Cause or Consequence?
The Interrelationship between Physical Activity and Fractures

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

Our study characterized the physically active and non-active circumstances during which fractures occur and explored long-term effects on physical activity following one or more fractures of the hip or pelvis, spine, upper limb, or lower limb. 9423 community-dwelling women and men aged ≥ 25 years, participating in the Canadian Multicentre Osteoporosis Study (CaMos) were included. Medical and lifestyle history, including self-reported physical activity, was obtained by interview at baseline, year 5 and year 10. Spinal radiographs were taken in people ≥ 50 years of age. Details of incident fractures were recorded yearly using questionnaires, and fractures were confirmed by X-ray. 1533 fractures were reported and confirmed (13% hip, 4% pelvic, 12 % vertebral, and 71% other). Most fractures occurred in women aged ≥ 50 years with a BMD *T-score* ≤ -1.0 SD. Descriptive analyses revealed that 65% of fractures occurred due to falls during daily activities. Sporting injuries accounted for 6% of all fractures. Vertebral fractures often occurred without fall or injury or due to other circumstances including lifting, bending, or carrying. Repeated measures Analysis of Variance identified decreased physical activity participation between baseline, year 5, and year 10 ($F_{(2,5503)} = 61.54$, $p<0.001$). Decreased physical activity in people who reported an incident fracture compared with no fracture was only significant at year ten ($F_{(2,5503)} = 7.24$, $p<0.01$). In adjusted multivariable regression analyses, having a hip or pelvic fracture between year 1 and year 5 was significantly associated with decreased physical activity at five-year follow up (-1857.87 MET-mins/week; 95% CI [-2587.46, -1128.29]). Other fracture types or multiple fractures of any type occurring between years one to five, and years five to ten were not associated with physical activity at five or ten-year follow-up. Previous activity, age, body mass index, education, and number of comorbidities were significant correlates. To maintain physical activity in people at risk of fracture, interventions should emphasize falls prevention while re-training safe movement patterns during activities of daily life. Further research to understand the long-term implications of fracture on physical activity is needed.

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Chapter 1: Introduction

Osteoporosis is a common metabolic bone disorder, characterized by fractures. Osteoporosis Canada estimates that approximately two hundred-thousand fractures occur each year,[1] with over 80% of reported fractures attributable to osteoporosis.[2,3] Approximately 1 in 3 women and 1 in 5 men worldwide are expected to experience an osteoporosis-related fracture in their lifetime[4,5] meaning that an osteoporotic fracture is more common than a heart attack, stroke and breast cancer combined.[6] The economic burden of fracture is significant, estimated at 4.6 billion dollars.[2] While fractures are a common injury in all stages of life,[7] older adults have a heightened risk of fracture due to declining bone strength with age.[8] Fractures occurring later in life have significant and long-lasting effects. Fractures related to osteoporosis are considered to signal or even induce progressive decline in health with age,[9] reducing quality of life, accelerating the progression towards frailty, and increasing the risk of subsequent fractures, comorbidity, and death.[9,10]

Physical activity, defined as "any bodily movement produced by skeletal muscles that results in energy expenditure" [11] is well established as a part of healthy living throughout the lifespan, and plays an important role in maintaining functional independence and mobility in older adults.[12] Physical activity is often suggested to reduce risk of fracture[13] by way of reduced falls[14] and improved bone mineral density.[15] However, some studies demonstrate a slightly greater risk of certain types of fractures in circumstances that involve physical activity,[16] or in individuals that are physically active. [17–20] Additionally, the incidence of a fracture may influence the extent to which an individual continues regular participation in physical activity.

In the Canadian Multicentre Osteoporosis Study (CaMos) population, fracture has been associated with reduced health-related quality of life[21–23] and increased frailty.[24] Both outcomes include aspects of physical functioning that are strongly related to physical activity,[25] therefore it seems possible that physical activity participation at follow-up will also be influenced by fracture.[25,26] During the weeks and months following fracture, sedentary behaviour is significantly increased while physical activity is significantly reduced.[27–31] Prolonged immobilization due to surgery or hospitalization, inability to complete active rehabilitation,[32] and fear of subsequent fracture may exacerbate functional limitations due to poor mobility, pain, and fatigue,[21,33,34] further reducing physical activity.[34] While many studies only examine physical activity changes in the short-term following fracture, it is possible that limitations persist over a longer period, even after the initial period of bone healing. [27,30,33] The effects of fracture on physical activity and sedentary behaviour over time, and in bones other than the hip, are not well documented. An analysis of patterns and predictors of sedentary time over ten years in the CaMos population did not consider the effect of fracture in the models.[35] While limitations exist in current research, there are strong incentives to better understand the causes and consequences of fracture. Balance and functional exercise programs are emerging as successful interventions that target fall and fracture prevention.[14] Characterizing the possible "causes" or circumstances during which fractures at the hip, pelvis, spine, and upper and lower extremity occur will provide an awareness of the types of activities that might be deemed risky and require greater caution, and allow for the inclusion of exercises and functional movement strategies that are targeted towards the specific ways in which fractures occur in community-dwelling females and males of different age groups. Determining if there are lasting consequences of certain types of fracture (i.e., hip pelvis, spine, upper and lower extremity, or multiple fractures) on physical activity behaviour will strengthen the rationale for prioritizing consistent and accessible post-fracture rehabilitation, as well as support the development of physical activity and exercise interventions that reduce potential long-term impacts of fracture, including loss of mobility, decreased physical activity, and risk of future fracture.

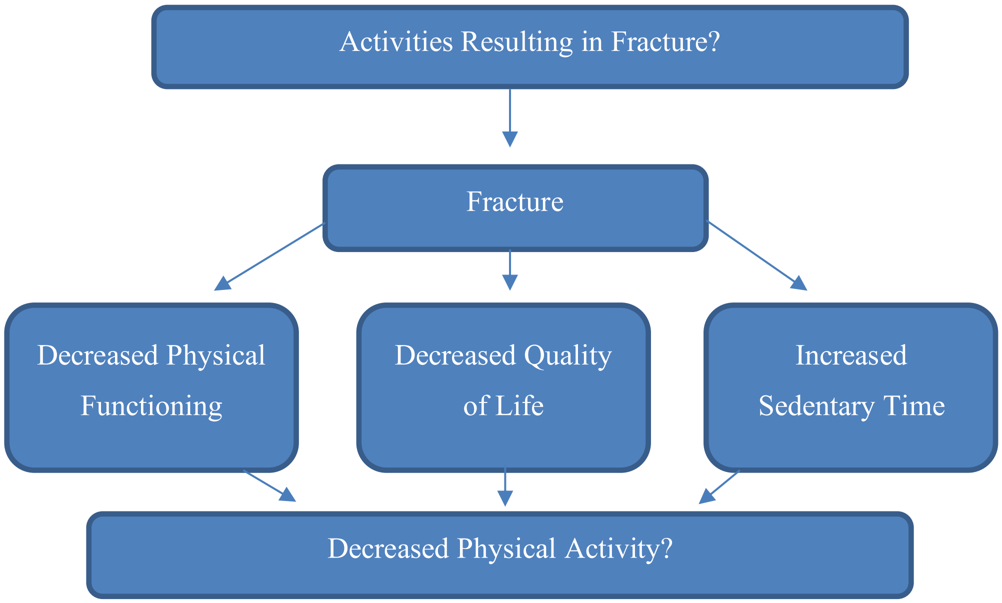

Figure 1: Conceptual framework for understanding physical activity and fracture in this thesis.

Chapter 2: Literature Review

2.1 Bone and Fracture

Bones are designed to be strong: they provide support for the human body, attachment sites for muscles to allow for mobility, and protection for internal organs. Fractures occur when the load applied to the bone exceeds the bone strength.[36,37] In young or healthy individuals, this means that fractures occur primarily due to acute trauma, repetitive strain, or pathology, however in individuals with reduced bone strength, fractures can occur more easily. Bone strength is determined by material composition and structure and reflects the integration of two main features: bone density and bone quality.[38] On a microscopic material level, bones consist of the mineral hydroxyapatite, primarily made up of calcium and phosphate, which is deposited within a collagen matrix. The balance between mineral and collagen allows for both rigidity (stiffness) and flexibility (toughness), with specific composition determining the resistance of each bone to fracture. On a macroscopic level, the size, shape, and distribution of bone tissue affects the strength of bone.[36,39] There are two types of skeletal bone: Cortical (or compact) bone is the densest layer of bone, primarily found on the outer surface of the diaphysis, or shaft, of long bones like the humerus or femur. Cortical bone is strongest along the longitudinal axis of the bone.[40] Trabecular bone (cancellous or spongy bone) is typically found in the epiphyses, or ends, of long bones, or in the vertebrae. Trabecular bone is composed of a porous, mesh-like lattice of trabeculae which are designed like struts. They are varied in direction and thickness and are typically aligned to provide strength against loading in different directions. Cortical thickness and porosity as well as the trabecular thickness and arrangement affect the ability of bone to withstand load,[39] while simultaneously adapting to applied loads.

The adaptive nature of bone contributes to structural integrity and can help explain variation in bone strength throughout the lifespan. To maintain bone density and quality, bones regularly undergo remodeling, a process of bone tissue resorption and formation carried out by bone cells. Bone remodeling occurs throughout the lifespan to replace mature or weakened bone with new bone. There are three types of bone cells: osteoclasts, osteoblasts, and osteocytes. Osteoclasts resorb bone that has become damaged or brittle, while osteoblasts synthesize and deposit new bone matrix before differentiating into osteocytes that are embedded within the bone matrix. Osteocytes are hypothesized to have several regulatory and signaling functions within bone, including acting as mechanosensors.[41] Bone remodeling can be stimulated through mechanical loading and forces placed on the bone, and osteocytes may sense bone deformation, stimulating osteoclast activity, and initiating the bone remodeling process. This means that weight-bearing activities as well as those that create strong muscle pull resulting in bone strain may be osteogenic. Conversely, with aging or disease, imbalance in osteoclast activity can shift bones towards net resorption, and disuse can reduce the stimulus for bone remodeling. Bones become less dense and weaken, increasing risk of fracture. This is the hallmark of osteoporosis, and the target of many pharmacological osteoporosis treatments.

2.2 Osteoporosis

Osteoporosis is defined "as a skeletal disorder characterized by compromised bone strength predisposing to an increased risk of fracture."[38] Clinically, osteoporosis is diagnosed following a fragility fracture or using bone mineral density (BMD) values obtained through dual-energy X-ray absorptiometry (DXA).[42,43] Fragility fractures are those that occur spontaneously, or due to a low-trauma incident such as a fall from standing height or less.[42] Fragility fractures can occur at any bone site, though fractures occurring at the hip, spine, pelvis, forearm, or wrist are often associated with osteoporosis.[44] BMD is expressed as a *T-score*; the number of standard deviations (SD) above or below the mean value of a healthy young adult population. The World Health Organization has defined osteoporosis as a BMD *T-score* of 2.5 SD or greater below the reference mean. Osteopenia is defined as a BMD *T-score* that is 1.0 to 2.5 SD below the reference mean. Bone loss leading to osteoporosis does not typically result in symptoms, however the resulting fractures are a significant source of morbidity.[45] Therefore, early identification of individuals at risk of fracture is important for disease prevention and management.

2.3 Assessment of Fracture Risk

Decreased BMD *T-score* at the femoral neck is used as a predictor of increased fracture risk,[46] though research has demonstrated that fracture risk can be better assessed when clinical risk factors (CRFs) are considered in addition to BMD.[39,47] Fracture risk assessment tools (FRAX) use country-specific data to predict the 10-year probability of having a hip fracture or major osteoporotic fracture of the spine, forearm or humerus. In addition to femoral neck BMD, CRFs considered in the FRAX tool include age, female gender, body mass index (BMI), history of previous fracture or parental hip fracture, current smoking, alcohol intake (> 3 drinks/day), use of glucocorticoids, and diagnosis of rheumatoid arthritis or other conditions predisposing to secondary osteoporosis. The Canadian Association of Radiologists and Osteoporosis Canada (CAROC) fracture risk assessment tool is simplified to determine the categorical risk of a major osteoporotic fracture within 10 years from age, sex, and BMD T-score at the femoral neck, in reference to white woman from the National Health and Nutrition Examination Survey III (NHANES).[48] Currently, use of one tool over the other is a matter of personal preference [45]. Key differences between the FRAX and CAROC tools are that BMD is optional for FRAX while it is required to determine an estimate using the CAROC assessment, and CAROC does not require access to a web-based program. FRAX is more universally used, as access to DXA equipment to accurately assess BMD is not required to determine an accurate prediction of fracture risk.[47] Additionally, FRAX considers a more comprehensive list of risk factors. Despite the differences in methodology, both tools have been validated using Canadian data and have good agreement.[49]

2.4 Falls and Fracture Risk

Fracture risk assessment tools capture many health and lifestyle characteristics, however there are many other factors that contribute to fracture risk. Certain activities and situations have been suggested to increase the risk of fracture. Falls are a leading cause of non-vertebral fracture,[50,51] and are thought to be a more clinically relevant predictor of fracture risk than BMD.[52,53] While not all falls result in fracture, most fractures are a result of a fall.[16] A recent analysis of the Global Longitudinal Study of Osteoporosis in Women found that falls were responsible for 70-85% of hip and non-vertebral fractures and nearly 50% of vertebral fractures in postmenopausal women up to age 85.[54] Vertebral fractures were less likely to be a result of a fall or injury.[50] While falls have been associated with icy winter conditions, studies demonstrate that fall-related fractures occur consistently year-round.[50]

The type and severity of fall-related fracture is associated with the direction in which a person falls, as well as the ability of an individual to regain control while falling, affecting the direction of impact on landing and the resulting loads applied to the bone.[55–59] Hip fractures are more likely a result of a lateral fall[60,61] or a fall that results in a sideways landing,[59] whereas falls in which the individual can extend their arms to break the impact may be more likely to result in a wrist, forearm, or humerus fracture.[57] Significant research exists on the effect of intentionally modified falling techniques or using external hip protection for reducing impact force or velocity, however there is mixed evidence of the efficacy in relation to fracture prevention.[59] A greater understanding of when and how different types of fractures occur is needed.

2.5 Physical Functioning and Fracture Risk

Osteoporosis has been closely associated with both sarcopenia (age-related decline in muscle mass, strength, and functional capability),[62] and frailty (age-related decline of physical, psychological, and social functioning,[63] often characterized by unintentional weight loss, weakness and muscle loss, fatigue, slow walking, and low physical activity). Fracture risk is increased in individuals with poor physical functioning and mobility.[64] Limitations in mobility and physical functioning are common even in healthy aging but are often exacerbated in individuals who are not physically active, have had previous fracture, or have comorbid health conditions. Individuals with impairments in balance, gait, muscular strength and endurance, and postural control may be more susceptible to trips and falls and may not have the capability to employ efficient compensatory mechanisms (like stepping, catching oneself, etc.), increasing risk of fracture.[64] Increased sedentary time as a result of comorbid health conditions or mobility impairments may mean an individual is spending significant time in a flexed seated posture contributing to large compressive loads on the spine for extended periods of time.[65] Exercise is often promoted as a valuable modifier of impaired physical functioning and mobility, particularly for individuals with sarcopenia that may be able to regain functional abilities through targeted practice.[66] However, caution needs to be taken to ensure that activities meet therapeutic goals to improve physical functioning without increasing risk of fracture.[67]

2.6 Physical Activity and Fracture

Many falls and fractures occur while participating in activities of daily living.[50,56] Physical activity often puts people in imbalanced positions, at increased movement speeds. Physical activity may expose individuals to tripping or slipping hazards which increase fall risk or may involve bending or rotational movements or complicated positions that increase forces applied to bones. Physical activities may also include distractions that result in less awareness of surroundings or reduced attention to safe movement patterns. While daily physical activity should be encouraged for general health, it is possible that certain activities may actually increase fracture risk, though very little is known about the types of activities that may be problematic for people at risk of fracture. Recently, thirty hip fractures were recorded during an analysis of 2377 video-captured falls in long-term care settings.[59] Most falls were a result of intrinsic causes (incorrect weight shift, loss of support, or collapse) compared with extrinsic causes (trip, bump, or slip), however statistically significant differences were not present in the cause of falls resulting in fracture compared with non-fracture falls. There were also no statistically significant differences in fracture risk due to activity (either walking or standing/transferring) at the time of fall, however the use of a mobility aid reduced fracture risk.[59]

Unfortunately, studies of physical activity do very little to illuminate the possible risks of fracture during physical activity.[14,68] Evidence suggests there are independent associations between physical activity and fracture incidence, however results vary by fracture site as well as type, volume, and intensity of physical activity.[18–20,69,70] A prospective cohort study of 77 206 women 50-79 years of age found that walking as well as strenuous yard work were inversely associated with hip fracture.[69] Additionally, mild physical activity was inversely associated with total fracture, hip fracture, and clinically reported vertebral fracture. Knee fracture and elbow fracture were positively associated with moderate to vigorous physical activity (MVPA), suggesting an increased risk of knee and elbow fracture in individuals participating in MVPA ≥ 9 MET-hours/week.[69] An Australian study including postmenopausal women and men over age 50 reported that women who walked for more than 3 hours weekly had a 51% increase in total fracture risk, and women who walked at least 6 times weekly had a 56% increase in total fracture risk. Walking also increased risk of fracture for men, but to a lesser extent. Total physical activity was not associated with increased fracture risk.[20] Additional studies have followed this trend of inconsistency – reporting that physical activity was associated with an increased risk of distal forearm/wrist fracture, however, was not associated with overall fracture risk,[70] and may reduce risk of hip fracture[19] or have no effect.[18,69] Published studies vary in length of study follow-up, method of statistical analysis, and method of reporting risk. In combination with the few available studies and limitations in the strength of associations, the effect of physical activity on fracture risk is not well understood.

