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ORIGINAL ARTICLE

Prevalence and risk factors for osteoporosis in type 1 diabetes—results from an observational study

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Abstract

Summary The prevalence of osteoporosis in individuals with type 1 diabetes (T1D) was investigated. Based on IOF/ADA recommendations, 36% had indications for anti-osteoporotic therapy. We propose that postmenopausal women and men with T1D and age > 50 years are screened for osteoporosis.

Purpose Type 1 diabetes is associated with an increased fracture risk and a lowering of the threshold for osteoporosis treatment has been recommended to be increased from a bone mineral density of a T-score ≤ − 2.5 to a T-score ≤ − 2.0. In this study, we aimed to investigate the prevalence and risk factors for osteoporosis in type 1 diabetes using the classic diagnostic criteria defined by WHO and the novel T-score cutoff of − 2.0 proposed by the ADA.

Methods In a cross-sectional study, data were collected from the type 1 diabetes clinic at Steno Diabetes Center Aarhus, Aarhus University Hospital, where active attenders in the clinic were offered screening for osteoporosis using DXA of the lumbar spine and hip in the time period 2020–2022.

Results A total of 764 individuals with type 1 diabetes had a DXA and of these, 25.5% had osteoporosis based on a vertebral fracture or T-score ≤ − 2.5, and 36% met ADA-treatment criteria with a vertebral fracture or T-score ≤ − 2.0. In multivariate analysis increasing age (OR = 1.3, 95% CI 1.0; 1.7) and a family history of osteoporosis (OR = 1.9, 95% CI 1.2; 3.0) were associated with an increased risk of osteoporosis, whereas an increase in BMI was associated with a decreased risk of osteoporosis (OR = 0.87, 95% CI 0.82; 0.92).

Conclusion The present study finds that a high proportion of individuals with type 1 diabetes have osteoporosis, and an even higher proportion meet the treatment criteria proposed by the ADA, and thus, early detection and treatment of osteoporosis may reduce the apparent increased fracture risk in type 1 diabetes.

Keywords Anti-osteoporotic treatment · Bone mineral density · Compliance · Osteoporosis · Type 1 diabetes

Introduction

Type 1 diabetes increases the risk of osteoporosis and fractures [1, 2]. Fractures in turn increase morbidity and mortality, especially in individuals with diabetes [3, 4]. Osteoporosis is defined by bone mineral density (BMD) criteria, and in Denmark, anti-osteoporotic treatment is also indicated with the presence of hip- or vertebral fracture after a low-energy trauma independent of BMD. Bone mineral density and age are some of the strongest determinants of fracture risk [5], and it is estimated that BMD is decreased by 22% in patients with type 1 diabetes compared to age-matched controls [1]. The risk of hip fracture, however, is increased up to sevenfold in type 1 diabetes [6] which cannot solely be explained by the decreased BMD [1]. Thus, in type 1 diabetes, there is a BMD-independent increase in fracture risk that may be caused by changes in bone turnover or quality or increased risk of falls [7]. The prevalence of osteoporosis in type 1 diabetes, however, is not well examined, and the same is true for the risk or prevalence of vertebral fractures (VFx) [8–11].

Timely identification of patients with osteoporosis is important as fracture risk can be markedly decreased by both

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pharmacological and non-pharmacological interventions. Even though the pathophysiology of increased fracture risk in type 1 diabetes may be different from that in the general population, recent studies show that diabetes does not negatively impact the efficacy of anti-osteoporotic treatment [12].

Although type 1 diabetes is a risk factor for fracture, screening for osteoporosis by dual-energy x-ray absorptiometry (DXA) is not systematically implemented in diabetes clinics in Denmark. Currently, patients are referred by their general practitioner or diabetologist for a DXA following patient request or if the treating clinicians identify an individual patient to be at a particular high risk.

The American Diabetes Association (ADA) published updated recommendations and the Bone and Diabetes Working Group of the International Osteoporosis Foundation (IOF) has made recommendations for bone health in individuals with diabetes in 2024 [13, 14]. ADA recommends assessment of fracture risk and monitoring of BMD in individuals with diabetes older than 65 years and in younger adults with multiple risk factors. Additionally, ADA and IOF recommend that anti-resorptive medications are considered already at T-scores ≤ -2.0 where the recommendation in the general population is T-score ≤ -2.5 targeting the BMD independent increased fracture risk [13].

Purpose

In the present study, we therefore aim to determine the risk factors and prevalence of osteoporosis as defined by the WHO (T-score ≤ -2.5) and by ADA/IOF criteria (T-score ≤ -2.0) in unselected individuals with type 1 diabetes attending a Danish university hospital diabetes clinic. Furthermore, we provide data on the relevance of limiting DXA to at-risk individuals and the impact on the diagnostic yield of lowering the diagnostic threshold for initiating osteoporosis treatment.

