# Bone health management through exercise in older adults with diabetes: Patient perspectives and experiences

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**Abstract**

**Background**: Fragility fractures and diabetes are major public health issues associated with significant morbidity and mortality. Fragility fractures cause pain, impaired mobility, and low quality of life. Type 1 (T1D) and type 2 (T2D) diabetes mellitus are clinical risk factors for fracture, regardless of bone mineral density. However, bone fragility is often overlooked as a secondary complication of diabetes, resulting in a care gap for high-risk individuals with diabetes. Many older adults with diabetes are not aware of the impact of diabetes on their bone health; therefore, they do not routinely engage in bone health management. Muscle strengthening, functional, and balance exercises are a promising strategy for fall and fracture prevention, given their ability to improve muscle and bone strength and mobility. However, participation in bone health-specific exercise remains low, especially amongst older adults. There is limited evidence on how older adults with diabetes perceive and engage in exercise as a strategy for managing their bone health and fall and fracture prevention.

**Objective:** The objective of this qualitative study is to analyze the perceptions and experiences related to exercise and bone health management in older adults with diabetes to better understand their opportunities, capabilities, and motivations of behavior.

**Methods:** A qualitative study was conducted using semi-structured interviews with older adults (≥50 years old) diagnosed with T1D. Participants were recruited via purposeful recruitment through diabetes clinics, social media, and patient-oriented organizations (e.g., Diabetes Canada, Diabetes Quebec, BETTER Registry for T1D). Semi-structured interviews determined the participants' perceptions, experiences, and behaviors related to exercise and bone health. A directed content analysis was conducted to identify codes for the data in each transcript and was categorized using the Capability, Opportunity, and Motivation (COM-B) of Behavior model.

Specifically, the six subcategories of COM-B: Physical Capability, Psychological Capability, Physical Opportunity, Social Opportunity, Reflective Motivation, and Automatic Motivation.

**Results:** We interviewed 11 participants with T1D (5 men, 6 women, mean age = 60 ± 7.5 years, mean age of diabetes diagnosis = 16 ± 11.0 years). One participant had a diagnosis of osteoporosis and 2 participants had experienced a fall in the past 6 months. Sixty-four percent of participants participated in moderate-intensity aerobic exercises 3-4 times a week. Only 27% of participants participated in resistance exercise ≥3 days a week. Balance and flexibility exercises were the least common, with 64% of participants not participating at all. Participants' behaviour was influenced by several factors, categorized by the COM-B model of behaviour. For Physical Capability, diabetes symptoms and/or complications and age affected physical activity participation, and previous experience in physical activity and exercise increased perceived capability. Psychological Capability was influenced by participants' limited awareness and knowledge about how diabetes affects bone health, lack of awareness of the benefits of exercises on bone health, and existing knowledge about the effects of exercise on diabetes & health. Physical Opportunity was affected by the limited information & resources about bone health management available to individuals with diabetes, and time for physical activity participation. Social Opportunity was influenced by the participant's relationship with HCPs, the lack of communication about bone health from HCPs, and age-related societal norms. Reflective Motivation was influenced by lack of motivation/incentive to exercise specifically for bone health, participants' goals of improving/maintaining their health & function, and the sense of community/connection through exercise. Finally, Automatic Motivation was affected by a lack of interest in bone health-specific exercises, exercise habit/routine, and fear of hyperglycemia/hypoglycemia related to exercise.

**Conclusion:** Addressing the identified health-related behaviors can improve participation in bone health-specific exercises, and thereby potentially reduce the risk of falls and fractures among older adults with diabetes. Future interventions should focus on personalized exercise plans, education, and social support systems to promote bone health, fall/fracture prevention, and overall health and well-being in this high-risk population.

**Résumé**

**Contexte:** Les fractures de fragilité et le diabète sont des problèmes majeurs de santé publique associés à une morbidité et une mortalité importantes. Les fractures de fragilité entraînent des douleurs, une mobilité réduite et une mauvaise qualité de vie. Le diabète de type 1 (DT1) et de type 2 (DT2) sont des facteurs de risque cliniques de fracture, indépendamment de la densité minérale osseuse. Cependant, la fragilité osseuse est souvent négligée en tant que complication secondaire du diabète, d'où des soins insuffisants pour les personnes à haut risque atteintes de diabète. De nombreux personnes âgées atteints de diabète ne sont pas conscientes de l'impact du diabète sur leur santé osseuse; par conséquent, ils ne s'engagent pas régulièrement dans une gestion de leur santé osseuse. Les exercices de renforcement musculaire, fonctionnels et d'équilibre sont une stratégie prometteuse pour la prévention des chutes et des fractures, en raison de leur capacité à améliorer la force musculaire, la force osseuse et la mobilité. Cependant, la participation à des exercices spécifiques à la santé osseuse reste faible, surtout chez les personnes âgées. Il existe peu de preuves sur la manière dont les personnes âgées atteintes de diabète perçoivent et pratiquent l'exercice physique en tant que stratégie de gestion de la santé osseuse et de prévention des chutes et des fractures.

**Objectif:** L'objectif de cette étude qualitative est d'analyser les perceptions et les expériences liées à l'exercice physique et à la gestion de la santé osseuse chez les personnes âgées atteintes de diabète afin de mieux comprendre leurs opportunités, leurs capacités et leurs motivations de comportement.

**Méthodes:** Une étude qualitative a été menée à l'aide d'entretiens semi-structurés avec des adultes plus âgés (≥50 ans) diagnostiqués avec le DT1. Les participants ont été recrutés de manière ciblée dans les cliniques du diabète, les médias sociaux et les organisations orientées

vers les patients (par exemple, Diabète Canada, Diabète Québec, BETTER Registry for T1D). Des entretiens semi-structurés ont permis de déterminer les perceptions, les expériences et les comportements des participants en matière d'exercice physique et de santé osseuse. Une analyse de contenu dirigée a été effectuée pour identifier les codes des données dans chaque transcription et a été catégorisée en utilisant le modèle de capacité, d'opportunité et de motivation (COM-B) du comportement. Plus précisément, les six sous-catégories de COM-B : capacité physique, capacité psychologique, opportunité physique, opportunité sociale, motivation réfléchie et motivation automatique.

**Résultats:** Nous avons interrogé 11 participants atteints de DT1 (5 hommes, 6 femmes, âge moyen = 60 ± 7,5 ans, âge moyen du diagnostic de diabète = 16 ± 11,0 ans). Un participant a reçu un diagnostic d'ostéoporose et deux participants ont fait une chute au cours des six derniers mois. 64 % des participants ont fait des exercices d'aérobie d'intensité modérée 3 à 4 fois par semaine. Seulement 27 % des participants ont fait des exercices de résistance ≥3 jours par semaine. Les exercices d'équilibre et de flexibilité étaient les moins courants, 64 % des participants n'en faisant pas du tout. Le comportement des participants était influencé par plusieurs facteurs, classés selon le modèle COM-B du comportement. Pour la capacité physique, les symptômes et/ou complications du diabète et l'âge affectaient la participation à l'activité physique, et l'expérience antérieure en activité physique et en exercice augmentait la capacité perçue. La capacité psychologique était influencée par la conscience et les connaissances limitées des participants sur l'impact du diabète sur la santé osseuse, le manque de sensibilisation aux bienfaits des exercices pour la santé osseuse, et les connaissances existantes sur les effets de l'exercice sur le diabète et la santé. L'opportunité physique était affectée par le manque d'informations et de ressources sur la gestion de la santé osseuse disponibles pour les personnes

atteintes de diabète, et le temps disponible pour participer à l'activité physique. L'opportunité sociale était influencée par la relation du participant avec les professionnels de la santé, le manque de communication sur la santé osseuse de la part des professionnels de la santé, et les normes sociétales liées à l'âge. La motivation réflexive était influencée par le manque de motivation/incitation à faire de l'exercice spécifiquement pour la santé osseuse, les objectifs des participants d'améliorer/maintenir leur santé et leur fonction, et le sentiment de communauté/connexion à travers l'exercice. Enfin, la motivation automatique était affectée par un manque d'intérêt pour les exercices spécifiques à la santé osseuse, les habitudes/routines d'exercice, et la peur de l'hyperglycémie/hypoglycémie liée à l'exercice.

**Conclusion:** Aborder les barrières et les facilitateurs identifiés peut améliorer la participation aux exercices spécifiques à la santé osseuse, réduisant ainsi le risque de chutes et de fractures chez les personnes âgées atteints de diabète. Les interventions futures devraient se concentrer sur des plans d'exercices personnalisés, l'éducation et les systèmes de soutien social pour promouvoir la santé osseuse, la prévention des chutes/fractures et le bien-être général dans cette population à haut risque.

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**Contribution of Authors**

**Rachel Shapiro:** Completed the acquisition, analysis, and interpretation of data, and wrote and edited the original draft

**Jenna C. Gibbs:** Supervision, conception, design, analysis, and interpretation of data, and revised work for important intellectual content

**Sofia Ferreira:** Completed the data acquisition and analysis

**Rosa Proietti:** Completed the data analysis

**Shane N. Sweet:** Reviewed the protocol, and provided important intellectual content

**Suzanne N. Morin:** Conception, design, recruitment of participants, reviewed the grant and protocol, and provided important intellectual content

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**List of Abbreviations**

aBMD: areal bone mineral density

AGEs: advanced glycation end products

BCW: behavior change wheel

BETTER: Behaviors, Therapies, Technologies, and hypoglycemic Risk in Type 1 diabetes

BMD: bone mineral density

COM-B: capability, opportunity, and motivation of behavior

DXA: dual-energy X-ray absorptiometry

HR-pQCT: high-resolution peripheral quantitative computed tomography

IGF-1: insulin-like growth factor 1

IL-6: interleukin 6

LADA: latent autoimmune diabetes in adults

OC: osteocalcin

OPG: osteoprotegerin

PINP: procollagen type 1 N-propeptide

QCT: quantitative computed tomography

RA: rheumatoid arthritis

RAGEs: receptors for advanced glycation end products

RANKL: receptor activator of nuclear factor kappa-B ligand

ROS: reactive oxygen species

T1D: type 1 diabetes

T2D: type 2 diabetes

TNF-alpha: tumor necrosis factor-alpha

TZDs: thiazolidinediones

vBMD: volumetric bone mineral density

## Chapter 1: Introduction

Osteoporotic fractures are a major public health concern associated with excess morbidity and mortality worldwide. The prevalence of osteoporosis increases with age and one in three women and one in five men will have a fracture in their lifetime (Johnell & Kanis, 2006; Osteoporosis Canada, 2021). Age-related reductions in bone mineral density (BMD) and bone strength result in a greater susceptibility to osteoporosis and fragility fracture. Fragility fractures typically occur from minimal to no trauma such as a fall from standing height, and cause pain, impaired mobility, loss of independence, and lower quality of life (Nevitt et al., 1998; Tosteson et al., 2001; Adachi et al., 2002). The prevalence of chronic metabolic diseases such as diabetes also increases with age and can contribute to bone fragility (osteoporosis, fractures), especially in older individuals. In fact, type 1 (T1D) and type 2 diabetes (T2D) represent well-established clinical risk factors for fragility fracture, independent of BMD (Vestergaard, 2007). With a prevalence of 9.5% for T1D and 20% for T2D in adults, it is estimated that around 463 million people have diabetes worldwide (Mobasseri et al., 2020; Sun et al., 2022; Saeedi et al., 2019). Additionally, there is a high prevalence of osteoporosis (27%) in patients with diabetes mellitus (Liu et al., 2023). Although age and duration of diabetes longer than 10 years are well-known predictors of fracture, bone fragility remains an under-recognized complication of diabetes in older adults.