Even in studies of exercise interventions, the effect of exercise or physical activity on fractures in people with osteoporosis is largely unknown. Broadly speaking, adverse events in people with osteoporosis are not consistently monitored or reported. A Cochrane review of exercise interventions in postmenopausal women with osteoporosis identified a non-significant reduction in fracture rate in the exercise group compared with the control (Odds Ratio 0.61, 95% CI (Confidence Interval) [0.23,1.64], 539 participants, 4 studies, I^2=37.08%),[68] however the confidence intervals were wide with two studies favouring the exercise intervention[71,72] and two studies favouring the control.[73,74] Only one study reported fracture rate as a primary outcome, while three studies reported fractures as adverse events,[68] which is consistent with a second Cochrane review of exercise interventions in individuals with vertebral fracture which identified only one study reporting fracture as a secondary outcome.[75] In this study, 4 individuals reported a fracture in the exercise group compared with 7 in the control group.[75] In a healthy, community dwelling population, Sherrington et al., (2019) reported low-certainty evidence that exercise may reduce the number of people experiencing fall-related fractures by 27% compared with control (Risk Ratio=0.73, 95% CI [0.56 to 0.95]; 4047 participants, 10 studies, I^2 = 0%). While there are undeniable benefits to physical activity and exercise, it remains possible that physical activity may contribute to fracture risk, particularly in individuals at high risk of fracture.

2.7 Health Consequences by Fracture Type

A fracture often facilitates a significant life change. In younger, healthy individuals, a fracture may result in several weeks of immobilization, modification, or reduction in physical activity participation, and have possible social and interpersonal consequences. In older populations, a fracture can facilitate or catalyze rapid decline in health. Fractures are independently associated with increased mortality,[9] frailty,[24] decreased quality of life, [21–23] decreased physical functioning, and increased sedentary behaviour. [30] Fractures occurring at different bone sites vary in the type and severity of effects, however impairments in physical function, quality of life, and pain are common.[76] Many fractures require emergency room visits, surgery, hospitalization, and eventual transition to long-term care.[2,3,77] Health care professionals prescribe medications, supplements, and mobility devices to manage fractures and related comorbidities.[2] Increased reliance on medical services may challenge feelings of independence, self-efficacy or self-confidence following a fracture.[78–80] Given the majority of the population is living longer, the incidence of fracture is becoming increasingly concerning. Individuals with any history of fracture have a significantly increased risk of subsequent fracture,[81] and outcomes following fracture progressively worsen with age,[82] meaning that a single osteoporotic fracture at any site may be enough to initiate declining active life participation.

2.7.1 Effect of Hip Fracture

In the adult population of the Canadian Multicentre Osteoporosis Study (CaMos), health-related quality of life was evaluated using both the Medical Outcomes Trust-36 item Health Survey (SF-36) and the Health Utilities Index (HUI) Mark 2 and 3 instruments.[83] Studies exploring the effect of fractures on quality of life demonstrate reductions in subscales that reflect physical functioning.[21–23,84] Loss of physical functioning manifests as an inability for people to independently perform any activities of daily living that require physical movement and strength.[85] In both women and men, hip fracture significantly reduces mobility (the ability to move independently), ambulation (walking ability) and the ability to complete self-care activities of daily living (i.e., eating, bathing, dressing oneself, toileting).[21–23] Impairments in physical functioning are often dependent on the severity of fracture and the degree of pain an individual experiences, as well as the feelings and perceptions that an individual has towards their ability to remain active.[85] Following hip fracture, individuals report an increased frequency and severity of pain that interrupted regular activity or required the use of analgesics.[22,23] Women with hip fracture report deficits in emotional attributes of the Health Utilities Index, suggesting reduced happiness and interest in life. It is understood that reduced mobility has broad effects on other domains of health-related quality of life.[86] Along with physical impairments post hip fracture, fear of falling and fear of subsequent fracture may self-impose limitations in physical functioning and physical activity.[87] The negative impact of hip fracture on quality of life has been shown to last for several years following fracture,[23,30] with nearly half of individuals unable to regain independent physical functioning.[33] In the CaMos population, HUI scores remained reduced for the entire follow-up period of five years after hip fracture in both men and women[23]. Adachi et al. (2003) has reported that time since last fracture was not strongly associated with HUI data, however the greatest differences were noted in individuals with hip, pelvis, or spinal fracture in the first year following fracture.[22]

2.7.2 Effect of Pelvic Fracture

Compared with hip fractures, data on the health effects of pelvic fragility fractures are extremely limited. Osteoporotic pelvic fractures often present similar limitations to that of hip fracture and are associated with pain or an inability to weight bear,[88] along with an increased rate of 1-year mortality.[82] In the CaMos population, women with pelvic fractures reported significant deficits in the physical functioning domain of the SF-36[21] as well as mobility, ambulation,[22,23] and self-care attributes of the HUI.[84] Due to the low number of pelvic fractures recorded in men, comparisons were not made at five-years follow-up,[22] however at ten-years follow-up, pelvic fractures continued to be associated with pain.

2.7.3 Effect of Vertebral Fracture

Vertebral fractures can be clinical or morphometric, meaning they have been diagnosed and reported, or appear as a deformity on a radiograph. In the CaMos population, health-related quality of life following vertebral fracture was also evaluated using both the Medical Outcomes Trust-36 item Health Survey (SF-36) and the Health Utilities Index (HUI) Mark 2 and 3 instruments. [83] Using the SF-36, both clinical and subclinical morphometric vertebral fractures resulted in decreased scores for physical functioning, role-physical and bodily pain scales.[21] After 5 years of follow-up, clinically reported vertebral fractures in women continued to negatively affect HUI attributes of mobility, ambulation, and the ability to complete self-care activities of daily living. Women additionally reported deficits in emotion and interest in life, as well as pain that continued to influence activity levels [23]. Men with vertebral fractures only reported deficits in attributes of pain.[23] Reduced health-related quality of life following vertebral fracture has often been associated with decreased physical functioning and increased self-reported pain in women over 65 years of age with osteoporosis.[76] In a cross-sectional study of women with a *T-score* less than or equal to 2.5 SD as well as confirmed vertebral fracture, reduced walking speed as well as pain were evident, and independently associated with most subscales on both the SF-36 and the International Osteoporosis Foundation's Quality of Life for Osteoporosis (QUALEFFO-41) scale.[76] Vertebral fractures are commonly associated with back pain and have also been associated postural changes and hyper-kyphosis. Pain and an increased kyphotic posture (as demonstrated by the occiput-to-wall test) may contribute to reduced functional performance on the timed up and go test, five times sit-to-stand test, four metre walk test and step test.[89]

2.7.4 Effect of Other Types of Fracture

There is variation in the evidence related to the impact of lower leg and upper extremity fracture on quality of life. Women in the CaMos population reported worsened quality of life in self-care and pain attributes following fracture of the lower leg, knee, ankle, or foot, while men reported deficiency in the dexterity attribute.[22] Fractures of the upper extremity, wrist and forearm do not appear to worsen quality of life outcomes compared with no fracture in women or men.[22]

2.8 Effect of Fracture on Physical Activity

Given reductions in health-related quality of life, particularly in physical functioning and mobility related attributes, increased reports of pain, and poor functional outcomes following fracture, it is unsurprising that physical activity is affected. Active time in the days and weeks following a fracture can be very limited[29–31,90–92] as individuals may be immobilized or rely on gait aids and supportive care to ambulate and perform physical activities of daily living. While studies examining physical activity and sedentary behaviour during recovery from fracture generally note improvements in physical activity over time when transitioning from hospital to rehabilitation to home settings,[27,93] daily step counts and active minutes remain low even with inpatient intervention.[31,92,94] Physical activity outcomes are most often reported in the acute period following hip fracture, and most hip fracture survivors do not regain former levels of physical activity.[30,31,95]

Individuals with better pre-fracture health and physical activity status, as well as those who participate in active rehabilitation (e.g., physiotherapy, occupational therapy, interventions to increase step count) during the acute healing period have improved mobility outcomes following a fracture.[30,95–98] In a study of working-aged (19-69 years) individuals with upper limb fracture, 9% of individuals reported problems with mobility, while 45% of individuals reported problems performing usual activities. In individuals with lower-limb fractures, 58% reported problems with mobility while 72% reported problems with usual activity and 61% reported pain or discomfort. Individuals with increased activity levels 2-weeks post-fracture were less likely to report impairments at the 6-month mark.[93] Not only is there need for early physical activity intervention following any type of fracture, but continued and progressive support throughout the healing process to facilitate the relearning of movement pattering, increase of muscle mass following immobilization and return to confidence in activities of daily life. Comprehensive treatment plans that involve this type of hands-on approach are often prescribed as part of a return-to-sport treatment plan for athletes, however, can be overlooked for individuals returning to the community.

In the CaMos population, only 37% of individuals reported participation in either physiotherapy or occupational therapy after leaving the hospital.[99] Rehabilitation services were used to a greater extent by individuals with hip fracture, compared with vertebral fracture or non-hip, non-vertebral fracture.[99] Therefore, is unclear whether active interventions continue to be followed beyond this acute period, and whether they are effective. A study of individuals with ankle fracture (not osteoporosis specific) demonstrated that physical activity MET (metabolic equivalent) minutes gradually improved in the first month following removal of immobilization, however when comparing to a general Australian cohort, the proportion of individuals in the ankle fracture cohort who met physical activity guidelines remained reduced, and sedentary time remained increased at one, three and six months following the removal of immobilization.[92] Following a fracture, the type of activities that individuals participated in changed as well. Individuals without fracture typically recorded most of their MET-minutes through vigorous activity, while walking was the main form of activity for individuals that had experienced an ankle fracture. [92] It would be valuable to understand how long deficits in physical activity, and deviations from normal activity patterns last in order to determine what support services individuals need and would take advantage of following a fracture.

We know very little about the long-term effects of fracture on physical activity levels. Studies examining physical activity after a fracture often do not have a follow-up period longer than six months.[92,93] Whether or not individuals ever return to the types and volume of physical activity they were participating in prior to a fracture is of interest. A study looking at the trajectory of hip fracture over a two-year period suggests that there were no significant differences between physical activity in the pre-fracture period compared with 2-years post-fracture, however 40% of the population with hip fractures was inactive after two years.[100] Age and frailty index were significant explanatory variables.[100] While Aboelmagd et al., (2018) paints a positive light on the trajectory of physical activity following hip fracture, only community-dwelling (non-institutionalized) individuals were included. We know that outcomes following hip fracture vary, however it is very common for individuals with hip fracture to transition to long-term care or supported living within the year.[101] In perhaps a graver analysis, a study of postmenopausal women with vertebral fracture found that over a 5.4-year follow-up, women with mild vertebral fractures were less likely to walk up a flight of stairs, and 50% did not complete any physical activity in the preceding week. Women with moderate to severe vertebral fractures were less likely to participate in walking-based activities and housework, and 70.8% did not complete any physical activity in the preceding week. They also reported a shorter duration of participation in physical activity.[102]

Overall, there is very limited research surrounding physical activity after fracture, particularly in individuals with osteoporotic fragility fractures, and evidence that is available has significant methodological differences.

2.9 Physical Activity as a Treatment for Osteoporosis

Regular participation in physical activities that promote the maintenance of balance and postural control, mobility, and strength is one of the most promising strategies for preventing falls and subsequent fractures.[14] However, individuals with osteoporosis are often advised against certain movements which increase compression or torsional loading on the spine or place the individual at an increased risk of fall-related fracture.[67] Some individuals carry pervasive beliefs that people with osteoporosis are unable to maintain previous activities due to risk of fracture, and therefore create activity limitations (e.g., lifting no more than 5-10 pounds) that restrict participation in daily activities.[67] Physical activity has largely been associated with a lower risk of fracture,[13,15] though some physical activities have been suggested to increase risk of fracture, particularly when they are not tailored to the ability and risk level of the individual, or are performed in very high doses (e.g., > 3 hours or 6 or more bouts of walking per week).[17,20] Exercises that challenge balance and improve muscular strength through functional movements have more benefit to falls and fracture prevention [14] while movements that encourage impact and loading of the bones and muscles through weight bearing or resistance training may help to encourage bone turnover to maintain or improve BMD.[103,104] In general, limitations in the methodology used in exercise trials in people with osteoporosis, and inconsistent reporting of interventions (including frequency, intensity, time, and type of exercises used), outcomes, and adverse events continue to challenge our ability to specify which type, intensity, and volume of exercise is most effective for reducing fractures.[105]

Without clear consensus on the safety, efficacy, and effectiveness of specific exercise interventions in people with osteoporosis,[106] exercise prescription is challenged. Scientific evidence does not always translate easily into clinical practice or patient populations and can be complicated by conflicting evidence and opinions. Recommendations and guidelines for physical activity and exercise in people with osteoporosis have been created to communicate available evidence,[107] and knowledge translation initiatives aim to disseminate knowledge and produce behaviour change in target populations.[108] However, there are many unique barriers to exercise participation in people with osteoporosis.[109]

A lack of exercise-related knowledge including which exercises to perform, how to safely modify exercise, and how to practice good postural alignment has been identified as a barrier by people with osteoporosis, as has lack of access to resources to improve knowledge.[108] People with osteoporosis have identified physicians and health-care providers as a preferred source of information,[110] and some have expressed that lack of guidance from a physician was a barrier to engaging in exercise.[108,110] Therefore, it is essential that health-care providers have the knowledge and tools necessary to communicate sound evidence about physical activity and exercise for osteoporosis or are able to refer to a trusted exercise professional with additional training in osteoporosis.

Individuals with osteoporosis vary in age, number of comorbid health conditions, level of mobility or physical impairment, treatment, and life situation. Some people have had one or more fractures while others have not. For those who have experienced a fracture, the bone site and circumstance in which a fracture occurred may affect their willingness to participate in exercise, but also may be indicative of the type of exercise or physical activity they prefer to perform. For example, an individual who fractured a bone while participating in a sport may be fearful to play the sport again, but that sport may have been their primary source of physical activity. Other people may not experience fear and may continue participating in the sport without modification.[108] If exercise programs for people with osteoporosis do not align with participant lifestyles and preferences in addition to targeting health-related outcomes, adherence to exercise will be low.

Some people with osteoporosis experience comorbid health conditions or pain that makes participation challenging, while others experience lack of self-efficacy, fear of falling, or fear of fracture.[108] Incorporating exercises that have benefits for osteoporosis while limiting exacerbation of comorbid symptoms (e.g., incorporating weight-bearing exercise for a person with both osteoporosis and osteoarthritis) requires expertise and creativity. In addition to meeting physical goals, appropriate exercise prescription for people with osteoporosis must instill confidence and a sense of safety in participants. As with exercise programs in other populations, factors that affect accessibility like affordability, time, location, relatability, and cultural or societal appropriateness must also be considered.[108,109]

While it is desirable for individuals with osteoporosis to be achieving therapeutic targets for exercise, a valuable starting point for post-fracture care may be to simply increase the time spent doing physical activities throughout daily life. Many *healthy* individuals do not meet recommended levels of physical activity,[111] and participation is further decreased in individuals with mobility challenges or those experiencing pain.[112] Individuals who have had a previous fracture may be even less likely than those without a fracture to take advantage of the systemic health benefits of physical activity, but we currently have very little evidence about how physical activity behaviour changes after fracture.

Physical activity interventions for osteoporosis are largely focused on the secondary prevention of fracture, with valuable recommendations targeting the prevention of falls, safe movement using "spine sparing" strategies, and maintenance of bone mineral density.[67] Many clinical trials of exercise in individuals with low bone mass exclude individuals who have had a previous fracture or are currently recovering from a fracture. There is minimal evidence related to tertiary prevention strategies for individuals in the months and years following their recovery from fracture. [75,106] Characterizing the activities in which fractures occur and identifying if a past fracture of the hip or pelvis, spine, or extremity modifies physical activity participation over a 5-year follow-up will allow us to tailor education programs and physical activity and exercise interventions towards the way fracture occurred and inform future post-fracture interventions to improve the trajectory of physical activity following fracture.

Chapter 3: Research Questions

3.1 Research Questions and Hypothesis

The aim of the investigation was two-fold. The first objective of this study was to describe the activities during which hip, pelvic, vertebral, and other types of fractures occur in the CaMos population and characterize the fractures that occur during physical activities in daily life or sporting activities compared with non-physical or sedentary activities. Possible activities resulting in fracture included the following: fell climbing a chair or ladder; fell on stairs; slipped or tripped in the home; slipped or tripped outside the home (other than sporting); sporting injury; fell out of bed or off a chair; motor vehicle accident; heavy object fell or struck body causing fracture; or bone broke with no fall or injury. Causes of each type of fracture were described by age group, sex, and bone mineral density *T-score*.

It was hypothesized that physically active situations that result in falls, including slipping and tripping either inside or outside the house, will account for most fractures in both males and females across all age groups and fracture types. We expected that sport-related fractures are likely to account for a greater percentage of fractures in adults under 50 years of age. Additionally, it was hypothesized that most fractures occurring due to low-activity or sedentary circumstances would be in individuals with low bone mineral density.

The second objective was to determine if there was a difference in volume of physical activity participation, measured in MET-minutes per week, over 5-year and 10-year periods for individuals who have experienced a fracture compared to individuals who have not experienced a fracture. It was hypothesized that physical activity participation (measured in MET-minutes per week) would decrease over time between baseline, year 5 and year 10 in both individuals who experienced a fracture over the study period as well as individuals that did not experience a fracture over the study period.

The third objective was designed to determine if a) having a fracture between Year 0 and Year 5 was independently associated with volume of physical activity participation at Year 5 in adults aged 50 years and older; and b) if having a fracture between Year 5 and Year 10 was independently associated with volume of physical activity participation at Year 10 in adults aged 50 years and older. The following covariates were controlled for: age group, sex, body mass index (BMI), BMD, number of co-morbid medical conditions (including diagnosis of osteoporosis), education, employment status, and physical activity at baseline.

It was hypothesized that the incidence of a fracture would be associated with reduced physical activity at 5-year follow up; that is a fracture between Year 0 and Year 5 would be independently associated with reductions in physical activity at Year 5, and a fracture between Year 5 and Year 10 years would be associated with reduction in physical activity at Year 10. It was expected that fractures of the hip and pelvis as well as multiple fractures of any type would have a more significant prolonged effect on physical activity compared with vertebral fractures or fractures of the upper or lower extremity. It was hypothesized that the number of years since most recent fracture would also affect volume of physical activity participation, with more recent fractures contributing to greater reduction in physical activity.

Chapter 4: Methodology

4.1 Design and Participants

This study is a secondary analysis of data from The Canadian Multicentre Osteoporosis Study (CaMos), a prospective cohort study that followed participants longitudinally for nineteen years.[113,114] The primary objectives of CaMos were to determine the burden of osteoporosis in Canada by estimating the prevalence and incidence of fractures and identifying changes and variation in bone mineral density. CaMos also aimed to understand the relationships between individual characteristics and exposures, and measures of bone mineral density and fracture occurrence. Additionally, CaMos sought to assess the impact of osteoporosis and fractures on health status.[113] CaMos recruited both an adult cohort and a youth cohort. For this analysis, only the adult cohort was included.

