



# Perceptions of fracture and fall risk and of the benefits and barriers to exercise in adults with diabetes

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## Abstract

**Summary** The increased risk of fractures and falls is under-appreciated by adults living with diabetes and by their healthcare providers. Strategies to overcome perceived exercise barriers and exercise programs optimized for bone health should be implemented.

**Purpose** The purpose of the study was to assess the perceptions of fracture and fall risk, and the perceived benefits of and barriers to exercise in adults  $\geq 50$  years old living with type 1 (T1D) and type 2 diabetes (T2D).

**Methods** Participants were recruited through social media and from medical clinics and invited to complete a self-administered online survey, comprising 38 close-ended questions and 4 open-ended questions.

**Results** A total of 446 participants completed the survey: 38% T1D, 59% T2D, and 3% with unreported diabetes type. Most participants did not believe that having diabetes increased their risk of fractures (81%) nor falls (68%), and more than 90% reported having not been informed about diabetes-related fracture risk by their physicians. Among exercise types, participation in moderate aerobic exercise was most common (54%), while only 31%, 32%, and 37% of participants engaged in strenuous aerobic, resistance, and balance/flexibility exercise, respectively. The most prevalent barrier to exercise for both T1D and T2D was a lack of motivation, reported by 54% of participants. Lack of time and fear of hypoglycemia were common exercise barriers reported by participants with T1D. Most participants owned a smart phone (69%), tablet (60%), or computer (56%), and 46% expressed an interest in partaking in virtually delivered exercise programs.

**Conclusions** Adults living with diabetes have limited awareness of increased fall and fracture risk. These risks are insufficiently highlighted by health care providers; strategies to overcome perceived exercise barriers and exercise programs optimized for bone health should be implemented.

**Keywords** Diabetes · Bone health · Fractures · Falls · Exercise · Survey

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## Introduction

Fragility fractures are a major public health concern and pose a large and increasing economic burden worldwide [1, 2]. It is estimated that 1 in 3 women and 1 in 5 men will suffer from a fragility fracture in their lifetime [1]. Although generally under-appreciated, it is well established that type 1 diabetes (T1D) and type 2 diabetes (T2D) are associated with increased risk of fractures [3, 4]. Fracture risk is greater in individuals with T1D compared with those with T2D [3–5]. A recent meta-analysis reported a relative risk (RR) of 4.93 (95% confidence interval [CI] 3.06–7.95) for hip fractures in T1D and a RR of 1.33 (CI 1.19–1.49) in T2D [3]. A retrospective study of individuals with T1D measured a cumulative 10-year fracture incidence of 17.8%, compared with 9.5% in individuals without diabetes [6]. The mechanisms underlying diabetes-related fractures are complex and multifactorial, and thought to be related to impaired bone quality and strength, and an increased risk of falls [7, 8]. In T1D, bone mineral density (BMD) is decreased, whereas in T2D BMD has been documented to be normal or increased [5]. Thus, other diabetes-related alterations such as decreased bone turnover, weakened bone material properties and impaired bone microarchitecture also contribute to bone fragility [7, 9]. Moreover, fracture risk is associated with longer duration of diabetes, poor diabetes control, presence of microvascular complications, insulin, and certain anti-diabetic medications use [3, 8]. Increased risk of falls partially account for increased fracture risk in older adults with diabetes and may be explained by hypoglycemia, particularly in those treated with insulin, as well as visual deficits, peripheral neuropathy, chronic gait impairments, and age-related factors such as cognitive decline and polypharmacy [3–5, 7, 8, 10]. Despite the growing body of evidence supporting an increased fracture risk in diabetes, affected individuals are not sufficiently alerted to skeletal complications of diabetes [11]. Resources that highlight bone fragility as a complication of diabetes, as well as prevention strategies to reduce the burden of fragility fractures in the diabetic population, are currently lacking [11, 12].

Exercise stands as a promising intervention for fall and fracture prevention in this population, given its ability to improve muscle and bone strength, and its association with reduced fall and fracture risk in older adults with osteoporosis [13, 14]. A combination of resistance and weight-bearing exercise has been shown to increase BMD in post-menopausal women [15]. Although the effect of weight bearing aerobic and resistance exercise seems to be protective against bone loss in people with T2D, these benefits are not emphasized in exercise recommendations for people living with diabetes in routine practice [16]. Current guidelines for individuals with T1D and T2D

recommend a weekly minimum of 150 min of moderate-to-vigorous intensity aerobic exercise, as well as resistance exercise on at least 2 days per week, which are identical to the guidelines for the general population targeting weight and glucose management [17–19].

Technology use among older adults is increasing [20]. Moreover, technology-based interventions for diabetes management, including those that specifically target exercise, are gaining popularity [21]. Thus, there is a potential to harness these tools to increase exercise participation and deliver tailored interventions to older adults with diabetes.

