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Sociodemographic, anthropometric, and lifestyle correlates of prediabetes and type 2 diabetes in europe: The Feel4Diabetes study

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Abstract *Background and aims:* The current work aimed to identify the predominant correlates of prediabetes and T2DM among a variety of socio-demographic, anthropometric and lifestyle indices, in a large sample of adults from families at high risk for T2DM.
Methods and results: In this cross-sectional study, 2816 adults were recruited from low-socioeconomic areas in high-income countries (HICs) (Belgium-Finland), HICs under austerity measures (Greece-Spain), and low/middle-income countries (LMICs) (Bulgaria-Hungary). A positive association between the male sex (OR, 95% C.I.2.77 (1.69–4.54)) and prediabetes was revealed compared to females, while there was a negative association between younger age (<45 years) (OR, 95% C.I. 0.58 (0.37–0.92)), and low/medium levels of waist circumference (OR, 95% C.I. 0.44 (0.22–0.89)) with prediabetes compared to older age and high levels of waist circumference, respectively. Concerning T2DM, 0–0.5 cups/day of fruits and berries (OR, 95% C.I.2. 13 (1.16–3.91)) and 150–300 g fish/week (OR, 95% C.I. 2.55 (1.01–6.41)) have a positive association compared to higher consumptions, respectively. Conversely, <1 cup/week legumes (OR, 95% C.I. 0.55 (0.31–0.99) as well as 0–0.5 servings (OR, 95% C.I. 0.34 (0.12–0.95) and 0.5–1 servings (OR, 95% C.I. 0.37 (0.19–0.71) of full-fat dairy/day have a negative association compared to higher consumptions, respectively.
Conclusion: These findings indicate the need for diabetes prevention measures targeting young adults and especially men, above 45 years of age, with central obesity and poor dietary habits and prioritize vulnerable groups and populations living in LMICs.
National Clinical Trial number: NCT 02393872

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1. Introduction

Type 2 diabetes mellitus (T2DM) accounts for 90% of diabetes cases worldwide and is considered a major public health challenge [1]. Based on global evaluations in 2019, 463 million adults aged 20–79 years had diabetes, 79.4% of these people lived in low- and middle-income countries [1,2], while 50.1% of them were unaware of their condition. Furthermore, prediabetes which signifies the risk of future development of T2DM and diabetes-related complications is estimated to account for 7.3% of the global adult population in 2017 and by 2045 is anticipated to increase to 8.3% [3]. T2DM and prediabetes can cause multiple damages to body systems, with undiagnosed and untreated patients having a greater risk of complications than those who receive treatment [4] leading to morbidity and mortality. Therefore, it is incontrovertible that they rank highly on the international health agenda and are considered a global pandemic and a threat to human health and global economies.

An array of risk factors is implicated in the pathogenesis of these non-communicable diseases including socio-demographic (older age, ethnicity, lower socioeconomic status) and lifestyle factors (overweight/obesity, unhealthy dietary habits, and physical inactivity) [5,6]. An interplay among determinants of prediabetes and T2DM is known within the larger physical-sociocultural environment and thus it is difficult to identify and evaluate the risk factors that play the most cardinal role in the development of these diseases [7,8]. Moreover, previous studies conducted in Europe are based mostly on data collected from one country, or they have not examined multiple risk factors at the same time taking into consideration the wide variety of risk factors that account for T2D and the interplay between them. Also, despite the disproportionally higher prevalence of this disease and its risk factors in certain population groups like low- and middle-income countries and low socio-economic status (SES) groups in high-income countries [7–9] previous studies have been done on the wider population instead of prioritizing specific high-risk groups [10–12].

Given its significant burden, it is imperative to identify the most vulnerable population groups in order to intensify our efforts and prioritize high-risk families, in future prevention initiatives. Therefore, the purpose of the present study is to identify the predominant correlates of prediabetes and diabetes among a variety of socio-demographic, anthropometric, clinical, and lifestyle indices, in a large sample of adults at high risk for T2DM from the Feel4-Diabetes study conducted in six European countries.

2. Methods

2.1. Design and study population

The Feel4Diabetes study (National Clinical Trial number, NCT 02393872) was a large school- and community-based intervention executed within two years (2016–2018). The purpose was to promote a healthy lifestyle including healthy eating and physical activity intending to alleviate the negative outcomes of obesity and obesity-related metabolic risk factors in vulnerable families in Europe. The present study is a secondary analysis of Feel4Diabetes community-based intervention utilizing only the baseline, cross-sectional data of the study.