The mechanisms underlying bone fragility in diabetes are complex, with low bone turnover, hyperglycemia, obesity, and insulin resistance contributing to alterations in bone strength and fall and fracture risk in individuals living with diabetes (Ge et al., 2022; Napoli et al., 2014; Shapiro et al., 2020). Meta-analyses demonstrate that individuals with diabetes are at a higher risk of any kind of fracture, compared to non-diabetic controls (Shah et al., 2015; Moayeri et al., 2017). Mechanistically, chronic hyperglycemia can upregulate osteoclast activity, leading to increased bone resorption and potentially, bone loss (Ge et al., 2022). For individuals with T1D, insulin deficiency causes a decrease in insulin-like growth factor 1 (IGF-1) (Shapiro et al., 2020), which is responsible for maintaining bone formation. In T2D, reduced bone turnover, insulin resistance, obesity-induced chronic inflammation and oxidative stress contribute to the degradation of bone tissue (Shu et al., 2012; Napoli et al., 2014; Furst et al., 2016). Notably, BMD is normal or even higher in individuals with T2D than in individuals without T2D. Interestingly, Ho-Pham and colleagues (2018) discovered that T2D was associated with higher trabecular BMD and lower cortical BMD, thus resulting in lower bone strength. In addition, while trabecular BMD was higher in individuals with T2D, trabecular microarchitecture is more porous, and thus weaker, compared to individuals without T2D (Ho-Pham & Nguyen, 2019). In addition, diabetes-related complications such as neuropathy and retinopathy increase the risk of falls (Rasmussen & Dal, 2019). Collectively, these mechanisms place individuals with diabetes at a significantly higher risk of fractures as they age. Due to the association between diabetes and fragility fractures, exercise represents a promising strategy to improve bone health and reduce fall and fracture risk in older adults with diabetes. Multi-component exercise interventions that include progressive resistance and balance training are recommended for fracture prevention due to their positive influence on BMD and fall-related risk factors (Benedetti et al., 2018). Exercise is recommended as a treatment measure to improve cardiometabolic health and blood glucose levels in people with diabetes (Praet et al., 2006). However, clinical trials investigating the effects of exercise interventions on bone strength in individuals with diabetes are sparse (Viggers et al., 2020). Person-centred strategies promoting safe and effective exercise to improve both musculoskeletal and metabolic health are needed to reduce fall and fracture risk in adults with diabetes, especially older individuals. Despite the benefits of exercise and physical activity in maintaining bone health, significant gaps persist in patient care regarding osteoporosis and anti-fracture approaches for older adults with diabetes. Notably, older adults with diabetes do not perceive themselves at risk for falls and fractures, and their participation in bone health-specific exercise (particularly, strength and balance training) is low (Drummond et al., 2022). As well, diabetes-specific tools, resources, and services focused on exercise for fracture and fall prevention are lacking.

Barriers, such as lack of time, resources, and physical limitations, may further hinder older adults' ability to engage in regular physical activity and exercise (Bethancourt et al., 2014). Previous research has investigated the common barriers and facilitators to exercise for older adults, individuals with diabetes, and individuals with osteoporosis. For individuals with diabetes, fear of hypoglycemia and a lack of time, energy, and motivation are the biggest barriers to participating in exercise (Brennan et al, 2021; Drummond et al. 2022). For individuals with osteoporosis, lack of exercise knowledge, fear of injury, and a lack of trust in HCPs are barriers to exercise (Ziebart et al., 2018). However, the unique barriers and facilitators of bone health-specific exercise and fall and fracture prevention amongst older adults with diabetes remain to be identified. Overall, there is limited evidence on how older adults with diabetes perceive exercise as a strategy to manage their bone health, and feasible strategies to deliver interventions to promote safe and effective fall and fracture prevention strategies within this population have not been investigated yet.

The objective of this study was to understand the perspectives and experiences related to exercise for the management of bone health and fall and fracture prevention in older adults with T1D and T2D. Using a qualitative approach involving semi-structured interviews, we applied the

Capability, Opportunity, and Motivation of Behavior (COM-B) Model and the Behavior Change Wheel framework (Michie et al., 2011) to organize codes and categories for behaviors and subsequent interventions related to bone health and fall and fracture prevention within this population. The results of this study will inform the development of a future diabetes-specific bone health intervention focused on exercise and education, which will be tested for its acceptability, usability, and potential efficacy to reduce fall and fracture risk.

## Chapter 2: Literature Review

### 2.1 Osteoporotic and Fragility Fractures

Osteoporosis is a bone disease characterized by low bone mineral density (BMD) and the deterioration of bone microarchitecture, leading to an increased susceptibility to fracture (Johnell & Kanis, 2006). Osteoporotic fractures are common among older adults and are a significant cause of morbidity and mortality worldwide. The prevalence of osteoporotic fracture varies depending on the site of the fracture and the population (Johnell & Kanis, 2006). Osteoporotic fractures include those of the vertebra, hip, wrist/forearm, humerus, femur, rib, and pelvis, with hip fractures typically having the most severe implications (Johnell & Kanis, 2006). Osteoporotic fractures cause pain, impaired mobility, loss of independence, and decreased quality of life (Nevitt et al., 1998; Tosteson et al., 2001; Adachi et al., 2002). Osteoporotic fractures, also often referred to as fragility fractures, result from minimal to no trauma (e.g., a fall from standing height). Osteoporotic fractures are more common in women than men, and the risk increases with age. Over the age of 50, 1 in 5 men and 1 in 3 women will experience an osteoporotic fracture (Johnell & Kanis, 2006; Osteoporosis Canada, 2021). Worldwide, more than 8.9 million osteoporotic fractures occur every year (Johnell & Kanis, 2006).

In addition to the physical implications of osteoporosis, the financial impact causes a significant burden for individuals and the healthcare system. Hopkins and colleagues estimated that the costs for osteoporotic fractures in terms of acute care, prescription drugs, rehabilitation, and long-term care increased by 83% from 2008 to 2016 (Hopkins et al., 2016). As of 2016, the overall cost of osteoporosis in Canada is estimated to be above $4.6 billion dollars (Hopkins et al.). As the demographic of the Canadian population ages, this overall cost will continue to rise.

## 2.2 Risk Factors for Osteoporotic/Fragility Fractures

Over 80% of all fractures in individuals over the age of 50 are caused by osteoporosis (Osteoporosis Canada, 2021). Risk factors for osteoporotic fractures include age, biological sex, calcium and vitamin D intake, physical activity, alcohol consumption, family medical history, previous fractures, medication use such as corticosteroids, and additional medical conditions such as rheumatoid arthritis (Haugeberg et al., 2000; Osteoporosis Canada, 2021).

Primary osteoporosis and secondary osteoporosis are two types of osteoporosis that differ in their causes and risk factors. Primary osteoporosis is the most common form of osteoporosis and is related to the aging process. Primary osteoporosis occurs due to a natural decline in BMD with age and is typically seen in postmenopausal women and older adults of both sexes. This type of osteoporosis is not caused by an underlying medical condition or medication use, but rather by a combination of genetic and environmental factors, including physical inactivity, poor diet, and lifestyle factors like smoking and excessive alcohol consumption (Osteoporosis Canada, 2021). Secondary osteoporosis, on the other hand, is caused by an underlying medical condition or medication use. Secondary osteoporosis is less common than primary osteoporosis and can affect individuals of any age. Certain medications, such as corticosteroids, can also cause secondary osteoporosis (Osteoporosis Canada, 2021).

Age is one of the most significant risk factors for primary osteoporosis. As we age, our bones become less dense and weaker, making them more prone to fractures. Age-related bone loss is characterized by an imbalance in bone remodeling, the process by which old bone is replaced by new bone (Warming et al., 2002). Specific mechanistic effects of aging on bone are further discussed in section 2.3.

Biological sex is another non-modifiable risk factor for osteoporosis. Females have lower BMD than males, and they lose bone more rapidly as they age due to hormonal changes associated with menopause. Estrogen is a hormone that plays an important role in maintaining bone structure by inhibiting bone resorption and promoting bone formation. In females, estrogen levels decline significantly after menopause (typically between the ages of 45-55 years), which can result in rapid bone loss and an increased risk of osteoporosis (Riggs et al., 2002). In addition to differences in BMD, other factors may contribute to sex differences in osteoporosis risk, including differences in body size and shape, muscle mass and strength, and levels of physical activity (Riggs et al., 2002; Howe et al., 2011).

Having a previous fracture is an indicator of osteoporosis and a strong predictor of future fractures (Morin et al., 2014). Prior fracture due to minimal trauma is highly suggestive of underlying osteoporosis (Morin et al., 2014). Therefore, healthcare providers often consider a history of fractures when assessing a person's future risk of fractures.

The most common cause of secondary osteoporosis is linked to the use of corticosteroids, and the extent of bone loss is directly related to the dosage and duration of exposure (van Staa et al, 2002). A daily dose of >5 mg of an oral corticosteroid can cause a decrease in BMD and an increase in fracture risk within 3 to 6 months (van Staa et al., 2002). A broad range of diseases can be treated effectively using oral corticosteroids, which are powerful immunosuppressants. Oral corticosteroids have a negative impact on gastrointestinal calcium absorption and stimulate excess bone resorption through osteoclastogenesis (Patschan et al., 2001). Eventually, corticosteroids impede bone remodeling by reducing the number of osteoblasts and increasing apoptosis of mature osteoblasts and osteocytes (Patschan et al., 2001).

Rheumatoid arthritis (RA) is a chronic autoimmune disease characterized by inflammation and destruction of the synovial joints. Individuals with RA tend to have higher levels of inflammatory cytokines compared to healthy controls, which may explain their increased risk of osteoporosis (Mateen et al., 2017). As corticosteroids are often used as a treatment for chronic inflammation in RA, they may also contribute to bone loss and risk of fracture in this population (Haugeberg et al., 2000). In addition, patients with RA often experience joint pain and stiffness, which can limit their ability to participate in physical activity and exercise, further increasing the risk of osteoporosis (Haugeberg et al., 2000).

To diagnose osteoporosis, the World Health Organization established general categories compared to young, healthy adult BMD norms based on measurements by dual-energy X-ray absorptiometry (DXA). A DXA scan is a medical imaging-based bone density test which measures the mineral content of bone to establish areal BMD (aBMD) and body composition. Dense tissue, like bone, absorbs more X-rays than soft tissue with the lower the aBMD, the greater the risk of fracture. A DXA scan is considered the gold-standard assessment method to diagnose and monitor osteoporosis. Osteoporosis is classified as a value of aBMD 2.5 standard deviations or more below the young, healthy adult mean (T-score <-2.5) (World Health Organization, 2003). As the risk of osteoporosis increases every year for adults, especially beyond the age of 50, it is important for older adults to undergo routine screening of aBMD (in women 65 and older, in men 70 and older) and assessment using the Fracture Risk Assessment Tool (FRAX) (National Osteoporosis Foundation, 2008).

Exercise is a promising strategy for fall and fracture prevention, given its ability to improve muscle and bone strength and functional mobility. Evidence-based physical activity guidelines exist, providing exercise recommendations for the prevention and treatment of falls and fractures (Morin et al., 2023; Giangregorio et al., 2014). The direct effects of exercise on bone health and fracture risk will be discussed in section 2.5.

### 2.3 Changes in Bone Mineral Density with Aging

During the development of the musculoskeletal system during childhood and adolescence, bone modeling predominates. Bone modeling refers to the process of bone growth and shaping on a given bone surface. This process involves the formation of new bone tissue and the removal of damaged bone tissue to accommodate changes in the body's size, shape, and biomechanical demands (Langdahl et al., 2016). Once peak bone mass is achieved, bone constantly undergoes a process known as remodelling. Remodeling is a regenerative process which couples the formation and resorption of bone to maintain BMD and bone strength, repair damage, and adapt to changes in mechanical loading (Demontiero et al., 2012). Bone declines naturally with age in both males and females (Warming et al., 2002). With aging, the balance between bone formation and bone resorption shifts to favour bone resorption (Demontiero et al., 2012). Therefore, aging is associated with a gradual deterioration of bone composition, structure, and function, and a higher likelihood of developing osteoporosis (Demontiero et al., 2012).

Bone loss related to aging is characterized as a decrease in subperiosteal apposition and an increase in endosteal bone resorption (Raisz & Seeman, 2001; Demontiero et al., 2012). Subperiosteal apposition is a process by which new bone tissue is added to the outer or periosteal surface of bone by specialized cells called osteoblasts. Osteoblasts are responsible for synthesizing and secreting the organic matrix of bone tissue. Osteoblasts also secrete collagen and other proteins to form the organic matrix of bone tissue, which is then mineralized to create strong, healthy bone. Subperiosteal apposition is a normal part of the bone remodeling process and is especially important during periods of growth and development (i.e., puberty), when bones are increasing in size and density. Subperiosteal apposition also occurs in response to mechanical stress or injury, which stimulates osteoblast activity and the deposition of new bone tissue (Raggatt & Partridge, 2010). However, during aging, subperiosteal apposition is attenuated by a decrease in mechanical stress/loading and hormonal imbalance and as a result, bone formation is decreased (Raisz & Seeman, 2001).