Methods

Study participants

The STROBE guideline was followed [15]. Screening for osteoporosis using DXA was introduced as a clinical service development at Steno Diabetes Center Aarhus, Aarhus University Hospital, in January 2020 and continued until the end of December 2022. Eligible individuals had a diagnosis of type 1 diabetes (the ICD-10 code DE10.X in the electronic health records (EHR)), were active attenders at the clinic, and were males older than 50 years or postmenopausal women older than 50 years. Staff at the diabetes clinic invited eligible patients during scheduled appointments at the clinic and referred them for a DXA upon acceptance from the patients. At the caregivers' discretion, patients with a short life expectancy or severe comorbidity, where anti-osteoporosis treatment would not be relevant or possible were not invited. Moreover, patients were not invited if they had contraindications for anti-osteoporotic treatment or if they had a DXA performed within 5 years prior to the initiative. DXA was scheduled between two appointments in the clinic. DXA results were given to the patient by their diabetologist at the regular follow-up visit or at an extra visit in patients where osteoporosis was diagnosed (Fig. 1a).

A project report was developed using the hospital's business intelligence (BI) system for the purpose of real-time progress overview and evaluation after finalizing the initiative. The report captured data from the EHR and included a target group overview (e.g., number of patients meeting inclusion criteria) and status of the initiative, e.g., how many patients had a DXA and how many had a DXA pending. The

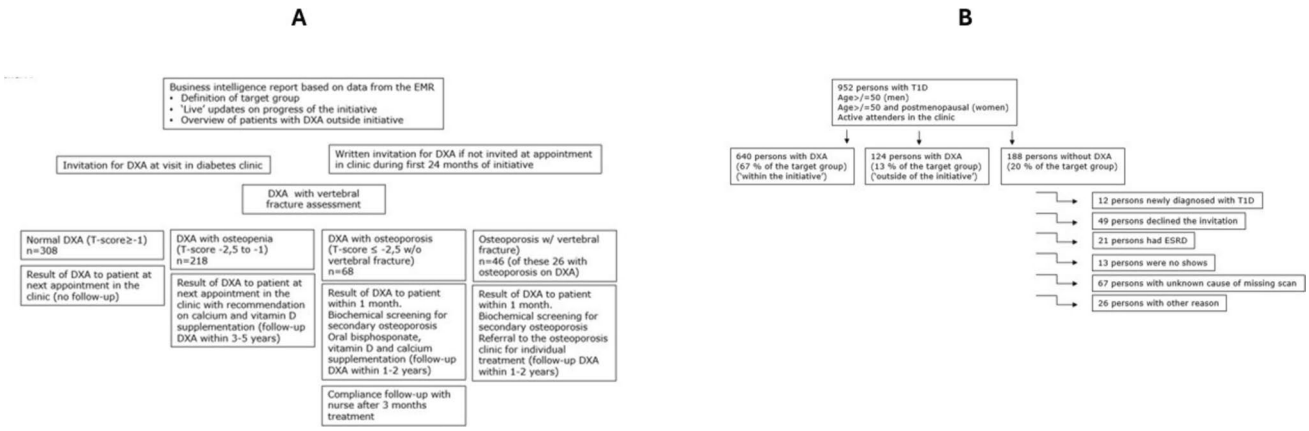

Fig. 1 Flowchart of included individuals (**A**) and reasons for non-participation (**B**)

report also included data at the individual level including the date of last DXA, the date of osteoporosis or osteopenia diagnosis, and the treatment status with anti-resorptive medication. The report utilized the ICD-10 diagnosis code DE10.x, Danish procedure codes for DXA (UXRE80 and UXRG80), ICD10 diagnosis codes for osteoporosis (DM80 and DM81), and osteopenia (DM858A).

After 24 months, we audited patients identified in the BI report with missing DXA and found that a subgroup of patients in the target group had not been referred for a DXA and an explanation for this was not documented in the EHR. These patients were contacted by mail and encouraged to contact the clinic for a DXA appointment (Fig. 1a).

DXA and vertebral fracture assessment

DXA was performed using five Hologic Horizon scanners (Hologic, Waltham, MA, USA, software Apex 13.5) at the Department of Endocrinology and Internal Medicine, Aarhus University Hospital. The stability of the scanners was assessed on a daily basis using a phantom provided by the manufacturer. The four newest DXAs are cross-calibrated with the oldest DXA to ensure similar results and the calibration is checked every 6 months.