The adult arm of CaMos recruited 9423 adult participants (69% women and 31% men) from 1995-1997 using randomly generated lists of residential telephone numbers. Included participants were 25 years of age or older, non-institutionalized, spoke English or French, and resided within 50 kilometres of one of the nine CaMos centres: St. John's, Halifax, Quebec City, Kingston, Toronto, Hamilton, Saskatoon, Calgary, and Vancouver. The CaMos population was defined to represent a general Canadian population, however Indigenous and northern communities were not included. Each CaMos study site was associated with a university research team located in the regional centre. Study development and oversight occurred at the National Coordinating office at the McGill University Health Centre. The adult cohort operated in two phases: The first phase was a five-year study, completed in 2002. The second phase included both a 10-year study, completed between 2005 and 2008, and a 16-year study, completed between 2012 and 2014. Participants that were included in this secondary analysis were women and men aged 25 years and older from the adult cohort of the CaMos study, with available data on physical activity participation; reported at baseline, five years, and ten years, with yearly fracture reports.

Detailed assessments were administered to CaMos participants by trained research staff at baseline, year 5 and year 10, including interviewer-administered questionnaires as well as physical assessments. The interviewer-administered questionnaires collected socio-demographic information, physical characteristics, medical conditions, medication use, falls history, fracture history, reproductive history, dietary intake, tobacco use, sunlight exposure, physical activity and sedentary behaviour, quality of life, and disability and health status. Physical assessments included DXA scans of all participants at the lumbar spine (L1-L4), femoral neck, total hip, greater trochanter, and Ward's triangle. Short-form questionnaires were mailed to participants on a yearly basis to collect information on fractures, hospital admissions, surgeries and medications related to osteoporosis. Reasons for loss to follow-up were recorded when possible, using yearly telephone logs maintained over ten years.

4.2 Outcome Measures

4.2.1 Fractures

Fracture data including number of fractures, bone site, date and time of fracture were collected by questionnaire at baseline, and annually from Year 1 to Year 19 via mailed questionnaires or questionnaires administered at a scheduled interview. Participants answered whether they had broken one or more bones in the past year, and which bones were broken. CaMos centre staff then followed up by phone call with participants to obtain consent to contact the treating physician or hospital, and clinically reported fractures were confirmed by original medical report or X-ray report. For each year, a possible eighteen fractures could have been reported by each individual: Participants could report up to three separate incidents per fracture questionnaire, with a possible six fractures occurring per incident.

Confirmed fractures occurring between Year 1 and Year 10 were grouped by fracture site: hip fracture, pelvic fracture, clinically reported vertebral fracture, wrist/forearm fracture, humerus fracture, rib fracture, and other fracture of the upper body or lower body. Other fractures included any fracture except for those previously specified and did not include fractures involving bones of the fingers, toes, or face[9]. Separate variables were created for individuals who reported multiple fractures between Year 1 and Year 5 and Year 5 and Year 10 of follow-up. Vertebral fractures that may or may not have come to clinical attention were confirmed by spinal radiograph in participants aged 50 years and older at baseline, Year 5, and Year 10. Points on the vertebral bodies were digitized and the anterior, posterior, and middle height of the vertebral body was measured. Ratios of vertebral body heights were used to determine the presence and severity of vertebral deformity.[114,115] For our analyses, vertebral deformities of the thoracic and lumbar spine (T4-L4) identified as Grade 2 or higher (≥ 25%) using the Genant's Semi-Quantitative criteria were considered a radiographic vertebral fracture. Fractures were summed for each person at all time points, and reported separately as an individual count, and by the number of people who presented with one or more vertebral fractures. All fractures were described by age, sex, and BMD *T-Score* at the femoral neck. BMD (g/cm^2) was measured at the lumbar spine (L1-L4) and the proximal femur (femoral neck, greater trochanter, total hip, and Ward's triangle) with dual-energy X-ray absorptiometry (DXA) and used to generate a BMD *T-Score* at baseline, year 5, and year 10 of follow-up. Five different DXA scanners were used across the nine centres (Hologic QDR 1000, 2000, or 4500 (Marlborough, MA, USA) and Lunar DPX or DPX Alpha (Piscataway, NJ, USA). To allow for BMD comparison between centres, all centres performed annual calibration using a Bona Fide spine phantom (BFP, Bio-Imaging Technologies, Newtown, PA, USA) beginning at the start of the study, and converted Lunar data into equivalent Hologic values[116]. DXA scans using Hologic densitometers were conducted by a single DXA technologist at each of the CaMos study centres, while DXA scans using the Lunar densitometers were conducted by two technologists. Analyses of DXA scans were performed centrally to remove operator bias.[116] Corrected BMD variables were created using correction factors and cross-calibration formulae.[117]

4.2.2 Circumstance of Fracture Occurrence

Circumstances in which fractures occurred during CaMos follow-up were reported annually between Year 1 and Year 19. For each fracture, participants were asked to select from a list how the fracture occurred. If fracture occurred for reasons other than those listed below, they were asked to specify the reason. For the present study, we reported fractures occurring between year 1 and year 10 by individual circumstance as well as categorized the circumstances in which a fracture occurred as 1) related to physical activities of daily living: e.g., fell climbing a chair or ladder, fell on stairs, slipped or tripped in the home, slipped or tripped outside the home (other than sporting); 2) related to sport e.g., sporting injury; 3) unrelated to physical activity: e.g., fell out of bed or off a chair, motor vehicle accident, heavy object fell or struck body causing fracture, bone broke with no fall or injury; or 4) other circumstance, described narratively.

4.2.3 Physical Activity

Physical activity is defined as “any bodily movement produced by skeletal muscles that results in energy expenditure”.[11] To determine physical activity participation, participants were asked the following question: “On average during the last year, how many hours in a week did you spend in the following activities: strenuous sports, vigorous work, moderate activity?”. Physical activity participation was self-reported as a range (e.g., never, 0.5-1 hour, 2-3 hours, 4-6 hours, 7-10 hours, 11-20 hours, 21-30 hours, 31 hours and over). We reported physical activity in MET-minutes per week. MET-minutes were calculated by multiplying the average time range of each activity by the metabolic equivalents (METS) defined in the Compendium of Physical Activities.[118] Using examples of activities provided in the CaMos questionnaire, metabolic equivalents were defined as follows: moderate activity = 4 METS, vigorous work = 6 METS, and strenuous sports = 8 METS.[118] We then summed the MET-minutes of moderate, strenuous, and vigorous activity to determine the total MET-minutes expended per week.

4.2.4 Demographic and Health Information

Health and demographic information including age, sex, body mass index (kg/m^2), level of education, location of CaMos centre, employment status and medical history was collected by interviewer-administered questionnaire at baseline, Year 5, and Year 10.

4.3 Statistical Analyses

All statistical analysis was performed using SAS University Edition software, Copyright ©2020 SAS Institute Inc. SAS and all other SAS Institute Inc. product or service names are registered trademarks or trademarks of SAS Institute Inc., Cary, NC, USA.

Descriptive statistics were used to describe demographic characteristics of participants, as well as medical status including the number of medical conditions, number of fractures, and bone mineral density *T-score* at the femoral neck. Categorical variables were expressed as a count (n) or percentage (%) and continuous variables were presented as a mean with standard deviation (SD). Descriptive statistics were also used to describe the circumstance in which fractures occurred, reported at each bone site (hip, pelvis, spine, upper extremity, lower extremity, and other) overall as well as by sex (male/female), age group (<50 years of age, 50-65 years, >65 years) and BMD *T-score* at the femoral neck (above -1 SD, -1 to -2.5 SD, below -2.5 SD) at baseline. Calculated levels of physical activity in MET-minutes/week were reported as a continuous variable.

To determine if there were differences in physical activity participation at Baseline, Year 5 and Year 10, a one-way repeated measures analysis of variance (rANOVA) was used. Physical activity participation (in MET-mins/week) was entered as the dependent variable, with time as the independent variable (related groups being baseline, year 5 and year 10 follow-up). We also tested the interaction effect of fracture status on physical activity over the three time points, comparing individuals who had a fracture over the ten-year study period with those who had no fracture. Two separate multivariable regression analyses[119] were used to examine the association between an incident fracture and physical activity. For both, independent variables were grouped as 1) hip or pelvic fracture; 2) vertebral fracture; 3) non-hip-non-vertebral fracture of the upper extremity; 4) non-hip-non-vertebral fracture of the lower extremity; 5) no fracture; or 6) multiple fractures of any type. The dependent variable was physical activity reported as MET-minutes per week at 5-year follow-up and 10-year follow-up, respectively. The models were adjusted for baseline physical activity MET-minutes or Year 5 physical activity MET-minutes respectively, as well as possible confounding factors. Covariates that were adjusted for include baseline/year 5 physical activity MET-minutes/week, age (years), sex, body mass index (kg/m^2), BMD (g/cm^2), number of medical conditions, level of education, and employment status (employed full-time; employed part-time; retired/other). Significance levels were set at $p < 0.05$. Both adjusted and unadjusted analyses are presented. Our research questions were designed to understand if a fracture occurring between year 0-5 or year 5-10 had an independent effect on physical activity at either 5 or 10 years, respectively (5-year follow-up). Analyses were conducted such that fractures occurring at any point during the 5-year segments were considered equally. To account for this limitation, a method similar to that published by Adachi et al., (2001)[21] was used. We performed a simple regression analysis to determine the effect of when the fracture occurred on physical activity levels. The two included variables were years since last fracture (e.g., 1,2,3,4,5 years) and physical activity MET-mins/week.

Table 1: Research Questions and Plan for Statistical Analyses

Question	Variables	Covariates	Statistical Analysis Plan
What are the circumstances in which hip, pelvic, vertebral, and other types of fracture occur in the CaMos population?	**Outcomes: Types of fractures:** Hip Fracture Pelvic Fracture Vertebral Fracture Non-hip/non-vertebral/non-pelvic fracture **Circumstance categories:** fell climbing a ladder or chair, fell on stairs, sporting injury, slipped or tripped inside home, slipped or tripped outside the home other than sporting, fell out of bed or off a chair from sitting position, MVA, heavy object fell and struck body causing fracture, bone broke with no fall or injury		Descriptive: data will be expressed as a count (n) or percentage (%). - For each fracture type: #/% due to each circumstance: total and by sex (M/F), age group (<50 years, 50-65 years, >65 years) and BMD *T-score* at femoral neck and lumbar spine (≥-1.0 SD, <-1 >-2.5 SD, or ≤-2.5 SD) - % of all fractures occurring during sport - % of all fractures occurring during daily physical activities
Is there a difference in volume of physical activity participation over time?	**Dependent variable:** Physical activity (MET-mins/week) **Independent variable**: Time (years)	- Incident Fracture during study period (Y/N)	Repeated measures ANOVA to determine differences between physical activity at baseline, year 5, and year 10.

Is having a fracture between Year 0 and Year 5 associated with physical activity at Year 5 in adults 50 years of age and older?
 	
Is having a fracture between year 5 and year 10 associated with physical activity at year 10 in adults 50 years of age and older?
	Dependent variable: Physical activity (MET-mins/week)
	
	Independent variable:
	Fracture type (Y/N)
	- 1 Hip/pelvic fracture
	- 1 Vertebral fracture
	- 1 non-hip, non-vertebral fracture
	    o Upper extremity
	    o Lower extremity
	- Multiple fractures of any type
		Baseline/Year 5:
		- Physical activity (MET-mins/week) at baseline
		- Age
		- Sex (M/F)
		- BMI
		- BMD *T-score* at Femoral Neck
		- Number of comorbid medical conditions
		- Education
		- Employment status (Employed full-time, employed part-time, retired/ other)
			Physical activity at Year 5 and Year 10 will be used as dependent variables in two separate multivariable linear regressions to determine the effect of fracture type on PA.

4.4 Privacy

Confidentiality was maintained throughout the original CaMos study. Participants were identified by a seven-digit number code, made up of the study site abbreviation and a five-digit numerical code. Participant names were known only to interviewers. Personal data forms were kept separately on a computer at each centre. Results were not reported in any way that would identify individuals.

Access to CaMos data for secondary analyses requires application to the CaMos Design, Analysis and Publication (DAP) Committee. Proposals are reviewed by the DAP committee and other CaMos researchers for scientific justification of objectives, methodological soundness, impact on CaMos, and plan for dissemination. Proposals may be approved, approved pending revision, or not approved. Once approved, an analytical database will track planned and conducted analysis of CaMos data. The proposal for this secondary data analysis project was submitted in August 2020 and was approved by the DAP Committee in October 2020. Ethics approval was obtained through The Office of Research Ethics at the University of Waterloo in September 2020 and renewed in July 2021.

Table 2: Demographic Data at Baseline, Year 5, and Year 10

Mean (SD) or Frequency (%)	Baseline (n=9423)	5-Year Follow-up (n=7652)	10-Year Follow-Up (n=5569)
Age (years)	62.1 (13.4)	65.8 (12.7)	68.8 (12.0)
Sex (%)	Female: 69.4 Male: 30.6	Female: 71.0 Male: 29.0	Female: 71.8 Male: 28.2
Femoral Neck BMD *T-Score* (SD)	Female: -1.49 (1.10) Male: -1.07 (0.85)	Female: -1.53 (1.08) Male: -1.13 (0.83)	Female: -1.57 (1.02) Male: -1.21 (0.81)
BMI (kg/m^2)	27.0 (4.9)	27.3 (5.0)	27.3 (5.0)
Location (%)			
Calgary:	11.3	11.5	11.2
Halifax:	11.2	10.9	11.2
Hamilton:	11.3	11.7	11.8
Kingston:	11.4	11.0	11.3
Quebec:	12.0	12.0	11.7
Saskatoon:	10.9	11.9	11.7
St. John's:	11.0	10.5	11.2
Toronto:	9.6	9.1	8.4
Vancouver:	11.3	11.4	11.5
Employment Status (%)			
Full-time:	41.6	39.4	28.5
Part-time:	8.1	8.3	8.6
Other:	50.3	52.3	62.9
Education Level (%)			
Elementary:	12.8	11.2	8.9
Some Secondary:	24.3	23.6	22.3
Secondary:	14.5	14.9	15.1
Some Post-Secondary:	7.3	7.5	8.0
Certificate or Diploma:	25.0	25.7	26.7
Degree:	16.1	17.2	18.9
Number of diagnosed medical conditions	1.6 (1.5)	2.3 (1.8)	2.0 (1.6)
Number of Prevalent Fractures	1.5 (1.0)	1.6 (1.2)	3.1 (2.2)
Total Physical Activity (MET-mins/week)	3555.3 (2876.8)	3374.9 (2818.1)	3316.6 (2723.1)
Moderate Physical Activity (MET-mins/week)	2913.2 (2357.9)	2869.1 (2341.5)	2766.5 (2338.2)
Vigorous Physical Activity (MET-mins/week)	380.2 (1485.0)	280.6 (1182.2)	331.4 (1248.3)
Strenuous Physical Activity (MET-mins/week)	261.3 (845.6)	225.2 (888.6)	220.6 (729.7)

Chapter 5: Results

5.1 Participant Characteristics

The CAMOS study enrolled 9423 adult participants between 1995 and 1997. Participant retention was 81% at 5-year follow-up (n=7652) and 59% at 10-year follow-up (n=5569). Missing participant data was due to death (n=1203), refusal to participate (n=1232), no contact (n=716), intermittent contact (those who had refused participation or were unable to be contacted, and then reactivated participation later in the study) (n=40), or reasons unknown.

Characteristics of participants at baseline, five-year and ten-year follow-up are described in **Table 2**. The mean (± SD) age at study entry was 62 ± 13.4 years. 70% of the included population was female, with an average BMD *T-score* of -1.49 ± 1.10 SD. The remaining 30% was male, with an average BMD *T-score* of -1.07± 0.85 SD. 44% of participants (n=4147) reported having previously fractured a bone in their lifetime, for an average of 1.5 ± 1.0 fractures occurring prior to study onset. Between zero and eight previous fractures at baseline were reported by 17% of participants under 50 years of age, 35% of participants aged 50-65 years and 48% of participants over 65 years of age. Types and circumstances of fractures occurring prior to study onset were not analyzed. Radiographic vertebral fractures that may or may not have come to clinical attention were identified by X-ray in 9% of people 50 years of age or older at baseline (n=731). On average, individuals reported 3555 ± 2876.8 MET-minutes of moderate to strenuous physical activity each week.

5.2 Number of New Fractures at 5- and 10-year Follow-up

1533 incident fractures were reported by 1223 participants between year one and year ten of follow-up and were confirmed by X-ray report from the treating physician. Fractures included 161 hip, 47 pelvic, 316 wrist or forearm, 134 humerus, 129 rib, and 148 vertebral fractures coming to clinical attention, as well as 308 fractures of the shoulder, knee, or leg, and 290 fractures of the hands, feet, or face. 229 people had multiple fractures over the ten-year follow-up period. 82% of all fractures, excluding bones of the fingers, hands, or face, occurred in females (n=1018) and 18% occurred in males (n=225). 93% of fractures were in individuals over 50 years of age (30% aged 50 to 65 years [n=367] and 63% aged 65+ [n=787]). 7% of fractures were in individuals under 50 years of age (n=89). 84% of fractures occurred in individuals with low bone mineral density at the femoral neck. 54% (n=582) had a BMD *T-score* between -1.0 and -2.5 SD from the reference mean, and 30% (n=323) had a BMD *T-score* less than -2.5 SD at baseline. 16% of fractures (n=175) occurred in people with normal BMD. BMD *T-score* data were missing from 1113 participants at baseline; therefore 163 fractures were not associated with BMD data.

In addition to fractures reported by participants and confirmed, 1249 new radiographic vertebral deformities of at least grade 2 severity were identified by X-ray of the thoracic and lumbar spine at year 5 (n=711) and year 10 (n=538). Radiographic vertebral fractures may or may not have come to clinical attention. Common sites for vertebral fractures were the T12 (16.4%) or L1 (16.4%) vertebrae. 75% of participants with radiographic vertebral fractures were female (n=510) and 98% were aged 50 years and older (23% aged 50-65 [n=156]; 75% aged 65+ [n=510]). In individuals where at least one new vertebral fracture was identified by spinal radiograph, 55% (n=346) had a BMD *T-score* between -1.0 and -2.5 SD and 36% (n=228) had a BMD *T-score* less than -2.5 SD at baseline. Only 9% of participants (n=59) with a new vertebral fracture had a BMD *T-score* greater than -1.0 SD at baseline.