Endosteal bone resorption is another important component of the bone remodeling process, which allows the body to replace old or damaged bone tissue with new, healthy tissue by the function of osteoclasts. Osteoclasts are large, multinucleated cells that are responsible for breaking down and removing bone tissue. Osteoclasts attach to the bone surface and secrete enzymes and acids that dissolve or resorb the mineralized matrix of the bone tissue. Bone resorption releases calcium and other minerals into the bloodstream, which can be used for other physiological processes throughout the body. Osteoclasts then phagocytize the broken-down bone tissue and remove it from the body. Endosteal bone resorption primarily occurs on the inner or endosteal surface of long bones, such as the femur or tibia. When endosteal bone resorption exceeds bone formation, there is a loss of BMD and bone strength, increasing the risk of osteoporosis and related fractures (Raisz & Seeman, 2001).

Menopause is a natural biological process that occurs in women as they age. It marks the end of a woman's reproductive potential, usually between ages 45 and 55, and is defined as the permanent cessation of menstrual periods (National Institute on Aging, 2021). During menopause, the ovaries stop producing eggs, and there is a decline in the production of estrogen. Estrogen plays a critical role in maintaining BMD by regulating osteoblast and osteoclast activity, inhibiting cell apoptosis, promoting calcium absorption, and regulating cytokine production (Riggs et al., 2002). The loss of estrogen during menopause leads to increased bone resorption (Riggs et al., 2002) and a net loss of bone mass, which if sustained chronically, can lead to osteoporosis. Specifically, estrogen suppresses osteoclast activity by inhibiting the expression of the receptor activator of nuclear factor kappa-B ligand (RANKL) and increasing the production of osteoprotegerin (OPG), a regulatory factor with a strong affinity for RANKL, thus inhibiting bone resorption (Bord et al., 2003). RANKL is a key factor in the differentiation and activation of osteoclasts, while OPG is a decoy receptor that binds to RANKL and prevents its binding to its receptor, RANK, on osteoclasts (Bord et al., 2003). The OPG-RANKL pathway leads to a decrease in osteoclast activity and prevents excessive bone resorption. Estrogen can also reduce the levels of pro-inflammatory cytokines such as interleukin-6 (IL-6) and tumor necrosis factor-alpha (TNF-α) (Girasole et al., 1992). IL-6 and TNF-α are known to promote osteoclastogenesis and bone resorption. Estrogen inhibits the production of IL-6 and TNF-alpha by immune cells and other cells in bone, thereby reducing bone resorption and promoting bone formation (Girasole et al., 1992).

While estrogen is more commonly associated with bone health in women, it also plays an important role in maintaining bone health in men. As men age, both estrogen and testosterone levels tend to decline, which can affect bone health (Turner et al., 1989). Estrogen is mainly produced by the conversion of testosterone to estradiol by the enzyme aromatase (Golds et al., 2017). Like postmenopausal women, men with low estrogen levels can experience a loss of bone mass and an increased risk of fractures. This can occur in conditions such as hypogonadism, in which the testes do not produce enough testosterone and, consequently, not enough estrogen, as well as in aromatase-deficient individuals (Golds et al., 2017; Turner et al., 1989).

## 2.4 Diabetes: An Overview

Diabetes is a chronic metabolic disorder characterized by high blood glucose. Insulin, the hormone that regulates blood sugar, facilitates glucose uptake into cells, and thereby regulates blood glucose levels. Elevated blood sugar or hyperglycemia can result from either insufficient insulin production (as in T1D) or ineffective use of insulin (as in T2D). Generally, individuals who exhibit symptoms of frequent urination, fatigue, unexplained weight loss, blurred vision, and numbness of the extremities will be recommended for diabetes testing by their HCP. Diagnosis of diabetes is characterized by a blood glucose exceeding 200 mg/dL for an oral glucose tolerance test (American Diabetes Association, 2022). As of 2019, it is estimated that 463 million people have diabetes worldwide (Saeedi et al., 2019). Diabetes-induced complications include but are not limited to hypertension, neuropathy, and retinopathy (Rasmussen & Dal, 2019).

T1D is an autoimmune disorder in which the immune system attacks and destroys the insulin-producing cells in the pancreas. The global prevalence of T1D is estimated to be 9.5% (Mobasseri et al., 2020), and is often diagnosed in early childhood or adolescence. As a result, individuals with T1D are dependent on insulin therapy to regulate blood sugar levels. T2D is characterized by insulin resistance and impaired glucose metabolism. Adults between the ages of 45 and 65 are most likely to receive a diagnosis of T2D, and its global prevalence is greater than 20% in older adults, with the highest prevalence being 24% in those aged 75-79 years old (Sun et al., 2022). A third category of diabetes, known as latent autoimmune diabetes in adults (LADA), displays characteristics of both T1D and T2D, such as the presence of autoantibodies and adulthood onset, respectively (Naik & Palmer, 2003). LADA symptoms tend to arise slowly after the age of 30 and is estimated to account for 2-12% of adult diabetes cases (Naik & Palmer, 2003). The diagnosis, treatment, and management of LADA is highly individualistic, making this population complex to categorize in populations for diabetes research.

### 2.4.1 Diabetes and Fracture

Although osteoporosis occurs in all populations, individuals with diabetes mellitus (type 1 and 2) have been shown to have a higher risk of fragility fracture. Individuals with T1D tend to have lower BMD, and therefore, more fragile bones that are prone to fractures (Vestergaard, 2007). Bone loss associated with T1D can be caused by insulin deficiency, chronic hyperglycemia, and oxidative stress from inflammation (Shapiro et al., 2020; Ge et al., 2022). In contrast, individuals with T2D usually have normal or even higher BMD. Fracture risk in older adults with T2D may be explained by the long duration of diabetes, poor glycemic control, certain anti-diabetic medications, and an increased fall risk due to diabetes complications (e.g., hypoglycemia, neuropathy) (Rasmussen & Dal, 2019).

### 2.4.2 Diabetes and Bone Fragility: Mechanistic Link

Several mechanisms may explain the increased risk of bone fragility in individuals with T1D, including imbalanced bone turnover, insulin deficiency, and inflammation. Insulin deficiency in T1D decreases insulin-like growth factor 1 (IGF-1) (Shapiro et al., 2020), which is an important hormone for bone health. IGF-1 stimulates osteoblast activity and bone formation and inhibits osteoclast activity and bone resorption. Therefore, a deficiency in IGF-1 can impair bone formation. Chronic hyperglycemia in T1D can lead to an increase in advanced glycation end products (AGEs), which can stimulate osteoclast activity and bone resorption (Ge et al., 2022). AGEs can also bind to receptors on cells known as RAGEs (receptors for advanced glycation end products), which trigger an inflammatory response, release of proinflammatory cytokines, and the production of reactive oxygen species (ROS). Oxidative stress promotes osteoblast apoptosis, and therefore a decrease in BMD and an increased risk of fractures (Ge et al., 2022).

The mechanistic link between bone fragility and T2D is complex and likely involves several factors, including chronic inflammation, hormonal dysregulation, and anti-diabetic medications. Obesity, which is often associated with T2D, is characterized by a state of chronic low-grade inflammation that can contribute to bone fragility. Adipose tissue produces pro-inflammatory cytokines such as IL-6 and TNF-α, which can increase bone resorption and decrease bone formation (Napoli et al., 2014). Oxidative stress is another potential mechanism linking diabetes, obesity, and bone fragility. ROS are generated in response to obesity and diabetes and can damage bone tissue and impair bone remodeling. In addition, adipose tissue produces hormones, such as leptin and adiponectin, which can affect bone metabolism (Napoli et al., 2014). Leptin's role in bone metabolism is complex, and evidence suggests contradicting effects. Leptin injections in leptin-deficient mice were found to increase bone formation and subsequently, BMD (Bartell et al., 2011). However, Ducy and colleagues (2000) found that bone formation increases in leptin-deficient and leptin receptor-deficient mice. Adiponectin, produced exclusively from fat tissue, has an anabolic effect on osteoblasts while suppressing osteoclasts (Oshima et al., 2005). While obesity is associated with T2D, bone loss in T2D can be independent of body weight. An experimental animal study found an overall decrease in bone formation in the non-obese type 2 diabetic rats versus controls (Fujii et al., 2008). In humans, there is a lower bone formation rate on trabecular, intracortical, and endocortical surfaces alongside reduced mineralized surface area, number of osteoclasts, and mineral apposition rate, which contribute to greater cortical bone porosity and larger spacing in trabecular bone in T2D. The impact of T2D on bone metabolism and reduced bone turnover may be attributed to bone turnover biomarkers, such as osteocalcin (OC) and the amino-terminal propeptide of procollagen type 1 (PINP). Both OC and PINP are markers of bone formation. OC is a protein produced by osteoblasts during the formation of the bone matrix. Similarly, PINP is a peptide synthesized during the formation of type 1 collagen, which is a component of the bone matrix. Serum levels of these biomarkers have been found to be decreased in patients with T2D (Shu et al., 2012). Both biomarkers indicate the rate of bone formation via concentration in the blood, therefore when their levels are low, this can indicate decreased bone formation, as seen in T2D. Hyperglycemia resulting from insulin resistance in T2D can also impair bone formation and bone health. Similar to T1D, chronic hyperglycemia can cause a higher concentration of AGEs, thus increasing pro-inflammatory cytokine release causing inflammation and skeletal fragility. Furst et al. (2016) identified a decrease in bone material strength in postmenopausal women with T2D may be associated with an accumulation of AGEs, since the inverse relationship of AGEs and bone strength was not found in the control group.

Meta-analysis results suggest that both diabetes types are at an increased risk of fracture, especially at the hip, regardless of BMD (Vestergaard, 2007). Individuals with T1D have a lower BMD while those with T2D have normal, and sometimes even higher, BMD (Tuominen et al., 1999; Vestergaard, 2007). A cross-sectional study using DXA compared participants with and without T1D and found lower whole body and lumbar spine BMD in the T1D group (Joshi et al., 2013). A meta-analysis of epidemiological studies using DXA to measure BMD in T1D versus healthy controls suggested an association between T1D and lower BMD at five measured sites (Pan et al., 2014). Body weight is often higher in patients with T2D, therefore if bone trauma occurs (via falls), the additional mass could cause a greater traumatic load on the bones (Vestergaard, 2007). However, some studies have shown that normal or higher BMD in T2D may have a protective effect on bone (Vestergaard, 2007).

Advanced imaging studies reveal substantial deterioration in bone quality and strength that contribute to bone fragility in diabetic populations. Shanbhogue et al., (2015) utilized high-resolution peripheral quantitative computed tomography (HR-pQCT) to identify that volumetric bone mineral density (vBMD) was lower in T1D adult patients in comparison to age-, gender-, and height-matched controls. Additionally, biochemical markers of bone turnover, such as OC, were lower in T1D patients, which might contribute to the increased skeletal fragility observed in these individuals. Sewing and colleagues (2022) also used HR-pQCT to assess individuals with long-standing T1D (disease duration ≥25 years) and found lower cortical thickness and cortical vBMD at the tibia. Additionally, reduced bone strength and stiffness in the tibia were attributed to the presence of diabetic neuropathy, possibly contributing to increased fracture risk (Sewing et al., 2022). Using HR-pQCT, Patsch et al., (2013) identified a 4.7-fold greater relative porosity at the distal radius in postmenopausal women with T2D and fragility fractures compared to those without T2D. Overall, their results suggested that deficits in stiffness and cortical bone quality were contributing factors of the fragility fractures in postmenopausal women with T2D. Pritchard et al., (2012) compared trabecular bone microarchitecture of the distal radius of postmenopausal women with T2D versus controls. When comparing the size of the marrow spaces in the trabecular bone, they found that those with T2D had larger holes within the trabecular bone network, which may explain the elevated fracture risk in this population.