BMD was measured at the lumbar spine and total hip, and the presence of vertebral fractures was assessed using vertebral fracture assessment (VFA). DXAs were performed by trained and experienced technologists, and different scanners were cross-calibrated against each other. For diagnosis of osteoporosis at the hip and femoral neck National Health and Nutrition Examination Survey (NHANES) III reference database for femoral neck measurements in Caucasian women aged 20–29 years was used as recommended [16].

Before the DXA, patients filled out a questionnaire with information about diabetes duration, presence of retinopathy or neuropathy, age at menopause, comorbidities, current medication, smoking, previous fractures, and family history of osteoporosis.

One of the authors (JS-L or TH) analyzed and interpreted the DXAs. Fracture was diagnosed on VFA based on the Genant semi-quantitative criteria [17]. Scans from patients with a possible VFx were re-read blinded to the initial assessment by another author along with scans without VFx. In case of non-consensus, a joint reading was performed, and if consensus was not obtained, a conventional x-ray of the thoracolumbar spine was ordered and read by an expert radiologist. A diagnosis of osteoporosis was given following the identification of one or more vertebral fractures (height reduction > 20%) or a T-score ≤ −2.5 at the lumbar spine or total hip. Patients with osteoporosis were recommended treatment with either alendronate (the majority), denusomab, zoledronate, or teriparatide based on contraindications and reimbursement criteria.

Osteoporosis treatment recommendation and assessment of compliance

Treatment with oral bisphosphonate (alendronate) was initiated in the diabetes clinic. Candidates for treatment with teriparatide were patients with either two vertebral fractures (≥ 25% reduction) or one vertebral fracture (≥ 25% reduction) and a BMD T-score of ≤ −3.0 at the hip or lumbar spine. These patients were contacted directly by the authors and offered treatment at the Department of Endocrinology and Internal Medicine. At the end of the initiative, compliance with the prescribed alendronate was audited using the national Danish prescription database. We calculated compliance from the duration of treatment and the number of redeemed prescriptions for alendronate and defined it as 100% when alendronate was purchased in a quantity allowing a pill for each week since treatment initiation.

Individuals scanned outside the initiative

To further assess the effect of the initiative, data were collected from the EHR on individuals with type 1 diabetes who had a DXA performed in the years 2015–2022 either before the initiative or who were referred to a DXA by a clinician not associated with the diabetes clinic. Age at the DXA, gender, BMI, diabetes duration, T-score of the hip and lumbar spine, and the presence of microvascular vascular complications were collected from the EHR. VFA was not routinely performed in these individuals and no questionnaire data were available.

Biochemistry

Blood sampling was performed at least once per year on all patients attending the clinic. Biochemical analyses were performed at an ISO 15189–certified laboratory that provides this service to the clinical departments. All results for the individual patients obtained between 2015 and the time of DXA for glycated hemoglobin (HbA1c) (Capillarys, coefficient of variation (CV) 6.5%), TSH (Atellica IM, CV 12%), hemoglobin (Sysmex, CV 7.5%), creatinine, (Atellica CH, CV 8.9%), and estimated glomerular function (eGFR, calculated by Chronic Kidney Disease Epidemiology Collaboration (CKD-EPI) equation) based on creatinine were included in the analyses. Spot-urine was sampled yearly for analysis of urine albumin-creatinine ratio (for urine albumin Atellica CH, CV 36%; for urine creatinine Atellica CH, CV 23%). Additionally, results for analyses of p-25 hydroxy-vitamin D (Cobas 8000, CV 18%) were collected in all individuals who had a measurement in the time interval 12 months before to 6 months after the DXA. Mean HbA1c and eGFR from 2015 to date of DXA were calculated. Mean HbA1c and eGFR were on

average collected over 4.2- and 5.7-year periods, respectively. All analyses were performed at the Department of Biochemistry, Aarhus University Hospital.

Ethical statement

As the osteoporosis screening initiative was a clinical service development, ethics committee approval was irrelevant. Permission was obtained from the Legal Office, Central Denmark Region, for retrieval of patient information from the EHR and for publication of data. As none of the included patients is identifiable at the individual level, consent from patients has not been obtained.

Statistical analyses

STATA 18 was used to perform statistical analyses. We performed unpaired *t*-tests to test for differences between the groups with and without osteoporosis (normally distributed data) or the Wilcoxon rank-sum test (data not normally distributed). Bartlett's test was used to determine if the *t*-test should be performed with equal or unequal variances. Data is presented as mean and 95% CI (normally distributed data) or median and interquartile range (data not normally distributed). Q-Q plots were inspected for normal distribution of data. To identify risk factors for osteoporosis, logistic regression was performed to test associations between different characteristics and osteoporosis. In the logistic regression, we grouped never-smokers and former smokers as one. We investigated if age, gender, HbA1c, family history of osteoporosis, microvascular complications, and diabetes duration were associated with prevalent vertebral fractures by logistic regression with results presented as odds ratios.