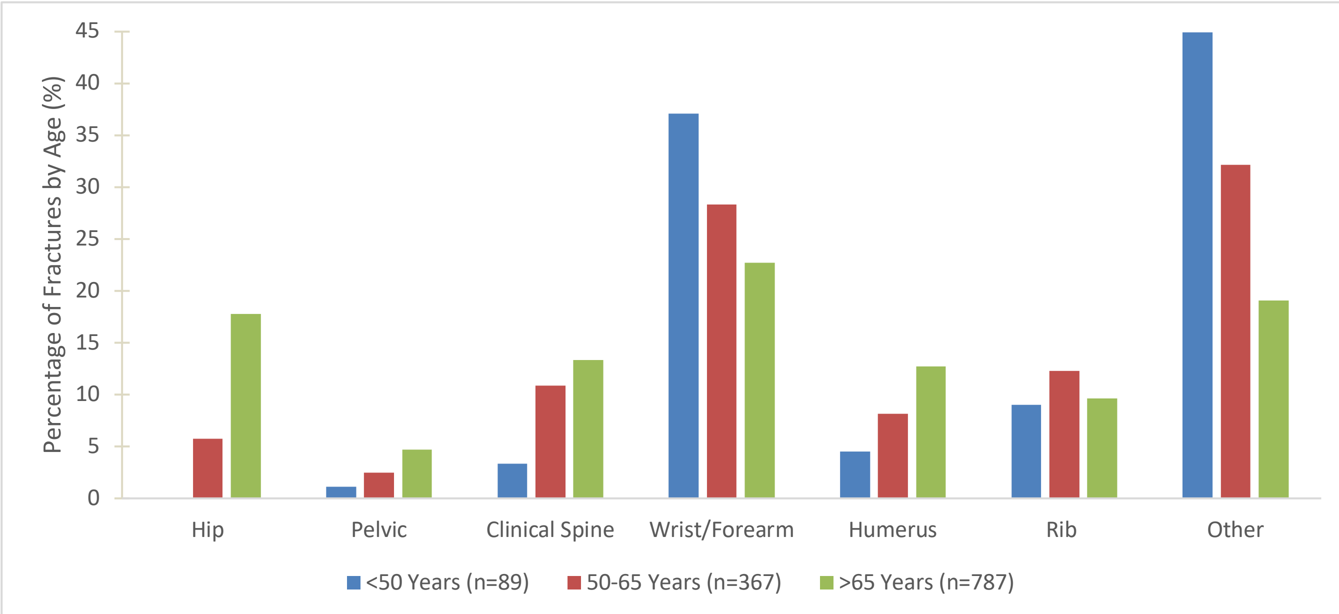

Figure 2: Percentage of Fractures Occurring between Year 1 and Year 10, reported by Age Category at Baseline. Values are expressed as a percentage of fractures that occurred in a given age category. Denominator (in brackets) is the number of fractures reported in each age category.

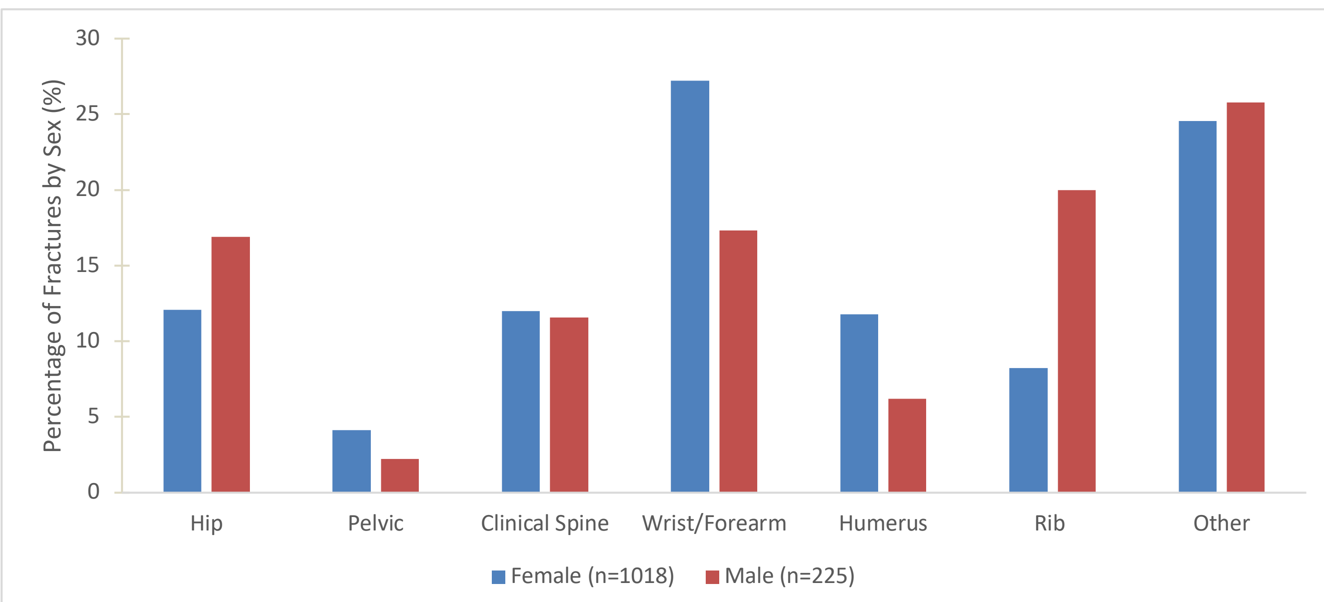

Figure 3: Percentage of Fractures Occurring between Year 1 and Year 10, reported in Females and Males. Values are expressed as a percentage of fractures reported by a given sex. Denominator (in brackets) is the number of fractures reported by males and females.

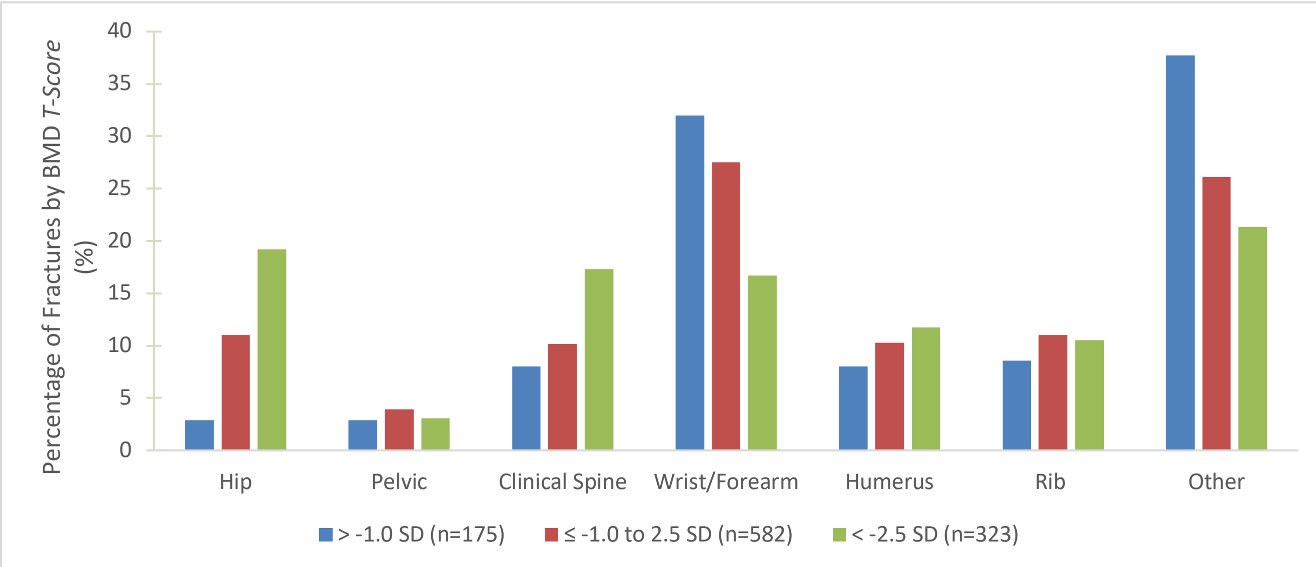

Figure 4: Percentage of Fractures Occurring between Year 1 and Year 10, reported by Femoral Neck BMD *T-Score* Category at Baseline. Values are expressed as a percentage of fractures occurring in a given BMD *T-Score* category. Denominator (in brackets) is the number of fractures reported in each category.

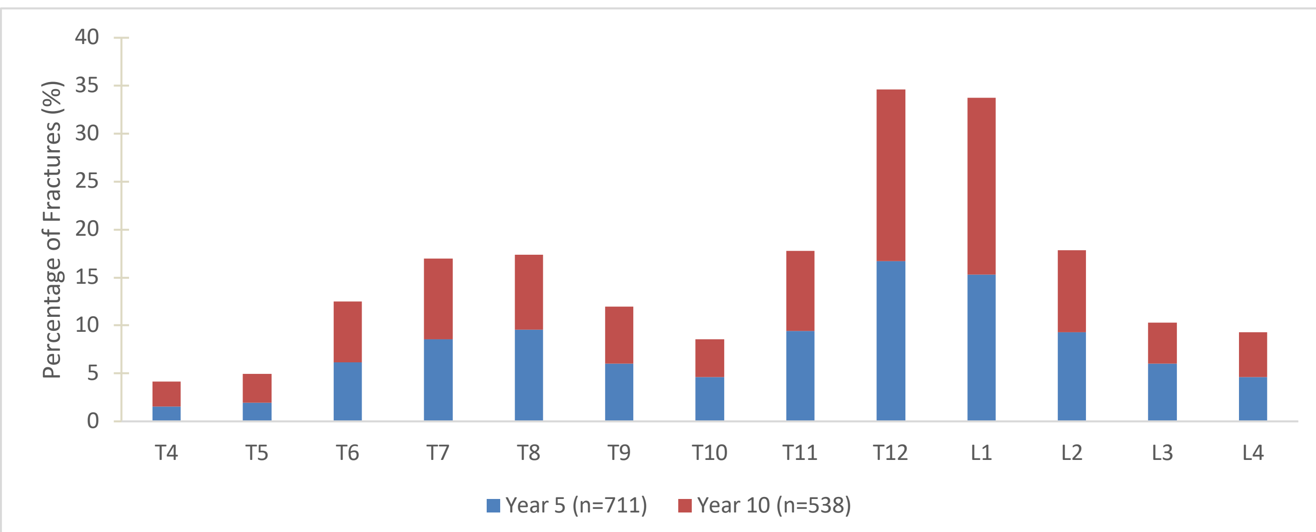

Figure 5: Vertebral Fractures Identified by Radiograph at Year 5 and Year 10 in Participants 50 Years of Age and Older. Values are expressed as a percentage of the total vertebral fractures identified by radiograph at Year 5 and Year 10.

5.3 Description of Fractures

5.3.1 Circumstances for Fracture

The circumstances in which fractures occurred are displayed by fracture type in **Figure 6** and **Table 3.** More than half of hip, pelvic, wrist or forearm, and humerus fractures occurred due to slips or trips. Hip fractures due to slips and trips often occurred in the home, while slips and trips resulting in pelvic fractures, wrist/forearm fractures, and humerus fractures often occurred outdoors. 41% of clinical vertebral fractures occurred without fall or injury. Sporting injuries were responsible for between 5-8% of non-vertebral fractures, but only 1% of clinical vertebral fractures. Details of sporting injuries (e.g., type of sport, mechanism for sporting injury resulting in fracture) were not available. Many participants reported fractures, particularly hip and spine fractures, occurring due to "other circumstances". Other circumstances were narratively described by participants and are summarized in **Appendix B.** Circumstances for fracture which were categorized as "other" included falls because of dizziness, fainting, or loss of consciousness, falls due to physical impairments (e.g., weakness, dyspnea, or balance impairment), falls associated with chronic conditions or disease (e.g., cancer, osteoarthritis, diabetic hypoglycemia, or a transient ischemic attack), fractures occurring during medical or para-medical care, fractures occurring during lifting, bending, or carrying tasks, fractures occurring due to work-related accidents, or fractures occurring due to assault, aggression, violence, or impact with another person. Individuals also reported fractures occurring due to minor injuries (e.g., stubbed toe, hit bed frame), or seemingly innocuous activities (e.g., while walking, reaching, or performing household tasks). Lifting of household objects (e.g., lifting a garbage bag, plant, vacuum, small furniture, a heavy object, or opening a window or basement trapdoor) was responsible for ten of the twenty-four vertebral fractures caused by other circumstances (7% of vertebral fractures and 0.8% of total fractures). Falls due to loss of balance, dizziness, or fainting were responsible for eighteen of the twenty hip fractures caused by other circumstances. Specific injury details are not reported.

Table 3: Percentage of Fractures Occurring by Circumstance between Year 1 and Year 10 (n=1243)

	Hip (n=161)	**Pelvis (n=46)**	**Clinical Spine (n=148)**	**Wrist/Forearm (n=316)**	**Humerus (n=134)**	**Other (n=437)**
	n (%)	**n (%)**	**n (%)**	**n (%)**	**n (%)**	**n (%)**
Slip/Trip at Home	51 (32)	11 (23)	16 (11)	60 (19)	33 (25)	62 (14)
Slip/Trip Outside	37 (23)	17 (36)	12 (8)	150 (47)	53 (40)	170 (39)
Fall on Stairs	5 (3)	3 (6)	10 (7)	28 (9)	12 (9)	49 (11)
Fall Climbing	7 (4)	1 (1)	7 (7)	14 (14)	2 (2)	13 (13)
Fall from Chair/Bed	14 (9)	1 (2)	10 (7)	4 (1)	12 (9)	13 (3)
Sporting Injury	8 (5)	3 (6)	2 (1)	25 (8)	5 (4)	25 (6)
MVA	0 (0)	0 (0)	6 (4)	6 (2)	1 (1)	25 (6)
Object Struck Body	0 (0)	2 (4)	1 (1)	3 (1)	1 (1)	5 (1)
No Fall/Injury	19 (12)	7 (15)	60 (41)	4 (1)	3 (2)	41 (9)
Other	20 (12)	2 (4)	24 (16)	22 (7)	12 (9)	34 (8)

Abbreviations: MVA; Motor Vehicle Accident

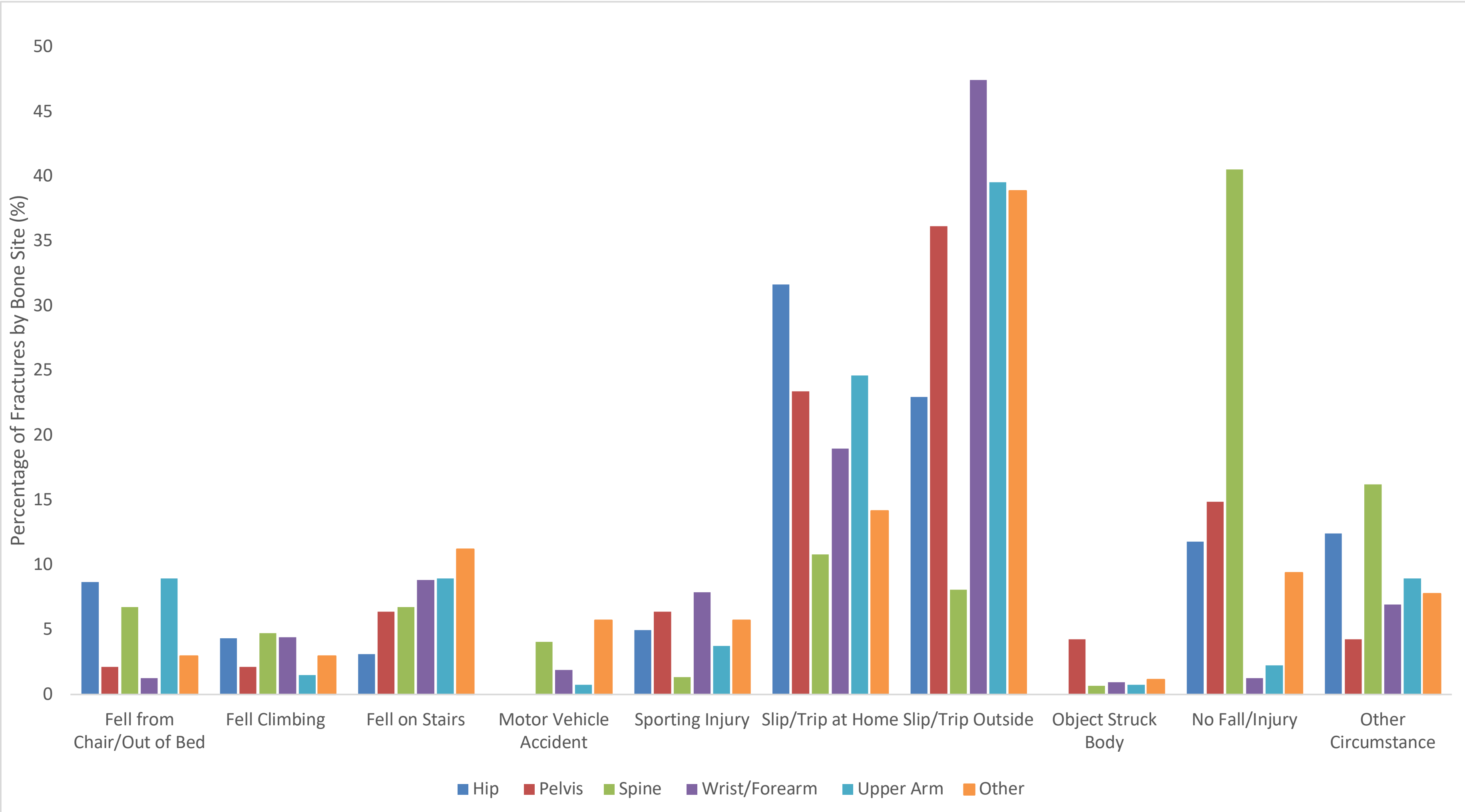

Figure 6: Percentage of Fracture Occurring Between Year 1 and Year 10 for each Circumstance, Grouped by Bone Site. Values are expressed as a percentage of the number of fractures that were reported at each given bone site. Denominator is the number of fractures at the hip (n=161), pelvis (n=47), spine (n=148), wrist/forearm (n=316), upper arm (n=134), or other (n=437); respectively.