The extent to which adults living with diabetes are aware of their increased risk for fall and fracture is unknown. This study aims to describe how adults with diabetes perceive risk for fractures and falls, and the benefits of exercise on bone health as well as barriers related to exercise and to determine interest in virtual monitoring and delivery of exercise programs.

## Methods

### Study design and participants

A self-administered online survey was developed and available from August 7 to September 30, 2020. Men and women aged 50 years and older with a self-reported diagnosis of diabetes were recruited from outpatient clinics in Montreal (Quebec, Canada), web pages, and social media platforms. Special efforts were made to reach adults with diabetes through targeted advertising and partnerships with Canadian diabetes-focused organizations, including Diabetes Canada (<https://www.diabetes.ca/>) and Diabète Québec (<https://www.diabete.qc.ca/en/>). Eligible members of the Behavior, Therapies, Technologies, and Hypoglycemic Risk in T1D (BETTER; <https://type1better.com/en/the-better-project/>) registry, a registry of people living with T1D in Quebec, were also invited by email to participate in our study.

The survey was developed to be self-administered; however, research personnel was available to assist participants recruited through outpatient clinics. The survey was posted on REDCap, a secure, web-based application designed to support data capture for research studies [22]. Survey completion was voluntary and anonymous. Participant's consent was assumed if the survey was completed and submitted. The study was approved by the McGill University Health Centre Research Ethics Board.

### Survey design and administration

The self-administered survey was developed by a multidisciplinary team including clinicians and researchers with

expertise in bone health, diabetes, and exercise. It comprised 38 close-ended questions and 4 open-ended questions, including a combination of questions from validated questionnaires, such as the Physical Activity Scale for the Elderly, and questions created by the research team [23]. The survey questions were designed to address 4 major themes: (1) perceived bone health and risk of falls and fractures; (2) perceived health benefits of exercise; (3) exercise participation and barriers to exercise; and (4) use of technology for monitoring health and fitness. Because we conducted the survey during the COVID-19 pandemic, we also inquired about its impact on participants' exercise patterns. Questions pertaining to demographic information and diabetes history were also included. The survey included two open-ended questions which assessed participants' perceptions of diabetes-related fracture and fall risk by inquiring about the main reasons supporting their beliefs. The remaining two open-ended questions assessed knowledge gaps related to how to exercise *safely* and how to exercise *effectively* to manage their health (Supplemental Appendix 1).

The survey was pilot-tested with 10 volunteers of similar demographics as the target population to assess clarity and length. The survey took approximately 15 min to complete. Comments and suggestions provided by the volunteers were incorporated into the final version of the survey prior to distribution. The final version of the survey was translated into French.

### Statistical analysis

Responses to close-ended questions were analyzed using descriptive statistics. Categorical variables were expressed as frequencies and percentages, and continuous variables were expressed as means and standard deviations (SD). Chi-square and independent *t*-tests were performed to compare characteristics between sexes (women, men) and diabetes type.

Odds ratios (ORs) with 95% confidence intervals (CIs) were estimated from multivariate logistic regression models to determine the association between participants' characteristics and perception that diabetes is related to risk of falls and fractures. The characteristics considered for these two models included age (categorized into 50–59, 60–69, 70+ years), sex, level of education, diabetes type, presence or absence of diabetes complications, osteoporosis diagnosis, previous BMD test, prior fragility fracture after age 40 years, or fall in the past 6 months. Participants with missing values were excluded. No interactions were considered. Data were analyzed using SAS Studio release 3.8 (2012–2018, SAS Institute Inc., Cary, NC, USA). Statistical significance for all tests was set at  $p$  value  $< 0.05$ .

Thematic content analysis was performed for responses to open-ended questions using NVivo software version 10 by QSR International Pty. Ltd. Preliminary open coding of participants' responses was conducted by a first analyst (KD)

using an inductive approach [24]. During a second coding cycle, axial coding was used to combine individual codes to create categories and subthemes. A second analyst (RB) reviewed all codes and consensus were reached through discussions. Finally, themes were constructed from the subthemes through a process of consolidation. An iterative process was used to refine and validate the coding [25]. Some participants answered open-ended questions in French. Both French and English data were coded simultaneously by a bilingual analyst (KD) and validated by the second bilingual analyst (RB).

### Results

Four hundred and forty-six respondents provided complete surveys; there were 154 incomplete surveys (largely unanswered) submitted through social media platforms. The majority of the respondents were women ( $N = 293$ , 66%), and most reported a diagnosis of T2D ( $N = 261$ , 59%) (Table 1). The mean age of participants was 64 (SD 9) years and the mean duration of diabetes was 22 (SD 16) years. Nearly all participants were receiving medication to control their diabetes (97%). Approximately one-third (T1D 29% and T2D 27%) reported experiencing complications of diabetes. Participants with T1D were on average younger (61 vs. 67 years), had a longer duration of disease (33 vs. 14 years), and were more likely to use insulin (99% vs. 31%) compared with those with T2D. Attainment of university level education was significantly more common in participants with T1D (46% vs. 27%,  $p < 0.001$ ).