We defined a family history of osteoporosis as a sibling or parent with a vertebral fracture, hip fracture, or a diagnosis of osteoporosis and calculated the diabetes duration as the number of years from diabetes diagnosis to the year of DXA. We defined diabetic nephropathy as albumin creatinine ratio > 30 at two measurements (microalbuminuria) and/or eGFR < 30 ml/min. ADA suggests that individuals with diabetes aged ≥ 65 years and individuals who have multiple fracture risk factors are recommended for screening with DXA. Thus, we investigated whether the presence of 3 or more risk factors (multiple) for fractures (female gender, BMI < 18 kg/m^2, family history of osteoporosis, smoking, diabetes duration > 10 years, HbA1c > 8%, neuropathy, retinopathy, and nephropathy) or age ≥ 65 were related to a T-score ≤ −2.0 as these risk factors are proposed by the ADA to determine type 1 diabetes at high risk of fractures and osteoporosis [13].

Results

Prevalence of osteoporosis in type 1 diabetes

A total of 952 individuals were active attenders in the diabetes clinic and had a diagnosis of type 1 diabetes and age > 50 years (men) or age > 50 years and postmenopausal (women) at the initiation of the DXA-initiative; 640 individuals underwent DXA as part of the initiative, and 17.8% were diagnosed with osteoporosis with BMD T-score ≤ − 2.5 at the total hip and/or lumbar spine (L1 to L4) and/or prevalent vertebral compression fracture(s) (7.7%). A total of 124 of the 952 individuals had a DXA performed outside the initiative in the period 2015–2022. Of these, 65.3% were diagnosed with osteoporosis based on the same criteria. Thus, in the full cohort of 764 individuals, 25.5% of those scanned from 2015 to 2022 had osteoporosis. Implementation of systematic screening for osteoporosis increased the proportion of patients having a DXA performed from 13% prior to the initiative to a total of 80% at the end of the initiative (Fig. 1 b).

Characteristics and possible predictors of osteoporosis

The baseline characteristics of the individuals who underwent DXA during the initiative are displayed in Table 1. Those diagnosed with osteoporosis were slightly older (65 vs 61 years, $p < 0.05$), had a lower BMI (25 vs. 27 kg/m^2, $p < 0.05$), and were more likely to have a history of smoking (19 vs. 12% and 28 vs. 24% current smokers and previous smokers, respectively), and a family history of osteoporosis (38 vs. 25%, $p < 0.05$) compared to those without osteoporosis. When assessing the prevalence of osteoporosis by 10-year age categories, there was a borderline significant trend towards an increasing prevalence of osteoporosis with increasing age (Fig. 2). The characteristics of the individuals grouped by gender and 10-year age categories are displayed in supplementary Table 1.

The characteristics of those scanned outside the initiative are displayed in supplementary Table 2.

Furthermore, the BMD T-scores of the hip and lumbar spine were significantly lower in those scanned outside the initiative. Supplementary Table 3 displays the characteristics of the individuals diagnosed with osteoporosis within or outside the initiative. The individuals with osteoporosis diagnosed outside the initiative were older (70 vs. 65 years, $p < 0.05$), had a lower proportion of males (23 vs. 54%, $p < 0.05$), a longer diabetes duration (39 vs. 32 years, $p < 0.05$), and were more prone to have a retinopathy or neuropathy ($p < 0.05$) compared to those scanned within the initiative.

Table 1 Characteristics of individuals who had a DXA within the initiative by osteoporosis status presented as mean and 95% CI unless other is specified

Variable	Non-osteoporotic ($n=526$)	Osteoporosis ($n=114$)
Patient characteristics		
Age (years)*#	61 (61; 62)	65 (63; 67)
Fracture risk factors		
Age ≥ 65 years (%)	33.4%	49.1%
Gender (% males)	61	54
BMI (kg/m^2)	27 (27; 28)	25 (24; 26) *
Smoking		
Current smoker (n)	62 (12%)	22 (19%)*
Previous smoker (n)	125 (24%)	32 (28%)
Never smoker (n)	339 (64%)	60 (53%)
Family history of osteoporosis (%)	25 (22; 29)	38 (29; 47) *
Years since menopause (years), women only#	13 (12; 14)	16 (12; 19)
Diabetes duration (years)	32 (30; 33)	32 (29; 35)
Retinopathy (%)	31 (27; 35)	38 (29; 48)
Neuropathy (%)	17 (13; 20)	17 (10; 25)
Nephropathy (%)#	13 (10; 16)	18 (11; 26)
Most recent HbA1c (mmol/mol)	60 (59; 61)	60 (58; 62)
Biochemical markers		
Average of previous HbA1c (mmol/mol)	61 (60; 62)	62 (60; 64)
Average of previous HbA1c (%)	7.7 (7.6; 7.8)	7.8 (7.6; 8.0)
TSH (u/l)	1.9 (1.8; 2.0)	1.8 (1.6; 2.1)
Hemoglobin (mmol/l)	8.7 (8.7; 8.8)	8.5 (8.4; 8.7) *
25 hydroxy vitamin D (nmol/l) ($n=240$)	84 (79; 88)	85 (77; 93)
Urinary albumine creatinine ratio (mg/g)$	6.4 (3.8; 16)	9.6 (5.4; 23) *
Estimated glomerular function (ml/min)$	90 (81; 90)	90 (76; 90)
Average of previous estimated glomerular function (ml/min)$	88 (81; 90)	88 (81; 90)