5.3.2 Circumstances of Fracture by Sex

Females reported 76% to 90% of all fractures of the hip, pelvis, spine, wrist/forearm, and humerus, and 65% of rib fractures. Most fractures in males and females occurred due to slips, trips, or falls, either at home or outdoors. A greater percentage of males who experienced a fracture reported it to be a result of a sporting injury, motor vehicle accident, fall while climbing, object striking body, or other circumstance while females reported a greater percentage of fractures due to slips and trips both indoors and outdoors, falls on the stairs, falls from a chair or bed, and fractures occurring with no fall or injury.

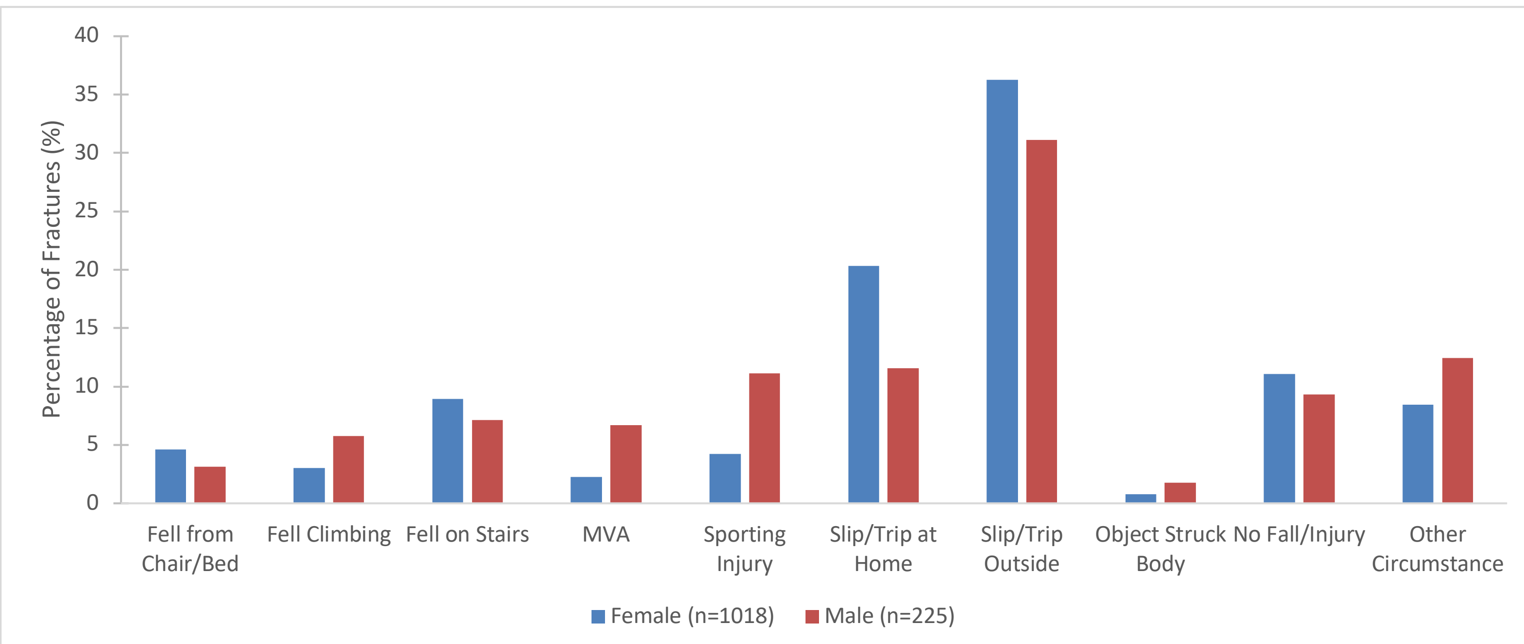

Figure 7: Percentage of Fractures Occurring Between Year 1 and Year 10 by Circumstance, Grouped by Sex. Values are expressed as a percentage of fractures reported by a given sex. Denominator (in brackets) is the number of fractures reported by males and females.

5.3.3 Circumstances of Fracture by Age Group and BMD *T-Score*

Slips and trips outdoors and at home accounted for the greatest percentage of fractures in individuals over 50 years of age while sporting injuries accounted for the greatest percentage of fractures in people under 50 years of age. Older individuals reported a greater percentage of fractures due to a fall from a chair or from a bed, or a fracture occurring without fall or injury, compared with younger individuals. Participants between 50 and 65 years of age reported a greater percentage of slips and trips resulting in fracture occurring outdoors, while individuals over 65 years of age reported the greatest percentage of slip, trip, or fall-related fractures occurring at home. Participants under 50 years of age did not report any fractures occurring due to a fall from a chair or bed, or an object striking the body, but reported a greater percentage of fractures occurring due to motor vehicle accidents.

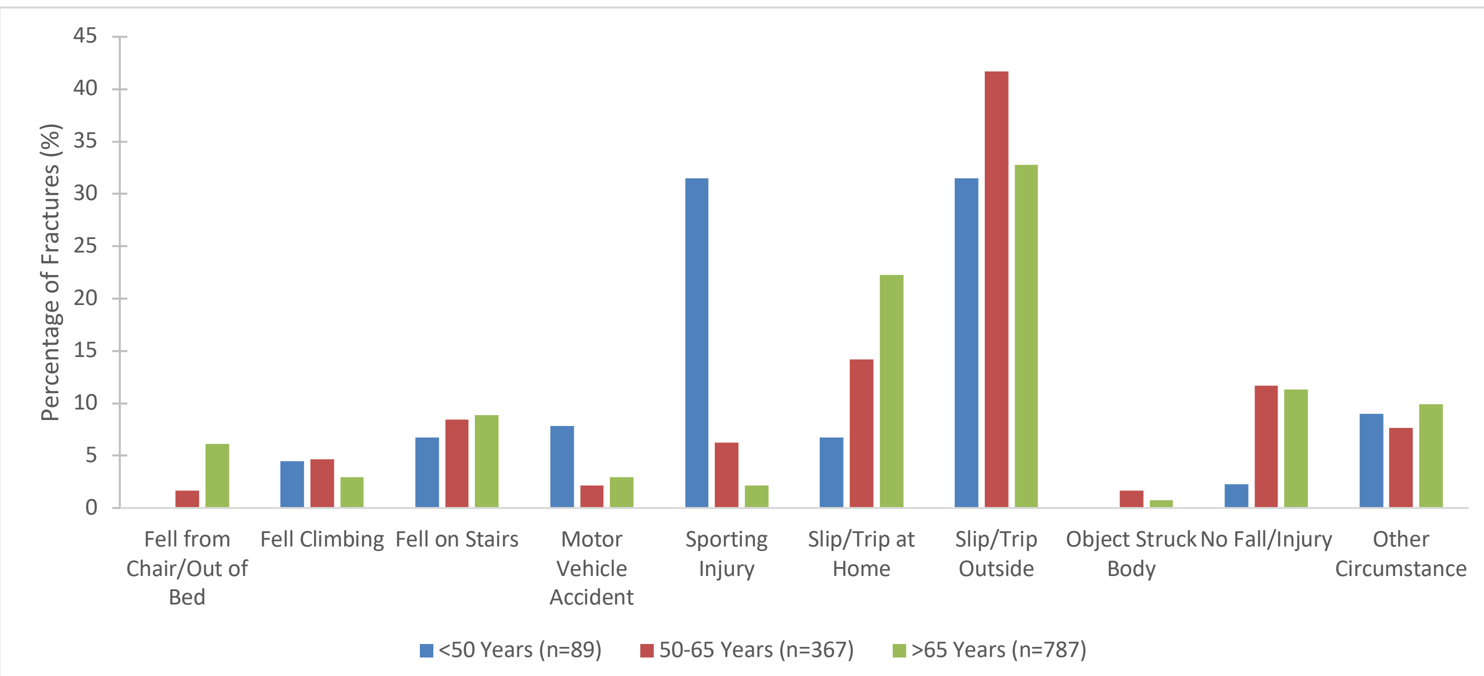

Figure 8: Percentage of Fractures Occurring Between Year 1 and Year 10 for each Circumstance, Grouped by Age Category at Baseline. Values are expressed as a percentage of fractures that occurred in a given age category. Denominator (in brackets) is the number of fractures reported in each age category.

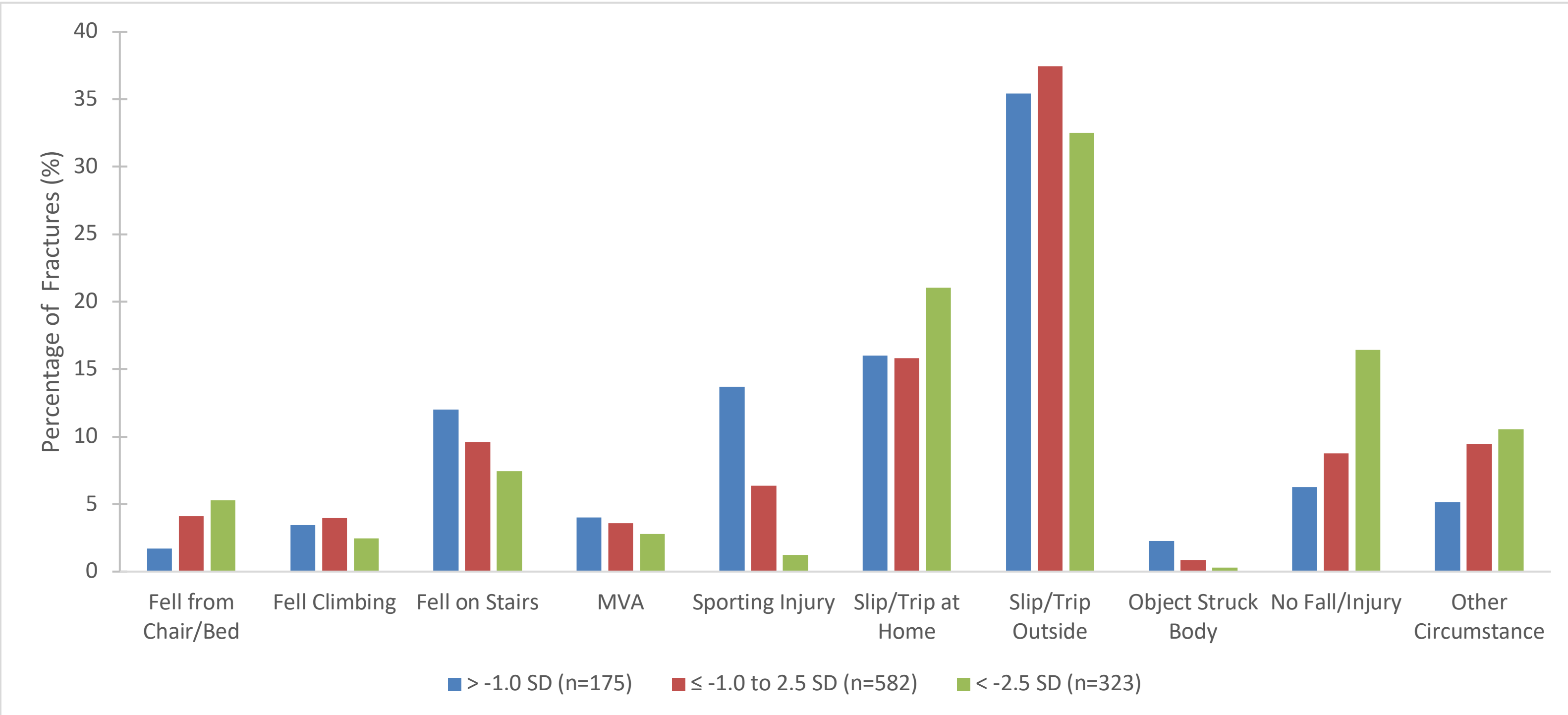

Figure 9: Percentage of Fractures Occurring Between Year 1 and Year 10 for each Circumstance, Grouped by BMD *T-Score* at Baseline. Values are expressed as a percentage of fractures occurring in a given BMD *T-Score* category. Denominator (in brackets) is the number of fractures reported in each category.

5.3.4 Circumstances of Fracture by Physical Activity Category

When categorized by level of physical activity, seventy-one percent of fractures occurred due to physically active circumstances (**Figure 11**). Sixty-five percent of fractures occurred while moving about during active daily life (n=997) and six percent of fractures occurred during sport (n=96). Sedentary activities (including no known fall or injury) accounted for fourteen percent of fractures, (n=208), and the remaining six percent of fractures were due to trauma. Nine percent of fractures occurred due to other circumstances (n=144), which were described as including circumstances split between physical activity, sedentary time, and trauma (**Table 10).**

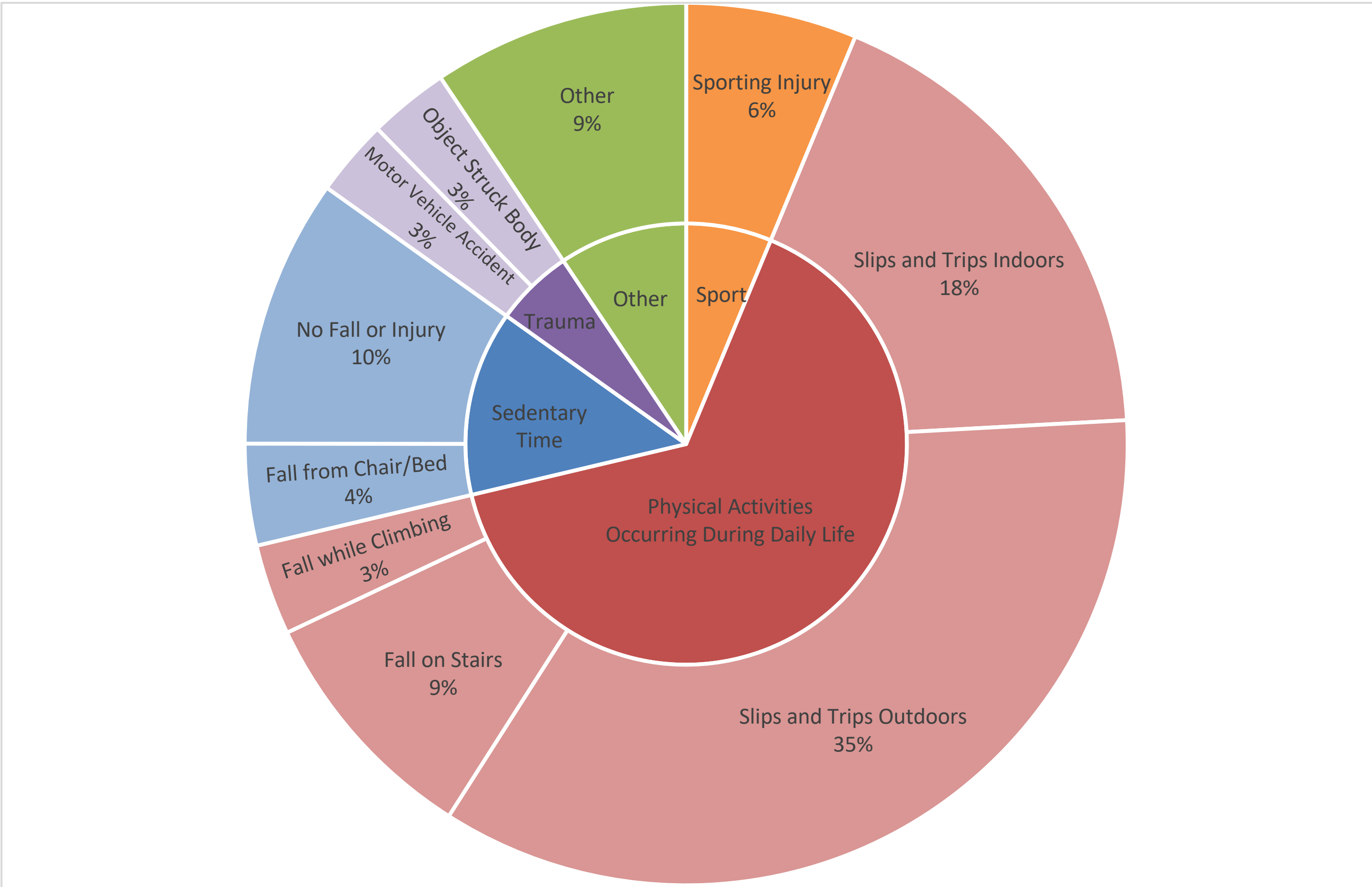

Figure 10: Circumstances for Fracture Grouped by Level of Physical Activity

5.3.5 Fracture Occurrence by Month

Fractures were consistently reported throughout the winter, spring, summer, and fall seasons (**Figure 12**). Over the ten-year follow-up period, the largest percentage of reported fractures occurred in July (summer) and December (late fall to early winter). The smallest percentage of fractures occurred during the month of September, corresponding with late summer to early fall. Seasonal trends varied by fracture site **(Figure 13).** The number of pelvic and spine fractures remained relatively consistent month to month. Higher rates of hip fractures occurred between February to April, and again in November. Wrist and forearm fractures fluctuated widely, spiking in February as well as July, while humerus fractures occurred most frequently in December.