Some medications used to treat T2D, such as thiazolidinediones (TZDs), can have negative effects on bone health (Schwartz et al., 2006; Meier et al., 2008). TZDs are a class of medication used to treat T2D by increasing the body's sensitivity to insulin to lower blood sugar levels. Schwartz et al. (2006) found that the long-term use of TZDs in older adults with diabetes was linked with additional bone loss, specifically in females. A nested case-controlled analysis by Meier and colleagues (2008) identified that diabetic individuals using TZDs had a 2-3-fold increase in risk of hip and non-vertebral osteoporotic fracture.

### 2.5 Diagnosis and Management of Bone Fragility in Diabetes

Osteoporosis can often present with no symptoms; therefore, many individuals are only diagnosed after a fracture occurs. To screen for osteoporosis, an HCP will first assess a patient's risk factors including age, fracture, medical history, medication use, and lifestyle. Subsequently, the patient will be sent for a DXA to determine whether their aBMD meets the criteria for osteoporosis. Although age and chronic medical conditions are risk factors for osteoporosis, bone fragility is often disregarded as a complication in patients with diabetes. Certain individuals with diabetes present with a higher risk of fracture than others, particularly older individuals, those with a long-standing diabetes diagnosis, and individuals with chronic complications.

Although DXA is the traditional gold standard for screening of BMD for osteoporosis, different three-dimensional imaging techniques, such as quantitative computed tomography (QCT), can be implemented to assess the quality, density, and microcomposition of bone in individuals with diabetes (Carballido-Gamio, 2022). DXA scans measure BMD in two dimensions. QCT scans allow for three-dimensional scanning of the trabecular bone's volumetric density, which is where most bone remodelling occurs.

Since low aBMD is a critical component of an osteoporosis diagnosis, the discrepancy in aBMD depending on diabetes type requires consideration. Standard osteoporosis diagnosis criteria are more applicable in individuals with T1D, who usually have low BMD. Strotmeyer et al. (2006) measured BMD by DXA and found that premenopausal women with T1D had significantly lower total hip, femoral neck, and whole-body BMD compared to premenopausal women without diabetes. Those with diabetes were also more likely to report a fracture, in comparison to their counterparts without diabetes (Strotmeyer et al., 2006). However, the relatively higher aBMD in individuals with T2D presents a challenge for identifying bone fragility since a smaller proportion of these individuals will have a BMD T-score meeting the criteria for osteoporosis (T-score ≤ -2.5) than among those without diabetes (Schwartz et al., 2011; Schacter & Leslie, 2017). Importantly, despite individuals with T2D not being classified as having osteoporosis, participants with T2D have been shown to have an increased fracture risk compared to those without T2D (de Liefde et al., 2005).

Interestingly, many individuals with diabetes are not aware of the impact and severity of diabetes on their bone health. Drummond et al. (2022) administered a survey to over 400 adults with diabetes (≥50 years old) and found that most participants did not perceive diabetes to increase their chances of experiencing fractures or falls. Of the same surveyors, over 90% reported that their doctors had not discussed their risk of diabetes-related fractures (Drummond et al., 2022). In another survey of 450 patients with T2D, only 33% were found to have a high level of osteoporosis knowledge and knowledge gaps regarding the importance of weight-bearing exercise for bone health were evident (Abdulameer et al., 2019). Therefore, although diabetes is a known risk factor for fragility fractures amongst HCPs, individuals with diabetes demonstrate a lower perception of bone fragility risk and are less likely to receive a DXA scan evaluation, obtain a formal diagnosis of osteoporosis, or receive osteoporosis treatment after experiencing a fragility fracture (Ross et al., 2022). As a result, patients with diabetes are also more likely to sustain a secondary fracture within two years (Ross et al., 2022). Therefore, bone fragility is often overlooked as a secondary complication of diabetes, resulting in a care gap for high-risk individuals.

From an intervention standpoint, no randomized clinical trials have directly evaluated the anti-fracture efficacy of osteoporosis treatment, like exercise, in patients with diabetes, and therefore, management is largely based on empirical knowledge and physician experience (Ferrari et al., 2018). Exercise plays an important role in both osteoporosis and diabetes management; however, the intersecting population of older adults with diabetes and osteoporosis requires precise considerations for the design and delivery of exercise to manage bone health.

### 2.6 Exercise and Bone Health

It is widely accepted that exercise-induced mechanical loading increases bone mass, and enhances osteoblast activity (Turner & Robling, 2005). Weight-bearing exercise, involving moderate-to-high magnitude loads (≥2-4 times body weight) and multidirectional movements, is considered most effective at inducing bone responses (Robling et al., 2001). Progressive resistance training is as an effective strategy to maintain bone strength via the direct pulling action of muscle on bone. Howe et al. (2011) summarized evidence from randomized control trials evaluating the effects of exercise versus no exercise on aBMD in postmenopausal women to consolidate the best type of exercise for preventing osteoporosis. They found a statistically significant, although small, improvement in aBMD in participants following aerobic exercise, resistance exercise, or walking programs, compared to controls/no exercise. A meta-analysis of the effect of exercise interventions on falls and fractures for older individuals found that resistance exercise training in combination with balance training was associated with the most significant decrease in falls and fractures (Wong et al., 2020). Resistance training, especially of the lower limb muscles, also leads to improvements in balance, mobility, and physical function (Howe et al., 2011). Substantial evidence supports the effectiveness of balance exercises, such as Tai Chi, in reducing the rate of falls (Thomas et al., 2019; Chen et al., 2023). For individuals with osteoporosis and vertebral fractures, a combination of resistance and balance training is recommended, and high-impact exercises should be avoided to mitigate fracture risks (Giangregorio et al., 2014).

### 2.7 Exercise and Diabetes

Physical activity is also effective for individuals with diabetes as it can improve blood glucose levels, blood pressure, body weight, and aid in the prevention and treatment of diabetic complications (Praet et al., 2006; Lu & Zhao, 2020). Bohn and colleagues (2015) found that individuals with T1D participating in physical activity at least once a week had improved cardiovascular function and blood glucose levels than those who were not physically active. Additionally, they found an inverse association between physical activity and occurrence of retinopathy in adults with T1D (Bohn et al., 2015). Praet et al. (2006) demonstrated that moderate-intensity exercise had a significant impact on glucose levels in long-standing, insulin-treated patients with T2D as the prevalence of hyperglycemia decreased within 24 hours. These findings suggest that regular exercise could effectively regulate blood glucose homeostasis in patients with T2D. However, limited research exists regarding the effects of exercise on bone health for both types of diabetes in older adult populations (Viggers et al., 2020). For individuals managing diabetes, exercise prescription should consist of aerobic and resistance exercise (Howe et al., 2011). Diabetes Canada highlights the benefits of regular physical activity, such as weight management, improved body composition, blood sugar management, and reduced complications of diabetes. In addition, flexibility and balance-enhancing activities are highly recommended for fall and fracture prevention (Thomas et al., 2019). It is imperative that older adults with diabetes, who are at risk for bone fragility, follow an individualized exercise program under professional guidance. However, most older adults with diabetes do not receive adequate guidance or education regarding their bone health, which underscores the importance of tailored exercise programs for fall and fracture prevention, especially for this population.

## 2.8 Barriers and Facilitators to Exercise in Older Adults with Diabetes and Osteoporosis

There are various barriers and facilitators to exercise unique to individuals with osteoporosis as well as older adults with diabetes. In a systematic review, Rodrigues and colleagues (2017) summarized the main barriers to exercise in patients with osteoporosis to be environmental factors (e.g., lack of time and transportation). Through focus groups and interviews, Ziebart et al. (2018) categorized barriers and facilitators to physical activity in 240 community-dwelling patients with osteoporosis using the COM-B Model. Their results included barriers in capability: disease-related symptoms affecting physical activity participation, a gap in physical activity knowledge, low self-efficacy for exercise; opportunity: access to individualized exercise programs, limited access to resources and time, physical activity preferences; and motivation: fear of injury, incentives to exercise, and trust in HCP. Of these results, the barriers of knowledge gaps, fear of injury, and lack of trust in HCPs were deemed unique to patients with osteoporosis (Ziebart et al., 2018). In a scoping review of 46 studies exploring barriers/facilitators of physical activity participation of individuals with T1D, the most common barrier to exercise for adults with T1D was hypoglycemia/the fear of hypoglycemia, followed by time, energy, motivation, and health professional support or advice (Brennan et al, 2021). Vilafranca Cartagena et al. (2021) organized the factors that influenced physical activity in patients with T2D into 7 categories and included barriers and facilitators. Socio-demographic factors such as age, disease duration, weight and biological sex. Personal factors such as education, lack of time, hypoglycemia, and habits. Motivation was in itself a factor, with a lack of being a barrier. Social support from HCPs and family worked as a facilitator while a lack of recommendation and information as well as a lack of access to facilities provided an obstacle to physical activity. Depression was identified as a mental barrier while pain and muscle/joint fatigue were categorized as clinical barriers. Lastly, they identified self-efficacy as a factor of physical activity facilitation (Vilafranca Cartagena et al., 2021). Drummond et al. (2022) identified lack of motivation, lack of energy, and physical limitations due to health, to be the leading barriers to exercise for older adults with diabetes.

Additionally, participation in bone health-specific and fall and fracture prevention exercises such as strength and balance exercises in older adults is also often low. Prince and colleagues (2023) found that the prevalence of older adults, 65 years and above, meeting balance exercise recommendations in Canada was only 16%. Additionally, results from the 2009 New South Wales Fall Prevention survey concluded that of older adults (≥65 years), only 12% reported participating in strength training and only 6% participated in balance training (Merom et al., 2012). The low participation in strength and balance exercise can possibly be attributed to a variety of factors. Burton et al. (2017) conducted a systematic review to describe the common barriers that older adults have regarding resistance training. Along with common physical activity/exercise barriers such as fatigue, lack of confidence, lack of time, fear of heart attack, stroke, or death during resistance training, and fear of appearing too muscular were deemed unique barriers to resistance training in older adults. For participation in fall-prevention activities, a significant barrier for older adults is the fatalistic view that falls (and possible resulting injuries) are accidental and not preventable (Bunn et al., 2008). Paired with other barriers such as underestimation of the risk of falling and stigma surrounding programs targeting older individuals (Bunn et al., 2008), older adults are less likely to participate in bone health-specific and fall and fracture prevention exercises. Therefore, the unique barriers and facilitators of bone health-specific strength and balance exercises amongst older adults with diabetes remain to be identified.

### 2.9 Capability, Opportunity, and Motivation of Behaviour Framework

In order to better understand human behaviours and how they can be changed, the Capability, Opportunity, and Motivation of Behaviour (COM-B) framework was proposed by Michie et al. (2011). The COM-B framework provides the explanation that behaviour is affected by three core factors: capability, opportunity, and motivation. Of the core factors, there are six subcategories: 1) physical capability, 2) psychological capability, 3) physical opportunity, 4) social opportunity, 5) reflective motivation, and 6) automatic motivation. Understanding these core factors enables the construction of theory- and data-driven interventions for behaviour change. In addition to COM-B, Michie and colleagues (2011) developed the Behaviour Change Wheel to further provide a framework that could be used to effectively and consistently understand and categorize behaviours, select behaviours to change, identify intervention options, and find techniques to implement such interventions for change. This process provides a systematic way of designing interventions by integrating mechanisms through which behaviours occur. The broad core factors encourage researchers to deliberately analyze behaviours in order to select the proper types of interventions, and therefore policies, to implement using theory. Therefore, increasing the consistency and validity of intervention planning and testing in future research using this methodological approach (Howlett et al., 2019). For exercise participation, understanding the drive of certain behaviours is crucial for physical activity implementation. Barrett et al. (2022) interviewed adults who had completed physical activity coaching to understand the participants' barriers, experiences, perspectives, and reflections on the program using COM-B. The researchers were able to identify the underlying drives behind participant behaviours using the six subcategories (except physical capability) as a way to reflect on the success of the physical activity training intervention and changes to be made. In the context of bone health and physical activity, after identifying barriers and facilitators of bone-specific physical activity in adults with osteoporosis, Ziebart and colleagues (2018) categorized themes into capability, opportunity, and motivation. Using the COM-B framework and Behaviour Change Wheel, intervention tactics were clearly identified for recommendation, leading to higher potential for a successful intervention in the future. Before implementing guidelines for bone-specific exercises for older adults with diabetes, it is beneficial to analyze patient behaviours related to exercise for the management of bone health and fall and fracture prevention in order to identify how these behaviours can be changed to encourage and increase bone-specific physical activity participation in this population.