#*t*-test performed with unequal variances, *$p<0.05$, $Median and IQR

In unadjusted analyses in the total cohort, increasing age, female gender, current smoking, longer diabetes duration, and presence of retinopathy or neuropathy were significantly associated with a higher risk of osteoporosis, whereas increasing BMI was associated with a lower risk of osteoporosis. HbA1c or nephropathy was not associated with the risk of osteoporosis. Information on family history of osteoporosis was only available for individuals within the initiative and was significantly associated with the risk of osteoporosis. Table 2 displays the multivariate-adjusted analysis of possible predictors of osteoporosis in type 1 diabetes. In the initiative cohort, only an increasing age (OR = 1.3, 95% CI:1.0; 1.7) and a family history of osteoporosis (OR = 1.9, 95% CI: 1.2; 3.0) were associated with an increased risk of osteoporosis, whereas a one kg/m^2 increase in BMI was associated with a decrease in risk of osteoporosis (OR = 0.87, 95% CI: 0.82; 0.92). In those scanned outside the initiative, only age was significantly associated with osteoporosis (OR = 2.3, 95% CI 1.1; 4.9).

In the total cohort age, female gender, current smoker status, and retinopathy were associated with an increased risk of osteoporosis, whereas BMI was associated with a decreased risk of osteoporosis (OR = 0.87, 95% CI 0.82; 0.92). Supplementary Fig. 1 displays the association between BMI categories and the presence of osteoporosis and reveals an OR of 11 (95% CI 4.8; 25) for osteoporosis in those with BMI < 20 kg/m^2 compared to those with a BMI ≥ 25 kg/m^2. There were no significant interaction terms between 10-year age categories and BMI categories. Prevalent vertebral fractures were associated with increasing age (OR 1.04, 95% CI 1.01; 1.07) and a family history of osteoporosis (OR 2.41, 95% CI 1.33; 4.40) also after adjustment for age and gender, but not with diabetes duration, neuropathy, retinopathy, nephropathy, or HbA1c.

Diagnostic cutoff according to ADA criteria

ADA recommends referral for DXA for individuals with multiple fracture risk factors or age ≥ 65 years. Within the initiative, where most risk factors were collected, 36% were aged ≥ 65 years and 79% had ≥ 3 fracture risk factors or