### Bone Health, Falls, and Fractures

Overall, 15% ( $N = 67$ ) of participants reported having an osteoporosis diagnosis, 14% ( $N = 64$ ) had sustained a fragility fracture, and 27% ( $N = 119$ ) reported a fall in the previous 6 months (Table 2). The most common skeletal site of reported fracture was the ankle-foot ( $N = 35$ ) followed by the wrist-hand ( $N = 19$ ). Falls were more commonly reported in those with T2D vs. T1D (31% vs. 21%,  $p = 0.03$ ). The minority of participants agreed with the statement that living with diabetes increased their risk of fractures (19%) or falls (32%). More than 90% of participants reported having not been informed about diabetes-related fracture risk by their physicians, and nearly 45% of participants reported having not been informed by their physicians about the benefits of exercise on bone health. These results did not differ between participants with T1D and T2D. Nevertheless, individuals with T1D were more likely than those with T2D to practice bone health management strategies (64% vs. 54%,  $p = 0.045$ ), such as using vitamin D supplements or consuming calcium-rich products..

**Table 1** Survey participants' characteristics, stratified by diabetes type

Participants' characteristics	Total* N=446	T1D n=171 (38)	T2D n=261 (59)
Age (years), mean (SD)	64 (8.8)	<b>61 (7.6)</b>	<b>67 (8.9)</b>
Sex			
Female, n (%)	293 (66)	<b>100 (58)</b>	<b>183 (70)</b>
Level of education, n (%)			
High school	121 (27)	<b>35 (20)</b>	<b>81 (31)</b>
College/professional degree	161 (36)	<b>55 (32)</b>	<b>102 (39)</b>
University degree	152 (34)	<b>78 (46)</b>	<b>70 (27)</b>
Duration of diabetes (years), mean (SD)	22 (16.3)	<b>33 (16.5)</b>	<b>14 (11.2)</b>
Pharmacological diabetes treatment, n (%)			
Oral medication	272 (61)	<b>26 (15)</b>	<b>234 (90)</b>
Insulin	254 (57)	<b>169 (99)</b>	<b>80 (31)</b>
Injectable (non-insulin) medication	43 (10)	<b>4 (2)</b>	<b>38 (15)</b>
None	12 (3)	<b>0 (0)</b>	<b>10 (4)</b>
Presence of diabetes complications, n (%)			
Yes	122 (27)	49 (29)	71 (27)
No or Unsure	324 (73)	122 (71)	190 (73)

Values in bold are significantly different between T1D and T2D with a  $p$ -value < 0.05.

Chi-square tests and independent  $t$ -tests were used to compare differences between groups.

\*Includes data from participants with T1D, T2D, and unknown diabetes type.

Women were more than twice as likely than men to report having had a dual-energy x-ray absorptiometry scan for BMD measurement (55% vs. 21%,  $p < 0.001$ ) and of having received a diagnosis of osteoporosis (18% vs. 8%,  $p = 0.003$ ). There were no differences in the reporting of prior fractures or falls between men and women. Being knowledgeable about osteoporosis and practicing bone health management strategies were more common in women than in men (43% vs. 27%,  $p = 0.001$  and 62% vs. 51%,  $p = 0.02$ , respectively).

Variables independently associated with holding the belief that diabetes may have an impact on fractures included having T2D (OR 2.0; 95% CI: 1.1–3.3 vs. T1D), reporting diabetes complications (OR 2.6; 95% CI: 1.5–4.5 vs. none), or a diagnosis of osteoporosis (OR 2.3; 95% CI: 1.2–4.7 vs. none). Variables independently associated with holding the belief that diabetes may have an impact on falls included having experienced a fall in the previous 6 months (OR 2.1; 95% CI: 1.3–3.5 vs. no fall), reporting diabetes complications (OR 2.7; 95% CI: 1.7–4.5 vs. none) and male gender (OR 1.7; 95% CI: 1.0–2.9 vs. female gender) (Table 3).

Participants who believed that diabetes increased their risk for fracture were asked to provide reasons supporting this belief. Eighty-six participants provided 112 responses: most pertained to impaired bone health ( $n = 38$ ), including low bone density and altered mineral absorption and metabolism, and increased fall risk ( $n = 26$ ) (Supplementary Table 1). Also, 141 participants who believed that having diabetes increased their risk of balance problems and falls were asked about the main reasons supporting their beliefs, and they provided 164

responses (Supplementary Table 2). Responses highlighted glycemic control ( $n = 39$ ), particularly hypoglycemia ( $n = 31$ ), and complications of diabetes ( $n = 34$ ), specifically neuropathy ( $n = 21$ ) as causes for increased fall risk. Other common responses included dizziness and light-headedness ( $n = 27$ ), and impaired balance ( $n = 25$ ).

