip fracture, considering age, sex, time since fracture and type of residence, as these are currently not available [98].
Bibliography


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