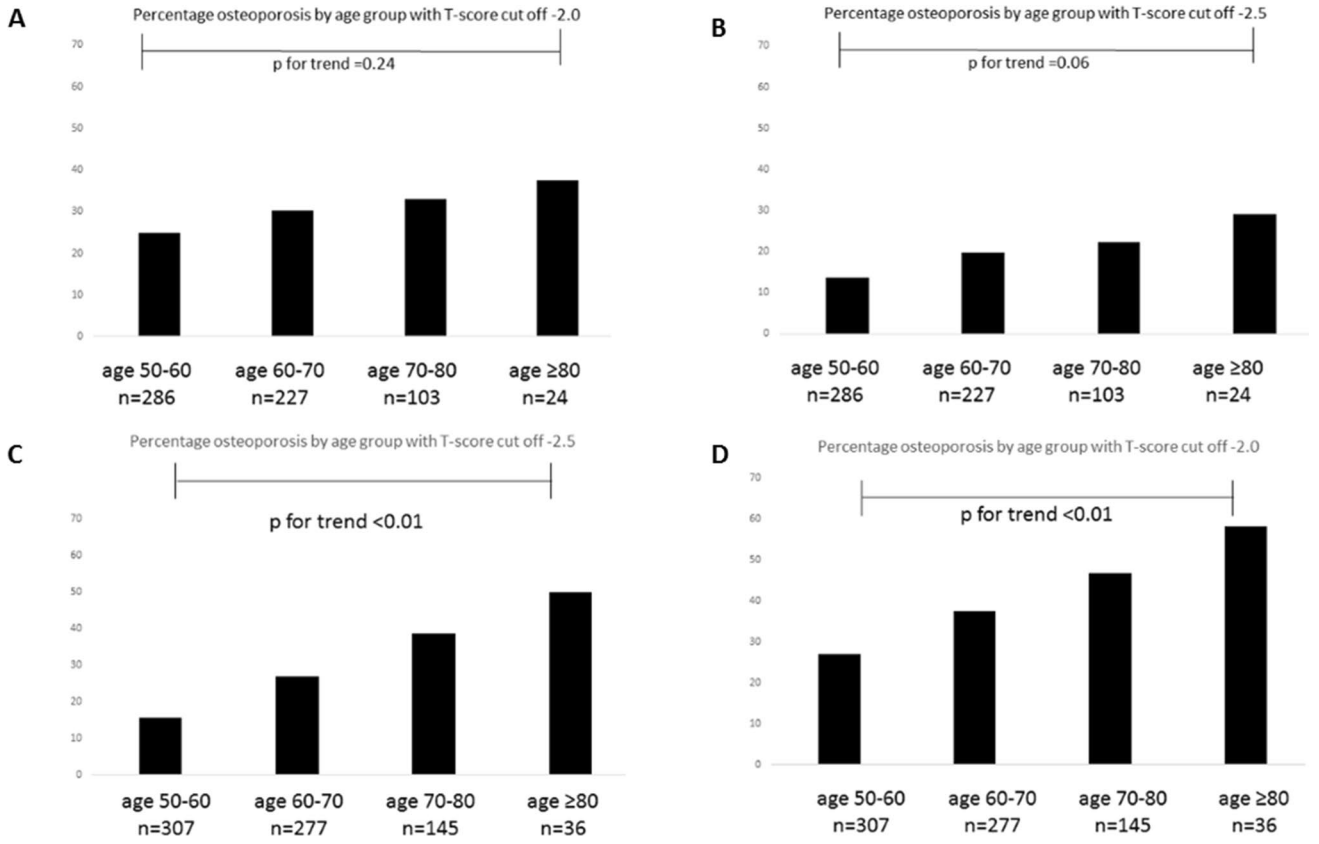

Fig. 2 The prevalence (%) of osteoporosis by 10-year age intervals in individuals with type 1 diabetes based on T-score cutoffs and prevalent vertebral fracture. **A** within the initiative and T-score cutoff of − 2.0, **B** within initiative and T-score cutoff of − 2.5, **C** total group within and without initiative and T-score cutoff of − 2.5, **D** total group within and without initiative T-score cutoff of − 2.0

Table 2 Odd ratio for an osteoporosis diagnosis by patient characteristics

Variable	Within initiative ($n=640$)	Outside initiative ($n=88$)	Total cohort ($n=718$)
10-year age group	1.3 (1.0; 1.7)*	2.3 (1.1; 4.9)*	1.4 (1.2; 1.8)*
Female gender	1.2 (0.7; 1.8)	1.6 (0.54; 4.9)	1.6 (1.1; 2.4)*
BMI (kg/m^2)	0.87 (0.82; 0.93)*	0.92 (0.83; 1.0)	0.88 (0.84; 0.92)*
Current smoker (yes/no)	1.6 (0.87; 2.9)	8.2 (1.1; 59)	1.9 (1.1; 3.1)*
Family history of osteoporosis	1.9 (1.2; 3.0)*	n/a	n/a
Diabetes duration (years)	1.0 (0.99; 1.0)	1.0 (1.0; 1.1)	1.0 (0.99; 1.0)
Retinopathy (yes/no)	1.3 (0.80; 2.1)	0.85 (0.21; 3.3)	1.8 (1.2; 2.7)*
Neuropathy (yes/no)	0.80 (0.42; 1.5)	0.69 (0.24; 1.9)	1.0 (0.63; 1.61)
Nephropathy (yes/no)	1.8 (0.96; 3.3)	0.9 (0.21; 3.8)	1.5 (0.9; 2.5)
Mean of previous HbA1c (mmol/mol)	1.0 (0.99; 1.0)	1.0 (0.99; 1.0)	1.0 (0.99; 1.0)

Mutual adjusted analysis. *$p<0.05$

age ≥ 65. Among these, 30% had a T-score ≤ −2.0 or VFx which was not statistically different from those with fewer risk factors (23%, $p=0.08$).

Thus, when applying the ADA or IOF criteria to the entire cohort, 36.0% had osteoporosis based on T-score ≤ − 2.0 or VFx. Of those scanned within the initiative, 28.6% had osteoporosis based on T-score ≤ − 2.0 or fragility fractures, and in those scanned outside the initiative, 74.2% had osteoporosis based on T-score ≤ − 2.0 or VFx.