### Exercise participation, perceived benefits, and barriers to exercise

Participation in moderate aerobic exercise was most common (54%). Comparatively, only 31%, 32%, and 37% of participants engaged in strenuous aerobic, resistance, and balance/flexibility exercises, respectively. Participants who engaged in these forms of exercise mostly did so 1–2 days per week (Table 4).

More than 90% of participants agreed with statements supporting the benefits of exercise on glycemic control, weight management, endurance, mobility, strength, functional capacity, and quality of life, and nearly 90% agreed with the benefits of exercise on blood pressure control. The health benefits that received the least recognition included exercise's ability to reduce fracture and fall risk and to improve mood, which were supported by 69%, 74%, and 79% of participants, respectively. More than 60% of participants reported that they wanted to be more physically active in the past year. The most prevalent barrier to exercise reported was a lack of motivation, followed by lack of energy and health condition/limitation. Among participants with self-reported T1D, lack of time and fear of hypoglycemia were also commonly reported barriers (Fig. 1).

**Table 2** Osteoporosis, fall and fracture history, and perceptions of bone health among survey participants, stratified by diabetes-type

Participants' characteristics	Total*	T1D	T2D
Previously had DXA scan, <i>n</i> (%)	193 (43)	71 (42)	116 (44)
Self-reported osteoporosis, <i>n</i> (%)	67 (15)	27 (16)	38 (15)
Fragility fracture after the age of 40, <i>n</i> (%)	64 (14)	31 (18)	33 (13)
Fallen in the past 6 months, <i>n</i> (%)	119 (27)	<b>36 (21)</b>	<b>80 (31)</b>
Believe that diabetes increases one's fracture risk, <i>n</i> (%)			
Yes	86 (19)	<b>25 (15)</b>	<b>58 (22)</b>
No or unsure	360 (81)	<b>146 (85)</b>	<b>203 (78)</b>
Believe that diabetes increases one's fall risk, <i>n</i> (%)			
Yes	141 (32)	48 (28)	86 (33)
No or unsure	305 (68)	123 (72)	175 (67)
Osteoporosis knowledge			
Neutral or knowledgeable <sup>1</sup>	306 (69)	114 (67)	184 (70)
Not knowledgeable <sup>2</sup>	140 (31)	57 (33)	77 (30)
Previously informed by physician of diabetes-related fracture risk, <i>n</i> (%)			
Yes	41 (9)	17 (10)	21 (8)
No or unsure	405 (91)	154 (90)	240 (92)
Previously informed by physician of the benefits of exercise on bone health, <i>n</i> (%)			
Yes	251 (56)	92 (54)	153 (59)
No or Unsure	195 (44)	79 (46)	108 (41)
Practice bone health management strategies <sup>†</sup> , <i>n</i> (%)			
Yes	261 (59)	<b>109 (64)</b>	<b>141 (54)</b>
No or unsure	185 (41)	<b>62 (36)</b>	<b>120 (46)</b>

DXA dual x-ray absorptiometry.

Values in bold are significantly different between T1D and T2D with a *p*-value < 0.05.

Statistical difference between groups (T1D and T2D) was evaluated using chi-square tests.

\*Includes data from participants with T1D, T2D, and unknown diabetes type.

<sup>1</sup>Knowledgeable includes participants who agreed or strongly agreed with the statement "I am knowledgeable about osteoporosis in general"; <sup>2</sup>not knowledgeable includes participants who disagreed or strongly disagreed with the previous statement.

<sup>†</sup>Assessed by participants' response to the question "Do you do anything specifically to keep your bones healthy?".

The COVID-19 pandemic had a variable effect on exercise patterns. Across all exercise types, an average of 59% of participants reported that their exercise participation had remained unchanged since the beginning of the pandemic, whereas less than 15% reported an increase in exercise participation. Participants were more likely to report decreased participation in aerobic exercise than other forms of exercise: 37% of respondents reported decreased participation in aerobic exercise while 29% and 28% reported decreased participation in resistance and balance/flexibility exercise, respectively.