**2.10 Knowledge Gaps and Rationale**

Osteoporotic fracture and diabetes are major public health problems associated with significant morbidity and mortality worldwide. Diabetes prevalence increases with age, and often co-exists with osteoporosis in older adults. However, bone fragility remains an under-recognized complication of diabetes in older adults and diabetes-specific tools, resources, and services focused on exercise for fracture and fall prevention are lacking. Exercise is a promising strategy for fall and fracture prevention, given its ability to improve muscle and bone strength and functional mobility. Yet, the benefits of exercise to reduce the risk of falls and fractures are not emphasized in existing exercise guidelines for people with diabetes and participation rates in bone-specific exercise (e.g., resistance and balance training) are low (Drummond et al., 2022). Diabetic complications (e.g., hypoglycemia, neuropathy, macro- and microvascular disease) may also be responsible for increased fracture risk through an increased risk of falls. Thus, significant uncertainty exists regarding diabetes-specific determinants of fracture risk, which further complicates osteoporosis management in older adults with diabetes. This emerging area of research is fundamental to reducing the burden of osteoporotic fractures and diabetes in Canada's aging population, in addition to targeting improvements in outcomes that are important to older adults, including their musculoskeletal health, mobility, and quality of life. Therefore, the objective of this qualitative study is to examine the perspectives and experiences related to exercise for the management of bone health in older adults with T1D and T2D. Specifically, we are interested in better understanding the behaviours related to bone health in older adults with diabetes so that we can identify safe and effective intervention options to reduce fall and fracture risk in this high-risk population. With the combined work of our research and specialists in the field of kinesiology and metabolic diseases, older adults with diabetes will have the chance to receive the proper treatment for the maintenance of their bone health.

## Chapter 3: Methods

### 3.1 Study Design

We conducted a qualitative study from a post-positivism perspective (Bradbury-Jones et al., 2017; Clark, 1998). Our study adheres to the COREQ reporting guidelines for qualitative research (Tong et al., 2007). Individual semi-structured interviews with older adults diagnosed with T1D and T2D were used to collect the data and a directed content analysis was performed. This research was primarily conducted through the lens of the lead researchers' (RS) experiences as a White cisgender woman and Canadian Master's student with an academic background in Kinesiology and Health Sciences. The study received ethics approval through the McGill University Health Centre Research Ethics Board. The protocol for this study entailed the inclusion of individuals with both T1D and T2D; for this thesis, we presented a preliminary analysis of only the T1D participants since recruitment for participants with T2D is still ongoing.

### 3.2 Definition of Concepts

When designing the interview guide, probing participants, and analyzing results, the terms 'physical activity, 'exercise', 'bone health-specific exercise', and 'bone health' were used as a way to better understand the participants' perspectives and experiences. We broadly define physical activity as any bodily movement which encompasses a wide range of activities, from unstructured daily tasks such as walking, gardening, and housework to more structured forms of movement like sports and recreational activities. Exercise is a subset of physical activity that is planned, structured, and repetitive, aimed at improving or maintaining one or more components of health and fitness. Exercise is specifically designed to improve cardiovascular health, muscle and bone strength, flexibility, and balance. Bone health-specific exercise is a form of physical activity specifically designed to improve bone health by directly increasing BMD and bone strength and reducing fall and fracture risk. These exercises typically involve weight-bearing aerobic and resistance activities that apply mechanical stress to the bones, stimulating bone formation and reducing the risk of osteoporosis and fractures, and functional and balance exercises that reduce the risk of falls. Examples of bone health-specific exercises include weightlifting, resistance band or body weight callisthenic exercises, walking, running, jumping, yoga, pilates, moderate-to-high-impact loading-based sports (e.g., racquet sports) and Tai Chi.

### 3.3 Recruitment and Screening

Adults (≥50 years of age) with T1D and T2D were recruited through local diabetes clinics, social media, patient-oriented organizations (i.e., Canadian Osteoporosis Patient Network, Diabetes Canada, Diabetes Quebec), and patient partners affiliated with members of our research team. We also sent our recruitment flyer by email to eligible members of the BEhaviors, Therapies, TEchnologies and hypoglycemic Risk in Type 1 diabetes (BETTER registry), a cohort of people living with T1D, and posted our advertisement on their social media pages and website. We included individuals if they were: 1) ≥50 years, and 2) diagnosed with T1D or T2D. Eligible participants must have had a diabetes diagnosis for at least 10 years, at least one diabetes complication, and/or a diagnosis of osteoporosis, a history of fragility fracture, and/or a fall in the past year (Picke et al., 2019). Once potential participants contacted the lab, they were purposefully selected in order to ensure variability and diversity in perspectives and experiences. While both diabetes types were recruited, the sample for this thesis included only individuals with T1D. We recruited 11 participants to allow a deep understanding of the participants' lived experiences and aimed to achieve equal numbers of men and women since patients may have different exercise barriers and preferences, and health behaviours depending on gender. The future final sample size will also aim for equal numbers of each diabetes type. Participants had to be able to verbally communicate in English or French.

Prior to study participation, a research team member contacted potential participants by telephone to screen for eligibility and explain the project and their responsibilities as a participant. If the individual was eligible and interested in participating, informed consent was obtained from each potential participant by reviewing a detailed information letter and signing an electronic consent form. We continued sampling until we collected sufficient data to enable an adequate understanding of the perspectives/experiences and properties of our key concepts.

### 3.4 Descriptive Survey

A demographics and health history questionnaire was administered electronically to each participant through the LimeSurvey system to obtain information on the participants' age, sex, gender, medical history, education level, and lifestyle behaviours (i.e., physical activity, calcium, and vitamin D supplementation), including questions from the validated Physical Activity Scale for the Elderly questionnaire (Washburn et al., 1993). Participant characteristics and outcomes were summarized using descriptive measures: mean (standard deviation) or median (minimum-maximum or interquartile range) for continuous variables and number (percentage) for categorical variables.

### 3.5 Interview Guide

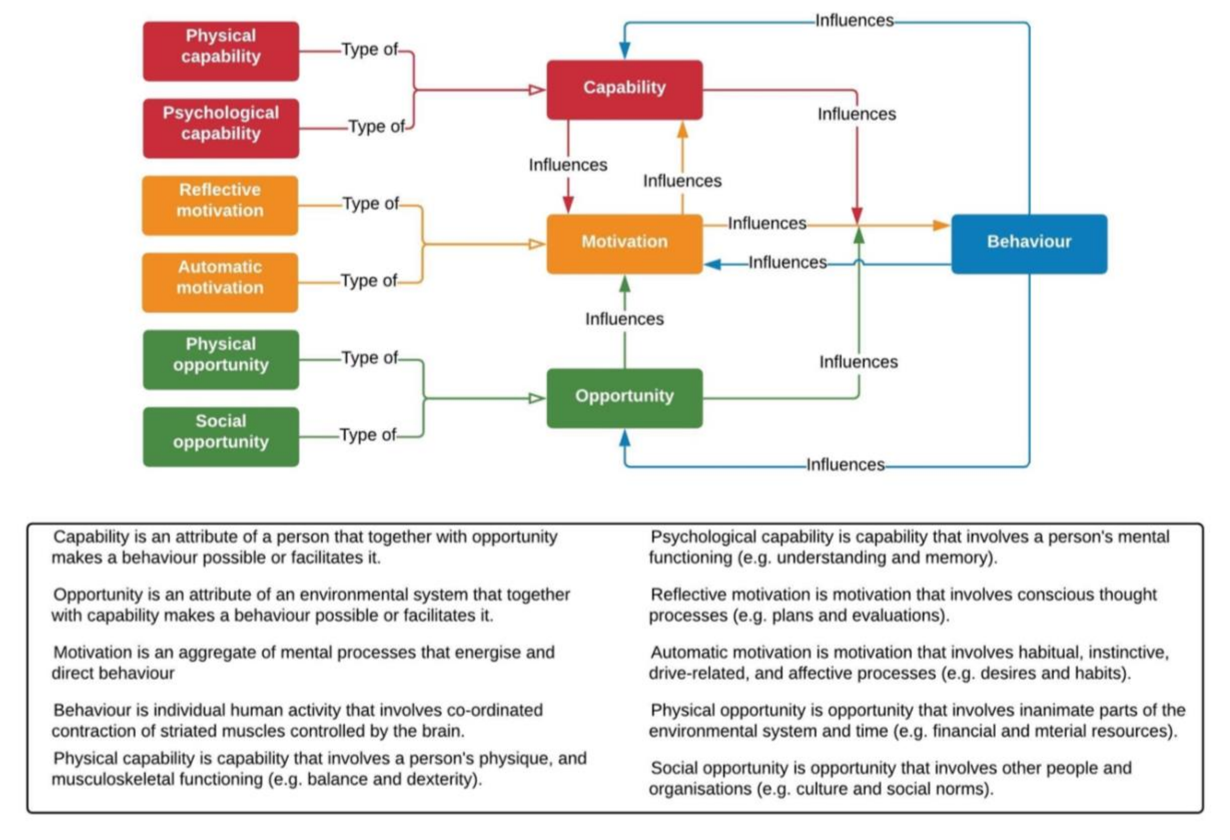
We conducted semi-structured interviews with each participant individually. Questions in the interview guide were informed by the Health Belief Model (Rosenstock et al., 1988), the COM-B model of behaviour framework (Michie et al., 2011), and results from our recent survey study (Drummond et al., 2022) and included prompts to ensure meaningful and in-depth responses. The semi-structured interviews were conducted by an interviewer (in English by RS, in French by SF) either via Microsoft Teams web conference or by telephone, and the duration of the interviews ranged from 30 minutes to 1 hour. The interviews contained questions regarding the participant's experiences managing their diabetes and bone health, their experiences participating in exercise, and factors that prevent/facilitate bone health-specific exercise (e.g., Which factors can get in the way and prevent you from exercising to manage your bone health?). We targeted mainly six areas of the COM-B model: 1) physical capability, 2) psychological capability, 3) physical opportunity, 4) social opportunity, 5) reflective motivation, and 6) automatic motivation. In addition, all participants were questioned about their opinions and preferences for future tools and services that could be used by HCPs to provide online programming involving exercise and education to manage bone health in people with diabetes (e.g., How do you feel about participating in an online program in a group? Would you prefer attending with a family member, friend, or caregiver?). Interviews were audio-recorded and transcribed verbatim. Interviews conducted in French were first transcribed in French and then translated into English to be coded. The interviewer also recorded their perception and contextual impression of the interview in a reflective journal.

### 3.6 Directed Content Analysis

Two reviewers conducted directed content analyses of the interviews, as described by Assarroudi et al. (2018) to systematically analyze and interpret the data within the context of the COM-B model of behaviour framework proposed by Michie et al. (2011). Directed content analysis is particularly well-suited for our research objectives as it allows us to focus on pre-existing concepts and theories while examining the transcription data. The COM-B framework suggests that behavior is influenced by three core components: Capability, Opportunity, and Motivation, each of which has sub-components. Capability encompasses Psychological Capability (awareness, knowledge and skills) and Physical Capability (physical ability). Opportunity includes Physical Opportunity (external factors) and Social Opportunity (social influences). Motivation involves Reflective Motivation (conscious decision-making) and Automatic Motivation (emotional and habitual responses) (**Figure 1**) (Michie et al., 2011; West & Michie, 2020). As such, the COM-B main categories and subcategories served as the categorization matrix for the coding process following transcription. We analyzed the transcripts, coding the participant's answers based on meaning and intent while considering context – these were our preliminary codes. These codes translated the transcription data from participants into organized data that was then categorized into the main categories of COM-B; comparison was done continuously alongside data analysis. A hybrid inductive/deductive approach (Fereday & Muir-Cochrane, 2006) was used for the coding and content analysis. Initially, transcripts were inductively coded to analyze the data and contextualize participants' perspectives and experiences. These codes were organized into the COM-B model. This methodological approach allowed for data-based codes to be categorized into a theoretical framework as a way to capture the reasoning for certain behaviours using theory. Two reviewers (RS as first for all transcripts; SF, RP, or JG as second) used NVivo coding software to code and organize, as well as clearly present the connection between raw data, the categorisation matrix, and the main findings. All reviewers read and familiarized themselves with primary COM-B (Michie et al., 2011) and qualitative research literature (Charmaz, 2014) as training to prepare for interpretation of codes and mapping during the content analysis. We conducted our analyses on a rolling basis and held regular peer debriefing sessions after every 3-4 interviews to deliberate and facilitate discussion amongst reviewers and achieve adequate understanding of the codes. First reviewer, RS, presented codes during the sessions and secondary coders had the opportunity to comment on the consistencies and differences. If there were any differences, the reviewers arbitrated until we reached agreement on the final codes. We maintained an audit trail during data collection and analysis to improve the results credibility and minimize biases (Forero et., 2018).