Prescription of anti-resorptive treatment

In total, 95/114 (83%) of patients diagnosed with osteoporosis within the initiative were prescribed anti-resorptive treatment; 76/95 (80%) alendronate, 12/95 Aclasta (13%), 3/95 teriparatide followed by Aclasta (3%), and 4/95 denosumab (4%). Nineteen patients (17%) did not receive treatment for osteoporosis at the time of audit; 7 patients declined treatment despite a clear diagnosis of osteoporosis, 3 patients had not received the result of the DXA, and 9 patients were not started on treatment for miscellaneous reasons.

Treatment compliance for alendronate was high. The number of redeemed prescriptions for alendronate corresponded to a compliance rate of 92.7%, assuming that all medicine purchased was taken. Compliance was checked in January 2023, and the mean follow-up ranged between 3 months and 3 years.

Discussion

The present study describes the prevalence and risk factors for osteoporosis in postmenopausal women and men ≥ 50 years of age with type 1 diabetes. In our study, we also explore whether universal screening for osteoporosis in type 1 diabetes is warranted or if DXA could be limited to a selected group of at-risk individuals.

We found that among active attenders in our type 1 diabetes clinic, 25.5% had osteoporosis using WHO diagnostic criteria. In the study, 640 individuals with type 1 diabetes were systematically evaluated for osteoporosis and compared to 124 individuals who were scanned outside the initiative. The prevalence of osteoporosis in the present study is lower than in the Danish general population as a study from 2005 estimated a prevalence of 41% in women and men aged ≥ 50 years. However, results from this study were extrapolated from mean BMDs collected across a number of separate research projects [18]. A study from Belgium, however, found a prevalence of osteoporosis of 22% among 6406 individuals from the general population with a mean age of 60.5 years which is closer to the osteoporosis prevalence that we report here [19]. According to the 2024 ADA guidelines, DXA is warranted in individuals with type 1 diabetes, and age > 65 years or multiple fracture risk factors and treatment should be recommended at a T-score ≤ − 2. When applying these screening and treatment criteria to our clinic, 79% of individuals included in our clinical initiative would be eligible for a DXA, and of these, 30% should be treated. This, however, was not significantly different from the prevalence outside the ADA target group (23%) and within our total study group where treatment based on ADA criteria should be offered to 36%.

Our findings suggest that by implementing systematic screening for osteoporosis, we identify a high proportion of persons affected by osteoporosis at an earlier stage of osteoporosis and at a younger age where more fractures potentially could be prevented. Moreover, in type 1 diabetes, osteoporosis is diagnosed in individuals with a particular high fracture risk at a given BMD underscoring the need for intervention. Increasing age, lower BMI, increasing diabetes duration, diabetes complications, and female sex have previously been reported as negative determinants of BMD and fragility fracture in type 1 diabetes. Age, diabetes duration, and complications are not independent risk factors, as the duration increases with age and the risk of complication increases with duration [20]. Accordingly, in our cohort using multiple adjustments, we identify the same risk factors for osteoporosis as in the general population, e.g., age, self-reported family history of osteoporosis, and BMI [21].

Previous clinical studies of osteoporosis prevalence in type 1 diabetes included fewer, more selected, and younger individuals than in our study. In the Epidemiology of Diabetes Interventions and Complications study, study survivors and responders from the Diabetes Control and Complications Trial (DCCT), thus a highly selected cohort, were invited for DXA in 2017–2019 [22]. Among the 1058 included individuals, the mean age was 59.2 years, and the mean BMI was 29.2 kg/m^2 and also included pre-menopausal women, and among these, only 6.4% had osteoporosis based on DXA T-score ≤ − 2.5 at the total hip, femoral neck, or lumbar spine. The younger age and higher BMI in this cohort may explain some of the differences to our findings, but it is also likely that it selected a healthy cohort whereas our findings are from a systematical clinical service. A study of 75 individuals (mean age 66) with type 1 diabetes from the Canadian Study of Longevity in Type 1 Diabetes found an osteoporosis prevalence of 16% [23]. Moreover, Leidig-Bruckner et al. reported site-specific osteoporosis prevalence in type 1 diabetes of 6% and 10% for younger men (mean age 46 years) and women (mean age 42 years) by DXA of the lumbar spine and femoral neck, respectively [24]. Finally, a meta-analysis including individuals from clinical studies by Qiu et al. showed a higher risk of low BMD in persons with type 1 diabetes compared to healthy controls [25] and another meta-analysis with data from 16 studies, and in total, 966 individuals with type 1 diabetes by Shah et al. reported a lower BMD at the femoral neck, but not lumbar spine in type 1 diabetes compared to controls [26]. The studies included in this meta-analysis, however, were relatively small with participant numbers ranging from 20 to 163, and 12 out of 16 studies included individuals younger than 50 years [26]. Thus, the present study is the largest real-world study to date of osteoporosis prevalence in an age group where treatment could be indicated to reduce future fracture risk, and we find

a higher proportion of individuals with osteoporosis than previously described.