### Exercise information needs

A total of 476 and 492 responses were provided to the two questions addressing exercise *safety* and *efficacy*, respectively. Numerous responses concerned recommendations for exercise type, frequency, duration, and intensity (*n*=85 for exercise safety and *n*=111 for exercise efficacy). Glycemic control surrounding

exercise was another major theme of inquiry (*n*=52 and *n*=28), particularly in participants with T1D. Separate analysis for T1D revealed a greater interest in aspects of glycemic control, such as hypoglycemia prevention and management, insulin management, and pre- and post-exercise nutrition, than did participants with T2D. There was also marked interest among all participants in accessing professional support for exercise, including exercise supervision/instruction, procurement of exercise programs, and professional consultation (*n*=38 and *n*=35, respectively). Other themes that frequently emerged included exercise safety, exercise location and motivation, and questions related to specific goals.

### Technology use and interest in virtual delivery of exercise programs

Over 80% of participants reported having access to at least one electronic device. The most widely used devices were smart or mobile phones (69%, *n*=307), tablets or iPads

**Table 3** Odds ratio (95% confidence intervals) for the belief that diabetes is related to fractures or falls among participants

Odds ratio (95% confidence interval)		Believes that diabetes is related to fractures	Believes that diabetes is related to falls
Men (reference = women)		1.3 (0.7; 2.3)	<b>1.7 (1.0; 2.9)</b>
Education (reference = university diploma)	High school	0.9 (0.4; 1.8)	1.5 (0.9; 2.8)
	College	0.8 (0.4; 1.6)	0.8 (0.5; 1.5)
Age (reference = 50–59 years)	60–69	0.8 (0.4; 1.5)	0.7 (0.4; 1.2)
	70+	0.9 (0.4; 1.9)	1.0 (0.5; 1.9)
Type 2 diabetes (reference = type 1 diabetes)		<b>2.0 (1.1; 3.3)</b>	1.42 (0.83–2.5)
Diabetes complications (reference = none/do not know)		<b>2.6 (1.5; 4.5)</b>	<b>2.7 (1.7; 4.5)</b>
Self-reported osteoporosis (reference = no osteoporosis)		<b>2.3 (1.2; 4.7)</b>	1.1 (0.6; 2.1)
Had a DXA (reference = no DXA)		1.1 (0.6; 2.1)	1.6 (0.9; 2.8)
Low trauma fracture after 40 years (reference = no fracture)		1.0 (0.5; 2.2)	–
Fall in the past 6 months (reference = no fall)		–	<b>2.1 (1.3; 3.5)</b>

DXA, dual x-ray absorptiometry.

Values in bold are statistically significant with a *p*-value < 0.05.

(60%, *n* = 267), and laptop and desktop computers (56%, *n* = 249 and 48%, *n* = 215, respectively). Nearly 60% of respondents (*n* = 257) expressed an interest in monitoring their physical activity using an electronic device. Moreover, 46% (*n* = 203) expressed an interest in participating in virtually delivered exercise programs.

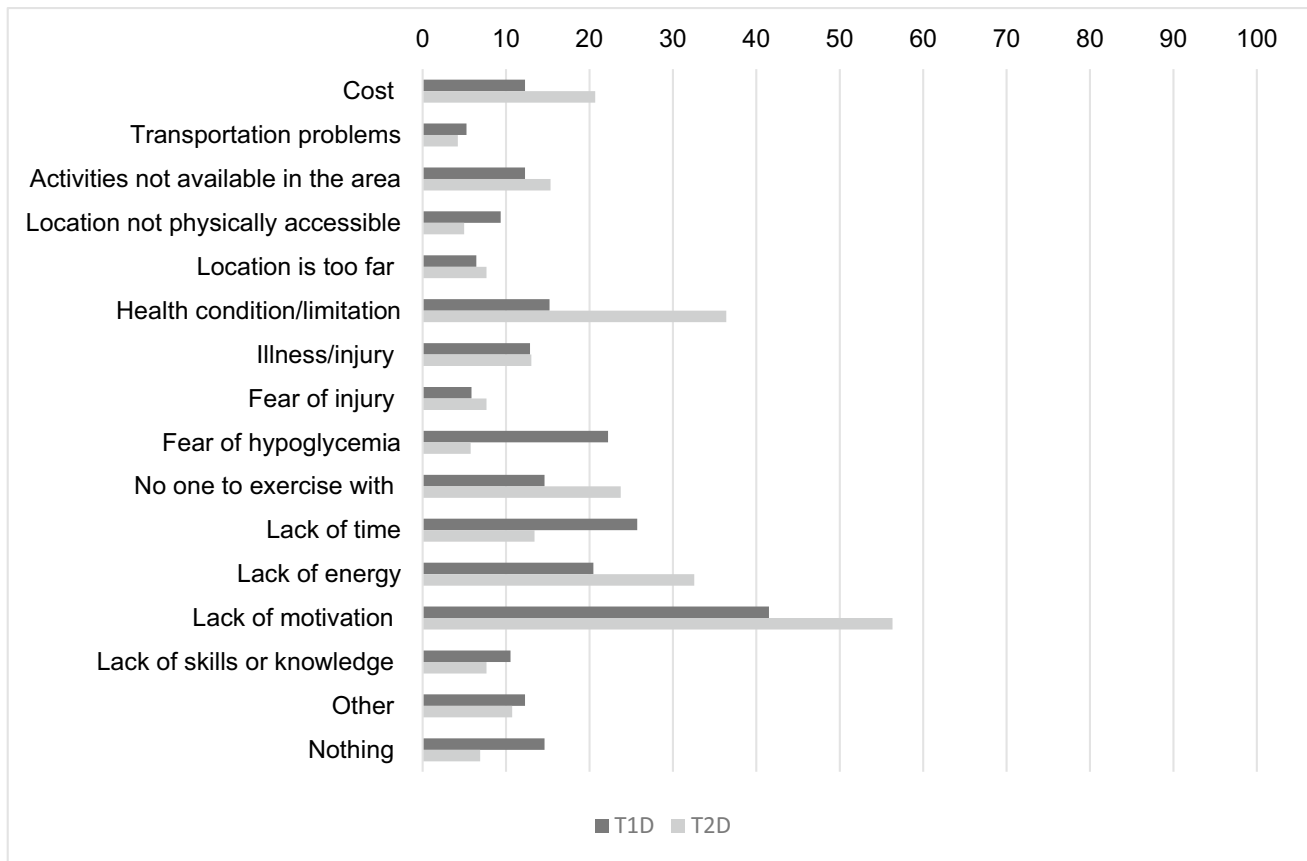
**Table 4** Exercise participation reported by participants for the past 7 days