**Figure 1**

*The COM-B Model of Behaviour*




*Note.* © 2020 Robert West et al. Adapted from "A brief introduction of the COM-B Model of behaviour and the PRIME Theory of motivation," by R. West and S. Michie, 2020, Qeios (https://doi.org/10.32388/WW04E6.2) CC BY 4.0

## Chapter 4: Results

### 4.1 Descriptive Characteristics

A total of 24 individuals were screened regarding participation in the study. Two were deemed not eligible due to having a diabetes diagnosis less than 10 years, and one participant although deemed eligible, did not sign the consent form and therefore, we did not proceed with the study. Once we reached 10 eligible participants, we began to purposefully recruit participants with either a diagnosis of osteoporosis or a history of falls/fragility fracture in order to gain the perspective of individuals with potential experience in bone health management. We screened 11 more participants, ten of which did not have a diagnosis of osteoporosis or history of falls/fragility fracture and therefore were not included, and one did have a diagnosis of osteoporosis and therefore was included. Our qualitative study included 11 participants with T1D with a mean age ± standard deviation (SD) of 60 ± 7.5 years (**Table 4.1**). Of these, five identified as men and six identified as women, and self-identified gender corresponded to biological sex at birth for all participants. Ten (91%) participants identified as White/Caucasian, and 1 (9%) identified as Métis. Twenty-seven percent had a high school diploma, 55% had a bachelor's degree, and 18% had a graduate degree. All participants had T1D with a mean ± SD age of diabetes diagnosis at 16 ± 11.0 years. All participants were on insulin therapy, and 36% reported having diabetes complications such as kidney disease (n=2), eye damage (n=2), heart disease (n=2), high blood pressure (n=1), nerve damage (n=1), or mental health disorders such as anxiety or depression (n=1).

Among the participants, 4 (36%) had had a DXA scan, and only one (9%) participant had a diagnosis of osteoporosis (**Table 4.2**). In the past six months, 2 (18%) participants had experienced a fall. Ten (91%) participants recorded engaging in bone health management strategies such as taking calcium (n=2) and vitamin D (n=6) supplements, consuming calcium and protein-rich foods and beverages (n=5), participating in aerobic exercises (n=9), flexibility exercises (n=4), and muscle-strengthening exercises (n=7), and other strategies such as eating lots of dairy products (n=1) and following an Ayurvedic diet (n=1).

Participants reported varying levels of engagement in different types of exercise over the past 7 days. For moderate-intensity aerobic exercise, the majority (64%) participated 3 to 4 days a week, while 27% participated 5 to 7 days a week. Time spent on this activity varied, with most participants (81%) exercising for at least 30 minutes per day. In terms of strenuous aerobic exercise, 54% of participants engaged ≥3 days a week, but 27% did not participate at all. Among those who did, 63% exercised for more than 30 minutes per session. Resistance exercise participation was lower, with 36% never engaging and 36% seldom participating. Only three participants engaged in resistance exercises ≥3 days a week. Balance and flexibility exercises were the least common, with 64% of participants not participating at all. Only 18% engaged in these exercises 3 to 4 days a week, and 9% participated 5 to 7 days a week (**Table 4.3**).

**Table 4.1** Demographic and diabetes characteristics in participants with T1D.

| **Participants' Characteristics** | **Total** <br> ***N* = 11** |
|---|---|
| Age (years), mean ± SD | 60 ± 7.5 |
| Sex, *n* (%) | |
| Male | 5 (45) |
| Female | 6 (55) |
| Gender, *n* (%) | |
| Man | 5 (45) |
| Woman | 6 (55) |
| Race or Ethnicity, *n* (%) | |
| White/Caucasian | 10 (91) |
| Metis | 1 (9) |
| Level of Education, *n* (%) | |
| High School | 3 (27) |
| Bachelor's Degree | 6 (55) |
| Graduate Degree | 2 (18) |
| Type of Diabetes, *n* (%) | |
| Type 1 | 11 (100) |
| Age of Diabetes Diagnosis (years), mean ± SD | 16 ± 11.0 |
| Pharmacological Diabetes Treatment, *n* (%) | |
| Insulin | 11 (100) |
| Presence of Diabetes Complications, *n* (%) | |

| | |
|---|---|
| Yes | 4 (36) |
| No | 7 (64) |
| Diabetes Complications, *n*[1] (%) | |
| Kidney Disease | 2 (18) |
| Eye Damage | 2 (18) |
| Heart Disease | 2 (18) |
| High Blood Pressure | 1 (9) |
| Nerve Damage | 1 (9) |
| Mental Health Disorders (anxiety, depression) | 1 (9) |
| Other | |
| Kidney Transplant | 1 (9) |

[1]Participants could select more than one option in response

**Table 4.2** Osteoporosis, fall history, and bone health characteristics in participants with T1D.

| **Participants' Characteristics** | **Total** <br> ***N* = 11** |
|---|---|
| Previously had DXA Scan, *n* (%) | |
| Yes | 4 (36) |
| No | 7 (64) |
| Presence of Osteoporosis, *n* (%) | |
| Yes | 1 (9) |
| No | 10 (91) |
| Fallen in the Past 6 Months, *n* (%) | |
| Yes | 2 (18) |
| No | 9 (82) |
| Practice Bone Health Management Strategies[1], *n* (%) | |
| Yes | 5 (45.5) |
| No | 5 (45.5) |
| Unsure | 1 (9) |
| Bone Health Management Strategies[2], *n* (%) | |
| Take calcium supplements | 2 (18) |
| Take vitamin D supplements | 6 (55) |
| Eat/drink foods and beverages rich in calcium and protein | 5 (45) |
| Participate in aerobic physical activity | 9 (82) |
| Do balance exercises | 4 (36) |
| Do flexibility exercises | 4 (36) |

| | |
|---|---|
| Do muscle strengthening exercises | 7 (64) |
| Other | |
| Eat a lot of dairy products | 1 (9) |
| Ayurvedic diet | 1 (9) |

*DXA* Dual x-ray absorptiometry
[1]Assessed by participants' response to the question "Do you do anything specifically to keep your bones healthy?"
[2]Participants could select more than one option in response

**Table 4.3** Physical activity and exercise participation in participants with T1D.

| **Participants' Characteristics** | **Total** $N$ **= 11** |
|---|---|
| Moderate Aerobic Exercise ≥10 Minutes at a Time, *n* (%) | |
| Seldom (1 to 2 days) | 1 (9) |
| Sometimes (3 to 4 days) | 7 (64) |
| Often (5 to 7 days) | 3 (27) |
| Hours Per Day of Moderate Aerobic Exercise, *n* (%) | |
| Less than 30 minutes | 2 (18) |
| 30 minutes but less than 1 hour | 3 (27) |
| 1 hour but less than 2 hours | 3 (27) |
| 2 hours but less than 4 hours | 3 (27) |
| Strenuous Aerobic Exercise ≥10 Minutes at a Time, *n* (%) | |
| Never | 3 (27) |
| Seldom (1 to 2 days) | 2 (18) |
| Sometimes (3 to 4 days) | 5 (45) |
| Often (5 to 7 days) | 1 (9) |
| Hours Per Day of Strenuous Aerobic Exercise, *n* (%) | |
| Less than 30 minutes | 1 (9) |
| 30 minutes but less than 1 hour | 4 (36) |
| 1 hour but less than 2 hours | 3 (27) |
| Resistance Exercise, *n* (%) | |
| Never | 4 (36) |

| | |
|---|---|
| Seldom (1 to 2 days) | 4 (36) |
| Sometimes (3 to 4 days) | 2 (18) |
| Often (5 to 7 days) | 1 (9) |
| Balance and Flexibility Exercise, *n* (%) | |
| Never | 7 (64) |
| Seldom (1 to 2 days) | 1 (9) |
| Sometimes (3 to 4 days) | 2 (18) |
| Often (5 to 7 days) | 1 (9) |

## 4.2 COM-B Model of Behaviour

The main codes identified were categorized into the six subcategories of the COM-B Model of Behaviour: physical capability, psychological capability, physical opportunity, social opportunity, reflective motivation, and automatic motivation (**Table 4.4**).

### *4.2.1 Physical Capability*

*Diabetes symptoms and/or complications affecting physical activity participation*

Participants reported that various diabetes-related symptoms and complications, such as high blood glucose, neuropathy, and kidney disease, significantly hindered their ability to engage in physical activities. These complications often were associated with decreased stamina and mobility, making it challenging to participate in certain physical activities and/or maintain a consistent exercise routine. For example, participants mentioned that managing blood glucose levels during and after exercise was particularly difficult, causing them to feel apprehensive about starting or continuing with an exercise program. Participant 2 (Man, 56) stated that "*If I have high blood sugar, it's harder to [exercise]…I have less endurance, less speed, less power… it impacts my abilities. (Participant 2, Man, 56)*

*Age affecting physical activity participation*

Age-related factors, such as reduced physical strength, flexibility, and endurance, further compounded the difficulties faced by participants in maintaining an active lifestyle, particularly affecting participation in exercises that are often recommended for older adults, such as balance and strength/resistance training. They found that "as [they've] aged, the body is deteriorating or slowing down, [the participant is] not able to be as active as [they] used to be… [they've] got shoulder problems now, knee problems, back problems" (Participant 12, Woman, 66). Several participants expressed that these age-related changes affected their exercise routines, often hindering their participation, which created a cyclic pattern of exercising less due to age and therefore feeling less physically capable. Participant 1 (Woman, 59) expressed, "my muscles have also become weaker [with age]… so that's challenging and I need to focus on that more, I haven't started doing that yet".

*Experience in physical activity and exercise*

All participants had some prior experience in physical activity, such as unstructured physical activity, exercising or playing a sport. This experience provided them with the knowledge and confidence to modify physical activity and exercise to suit their current capabilities. Participant 9 (Man, 57) had been physically active since he was young, and after his diabetes diagnosis, he "wanted to make sure that exercise was [still] part of what [he] did because [he] didn't want [his] sugars to go high and [he] wanted it to be easier to control". Additionally, when probed regarding their capability to manage their bone health or follow an exercise program related to bone health and fall/fracture prevention, participants did not perceive themselves as having any physical limitations to do so, yet bone health management was not a priority of their current exercise routines. For example, even after having received a bone density scan, Participant 3 (Man, 78) remained confident that his continuous participation in exercise helped mitigate any significant decrease in bone health.

> *I've obviously managed somehow, and I presume it's just through a reasonable diet and probably exercise too, that I've managed to maintain my bone health in a relatively good condition for a 78-year-old male. (Participant 3, Man, 78).*

#### *4.2.2 Psychological Capability*

*Limited awareness and knowledge about how diabetes affects bone health*

Most participants were unaware of the specific ways in which diabetes could affect their bone health. Furthermore, they lacked information on how diabetes-related factors, such as insulin resistance and inflammation, could contribute to bone fragility and higher fall and fracture risk. We identified that participants lacked awareness; a conscious recognition that diabetes can affect bone health, as well as knowledge; understanding of the specific mechanisms and implications on diabetes on bone health. Awareness is typically established first, in order to gain knowledge. One participant "[didn't] even understand why there's an issue with [her] bones related to diabetes" (Participant 10, Woman, 55). She even asked, "I don't understand, what is the reason being? Why is it related?". Participant 1 (Woman, 59) expressed that there was a "[lack of] education. It's not something you hear, or people think about. The general public has no idea that diabetes affects bone health – a lot of [persons with diabetes] don't know that". This gap in knowledge made it difficult for them to prioritize bone health-specific exercises into their current exercise routines. For example, Participant 2 (Man, 56) shared that "[he] never really thought about [bone health] in the context of [his] diabetes…[he] never really thought of it, and so bone health has never actually been something that was a concern".