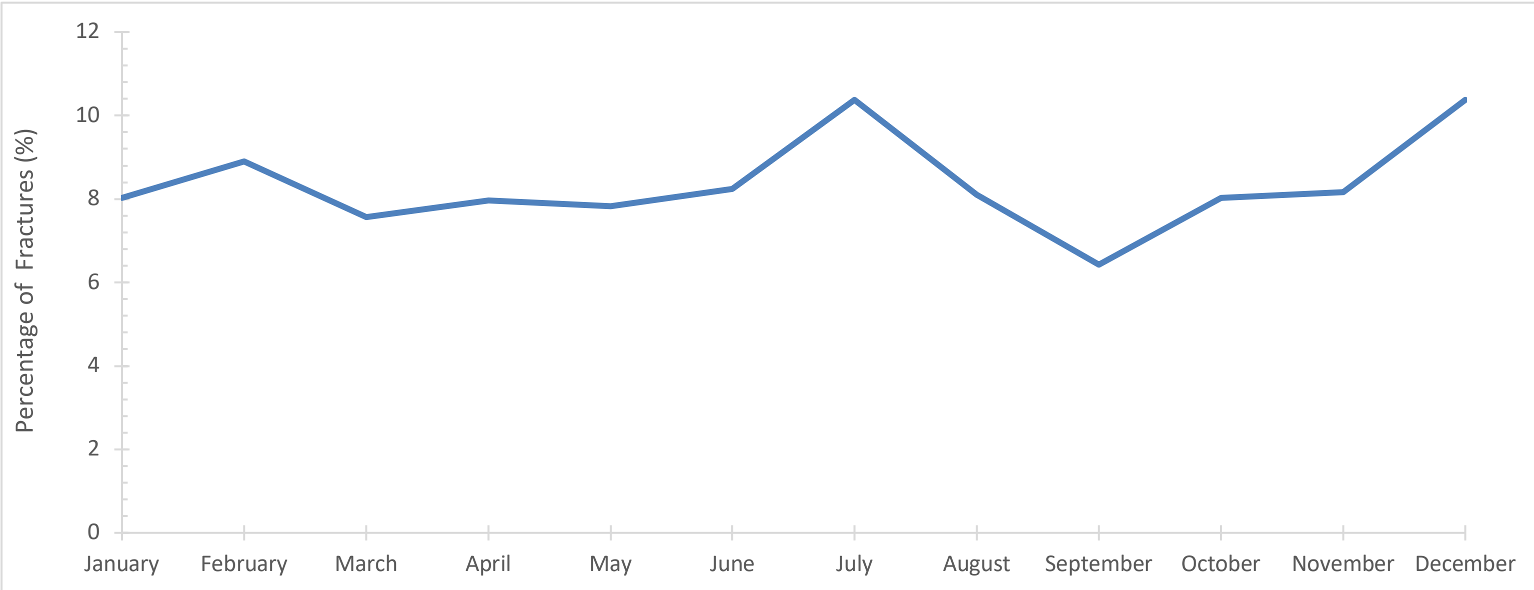

Figure 11: Total Confirmed Fractures between Year 1 and Year 10, by Month. Values are expressed as a percentage of total fractures.

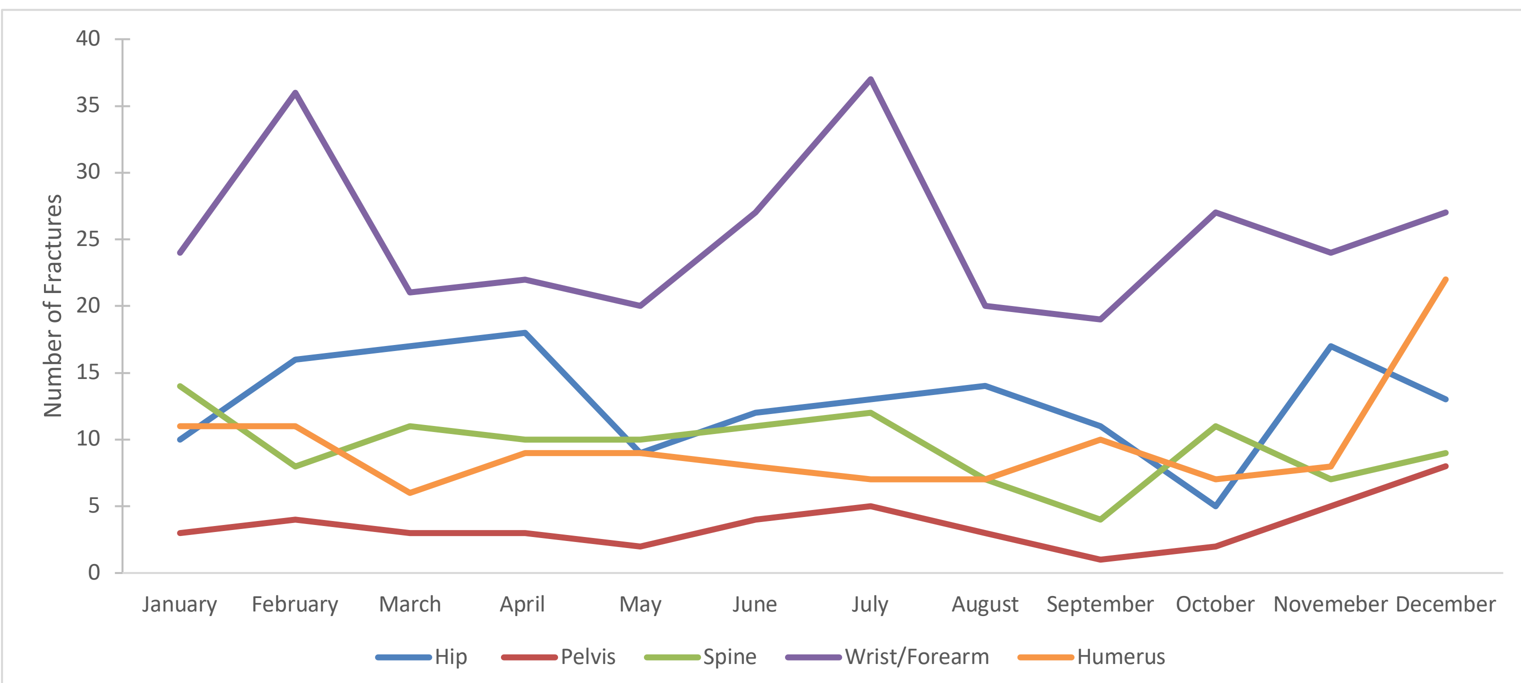

Figure 12: Annual Trends in Number of Confirmed Fractures Occurring Between Year 1 and Year 10.

5.4 Physical Activity Participation

The intensity and time spent participating in physical activity over a seven-day period was self-reported by participants, and is summarized overall, and by age group, sex, and BMD *T-score* at Baseline, Year 5, and Year 10 **(Table 3).** At all study time points, male participants reported a greater volume of typical physical activity participation than females. The average volume of physical activity appeared to be greater in adults under 50 years of age and those with a BMD *T-score* greater than -1.0 SD. Typical physical activity MET-mins per week appeared to decline with increasing age and decreasing BMD.

Table 4: Physical Activity (MET-mins/week) by Sex, Age Group, and BMD *T-Score*

Physical Activity Mean (SD)	Sex		Age Group (Years)			BMD *T-Score* (SD)		
	Male	**Female**	**< 50**	**50 – 65**	**65+**	**> -1.0**	**-1.0 - 2.5**	**< -2.5**
Baseline (MET-mins/week)	3610.5 (3309.0)	3530.9 (2663.7)	4193.2 (3496.5)	3764.6 (2866.4)	3138.4 (2533.6)	3839.9 (3119.6)	3697.3 (2790.5)	3241.4 (2559.7)
n=	2879	6536	1668	3458	4289	2906	4294	1082
Year 5 (MET-mins/week)	3412.2 (3127.3)	3359.6 (2680.8)	4285.2 (3409.7)	3714.8 (2885.9)	3011.3 (2591.6)	3563.5 (2862.4)	3421.1 (2831.0)	3030.3 (2360.9)
n=	2222	5425	753	2589	4305	2105	3531	901
Year 10 (MET-mins/week)	3484.8 (3145.3)	3250.6 (2534.7)	4110.3 (3175.4)	3982.8 (2967.4)	2958.3 (2469.0)	3726.7 (2919.9)	3407.7 (2705.0)	3021.8 (2355.0)
n=	1570	3997	450	1580	3537	1416	2758	660

5.4.1 Changes in Physical Activity over Study Period

Changes in average physical activity participation were observed between baseline, year 5, and year 10 of follow-up. Only individuals with data at all three time points (n=5506) were included in the analysis. A repeated measures ANOVA determined that there was a statistically significant difference in physical activity MET-mins between at least two time points ($F\ (2,5503) = 61.54$, $p < 0.001$) in the entire population, regardless of fracture status. Post-hoc analysis identified that physical activity decreased significantly between baseline, year 5, and year 10 of follow-up (p > 0.001). A significant interaction effect was present between physical activity MET-mins and fracture status (F (2,5503) = 7.24, p <0.01). Post-hoc analysis revealed that differences in physical activity participation between people who had experienced a fracture and people who had not experienced a fracture during the study period were only significant at year 10 (p > 0.05). There were no significant differences in physical activity in relation to fracture status at baseline or year 5.

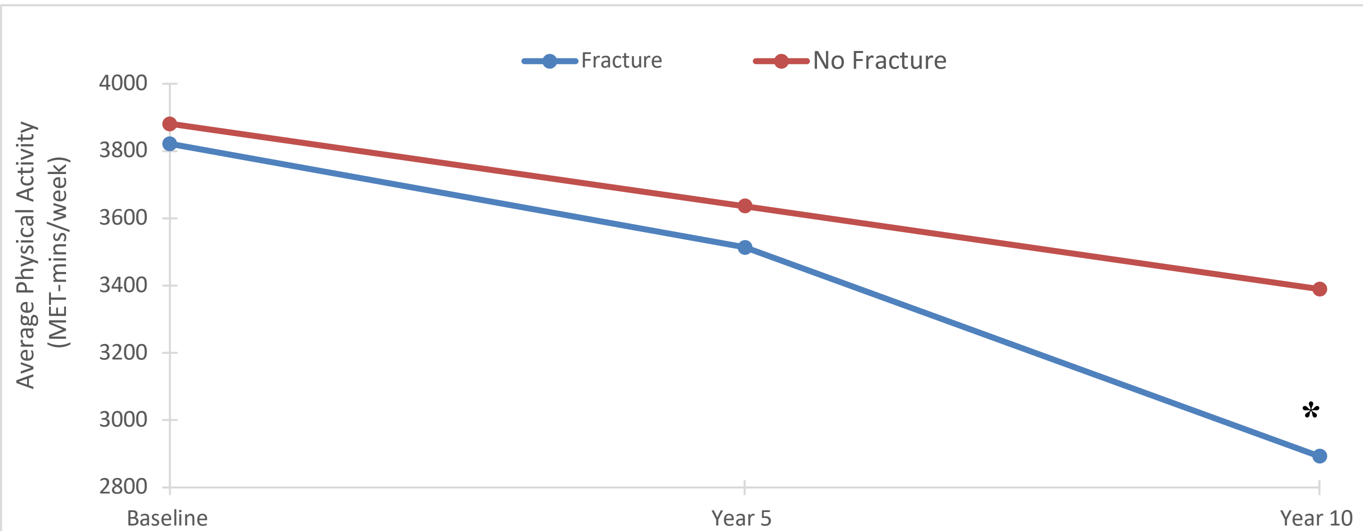

Figure 13: Change in Mean Physical Activity in Relation to Fracture Status

* Indicates significant difference between people who had fracture versus no fracture (p <0.001)

Table 5: Average Self-Reported Physical Activity (MET-mins/week) over Follow-up Period

	N	Baseline Physical Activity Mean (SD)	Year 5 Physical Activity Mean (SD)	Year 10 Physical Activity Mean (SD)
Fracture	787	3821.5 (2291.9) *	3513.2 (2880.1) *	2892.6 (2535.8) *
No Fracture	4719	3881.1 (2902.3) *	3636.6 (2822.1) *	3389.7* (2745.7) *†

* Indicates significant difference between repeated time points (p <0.0001)

† Indicates significant difference between fracture and no fracture (p <0.05)

5.5 Impact of Fracture on Physical Activity in Individuals 50 Years of Age and Older (Predictors of Physical Activity)

The unadjusted multivariable regression models for physical activity at Year 5 and Year 10 were both statistically significant however only accounted for 0.57% of the variance in physical activity at year 5 (R^2= 0.0057) and 0.53% of the variance in physical activity at year 10 (R^2= 0.0053) (**Table 6** and **Table 7**). At year 5, hip or pelvic fracture, and clinically reported vertebral fracture were significantly associated with physical activity at year 5 such that having at least one hip or pelvic fracture reduced physical activity by 1857 MET-minutes per week and reporting at least one vertebral fracture reduced physical activity by 1022 MET-minutes per week. At year 10, hip or pelvic fracture, clinically reported vertebral fracture, and fracture of the upper limb were significantly associated with physical activity. Having at least one hip or pelvic fracture reduced physical activity by 1303 MET-minutes per week. Having at least one reported vertebral fracture reduced physical activity by 1135 MET-minutes per week, and at least one fracture of the upper limb reduced physical activity by 369 MET-minutes per week. Fractures of the lower limb, vertebral fractures identified by radiograph that may or may not have been clinically reported, and multiple fractures of any type were not significantly associated with physical activity.

Adjusted multivariable regression models for physical activity at year 5 and year 10 were also statistically significant and accounted for 18% of variance in physical activity at year 5 (R^2= 0.176) and 19% of variability at year 10 (R^2= 0.192) (**Table 8** and **Table 9)**. After adjusting for age, sex, BMI, BMD *T-score* at the femoral neck, level of education, number of comorbid health conditions, and employment status, only hip or pelvic fractures occurring between baseline and year 5 remained significantly associated with physical activity at year 5 such that having at least one hip or pelvic fracture decreased physical activity by 1179 MET-minutes per week. At year 10, the association between physical activity levels and having a hip or pelvic fracture between year 5 and year 10 were no longer significant. There was a significant positive association between previous physical activity and physical activity at year 5 and year 10 of follow up. Simple linear regression analyses showed no significant associations between the number of years since a fracture occurred and physical activity (**Table 10)**.

Table 6: Unadjusted Variance in Physical Activity at Year 5; Multivariable Regression (n=6894)

Variable	Parameter Estimate	Standard Error	t Value	95% Confidence Interval	
Hip or Pelvic Fracture	-1857.87	372.18	-4.99*	-2587.46	-1128.29
Spine Fracture	-1022.31	373.60	-2.74*	-1745.68	-289.95
Lower Limb Fracture	-380.60	294.42	-1.29	-957.75	196.55
Upper Limb Fracture	-250.10	212.58	-1.18	-666.83	166.62
Multiple Fractures	-223.55	371.38	-0.60	-951.56	504.46
Radiographic Vertebral Fracture	-20.80	154.22	-0.13	-323.11	281.52
Model: $R^2 = 0.0057$, p<.0001					

* Significance level α < 0.05

Table 7: Unadjusted Variance in Physical Activity at Year 10; Multivariable Regression (n=5117)

Variable	Parameter Estimate	Standard Error	t Value	95% Confidence Interval	
Hip or Pelvic Fracture	-1303.62	358.28	-3.64*	-2005.99	-601.24
Spine Fracture	-1135.32	424.64	-2.67*	-1967.80	-302.83
Lower Limb Fracture	-638.49	312.66	-2.04*	-1251.43	-25.55
Upper Limb Fracture	-369.71	242.84	-1.52	-845.77	106.35
Radiographic Vertebral Fracture	-171.29	178.92	-0.96	-522.06	179.47
Multiple Fractures	275.10	368.73	0.75	-447.77	997.97
Model: $R^2 = 0.0053$, p <.0001					

* Significance level α < 0.05

Table 8: Adjusted Variance in Physical Activity at Year 5; Multivariable Regression (n=5319)

Variable	Parameter Estimate	Standard Error	t Value	95% Confidence Interval	
Total MET-mins at Baseline	0.36	0.01	29.58*	0.34	0.38
Age (Year 5)	-33.71	4.39	-7.68*	-42.21	-25.10
Comorbidities	-85.60	20.56	-4.16*	-125.91	-45.29
Body Mass Index	-29.22	7.62	-3.84*	-44.15	-14.29
Level of Education	-43.82	17.76	-2.47*	-768.63	-9.01
Hip or Pelvic Fracture	-1179.61	466.15	-2.53*	-2093.45	-265.77
Sex	190.01	77.43	2.45*	38.21	341.80
Lower Limb Fracture	-449.18	285.55	-1.57	-1008.97	110.62
Spine Fracture	-373.40	379.61	-0.98	-1117.60	370.79
Radiographic Vertebral Fracture	122.92	152.30	0.81	-175.66	421.50
Employment Status	31.71	40.15	0.79	-47.00	110.43
BMD *T-Score* at Femoral Neck	21.90	39.99	0.56	-54.53	98.32
Upper Limb Fracture	-67.47	215.31	-0.31	-489.57	354.63
Multiple Fractures	80.53	399.60	0.20	-702.84	863.91
Model: $R^2 = 0.18$, $p < .0001$					

* Significance level α < 0.05

Table 9: Adjusted Variance in Physical Activity at Year 10; Multivariable Regression (n=4267)

Independent Variable	Parameter Estimate	Standard Error	t Value	95% Confidence Interval	
Total MET-mins at Year 5	0.35	0.01	26.23*	0.33	0.38
Age (Year 10)	-46.38	4.95	-9.37*	-56.09	-36.68
Comorbidities	-96.55	22.08	-4.37*	-139.86	-53.26
Body Mass Index	-36.83	8.18	-4.50*	-52.87	-20.80
Level of Education	-46.94	19.68	-2.44*	-86.52	-9.34
Spine Fracture	-836.37	433.51	-1.93	-1686.34	13.59
Lower Limb Fracture	-590.80	313.98	-1.88	-1206.36	24.76
Multiple Fractures	660.32	391.63	1.69	-107.48	1428.11
BMD *T-Score* at Femoral Neck	47.70	44.04	1.08	-38.64	134.05
Hip or Pelvic Fracture	-410.52	402.10	-1.02	-1198.86	377.81
Sex	-40.42	85.68	-0.47	-208.41	127.56
Employment Status	-8.11	44.72	-0.18	-95.79	79.58
Upper Limb Fracture	-29.75	248.97	-0.12	-517.85	458.35
Radiographic Vertebral Fracture	3.43	169.90	0.02	-329.66	336.51
Model: R^2 = 0.19, p<.0001					

* Significance level α < 0.05

Table 10: Simple Linear Regression for Effect of Time Since Last Fracture on Physical Activity at Year 5 and Year 10

Variable	Parameter Estimate	Standard Error	t Value	95% Confidence Interval	
Years Since Last Fracture (Year 5)	29.44	78.30	0.38	-124.34	183.21
Model: R^2 = 0.0002, p <0.71					
Years Since Last Fracture (Year 10)	95.54	82.79	1.15	-67.11	258.18
Model: R^2 = 0.0026, p <0.25					

* Significance level α=0.05

Chapter 6: Discussion

Our study identified that most fractures occur due to adverse events during daily physical activity such as a slip or trip indoors or outdoors, a fall while climbing, a fall on the stairs, or a sporting injury. Self-reported physical activity participation decreased significantly over the study period in all participants. People who had a history of fracture reported significantly lower levels of physical activity at year 10 compared to those with no fracture history. In adjusted regression analyses, previous incident hip or pelvic fracture was significantly associated with decreased physical activity at year five, however no other fractures were associated with physical activity at five-year follow-up. The number of years since a fracture occurred was also not significantly associated with physical activity. Overall, fractures often occur during routine activities, and having a fracture may have lasting consequences on physical activity participation.