Based on VFA, we found VFx prevalence ranging from 5% in females between 50 and 60 years and up to 15% in males aged 70–80 years. The VFx prevalence in the present study is comparable to previous studies where a cross-sectional study reported a prevalence of VFx comparable to the general population at 2.4% in relatively young individuals with type 1 diabetes (mean age 43 years) [27]. Another cross-sectional study reports a VFx prevalence of 15% in older individuals with type 1 diabetes (mean age 61 years) [28]. In contrast to these findings, Zhukouskaya et al. reported a 24% prevalence of VFx in young (mean age 31 years) individuals with type 1 diabetes. The discrepancies in the finding of a high prevalence of VFx in the younger individuals with type 1 diabetes and lower prevalence of VFx in older groups may be due to differences in the cohorts but may also be explained by differences in assessment of vertebral fractures as the latter study mainly reported mild VFx of 20–25% compression. Thus, based on our systematically collected data, the prevalence of VFx in type 1 diabetes is comparable to the general population [29]. We found that increasing age and a family history of osteoporosis are associated with the presence of VFx, whereas Leanza and colleagues [30] reported that neuropathy, increasing diabetes duration, and poor glycemic control were associated with prior non-vertebral fragility fractures. Discrepancies between the studies may relate to fracture types and a younger age (mean age of 42 years) in the study by Leanza et al. [30].

Systematic evaluation of fracture risk and diagnosis of osteoporosis requires that subsequently an efficient treatment is instigated. We found that relevant treatment for osteoporosis was prescribed to almost all persons in whom it was indicated, and that adherence was high. A recent meta-analysis on the benefit of anti-resorptive therapy on fracture risk in people with diabetes found that treatment is equally effective in people with and without diabetes [12]. In the present study, treatment for osteoporosis was prescribed to 95 of 114 individuals with diabetes and an audit of the pattern of redemption of prescriptions for oral bisphosphonate showed excellent persistence to treatment of more than 90%. This seems like an unlikely high adherence, but similar levels were found in a Swedish register study where adherence was more than 80% to lipid-lowering therapy in individuals with type 1 diabetes older than 53 years [31]. In comparison, one-third of unselected Danish individuals with osteoporosis discontinued alendronate treatment within 2 years after initiation [32].

The strengths of this study are the relatively large sample size and low risk of selection bias as all postmenopausal women and men ≥ 50 years of age with type 1 diabetes from our clinic have been offered referral for DXA. All DXAs and VFA assessments have been evaluated by osteoporosis specialists. Data on osteoporosis risk factors and diabetes complications from questionnaires and EHR were systematically collected. To further underline the impact of systematic DXA on individuals with type 1 diabetes, we compared individuals scanned as part of the clinical service development with persons scanned prior to or during the initiative following non-systematic referral, and we found that more individuals are diagnosed with osteoporosis when DXA is systematically implemented. This numerical increase in osteoporosis cases is due to the fact that more individuals are offered DXA. The limitations of the study are that some individuals declined referral for DXA. Whether this group differs from the included group is unknown. Follow-up studies in our clinic could include analyses of 5-, 10- and 15-year incident fractures to investigate if fracture rates differ among participants and non-participants. Moreover, several DXA scanners were used for BMD assessment; however, the scanners are cross-calibrated and have a CV of 1%.

In conclusion, the present study finds a treatment indication for anti-osteoporotic therapy in 25.5 to 36% of people with type 1 diabetes older than 50 years depending on the diagnostic criteria used. As effective treatment can be offered, this high prevalence of osteoporosis calls for an efficient setup for a stringent focus on bone health in type 1 diabetes clinics. These findings support the use of systematic DXA scanning of individuals with type 1 diabetes in clinical practice and we propose that all postmenopausal women and men aged 50 with type 1 diabetes should be screened for osteoporosis.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00198-025-07443-y.

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Data availability The datasets generated during and/or analyzed during the current study are not publicly available due to Danish legislation but may be available from the corresponding author and legally obtained permission upon reasonable request.

Declarations

Conflicts of interest JS-L reports no conflicts in relation to this work. Outside this work JS_L has received honoraria for lectures for UCB. TH reports no conflicts in relation to this work. Outside this work TH has received honoraria for lectures for UCB, Amgen, AstraZeneca, and Astellas Pharma. BLL reports no conflicts in relation to this work. Outside this work BLL has received honoraria for lectures and advisory

boards for UCB, Gedeon-Richter, Mereo, Samsung-Bioepis, Amgen, Astellas and AstraZeneca.

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