	<i>N</i> = 446
Moderate aerobic exercise, <i>n</i> (%)	204 (46)
Never	
Seldom (1 to 2 days)	92 (21)
Sometimes (3 to 4 days)	80 (18)
Often (5 to 7 days)	70 (16)
Strenuous aerobic exercise, <i>n</i> (%)	
Never	308 (69)
Seldom (1 to 2 days)	66 (15)
Sometimes (3 to 4 days)	40 (9)
Often (5 to 7 days)	32 (7)
Resistance exercise, <i>n</i> (%)	
Never	304 (68)
Seldom (1 to 2 days)	81 (18)
Sometimes (3 to 4 days)	45 (10)
Often (5 to 7 days)	16 (4)
Balance/flexibility exercise, <i>n</i> (%)	
Never	280 (63)
Seldom (1 to 2 days)	97 (22)
Sometimes (3 to 4 days)	48 (11)
Often (5 to 7 days)	21 (5)

## Discussion

We have documented that older adults living with diabetes have a limited awareness of the association between diabetes and increased fracture and fall risk, even though an important proportion reported a diagnosis of osteoporosis, having sustained a fracture or fallen in the previous 6 months. Exercise participation in this population was also noted to be suboptimal and constrained by low levels of motivation and energy and health limitations, which were identified as prominent barriers to exercise. Finally, significant knowledge gaps pertaining to bone health and exercise were identified.

Previous studies in Ireland and Palestine similarly detected low perceived susceptibility to fractures among adults with diabetes [11, 26]. A group of Irish adults with T1D and T2D were found to have low levels of concern and understanding of diabetes-induced bone disease, and a minority (37% with T1D and 23% with T2D) regarded fractures as a complication of diabetes [11]. Moreover, in an investigation of Palestinian adults with T1D and T2D, more than 50% did not believe that they were susceptible to osteoporosis [26]. We detected even lower levels of perceived susceptibility to fractures in our North American population of diabetic adults. The Palestinian study, as well as a study of adults with T2D in Malaysia, also detected poor osteoporosis knowledge, which was assessed using validated scales [26, 27]. In contrast, nearly 70% of our population claimed to be knowledgeable about osteoporosis; however, we did not evaluate actual bone health knowledge in this survey and relied on self-report. Higher education levels within our population compared with other studies may have also



**Fig. 1** Percentage of participants who provided the following answers when asked “In the past 12 months, what prevented you from being more physically active?” by diabetes type

contributed to greater perceived osteoporosis knowledge, despite this not translating to knowledge of fracture and falls risk.

Our study adds to the existing literature by also assessing perceptions of diabetes-related fall risk. We found that most adults with diabetes were unaware of this risk, which was unexpected given that fall risk is much higher in older adults with diabetes compared with healthy adults of a similar age, and that many participants had reportedly confronted this adverse event in recent months [10]. Our findings, in conjunction with previous reports, highlight a need to raise awareness and educate adults with diabetes about their increased risk of fractures and falls. Moreover, one might argue that special efforts should be made to target interventions to select groups, such as women and individuals with T1D, for whom fracture risk is greater [3–5].