6.1 Physical Activity as a Cause of Fracture

Our findings demonstrate that 60-80% of non-vertebral fractures of the hip, pelvis, wrist/forearm, or humerus, and 30% of vertebral fractures are a result of slips, trips, or falls occurring indoors or outdoors. Analyses of the Global Longitudinal Study of Osteoporosis in Women (GLOW) has previously reported higher rates of fall-related fractures; with falls accounting for 70-85% of non-vertebral fractures and 50% of vertebral fractures[16]. Inclusion criteria for the analyses of GLOW was limited to women 55 years of age and older, stratified such that two-thirds of the sample were over age 65. Women who had multiple incident fractures post-baseline assessment were excluded. Our study characterized all fractures occurring in men and women 25 years of age and older over a ten-year follow-up period, although 93% of the sample was over age 50. Despite differences in methodology, we also found that circumstances involving falls were responsible for a greater percentage of fractures in women and in participants over 50 years of age compared with the overall sample. The inclusion of a broader population allows us to determine patterns in the types of fractures and circumstances for fracture and identify opportunities to target interventions by age group and sex. By retaining individuals who had multiple fractures, we are able to capture results from participants who are at higher risk of fracture and may have more comorbid health conditions.

The types of fractures that people reported and how the fractures occurred varied by age group and between females and males. A greater percentage of fractures in men were caused by sporting injuries, falls while climbing, motor vehicle accidents (MVAs), and "other" circumstances compared with women. Fractures due to sporting injuries, falls while climbing, MVAs, or other circumstances also accounted for a greater percentage of fractures occurring in people under 50 years of age. Previous analysis of two prospective cohort studies of men and women in the United States reported that low-trauma fractures in men primarily occurred due to slips, trips, and falls (65%), while high-trauma fractures in men occurred due to sport and recreation (22%), falls from ladders, roofs, and trees (28%), motor vehicle accidents (21%), and other circumstances.[120] Similar to men, low trauma fractures in women were also primarily due to slips, trips, or falls (71%), however in women, high trauma fractures were primarily caused by motor vehicle accidents (54%).[120] While CaMos did not categorize circumstances of fracture as low trauma or high trauma, the similarity of categorization between studies implies that a greater proportion of high-trauma fractures occur in men, and in adults under 50 years of age. The types of activities that people participate in are likely to affect where and how they experience a fracture. Men often participate in significantly more outdoor cleaning and maintenance, while women often participate in significantly more indoor cleaning, meal preparation, and unpaid housework.[121] During leisure time, men often engage in significantly more physical activity and recreation, while women often engage in significantly more socializing and communicating.[121] As such, physical activity interventions that provide instruction for safe participation in preferred activities and activities performed as a part of habitual roles and responsibilities may help eliminate barriers to physical activity. People with osteoporosis have previously reported that publicly funded fall- or fracture-prevention programs are too short, or do not meet their individual needs,[108] and some men have expressed preference towards physical activity participation that involves "sports or chores around the house" rather than group exercise classes.[108] Comparing the types of activities that people tend to participate in with the types of activities during which fractures occur allows us to identify and communicate possible high-risk situations for women and men during common locations and activities, which may facilitate long term uptake of safe physical activity participation.

Evaluation of "other" circumstances for fracture provided insight into the unique situations in which fractures occur as a part of daily life. Several individuals reported a fracture occurring due to household tasks or work-related activities that involved bending, lifting, or carrying, unusual body positions, or rapid transitions between movements. Movements that place increased loading forces on the spine are often discouraged in individuals at increased risk of fracture.[107] Household and work-related activities often cannot be fully avoided, but training can be provided to educate individuals on safe movement patterns and spine sparing strategies that can be incorporated into daily life. For example, modifying daily activities to avoid lifting from the floor, using a hip hinge rather than bending all the way forward, carrying objects in both hands with the loads close to the body, stepping with both feet to turn the body rather than twisting to the side, and regularly practicing challenging static and dynamic balance exercises to prevent falls may also help prevent fractures.[67] Programs such as the Lifestyle-Integrated Functional Exercise (LiFE) program have demonstrated success in making conscious movement a part of everyday behaviour.[122] In LiFE, programing is developed with the input of participants, and is designed to fit within regular daily activities. Movements are taught and progressed using basic principles of balance training (e.g., reduce base of support, move to the limits of sway, swift weight) and strength training (e.g., load your muscles, sit to stand, up the stairs).[122,123] Programs like LiFE may meet some of the goals of exercise programs for osteoporosis, including falls prevention,[123] and improved muscular strength and balance,[123,124] however the movements and safety advice incorporated into LiFe are not targeted for fracture prevention. Additionally, younger, or healthier individuals may require greater stimulus (e.g., greater muscle loading, more challenging balance positions) to see improvements in balance and strength,[125] which may result in that person placing themselves in positions that further increase risk of fall or fracture. By understanding the specific situations in which fractures occur, physical or occupational therapists and trained exercise professionals can provide unique recommendations for proper body mechanics and postural alignment during everyday activities, and interventions can be targeted to the workplace, home, or outdoor environments in which fractures have occurred.

While certain bone sites and circumstances for fracture are more commonly attributed to osteoporosis,[44] our results suggest that in people with osteoporosis, fractures occur consistently across all major bone sites, while people with osteopenia or normal BMD experience a greater percentage of fractures concentrated at the wrist, or "other" bones of the upper or lower body that are not commonly characterized as osteoporotic fractures. When comparing fractures by circumstance, low-trauma fragility fractures, such as fractures due to no fall or injury, falls from a chair or bed, and slips or trips at home were more common in individuals with osteoporosis than those with a BMD *T-score* categorized as "normal" or "osteopenia", and accounted for a greater percentage of fractures at the hip, pelvis, or spine. Fractures due to sporting injuries, falls on stairs, and motor vehicle accidents accounted for a greater percentage of fractures in individuals with normal BMD than individuals with low BMD. Based on previous characterization of low and high-trauma fractures in women and men,[120] it is suspected that the increased percentage of fractures in men and those with normal BMD is a result of circumstances involving a traumatic or high-energy event. It is important to note that our findings indicate that in groupings of people with and without low BMD, the percentage of fractures due to high-trauma circumstances like motor vehicle accidents, an object striking the body, or a fall on the stairs or while climbing range by only one to two percent. The percentage of fractures due to sporting injury has a range of sixteen percent between people with normal BMD and people with osteoporosis. Recent evidence suggests that regardless of whether a previous fracture was caused by high-trauma or low-trauma circumstances, BMD may be decreased, and subsequent fracture risk (including risk of a major osteoporotic fracture) may be increased.[120,126] This has implications for the way we study, diagnose, and treat fractures, particularly in men and people under 65 years of age. The 2010 clinical practice guidelines for the diagnosis and management of osteoporosis in Canada recommends fracture risk assessment for women and men over 50 years of age, and BMD testing for everyone 65 years of age and older, as well as those with clinical risk factors including previous fragility fracture.[45] Pharmaceutical management for osteoporosis is widely recommended in individuals with a BMD *T-score* <-2.5 SD, and previous fragility fracture is often considered an indicator for treatment consideration due to the increased risk of subsequent fracture.[45] However, in individuals with fragility fracture, clinical diagnoses of osteoporosis are low in both women[127] and men,[128] despite having a bone mineral density or fracture history indicative of osteoporosis. Studies of osteoporosis often exclude individuals who did not experience a fragility fracture, and osteoporosis practice guidelines do not recommend further testing for BMD for non-fragility fractures in adults under 65 years of age, therefore clinical diagnoses of osteoporosis in individuals with a high-trauma fracture are likely even lower.[127–130] Our descriptive findings support that high-trauma fractures account for a similar percentage of fractures in individuals with normal bone mineral density and low bone mineral density. Just because a circumstance for fracture is considered high trauma does not mean that the fracture should not be treated as an osteoporotic fracture, or that further assessment of BMD or fracture risk is unnecessary. Expansion of research study criteria as well as clinical practice guidelines[45] to include individuals with high-trauma fracture may reduce the osteoporosis care gap, resulting in earlier identification, better access to resources for subsequent fracture prevention, and better long-term health outcomes in all women and men at increased risk of fracture.

In addition to expanded fracture risk assessment to improve early identification of fractures, there is a need for health care providers to take reasonable measures to prevent fractures in their patients. Several individuals reported fractures occurring while they were in the hospital for another procedure, as part of an orthopaedic surgery (e.g., knee or hip replacement), or under the care of a chiropractor or volunteer. Many participants also reported having a fracture from a fall due to dizziness, fainting, or a diagnosed medical condition. Commonly prescribed medications, such as those for hypertension, cardiac arrythmias, diabetes, depression, pain, or sleep often have side effects that increase risk of falls,[131] therefore communication with patients surrounding treatment risks is important in preventing fractures. Osteoporosis-specific education and training programs that highlight common risk factors and circumstances for fracture, as well as positions or movements that may be more likely to result in a fall or fracture may be beneficial for both healthcare and allied health professionals. A few participants reported fractures occurring due to aggression, assault, or an altercation with another person. While the situations of violence resulting in fracture are unknown, Canadian fracture clinics disproportionately treat females who have experienced domestic violence resulting in fracture.[132,133] To provide comprehensive care, health professionals interacting with individuals with fracture should be trained to be aware of signs of abuse, and additional support resources, beyond immediate fracture treatment, should be available for those who need them.[132]

There is some seasonal variation in fracture occurrence, with a greater percentage of hip fractures and humerus fractures occurring during winter months, while percentages of wrist fractures spike in the winter and the summer. Previous studies that observed seasonal variation in fracture rate have suggested that reduced levels of sun exposure during the winter months may contribute to reduced synthesis of vitamin D, and icy conditions may result in increased slips and falls.[16] Winter weather patterns are inconsistent across Canadian provinces, and the effect of vitamin D on falls and fall-related fractures is inconclusive,[134] therefore we cannot draw the same conclusions. However, mild summer temperatures are more consistent across provinces, and Canadians are 86% more likely to be physically active in the summer compared to the winter.[135] Increased physical activity has been closely associated with wrist fracture,[70] and we have demonstrated that nearly half of all wrist fractures occur due to slips and trips outdoors, therefore seasonal increases in physical activity may help to explain the increase in wrist fractures reported in June and July.

6.2 Trajectory of Physical Activity between Baseline and Year 10

The average physical activity levels reported by participants at baseline, Year 5, and Year 10 were extremely high. CaMos participants reported an average of 3415 MET-mins of physical activity per week, suggesting that they participated in 9 to 14 hours of moderate to vigorous physical activity in a typical week, far surpassing the 150 minutes weekly of moderate to vigorous physical activity recommended for Canadians. As our sample was drawn from an average Canadian population, it is likely that self-reported physical activity values are overestimated. Only 16% of Canadian adults actually achieve the guideline recommendations for physical activity when measured with an accelerometer,[111] which is in stark contrast to the two-thirds of Canadians who appeared to have met physical activity guidelines based on self-reported data.[136] Activity measured with the accelerometer is typically accurate when compared with gold standard measurements of energy expenditure, however correlation between accelerometer-measured physical activity data and physical activity questionnaires is very dependent on the type of questionnaire used, and accelerometer measured physical activity is often reduced compared with self-reported data.[137] Physical activity described was meant to include all physical activities of daily living, including work and recreation, and was not limited to planned, structured exercise, however the variables we selected did not break down activity as such. To report both time and intensity of the activity as a single variable, physical activity values were converted to MET-minutes using established metabolic equivalents for moderate, vigorous, and strenuous activity. Metabolic equivalents were compared to the example activities provided for each category to ensure accuracy. Examples of moderate activity (4 METS) included housework, brisk walking, golfing, bowling, cycling on level ground, and gardening. Examples of vigorous work (6 METS) included moving heavy furniture, loading, or unloading trucks, shovelling, weightlifting, or equivalent manual labour. Strenuous sports (8 METS) included jogging, cycling on hills, tennis, racquetball, swimming laps, and aerobics. It is likely that not all individuals engage in activities at an equivalent intensity, and therefore the metabolic cost of each activity may be overestimated for some and underestimated for others.

Consistent with our hypothesis, we identified that physical activity levels declined over the ten-year follow-up period in individuals who experienced a fracture as well as those who did not. However, people who had experienced at least one fracture over the study period reported significantly lower physical activity at year 10 compared to people who had no fractures. With increasing age, there is a decrease in physical activity participation[111,138] and an increase in the number of people who fracture. Across our study population, participants reported having experienced an average of 1.6 ± 1.2 fractures up to year 5 of follow-up. By year 10 of follow-up, the average number of previous fractures was nearly doubled at 3.1 ± 2.2 fractures. It is possible that the combined effect of fractures with increasing age may negatively affect physical activity. Fractures are commonly associated with pain, limitations in mobility, decreased quality of life,[21,23,84] fear of falling,[78] and poor functional outcomes,[76,139] and people who have had a fracture typically experience periods of prolonged sedentary behaviour.[27,28,30,31] Therefore, continued study of physical activity outcomes in the short-term and long-term following fracture may be valuable. When developing programs or initiatives to engage aging Canadians in physical activity, special consideration to the barriers and facilitators of physical activity in people who have experienced a fracture is necessary.

6.3 Effects of Fracture on Physical Activity

After adjusting for confounding factors, our findings indicate that having one or more hip or pelvic fractures between year 1 and year 5 was significantly associated with a decrease in physical activity participation at year 5, however a hip or pelvic fracture occurring between year 5 and year 10 was not significantly associated with physical activity. No other fracture types were significantly associated with physical activity at five-year follow-up. We hypothesized that hip or pelvic fractures as well as multiple fractures of any type would have a significant and prolonged effect on physical activity. We also expected that results would have been consistent between multivariable regressions as they both considered fractures over a five-year period of follow-up. It is unclear why a hip or pelvic fracture occurring between year 1 and year 5 was significant, however a hip or pelvic fracture occurring between year 5 and year 10 was not. It is possible that loss to follow-up influenced our results. The lasting effects of hip fracture are well known,[80,139] with a past hip fracture significantly impacting life trajectory through reduction of mobility, loss of independence, decreased quality of life,[21,23,84] and increased risk of mortality.[82] Therefore, it was expected that a hip fracture would also result in a reduction of physical activity[30,31] at both time points. One study examining the trajectory of physical activity after hip fracture also demonstrated no significant change in physical activity two years post-hip fracture.[26] Aboelmagd et al., (2018) also relied on self-reported physical activity data using a questionnaire specific to older adults. Questions about the frequency of participation in mild, moderate, and vigorous activity were asked, however details surrounding the amount of time per bout of activity were not captured.[26] Therefore, further research of the long-term impact of hip or pelvic fracture on physical activity using higher quality physical activity data may produce different results. Previous studies in the CaMos population have identified that having one or more low-trauma hip or spine fractures had significant effects on the mobility aspect of the Health Utilities Index Mark 2 (HUI2) at both five and ten-year follow-up. The ambulation aspect of the Health Utilities Index Mark 3 (HUI3) was significantly affected by previous hip and spine fracture at year 5, and hip and forearm fracture at year 10.[23,84] It is interesting that despite fractures significantly affecting self-reported mobility and ambulation, participants did not perceive limitations in mobility or ambulation as affecting physical activity in our study. It is important to note that we included fractures due to any circumstance, not just low trauma circumstances in people aged 50 years and older. The discrepancy in findings between our study and previous studies of the attributes of quality of life suggests that the perception of typical physical activity participation is based on more than perceived physical ability to move and may more accurately reflect an individual's occupation and participation in expected life roles.[26]

We expected that having multiple fractures would have significantly affected physical activity at five-year follow-up. Individuals who have a history of fractures are more likely to sustain a second fracture,[10,140] particularly when multiple fractures occur simultaneously,[141] and individuals who sustain multiple fractures simultaneously also have increased risk of mortality.[142] There is some indication that increased risk stems from patients not receiving appropriate fracture risk assessment, clinical diagnosis, or treatment of osteoporosis following the initial fracture.[140,143] It has been suggested that regardless of whether the fracture is "mild", occurs earlier in life, or is a high-trauma fracture thought to be unrelated to osteoporosis,[126] all fractures should be treated as a serious injury with possible lasting consequences. Eighteen percent of individuals who had a fracture reported multiple fractures over the study period, with some fractures occurring simultaneously. It is possible that if that both fractures healed at the same time, disruptions in physical activity were not viewed as any more serious than one fracture and did not affect an individual's overall perception of their typical physical activity patterns. Additionally, we considered multiple fractures to be more than one fracture of any type. Had we only included multiple major osteoporotic fractures we may have produced a different result. People may be more aware of the limitations and risks associated with fractures typically considered osteoporotic, and reduce physical activity based on perceived need or recommendation.[44,67] Finally, we hypothesized that the number of years since fracture would be significantly associated with physical activity, however it was not. The method we used was similar to that used by Adachi et al. (2001), which also reported no significant effect of years since last fracture on health-related quality of life. It is likely that the time period of yearly fracture collection compared with physical activity at five-year follow-up was not sensitive enough to detect changes in physical activity and associate them with any one acute factor.

6.4 Clinical Relevance

Individuals who have experienced a fall-related fracture often become fearful of falling.[78,108,109] Many fractures occur while people are moving about in their daily lives; therefore, it is understandable that individuals who experienced a fracture during physical activity may be more likely to avoid the activity that caused the fracture. However, exercise may reduce fear of falling[144] as well as reduce the rate of falls, the number of people who fall, and reduce the number of falls that result in fracture.[14] Avoiding physical activity is not a reasonable solution for preventing fracture. To reduce fracture risk while balancing the positive health outcomes of physical activity, it is essential that quality exercise programs that prioritize weight-bearing aerobic and muscular strengthening activities, proper body mechanics, and balance challenges to prevent falls are accessible to those who have had a previous fracture. Targeting our interventions to the way in which people experience a fracture is essential. Physical activity and exercise programs that involve balance and functional strengthening exercises integrated into physical activities of daily living show promise in reducing falls and fall-related fractures.[14,134] Functional exercise programs teach ways to incorporate exercise into daily life (e.g., using a squat to pick up a laundry basket). To build on current programs, our study has highlighted the types of activities and the locations of falls (indoors or outdoors) in which fractures occur. By examining the common circumstances in which fractures occur, we can understand the activities that males and females of different age groups participate in on a daily basis, which provides an indication of the types of activities they enjoy and find value in. Targeting functional interventions towards the ways that people have fractured in the past may allow researchers and clinicians to select specific movements to improve functional strength and balance, and to coach safe movement strategies that are relevant to physical activities typically performed in daily life. By tailoring exercise programs to the unique needs of an individual at risk of subsequent fracture, exercise programs for fracture prevention may have greater participation and retention.