*Lack of awareness of the benefits of exercises on bone health*

Participants also expressed a lack of awareness regarding the benefits of exercise on bone health. While they understood the general health benefits of exercise as it applies to maintaining and improving muscle strength, function and balance, they did not fully grasp how exercises like weight-bearing aerobic, resistance, and balance training could strengthen bones and reduce the risk of falls and fractures. Participant 10 (Woman, 55) mentioned that "we talk about how you should train your muscles too, at least 10 minutes…three times a week, or something like that, to manage menopause and the effect of losing muscle. But it isn't very related to the health of the bones". This lack of knowledge highlights the need for targeted education on bone health-specific exercise benefits and how to engage in such exercises in a safe and effective manner.

*Awareness and knowledge about effects of exercise on diabetes & health*

Despite the clear knowledge gaps related to the influence of exercise on bone health, a significant number of participants were aware and possessed knowledge that exercise could positively impact their diabetes management and overall health. They recognized that exercise could help regulate blood sugar levels, improve cardiovascular health, and enhance their quality of life.

> *I've always been aware of the fact that heart disease and stroke are more common with diabetes. So, I've always felt that cardiovascular training is very important, so I've always done a lot of [cardio]. (Participant 1, Woman, 59)*

When asked about his choice of regular physical activity, Participant 14 (Man, 63) said he and his wife take a walk every morning because "we know it's good for us and that's why we do it!". The knowledge and education surrounding the effects of exercise on diabetes and health was evident and participants had a strong psychological awareness and therefore, psychological capability to understand these benefits and engage in exercise for their diabetes management. Participants even expressed a desire for more information on how exercise can benefit their overall health, specifically, their bone health.

### *4.2.3 Physical Opportunity*

*Limited information & resources about bone health management*

Participants reported a lack of accessible information and resources on managing bone health, especially through exercise. Participant 4 (Woman, 53) mentioned that there was information regarding the "circulatory system… [how to] prevent amputations, blindness, kidney failure…[but] there's no messaging there with regards to any impact [diabetes has] on your bones". Participants found the lack of reliable resources on appropriate exercises, nutrition, and other strategies to improve bone health made it challenging for them to implement effective bone health management practices. Additionally, some participants speculated that their HCPs also lacked the resources and education needed regarding diabetes and bone health. For example, Participant 1 shared that "we're not told that we need to look after our bone health and be aware of what's going on… I think a lot of GPs don't know". This overlaps with the category of social opportunity; HCPs have limited information and resources and therefore, do not share the necessary information with patients.

*Time affecting physical activity participation*

Time constraints were a significant barrier to physical activity (including bone health-specific exercise) for many participants. Busy schedules, caregiving responsibilities, and other daily commitments often left little time for exercise. Timing in terms of season and weather was also a common deciding factor for participants when it came to what kinds of physical activities they engaged in and how often. Participant 11 (Woman, 61) shared her biggest barriers to physical activity were "bad weather, number one…number two…work schedule". The external factor of lack of time suggests that patients require flexible access to bone health-specific exercise programing that can be integrated into their busy schedules.

#### *4.2.4 Social Opportunity*

*Relationship with health care providers*

The relationship between participants and their HCPs played a crucial role in their access to bone health management. Supportive and open interactions with HCPs assured participants to trust their physicians' course of action for their treatment plan in regard to bone health. For example, when Participant 14 (Man, 63) inquired about getting a bone density scan, his endocrinologist told him "not unless [you] have a problem", and since he trusted his HCP, he did not feel concerned to probe on the topic of bone health any further. In comparison, Participant 1 (Woman, 59) had an endocrinologist who was knowledgeable in bone health research and had sent her to get bone density scans starting in her twenties. The participant felt more compelled to take care of her diet and keep up her physical activity when her HCP suggested that these good lifestyle choices would improve/maintain her bone health.

> *She found a slight diminishing of bone, but it stayed pretty much the same since then…My doctor seems to think it's because I exercise a lot that I haven't lost a lot of health in my bones…I take calcium, I take vitamin D, mainly for that reason. (Participant 1, Woman, 59)*

Participant 9 (Man, 57) shared that even though his HCP had never mentioned bone health, he would ask, since he has known his endocrinologist for a long time, and he knows he can discuss it with them. When speaking about the implementation of a bone health-specific exercise program, Participant 2 (Man, 56) expressed, "if my endocrinologist gave [a bone health-specific exercise program] to me, I feel I would have immediate trust in the program". This supportive relationship and trust between HCPs and their patients provide a social opportunity where HCPs can offer recommendations and referrals or communicate strategies for how to engage in safe and effective bone health-specific exercises.

*Lack of communication about bone health from health care providers*

Participants highlighted a significant gap in communication from HCPs regarding bone health. They reported that discussions with their physicians/specialists rarely included information on how to maintain or improve bone health, especially through exercise. For example, Participant 4 (Woman, 53) shared that "when [she has] seen two different endocrinologists and [she's] certainly seen the nurse practitioner, but nobody's brought up bone health at all". This lack of communication left many participants unaware of their risk or the steps they could take to maintain/improve their bone health and reduce fall and fracture risk.

*Age-related norms*

Societal norms and expectations related to age influenced participants' willingness and ability to participate in exercise, specifically for bone health. Some participants expressed that aging came with a higher risk of falling and decreased mobility, and therefore tried to avoid exercises that they perceived as a fall/injury risk, such as lifting heavy weights or walking/running outside. Others felt motivated by these norms to remain committed to staying active to avoid typical age-related health decline, such as turning into "a little feeble old lady all hunched over" (Participant 4, Woman, 53). The societal norms that associate with aging are additionally reflected in patients' motivation to improve their health through exercise.

#### *4.2.5 Reflective Motivation*

*Lack of motivation/incentive to exercise for bone health*

Despite recognizing the general health benefits of exercise, participants often lacked specific motivation or incentives to engage in bone health-specific activities, such as weight-bearing aerobic exercises and resistance training. Participant 2 (Man, 56) shared that even when he tells himself "'you need to do this for your diabetes, it's good for your health', [it] does help [him] get out of bed…but not enough". Interestingly, Participant 12 (Woman, 66) who had osteoporosis, mentioned that she "[has] not focused in on [bone health] at all…it hasn't been at the top of [her] list of things to think about and worry". Even with an osteoporosis diagnosis, the participant lacked motivation to follow any exercise regimes focused on bone health since it was not a priority. This finding suggests that targeted motivation and support to prioritize bone health-specific exercises, such as weight-bearing aerobic, resistance, and balance training, within their broader exercise regimen is required.

*Goals of improving/maintaining health & function*

All participants were highly motivated to exercise by their desire to improve or maintain their health and functional abilities, such as strength, stability, flexibility, mental health, mobility, and weight management. They recognized that engaging in physical activity could help them achieve these goals, leading to better diabetes management, enhanced mobility, and overall well-being. These goals varied from person to person and depended on many factors such as previous health complications, identity in sport/physical activity, and personal health status.

*I like to be fit, I like to be active…I like to know that if I walk onto a tennis court, volleyball, basketball court, that I can perform the skills similar to the way I used to perform them, and that's all balance and body dynamics. (Participant 9, Man, 57)*

This motivation was a strong facilitator for many participants to incorporate exercise into their routines and could be used to incentivize patients to participate more in bone health-specific exercises in the future.

*Sense of community/connection through exercise*

Participants valued the sense of community and connection that came from participating in group exercises or activities. This social aspect of exercise provided additional motivation and made the experience more enjoyable. Group activities helped participants stay committed to their exercise routines and provided a supportive environment to share challenges and successes. Participant 2 (Man, 56) expressed how he began attending workout classes at a gym that contained exercises, such as weightlifting, that he usually did not find interesting. However, the community of the new workout class motivated him to partake:

*What motivated me is that I go to the gym, and someone tells me what to do and they create a feeling of community. So, I feel like I'm belonging to something. (Participant 2, Man, 56)*

### ***4.2.6 Automatic Motivation***

*Lack of interest in bone health-specific exercises*

Interest in physical activity/exercise or lack thereof was a strong determinant of a participants' motivation to partake in bone health-specific exercises. Participants showed varying levels of interest in bone health-specific exercises. Participant 10 (Woman, 55) had tried to introduce muscle-strengthening exercises into her routine, but she was not motivated and stopped because she just did not enjoy it: “Honestly I hate doing exercises for the muscles!” On the other hand, Participant 14 (Man, 63) became very interested in Tai-Chi, and therefore continued to include the balance-specific exercise in his routine. This variation in interest highlights the importance of providing diverse and engaging exercise options to meet individual preferences and needs.

*Exercise habit/routine*

Established exercise routines and habits were beneficial for maintaining consistent physical activity as it seemed to unconsciously motivate patients. Participants who had developed regular exercise habits found it easier to stay active and incorporate new exercises into their routines. For example, Participant 2 (Man, 56) said “[his] diabetes is easier to manage when [he] is exercising consistently… [and he] think[s] it might has something to do with routine”. Participant 11 (Woman, 61) shared that even when she did not feel confident in her abilities to do muscle-strengthening exercises, them being a part of her routine kept her motivated to do them. These habits could serve to help participants overcome barriers related to time and motivation.

*Fear of hyperglycemia/hypoglycemia related to exercise*

Fear of experiencing hypoglycemia or hyperglycemia during or after exercise was a significant barrier for many participants. This fear often led to hesitation or avoidance of physical activity and exercise, as participants were concerned about managing their blood glucose levels. For example, for Participant 2 (Man, 56), “exercise is the one time that [he] ever worr[ies] about having a blood sugar low”. For Participant 8 (Man, 52), “it’s a challenge to stay active and especially when doing so, [it] is very challenging for [his] blood sugar control”. The barrier of the fear of hypo- or hyperglycemia related to exercise is quite unique to individuals with diabetes, and therefore needs to be strongly considered when implementing a bone health-specific exercise program that may include exercises that the participants are not used to and do not know how their blood glucose will be affected.

**Table 4.4** Mapping main codes to intervention functions using COM-B and BCW Frameworks

| **COM-B Components** | **Main Codes** | **Is there a need for change?** | **BCW Interventions** |
|---|---|---|---|
| Physical Capability | 1. Diabetes symptoms and/or complications affecting physical activity participation<br>2. Age affecting physical activity participation<br>3. Experience in physical activity | Yes: individuals age, health status, and level of experience needs to be considered | Enablement<br>Training |
| Psychological Capability | 1. Limited awareness and knowledge about how diabetes affects bone health<br>2. Lack of awareness of the benefits of exercises on bone health<br>3. Awareness and knowledge about effects of exercise on diabetes & health | Yes: individuals with T1D need diabetes & bone health-specific exercise knowledge | Education<br>Enablement<br>Training |
| Physical Opportunity | 1. Limited information & resources about bone health management | Yes: individuals with T1D need flexible access to bone health | Enablement<br>Environmental restructuring |

| | | | |
|---|---|---|---|
| | 2. Time affecting physical activity participation | management resources | |
| Social Opportunity | 1. Relationship with health care providers<br>2. Lack of communication about bone health from health care providers<br>3. Age-related norms | Yes: health care providers need to facilitate more communication about bone health management with individuals with T1D | Enablement<br>Environmental restructuring |
| Reflective Motivation | 1. Lack of motivation/incentive to exercise for bone health<br>2. Goals of improving/ maintaining health & function<br>3. Sense of community/connection through exercise | Yes: individuals with T1D need motivation to do bone-specific exercises | Persuasion<br>Incentivization |
| Automatic Motivation | 1. Lack of interest in bone health-specific exercises<br>2. Exercise habit/routine<br>3. Fear of hyperglycemia/hypoglycemia related to exercise | Yes: individuals with T1D need to increase interest in integrating bone health-specific exercise into routine while maintaining | Modeling<br>Persuasion<br>Incentivization<br>Coercion |

| | | |
|---|---|---|
| | | blood glucose in a healthy range |

*BCW:* Behavior Change Wheel
*COM-B:* Capability, Opportunity, and Motivation Behavior Model

# Chapter 5: Discussion

## 5.1 Main Findings

We identified several unique perspectives and experiences that affect exercise and physical activity participation for the management of bone health in older adults with T1D including bone health management and exercise knowledge gaps, limited incorporation of bone health education into diabetes resources/programming, and lack of motivation to exercise to manage bone health and prevent falls and fractures. Notably, our participants with T1D had a limited knowledge of how their diabetes affects their bone health and lacked awareness of the benefits of exercise for fall and fracture prevention. Furthermore, participants reported limited access to information and resources around bone health management, which stems from the lack of communication about the link between diabetes and bone health from their HCPs and the omission of bone health-related information from existing resources and programs. Additionally, participants' motivation to engage in exercises for fall and fracture prevention (i.e., progressive resistance training, balance and functional training) heavily relied on their specific goals, interests, and fears. Our next steps are to apply these findings using the BCW intervention functions to design an intervention to increase bone health-specific exercise knowledge and participation in older adults living with diabetes.