Interestingly, greater self-reported knowledge of osteoporosis and the more common practice of bone health management strategies among women compared to men did not translate to an increased awareness of the association between diabetes and risk of fractures or falls in this population subgroup. It is possible that women

with diabetes may be more inclined to associate risk of fractures with female sex, a well-known risk factor for osteoporosis, rather than diabetes. The reason for which men were significantly more likely than women to recognize the association between diabetes and fall risk is unclear and surprising given that fall risk is greater among women with diabetes [28]. The wide confidence intervals around these sex-based estimates caution against robust conclusions.

Health care professionals are an important source of diabetes-related information for individuals with diabetes [11]. Nevertheless, less than 10% of our participants reported being informed by their physicians about these risks. This highlights a missed opportunity by physicians and other health care professionals to educate adults with diabetes about diabetes-associated skeletal fragility, as well as to counsel them on appropriate management. General practitioners, endocrinologists, diabetologists, bone specialists, nurses, nurse practitioners, and dieticians can equally play a role in helping raise awareness among individuals with diabetes regarding the interaction of diabetes and bone health.

The Bone and Diabetes Working Group of the International Osteoporosis Foundation as well as the Endocrine Society previously published guidelines on the identification and management of fall and fracture risk in diabetes [12, 29]. Nevertheless, current Canadian osteoporosis and diabetes clinical practice guidelines do not mention bone fragility as a complication of diabetes. Therefore, one can argue that physicians are not sufficiently alerted to the association between diabetes and bone health, which has resulted in suboptimal patient counseling on this topic.

Exercise is regarded as an important component of diabetes management, in light of its health benefits on glycemic control, insulin sensitivity, blood pressure, lipid profile, and weight maintenance, as well as its ability to mitigate cardiovascular disease risk [17]. Despite this, exercise participation in our population was below current guidelines for both individuals with diabetes and the general population [17–19]. Previous studies have similarly detected suboptimal physical activity participation among adults with diabetes, as well as greater rates of inactivity compared with the general population [30, 31]. While low physical activity levels may be partially accounted for by diabetes-related factors, such as disability related to diabetes complications and comorbidities, socio-demographic and health factors such as older age, female gender, lower education and income, and higher body mass index have also been associated with diabetic individuals not meeting physical activity guidelines [30, 31]. These findings underscore the need for tailored interventions to increase physical activity participation among adults with diabetes. Furthermore, interventions may need to be tailored to the needs and expectations of certain population subgroups, such as older people with diabetes, who are less likely to meet current guidelines [30, 31].

Future exercise interventions for this population must also account for perceived barriers to exercise, namely lack of motivation, which was identified as a salient barrier in our sample and by previous reports of adults with diabetes [32, 33]. A promising strategy to address this is self-monitoring using wearable activity monitoring devices such as pedometers or mobile technologies, which are inexpensive, are increasingly accessible, and have demonstrated success in increasing exercise participation among people living with diabetes [34]. These interventions may be particularly effective when combined with a physical activity goal, or when they include additional features such as goalsetting, feedback on performance, and prompts [21, 34]. Widespread technology use, as well as expressed interest by more than half of our study participants in monitoring exercise using electronic devices, is encouraging for the prospect of implementing exercise interventions that incorporate self-monitoring. Motivational interviewing is another promising strategy to increase physical activity participation among people with diabetes; however, this approach may be difficult

to implement in primary practice and its effectiveness as a stand-alone intervention requires further investigation [35]. Alternatively, more straightforward motivational approaches such as positive reinforcement and counseling by health care professionals may be utilized to encourage exercise participation among adults with diabetes [36, 37].

Previous reports have identified fear of hypoglycemia as the strongest barrier to exercise in adults with T1D [38, 39]. Fear of hypoglycemia was also among the more common barriers to exercise reported by participants with T1D. This point, as well as the interest in being informed of strategies to prevent hypoglycemia by participants with T1D, underscores the need for improved patient education on this topic. Exercise education provided to older adults with diabetes will also need to address other knowledge gaps that were identified in this population, such as how blood sugar can be affected by exercise, as well as the recommended types, frequency, duration, and intensity of exercise.

Patient education has been identified as a prominent facilitator to physical activity in those with diabetes, and an important component of diabetes self-management [39]. Furthermore, there is evidence to suggest that individuals with diabetes prefer one-on-one exercise support and advice from their health care providers, rather than group interventions [33]. Despite this, ours and previous studies have found that physical activity counseling provided to individuals with diabetes by their health care professionals is suboptimal [40]. Lack of knowledge or training in physical activity, as well as lack of time and lack of success in changing patient behaviours, were cited as major barriers to this practice [41]. Moreover, physicians are generally less comfortable providing detailed physical activity advice, which may be required for many members within our target population. A possible method to address these challenges is by providing training to health care professionals on the particularities of exercise in older adults with diabetes, such as hypoglycemia prevention, fall prevention, and exercise guidelines [39]. Moreover, public health messages and educational resources intended for the diabetes community may be utilized to promote exercise and communicate exercise guidelines for this population.