6.5 Limitations

There are several limitations to our study. We performed a secondary analysis of CaMos data collected over a ten-year period between 1995 and 2008. All participants were community-dwelling and resided within 50 km of a major Canadian city. Therefore, the trends observed in this population may not be consistent with individuals living in residential care, rural or remote settings, or in different social or environmental climates.

Fracture data was self-reported via yearly mail-in fracture questionnaires. Self-reporting of fractures may introduce error as participants are required to accurately recall past events. An effort was made to reduce the impact of biased self-reporting by including only fractures that had been verified by X-ray, obtained from the participant's medical records. Obtaining fracture data using this method assumes that all individuals survived the fracture, and that participants reported all injuries resulting in fracture to their health care providers, who diagnosed the fracture by X-ray. However, it is possible that some fractures were forgotten or misrepresented, or questionnaires were not consistently completed. It is also possible that some fractures were never brought to clinical attention, meaning the fracture was first identified by X-ray and the participant was later informed that a fracture occurred. If a fracture was not brought to clinical attention by the participant, it is likely that circumstances for fractures would be either missing or inaccurately reported. To avoid double counting of vertebral fractures, radiographic vertebral fractures that were identified by X-ray taken at baseline, year 5 or year 10 as part of the CaMos study were not included in descriptive summaries of clinically reported fractures.

Many longitudinal cohort studies rely on questionnaires to obtain data on physical activity, despite limitations in the validity of self-reported data. Self-reported physical activity data has been shown to overestimate the volume of active time[137,145,146] and underestimate sedentary time[147] compared with data measured directly by accelerometer, inclinometer, or other activity monitoring device. Additionally, validated recalls over 7 days or a "typical week" are shown to be less reliable compared with device-measured values of physical activity[147]. The physical activity questionnaire used in the CaMOS study was a recall of the physical activities performed over an average week during the previous year. The questionnaire was created by the University of Hawaii Cancer Research Centre and has similarities to the International Physical Activity Questionnaire (IPAQ) or Global Physical Activity Questionnaire (GPAQ), however validation of the University of Hawaii Cancer Research Centre questionnaire in general populations or against other physical activity recall tools has not been published. Despite concerns with validity, self-reported physical activity data provides insight into the participant's perception of their own physical activity behaviour. It is unclear whether our data is accurate enough to detect true differences in physical activity habits over time and between individuals who have experienced a fracture and those that have not. We did not consider self-reported data of sedentary time or compare reported sedentary time with reported physical activity to ensure the self-reported time spent in physical activity aligned within a normal 24-hour day.

It is possible that missing data due to sporadic participation or loss to follow-up influenced our results. Efforts were made to limit the effects of missing data. For example, all X-ray confirmed fractures that indicated the site and circumstance for fracture were included. If participants were missing BMD *T-score* data, they were only excluded from that descriptive analysis. Statistical analyses were only performed for subjects with full datasets. Preliminary exploration of the data suggested that individuals who did not continue participation in the CaMOS study appeared to be older, have a higher number of comorbid health conditions, and report lower levels of physical activity. 1203 participants were lost due to death. As it was unclear if data were missing at random, it was determined that imputation would not be appropriate.

Lastly, physical activity is influenced by numerous physical, environmental, and psychosocial factors. For regression analyses, we selected several independent variables expected to influence physical activity. It is possible that interactions between independent variables affected the variance explained by our exploratory model. To limit multicollinearity in regression models, only select predictor variables that were expected to have confounding effects[35] were included in the regression equations. Actual predictors of physical activity likely go beyond what is included in the models and may be highly specific to each individual's life situation, therefore limiting our confidence in the presented regression models.

6.6 Future Directions

Our study was designed to observe physical activity changes up to five years following a fracture, however, we were limited by the experimental design of the original CaMos dataset. To build on our current work, studies that measure physical activity at more frequent time intervals using more reliable methodology (e.g., accelerometry) are warranted. Current studies of physical activity following fracture that use accelerometry are typically less than 6 months in duration, therefore maintaining a longer study duration, while increasing the frequency of physical activity measurements would be helpful in understanding fluctuations in physical activity in relation to falls and fractures. Additionally, fracture alone may not be significantly associated with physical activity participation, but there may be better predictors of physical activity which are influenced by fracture. Examining physical performance measures in addition to physical activity data would provide a more detailed understanding of the impact that fracture has on physical activity and mobility, beyond the scope of a questionnaire. Further study of the association between quality of life or frailty indicators and physical activity participation would also be interesting.

To understand the mechanisms of different types of fractures, further study of the circumstances for fracture as well as the circumstances for falls that result in fracture may be valuable. The impact of directional falling on fracture risk has previously been evaluated,[55,57] supporting the use of personal safety equipment such as hip protectors to prevent hip fractures.[59] However, studies that are able to monitor for the circumstances and mechanisms of fracture are typically conducted in long-term care or residential settings and may not reflect the situations or needs of active community-dwelling individuals.

The inclusion of open-ended descriptions of "other circumstances" leading to fracture provided insight into the locations and situations in which individual fractures occurred. Most fractures appeared to occur during activities of daily living, however specific details as to how and when fractures occurred, as well as the types of activities a person was engaged in when a fracture occurred were not collected. Questionnaires are able to capture and characterize a large population, however further qualitative research to understand the situations and movements people were performing when they experienced a fall-related or other type of fracture could help researchers and clinicians to identify high-risk situations at home, at work, outdoors, and in the community, and develop guidelines to communicate appropriate strategies for safe performance of daily activities. Education surrounding functional strengthening and the use of spine sparing strategies in sport and physical activities of daily life may be an effective way to prevent falls and fractures occurring during daily activities. However, further research into the uptake and effectiveness of movement retraining strategies in clinical programming, and in individual's daily lives is needed. Understanding the mechanisms for injury has allowed for athlete retraining to prevent injury, therefore exploring the feasibility of implementing similar models for adults at increased risk of fracture would be of interest.

6.7 Conclusion

We explored possible causes of fracture, as well as the consequences of fracture on physical activity participation over a five- and ten-year period in the Canadian Multicentre Osteoporosis study. Most fractures were a result of falls occurring during routine physical activities. Vertebral fractures often occurred without a fall or injury or were caused by other circumstances. There was a significant decrease in reported physical activity over the study period, suggesting that with age, individuals report reductions in the volume of physical activity they participate in. At year 10, individuals who had at least one fracture over the study period reported significantly lower physical activity then those who had no fracture history. Having a hip or pelvic fracture between year 1 and year 5 was significantly associated with a reduction in physical activity at five-year follow-up. No other fracture types were significantly associated with physical activity. There was no significant association between the number of years since last fracture and physical activity. While our results do not establish a clear relationship between fracture status and physical activity, it is evident that volume of physical activity decreases over time, while the number of fractures increases. Further research is needed to understand the implications of hip, pelvic, or other fracture on physical activity in the long term. Strategies to reduce falls during physical activities of daily living are becoming more widely implemented, however the choice of intervention should consider an individual's fracture risk, and should be targeted towards how, when, and where serious fall-related injuries, such as fractures, occur. To prevent fractures and ensure physical activity targets for optimal health are being achieved, active interventions that target falls prevention while simultaneously promoting awareness of safe movement patterns during activities of daily life should be emphasized.

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Appendices

Appendix A

Table 11: Total Confirmed Fractures Occurring between Year 1 and Year 10 of Follow-up by Circumstance (n=1533)

Fracture Site	Hip (n=161)	Pelvis (n=47)	Spine (n=148)	Wrist/Forearm (n=316)	Upper Arm (n=134)	Rib (n=129)	Other (n=308)	Hands/Feet/Face (n=290)
Fell from Chair/ Out of Bed	14	1	10	4	12	5	8	3
Fell Climbing	7	1	7	14	2	6	7	7
Fell on Stairs	5	3	10	28	12	8	41	30
Motor Vehicle Accident	0	0	6	6	1	14	11	5
Sporting Injury	8	3	2	25	5	4	21	28
Slip/Trip at Home	51	11	16	60	33	25	37	41
Slip/Trip Outside	37	17	12	150	53	25	145	96
Object Struck Body	0	2	1	3	1	0	5	33
No Fall/Injury	19	7	60	4	3	30	11	17
Other Circumstance	20	2	24	22	12	12	22	30

Table 12: Confirmed Fractures Occurring between Year 1 and Year 10 of Follow-up by Circumstance and Age Group at Baseline (n=1533)

Fracture Site	Hip (n=161)			Pelvis (n=47)			Spine (n=148)			Wrist/Forearm (n=316)			Upper Arm (n=134)			Rib (n=129)			Other (n=308)			Hands/Feet/Face (n=290)		
Age Group (Years)	<50	50-65	>65	<50	50-65	>65	<50	50-65	>65	<50	50-65	>65	<50	50-65	>65	<50	50-65	>65	<50	50-65	>65	<50	50-65	>65
Fell from Chair/Out of Bed	0	0	14	0	0	1	0	2	8	0	1	3	0	2	10	0	0	5	0	1	7	0	0	3
Fell Climbing	0	2	5	0	0	1	0	2	5	3	7	4	0	1	1	0	2	4	1	3	3	1	4	2
Fell on Stairs	0	1	4	0	0	3	0	4	6	1	7	20	0	4	8	0	2	6	5	13	23	8	12	10
Motor Vehicle Accident	0	0	0	0	0	0	2	0	4	3	0	3	0	0	1	0	5	9	2	3	6	2	2	1
Sporting Injury	0	3	5	1	1	1	1	1	0	11	8	6	1	3	1	3	1	0	11	6	4	8	14	5
Slip/Trip at Home	0	3	48	0	3	8	0	4	12	2	19	39	1	5	27	1	4	20	2	14	21	3	18	21
Slip/Trip Outside	0	6	31	0	2	15	0	7	5	11	56	83	1	10	42	0	12	13	16	60	69	11	28	57
Object Struck Body	0	0	0	0	1	1	0	0	1	0	0	3	0	1	0	0	0	0	0	4	1	12	10	11
No Fall/Injury	0	3	16	0	2	5	0	15	45	0	1	3	0	1	2	2	16	12	0	5	6	3	10	4
Other Circumstance	0	3	17	0	0	2	0	5	19	2	5	15	1	3	8	2	3	7	3	9	10	7	12	11
Total	0	21	140	1	9	37	3	40	105	33	104	179	4	30	100	8	45	76	40	118	150	55	110	125

Table 13: Confirmed Fractures Occurring between Year 1 and Year 10 of Follow-up by Circumstance and Sex (n=1533).

Fracture Site	Hip (n=161)		Pelvis (n=47)		Spine (n=148)		Wrist/Forearm (n=316)		Upper Arm (n=134)		Rib (n=129)		Other (n=308)		Hands/Feet/Face (n=290)	
Sex	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**
Fell from Chair/Out of Bed	10	4	1	0	9	1	4	0	11	1	5	0	7	1	2	1
Fell Climbing	5	2	0	1	6	1	10	4	1	1	2	4	7	0	2	5
Fell on Stairs	3	2	3	0	9	1	24	4	11	1	4	4	37	4	29	1
Motor Vehicle Accident	0	0	0	0	3	3	3	3	1	0	11	3	5	6	4	1
Sporting Injury	3	5	2	1	1	1	19	6	5	0	2	2	11	10	18	9
Slip/Trip at Home	42	9	11	0	15	1	57	3	30	3	18	7	34	3	36	6
Slip/Trip Outside	28	9	16	1	10	2	133	17	47	6	14	11	121	24	75	21
Object Struck Body	0	0	1	1	1	0	3	0	1	0	0	0	2	3	23	10
No Fall/Injury	17	2	6	1	52	8	4	0	2	1	22	8	10	1	15	2
Other Circumstance	15	5	2	0	16	8	20	2	11	1	6	6	16	6	19	11
Total	123	38	42	5	122	26	277	39	120	14	84	45	250	58	223	67

Table 14: Confirmed Fractures Occurring between Year 1 and Year 10 of Follow-up by Circumstance and BMD-*T-score* at Baseline (n=1348)

Fracture Site	**Hip (n=131)**			**Pelvis (n=38)**			**Spine (n=127)**			**Wrist/Forearm (n=270)**			**Upper Arm (n=112)**			**Rib (n=113)**			**Other (n=287)**			**Hands/Feet/Face (n=268)**		
Femoral Neck BMD *T-Score*	**> -1.0 SD**	**-1.0 - -2.5 SD**	**<-2.5 SD**	**> -1.0 SD**	**-1.0 - -2.5 SD**	**<-2.5 SD**	**> -1.0 SD**	**-1.0 - -2.5 SD**	**<-2.5 SD**	**> -1.0 SD**	**-1.0 - -2.5 SD**	**<-2.5 SD**	**> -1.0 SD**	**-1.0 - -2.5 SD**	**<-2.5 SD**	**> -1.0 SD**	**-1.0 - -2.5 SD**	**<-2.5 SD**	**> -1.0 SD**	**-1.0 - -2.5 SD**	**<-2.5 SD**	**> -1.0 SD**	**-1.0 - -2.5 SD**	**<-2.5 SD**
Fell from Chair/Out of Bed	0	6	6	0	0	0	0	3	4	2	1	0	1	7	3	0	2	2	0	5	2	0	3	0
Fell Climbing	0	3	3	0	1	0	1	3	3	2	8	1	0	1	0	1	5	0	2	2	1	2	4	0
Fell on Stairs	0	2	2	1	2	0	1	4	4	7	12	6	4	6	2	2	5	0	6	25	10	9	17	3
Motor Vehicle Accident	0	0	0	0	0	0	1	4	1	1	4	1	0	0	1	2	8	3	3	5	3	3	2	0
Sporting Injury	0	6	2	2	1	0	0	2	0	8	14	1	1	3	0	1	3	0	12	8	1	15	10	2
Slip/Trip at Home	2	18	17	0	5	2	3	9	3	10	24	13	3	13	12	4	5	11	6	18	10	10	21	7
Slip/Trip Outside	0	16	16	1	10	4	2	2	7	24	79	28	3	22	17	1	15	4	31	74	29	15	56	17
Object Struck Body	0	0	0	1	1	0	0	0	1	0	3	0	0	0	0	0	0	0	3	1	0	4	22	5
No Fall/Injury	2	4	9	0	2	3	4	19	27	0	2	1	1	2	0	3	15	11	1	7	2	4	7	5
Other Circumstance	1	9	7	0	1	1	2	13	6	2	13	3	1	6	3	1	6	3	2	7	11	9	12	4
Total	5	64	62	5	23	10	14	59	56	56	160	54	14	60	38	15	64	34	66	152	69	71	154	43

*There is missing BMD *T-score* data at baseline, therefore only participants with available data were represented

Table 15: Confirmed Fractures Occurring during Sport, Physical Activities of Daily Living, and Sedentary Time (n=1533)

Fracture Site	Physically Active Sport (n=96)	Physically Active Daily Living (n=997)	Sedentary Time (n=208)	Trauma (n=88)	Other (n=144)
Hip	8	100	33	0	20
Pelvis	3	32	8	2	2
Spine	2	45	70	7	24
Wrist/Forearm	25	252	8	9	22
Humerus	5	100	15	2	12
Rib	4	64	35	14	12
Other	21	230	19	16	22
Hands/Feet/Face	28	174	20	38	30

Physically Active Sport: sporting injury; **Physically Active Daily Living:** fell climbing ladder, fell on stairs, slipped or tripped inside, slipped or tripped outside; **Sedentary Time:** fell from chair or out of bed, no fall or injury**; Trauma:** motor vehicle accident, heavy object fell and struck body; **Other:** described narratively in Table 7.

Table 16: Years between Fracture and Follow-up (Year 5 or Year 10)

Years between Fracture and Follow-up	Number of Fractures
0 Years	348
1 Year	294
2 Years	290
3 Years	269
4 Years	300

Appendix B

Table 17: Descriptive Summary of "Other" Circumstances for Fracture

Sport	Physical Activity During Daily Living	Sedentary Time	Trauma	Other
- Refracture after swimming - Stepping from boat - Fell on boat - Golf club fell on wrist	- Bending down, hit object - Bending to pick up object - Fell during bending activity - Rose from chair and fell - Pushing off from chair - Walking without walker - Trying to put walker in car - Fell while walking - Playing (with children, with dog) - Changed seats on the bus - Dog leash wrapped around hand - Doing laundry - Washing car - Opened window - Reaching to get something - Used arm to prevent fall - Breaking up frozen snow - Ground gave way while gardening - Lifting vacuum upstairs - Lifted garbage - Lifted plant - Lifting basement trapdoor - Lifted heavy object - Lifting another person - Moving small furniture - Moving heavy furniture - Pulling hose/water lines - Pushing an object	- Bending in seated position - Leaning back in seat to pick up heavy object from back seat of car - Uncrossing legs and foot brushed against footstool	- Aggression - Assault - Mugged - Punching someone - Was pushed - Chiropractor - Heimlich maneuver - Dropped by volunteers - Child landed on chest while playing - Collided with another person - Automatic door struck body - Hand caught on object - Door slammed on foot - Got jammed in door - Hand caught in machine - Fixing bike pedal, jammed into ribs - Object struck body (did not fall on body) - Fell onto object - Fell from 8-feet - Fell off roof - Skidded into rail - Injury from machine - Injury from power tool - Stubbed on object	- Loss of consciousness - Fainting - Collapsed due to weakness - Dizziness (and fall) - Vertigo (and fall) - Cognitive impairment affecting balance - Had "mini stroke" and fell - Stood up and fell because "foot asleep" - Knee locked due to arthritis - Diabetes related falls or fainting - Knee/leg gave out - Cancer - Pathological fracture due to Breast Cancer - Loss of consciousness due to virus - Fracture occurred while in hospital for dyspnea - During hip surgery - During knee replacement surgery - Femur infection following cortisone injection

	- Turned foot/ankle while walking/walking down slope - Turned ankle wearing sandals - Twisted ankle when jumping - Jumped off scaffolding - Jumped out of bed and banged leg on floor - Bumped into door/table or another object - Fell at work - Fell from counter - Fell from dresser while cleaning - Fell in nursing home - Loss of balance		- Using toe for leverage to force a pipe - Fell down elevator shaft - Work related accident	- Fracture occurred while chest drainage tube was being inserted - Amusement Park ride