Similar to our findings, several studies have reported that physical limitations due to diabetes symptoms/complications and aging significantly reduce capability of physical activity and exercise participation among older adults (Lascar et al., 2014; Hallal et al., 2012; Meredith et al., 2023). Additionally, physical activity levels decrease with age and older adults with diabetes tend to be less active than older adults without diabetes (Hallal et al., 2012; Zhao et al., 2011). Most of our participants engaged in frequent moderate intensity aerobic exercise, and although this is consistent with previous literature in older adults with diabetes (Drummond et al., 2022), a limited proportion of our sample performed exercise known to be beneficial for bone health and fall and fracture prevention. Drummond and colleagues (2022) found similar results in a cross-sectional survey study of 446 adults with diabetes in which only a third of respondents reported engaging in the recommended frequency of resistance and/or balance/flexibility exercises. Our findings confirmed this and inferred that participants' psychological capability plays a significant role in their behaviours related to exercise and physical activity participation to manage bone health, as well as future intervention considerations. While older individuals with diabetes are mostly aware of existing physical activity guidelines, such as those recommended by the Canadian Society for Exercise Physiology, Diabetes Canada, or the American Diabetes Association (CSEP, 2020; Sigal et al., 2018; Colberg et al., 2016), they are unfamiliar with how to safely and effectively incorporate exercises to manage bone health and prevent falls and fractures. It was challenging to probe participants on their perspectives and experiences regarding bone health-specific exercises since they lacked exposure and knowledge on the topic, and often made inferences or guesses based on context. Although our participants were older adults with long-standing T1D with/without history of complications, we may not have fully captured the experiences of individuals with diabetes that are expected to be more engaged/aware in bone health management, such as those above the age of 70 years and those with a diagnosis of osteoporosis and/or history of fracture. For example, initially a participant said they had no experience in bone health-specific knowledge or exercise, but then later mentioned that they participated in resistance training for strength or yoga for balance. Therefore, even if bone health was not something they had ever thought about, the discussion of bone health during the interview exposed participants to the topic. It is worth noting that as the interviews progressed, participants would begin to draw connections between their exercise/lifestyle habits and their bone health (i.e., adequate exercise and dietary calcium intake can improve/maintain bone strength ). An improved understanding of these behaviours linked to psychological capability could translate into addressing the knowledge gaps about exercise to manage bone health in older adults with diabetes as well as concerns about safety and individualization of future diabetes-specific education and exercise programs.

Lack of time and information from HCPs are common barriers to exercise and physical activity in individuals with diabetes and osteoporosis (Brennan et al, 2021; Vilafranca Cartagena et al., 2021; Ziebart et al., 2018). Brennan et al. (2021) and Vilafranca Cartagena et al. (2021) conducted scoping reviews on the barriers and facilitators to physical activity in adults with T1D and T2D, respectively. Both studies' findings suggested that individuals with T1D and T2D face barriers that limit their physical and social opportunities to physical activity (i.e., time, work), lack of advice from HCPs regarding suitable physical activity (Brennan et al., 2021), and poor access to parks and gymnasiums (Vilafranca Cartagena et al., 2021). Ziebart and colleagues (2018) used the COM-B model to identify the common physical and social opportunity barriers to bone health-specific exercises in adults with osteoporosis to be lack of access to exercise programs that meet needs and preferences and limited resources and time. Several of our participants reported that they had never been told by their HCPs that bone health should be a concern. More commonly, bone health management and fall and fracture prevention may become a focus of care in those at higher risk of falls and fractures, such as postmenopausal women and men aged 70 years and older. However, for older adults with T1D, factors such as insulin deficiency and inflammation from their long-standing diabetes can decrease their BMD, which can lead to a higher risk of fracture (Ge et al., 2022). Several participants admitted that they were hearing about diabetes and osteoporosis/fracture risk for the first time during our interview. Participants who had previously discussed bone health with a HCP were often told that it should not be of concern yet, either because the participant was too young, not a woman, or had not experienced a fragility fracture yet. Therefore, there is a need to facilitate greater access to information regarding bone health management and fall and fracture prevention in older adults with T1D, especially once they reach 50 years old, since T1D is a risk factor for fragility fracture. Ferrari et al. (2018) suggested a fracture prediction algorithm that includes diabetes as a risk factor, which could provide improved screening, diagnosis, and bone health management in individuals with diabetes. Participants also reported a significant gap in communication and knowledge regarding bone health from their HCPs. The relationship between HCPs and their patients plays a crucial role in a patient's exercise and health care habits. Through advice, counselling, and motivation, physicians can encourage their patients to participate in physical activity and exercise, which would be especially beneficial to individuals with diabetes. Di Loreto et al. (2003) found that physicians promoting physical activity to their patients with T2D led to adoption and maintenance of physical activity participation as well as significant improvements in the participants' BMI and blood glucose levels. Therefore, having HCPs refer and promote physical activity as a part of diabetes management may lead to better diabetes and health outcomes. Since our participants expressed having supportive and communicative interactions with their HCPs, we should leverage the trust between patient and HCP when implementing knowledge translation interventions and resources regarding bone health management through various methods such as general advice, motivational interviewing, and physical activity counselling (Armstrong et al., 2013; Martiskainen et al., 2022).

The motivation to exercise was strongly influenced by each participants' personal incentives, whether it was to improve strength and flexibility, maintain health (largely related to their T1D), or prevent mobility impairment and frailty. In T1D, typically women are more focused on weight loss while men are more focused on staying in good shape as motivators for exercise (Logan et al., 2024). Interestingly, the breadth of reasons we identified as to why participants exercised ranged from weight loss/management and improvements in cardiovascular health to a sense of social and community connection, with no apparent differences between men and women. Most participants had a sport or mode of exercise that they preferred, typically walking and running, and their motivations related more to internal factors (e.g., health, longevity) compared to external factors (e.g., physical appearance). Interestingly, exercise adherence relied greatly on the participants' interest in the activity, independent from the potential health/fitness benefits. If the participant did not enjoy participating in a specific type of exercise, they expressed difficulty in adopting and/or maintaining participation even if prescribed by their HCP. This finding suggests that the automatic influence of low interest may out-influence the participants' psychological capability. Older adults often lose interest, and therefore motivation, in certain physical activities when their self-perception, values, and physical activity goals do not align (Duda 1991). Ferrand and colleagues (2008) found that adults with T2D reported intrinsic motives such as enjoyment towards physical activity participation following their participation in a patient association-related physical activity program. These findings support the importance of self-determination and interest as a key motivator in physical activity participation amongst older adults with diabetes. Even if participants are presented with the knowledge needed to understand the relationships between diabetes, exercise, and bone health, they must have an interest in doing the recommended exercises in order to adhere to the program. Educational programming, such as diabetes self-management and education, may provide individuals with diabetes with the confidence, interest, and self-efficacy to potentially increase participation in positive diabetes care activities such as better blood glucose management and physical activity/exercise (Hermanns et al., 2013; Davidson et al., 2022).

None of our participants had a strong incentive to exercise for their bone health specifically. Even the one participant with osteoporosis had other motivations and priorities regarding health and exercise, such as diabetes management. Fear of hyperglycemia or hypoglycemia had a strong influence on participant's exercise habits, which is a well-known barrier to physical activity in T1D (Brazeau et al., 2008). From experience, many participants knew how certain exercises would influence their blood glucose levels. However, they were not very familiar with how bone health-specific exercises, such as resistance, functional, and balance training, would affect their blood glucose levels and insulin management. Therefore, education about blood glucose management during bone health-specific exercises needs to be incorporated into future diabetes-related programs in order to decrease individuals' fear and in turn, increase their motivation to participate in bone health-specific exercises and exercise in general.

### 5.2 Behaviours to Change & Future Interventions

From our main findings of the various codes within the COM-B Model components, we can further suggest if change in behaviour is needed and using the BCW, we can identify the interventions that need to be implemented to promote fall and fracture prevention in older adults with diabetes. As seen in **Table 4.4**, we found that there is a need for change in all six components of the COM-B Model. Specifically, in order to promote physical capability, an individual's age, health status, and level of physical activity experience should be evaluated and considered before administering an exercise program. For psychological capability, individuals need more knowledge regarding their diabetes, exercise, and bone health, and this can be done through education and training. Individuals with diabetes also require flexible access to bone health management resources, either from their HCPs or other informational sources (e.g., websites, social media pages of reputable associations (e.g. Diabetes Canada)). HCPs should also be encouraged to facilitate discussions regarding bone health management and fall/fracture prevention with their patients. Another crucial element is the individual's motivation to do bone health-specific exercises, and this can be increased via incentive-based interventions such as financial or non-financial incentives (e.g., recording a workout to enter a chance to win a prize). Lastly, an individual's subconscious automatic motivation strongly affects their behaviour, and thus older individuals with T1D need to increase their interest in integrating bone health-specific exercise into their routines while maintaining healthy blood glucose ranges.

In addition to organizing the data onto the COM-B Model to identify potential behaviours to change, we asked participants about their preferences for a future bone health-specific exercise and education program. This included preferences on mode, frequency, duration, cost, and accessibility. Future detailed analysis of these findings will further support the co-creation of a bone health education and exercise intervention for older adults with diabetes.

### 5.3 Strengths and Limitations

Conducting qualitative, semi-structured interviews was a strength of this study as it provided in-depth insights into participants' experiences and perspectives. We had two reviewers for each transcript, with the first reviewer coding all of the transcripts, continuously discussing the codes and themes. Additionally, the interview guide and content analysis were theory-driven using the COM-B Model of Behaviour, which provided a framework onto which we could organize our findings. Another strength is the study's future potential for identifying diabetes type-specific differences once data collection/analysis in the participants with T2D is complete, and assessing any gender-specific factors.

The small sample size of only 11 participants may limit the generalizability of the findings. Participants were recruited via purposive sampling, which may have introduced a selection bias towards participants who were deemed to meet the criteria of interest. Additionally, most of the participants were recruited from the BETTER registry of people with T1D with a high interest in research and likely greater knowledge/education regarding the key concepts of our study. This may be a limitation as these participants may not be representative of the T1D population as a whole. The descriptive characteristics of our sample of participants, however, did similarly reflect other studies with larger cohorts of T1Ds such as Drummond et al. (2022) with a similar mean age and level of education. Additionally, in qualitative studies involving older adults with T1D in North America, there tends to be a higher participation of women, Caucasian individuals, those with a higher education level, and those of middle-to-upper socioeconomic status (Lewis et al., 2022; Logan et al., 2024; Drummond et al., 2022), which is consistent with the population our sample represented. Future efforts to capture less studied and underrepresented groups of individuals with T1D is important and highly recommended.

The use of interviews may also introduce recall bias and interviewer bias. Participants might not accurately recall events or experiences, and interviewers may subconsciously probe to subtly influence the participants' answers. We will be interviewing HCPs to provide further insight on perspectives and experiences related to bone health management in their older patients with diabetes.

### 5.5 Conclusions

Our findings indicate significant gaps in bone health and exercise-specific knowledge, behaviours, and resources, which may affect how bone health management and fall and fracture prevention is implemented in older adults with T1D. The lack of awareness about the connection between diabetes and bone health, combined with limited motivation, knowledge, and access to appropriate resources/programs, underscores the need for targeted bone health interventions involving education and exercise, in older adults with T1D. By applying the COM-B Model and BCW framework, strategies can be designed to improve knowledge, motivation, and access to resources/programs related to bone health-specific exercise for older adults with diabetes. A diabetes-specific bone health intervention could lead to better health and quality of life for older adults living with diabetes. Future research should focus on implementing and evaluating the effects of these interventions to confirm their effectiveness and long-term adoption in clinical and community settings.

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