Of particular interest, we found that current exercise practices in older adults with diabetes are not optimized for bone health. Within our population, there was low reported participation in resistance, balance, and flexibility exercise, which can reduce fall and fracture risk in susceptible individuals, notably when combined [13, 42]. Similar studies to ours reported that approximately 75% of their diabetic participants perceived the protective effect of exercise on osteoporosis [26, 27]. Neither ours nor the aforementioned studies assessed patients' knowledge of the differential effects of various forms of exercise on fracture and fall risk. Thus, it is possible that while



some may regard exercise as being beneficial to their bone health, they may not be informed of the importance of including resistance and balance exercise in their exercise regimens. Compared to moderate aerobic exercise, participation in strenuous aerobic exercise was much less common. Although current exercise guidelines for individuals with diabetes recommend moderate-to-vigorous aerobic exercise, meta-analyses consistently report an advantage of higher-intensity exercise on reducing HbA1C, a marker of glycemic control [43, 44]. Taken together, future exercise interventions intended for this population should emphasize resistance and balance as well as higher intensity aerobic exercise.

Systematic reviews and meta-analyses have detected a benefit of targeted exercise interventions on fall-related outcomes such as balance, gait, and lower-limb strength in adults with diabetes [45, 46]. However, few of the included studies investigated the impact of the exercise programs on fall rates and fall risk. Evidence supporting the impact of exercise programs on fracture outcomes in community-dwelling elderly individuals, let alone those with diabetes, is also limited [13]. We were particularly interested in assessing study participants' interest in partaking in virtually delivered exercise programs, and found that this appealed to nearly half of our participants. Studies of exercise programs aimed at fall prevention delivered using video-conferencing have shown that this method is associated with good compliance and is effective at reducing falls and fall risk factors in older adults at risk of falls [47, 48]. Although the results of these studies may not be generalizable to our population, they indicate a potential for implementing virtual exercise programs aimed at reducing fall, and thus fracture risk, in older adults with diabetes. Virtual exercise programs have advantages over both community-based and unsupervised home-based exercise programs, given that they enable exercise supervision in a format that increases accessibility [48]. For individuals with limited or no access to technological means, we propose the development of simple exercise routines that can be made distributed in clinics and other health care establishments; monitoring can be done via simple and easily available tools such as pedometers.

A major strength of this study is the large number of participants, including a great proportion of participants with T1D. This is likely a reflection of successful recruitment from the Quebec provincial BETTER registry of people with T1D. Many participants (57%) were recruited through social media demonstrating the efficacy of this recruitment strategy for specific cross-sectional studies, while keeping costs low.

This study's limitations are mostly related to survey methodology, namely selection bias; although participants who responded to the survey likely constitute a select group with a special interest in diabetes management and/or exercise, we

feel they represent the adult population with diabetes, since our results are in keeping with previous reports. Although the diagnoses of diabetes and fractures were self-reported, the self-ascertainment of these conditions is robust, except for fractures of the spine. Our sample size limited our ability to conclude regarding whether fracture sites were comparable to other reports in the literature. Study data was collected during a period of time when restrictions related to the COVID-19 pandemic (i.e., lockdowns, gym closures, and social distancing) presumably impacted exercise behaviours by our participants. To circumvent this limitation, we assessed how participants' engagement in aerobic, resistance, and balance/flexibility exercise differed since the beginning of the pandemic. Finally, we conducted the survey through social media which limits access to participants who do not own electronic devices, do not have the required e-health literacy to answer questionnaires online, or were not fluent in French or English. Although increasing access to electronic devices and improving e-health literacy in the older population have been noted, this limits the generalizability of our results [49].

The current study revealed that adults 50 years or older living with diabetes have a limited awareness of their increased risk of fractures and falls. Furthermore, the benefits of exercise on bone health are under-recognized by this population. This, along with the perceived barriers and knowledge gaps related to exercise, has resulted in exercise participation by these individuals not meeting current practice guidelines. Our findings highlight an opportunity by health care providers to educate adults with diabetes about their increased risk of fractures and falls, and to promote exercise for skeletal health. Self-monitoring of exercise using wearable activity monitors or mobile applications also has the potential to increase motivation to exercise, which was identified as a salient barrier to exercise in this population.

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## Declarations

**Conflict of interest** KD, JG, RW, WH, VT, CG, CB, and SNM report that they have no conflicts of interest. RB is employed by the Dairy Farmers of Canada at the time of submission but had no association with the organization at the time of project conceptualization, analysis, or writing.

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