The recruitment of the population included families from “vulnerable” social groups from six European countries. “Vulnerable” groups are defined as the population from low/middle-income countries (Bulgaria, Hungary), low socio-economic areas in high-income countries (Belgium, Finland), and countries under austerity measures (Greece, Spain). In Bulgaria and Hungary, all areas within the selected provinces were considered “vulnerable” and therefore eligible to participate in the Feel4Diabetes-program. In Greece, Spain, Finland, and Belgium, the municipalities/school districts/other equivalent units in the selected provinces were grouped in tertiles according to socio-economic indices retrieved from official resources and authorities (For example in Greece, information was retrieved from the Hellenic Statistical Authority) and consequently “vulnerable” areas were randomly selected only from the tertile with the lowest education level or the highest unemployment rate. Then, in all countries, after the necessary approvals were obtained from the local authorities (Ethics Committees, Ministries, Municipalities, etc.) lists were created based on the schools located in the selected “vulnerable” areas, and primary schools were randomly selected and recruited from each area until the recruitment goal was achieved. This sample included children from the first three grades of compulsory education. The final sample after a 20% exit rate was 11,511 families (“all families”), of which 2230 were “high-risk families”, in which at least one parent met the criterion of the Finnish Diabetes Risk Score (FINDRISC) that assesses the risk of developing T2DM. The design of the study started in 2015, the recruitment began in January 2016 and the initial measurements which are used in the analysis of the present study were carried out between April-June 2016 while in three countries (Finland, Hungary, Bulgaria) they were carried out during August-September 2016. For the present study adults from the “high-risk families” for developing T2DM, with full data at baseline, were included in the analysis. More details regarding study design can be found elsewhere [13].

2.2. Ethical approvals and consent forms

The Feel4Diabetes study complies with all the conditions set out in the Helsinki Declaration and the Council of Europe conventions on human rights and biomedicine. All countries participating in this study, before the program started, received approval from the relevant ethics committees and local authorities. Prior to entering the study, all parents/guardians independently completed and signed a specific consent form. More details regarding the approvals received by each country can be found elsewhere [13].

2.3. Measurements

In order to assess sociodemographic, anthropometric and lifestyle correlates of prediabetes and T2DM, data were collected using specific criteria in the participants of the group “high-risk families” at the baseline (2016). All the measurements were transacted by rigorously trained research assistants, using standardized protocols and equipment that were calibrated before the start of the measurements.

2.4. Anthropometry

All anthropometric measurements were taken twice by dyads of researchers. The third measurement was also taken, in the case that the previous two measurements differed by > 100 g for weight, > 1 cm for height, or >1 cm for waist circumference. For the height measurement, the participant had to remove the shoes and any other clothing or object that could impede the procedure. The nearest tenth of a centimeter (i.e. 0.1 cm) was recorded using telescopic stadiometers: SECA 213, SECA 214, SECA 217, and SECA 225. For the weight measurement, the participant had to wear light clothing and remove the shoes. The nearest 0.1 kg was recorded using electronic weight scales: SECA 813 and SECA 877. All volunteers were categorized by the Body Mass Index (BMI) cut-off points, BMI was calculated by the formula [weight/height^2]. For the waist circumference measurement, the participant had to remove heavy or tight clothing that can change the shape of the waist and the measurement was made between the lowest rib margin and the iliac crest at the midaxillary line. The nearest tenth of a centimeter (i.e., 0.1 cm) was recorded using a non-elastic measuring tape (SECA 201) and the World Health Organization (WHO) cut-off points were used for their classification [14].

2.5. Physical activity (PA)

Physical activity was assessed through a specially designed self-reported questionnaire. It included questions about the frequency, intensity, and type of PA of the participant during the previous seven days, the contribution of other people in the decision for physical activity as well as the time and the reason for adopting a sedentary life as a habit. Participants were also asked about the minimum recommended duration of physical activity for adults.

2.6. Blood test

Blood tests were performed on the same day with the anthropometric measurements by professional staff on all participants in the morning (8:30–10:30) after 12-h overnight fasting. Measurements of fasting plasma glucose (FPG), fasting serum insulin and glycosylated hemoglobin (HbA1c%) were acquired. Blood samples directed for glucose measurement were collected in tubes with sodium fluoride (10.0 mg) and potassium oxalate (8.0 mg) for the inhibition of glycolysis. For the insulin measurements, blood samples were collected in tubes that contained a clotting activator and gel for serum separation. For Hba1c measurements, blood samples were collected in tubes with added anticoagulant (i.e., K3 EDTA Plasma glucose was measured by standard enzymatic procedures, insulin was measured by Electrochemiluminescence (ECLIA) method and HbA1c was determined via high-performance liquid chromatography. For all three glycemic profile markers the intra-assay coefficients of variation were within the acceptable thresholds in all study centers (i.e., <2% for FPG, <5% for serum insulin, and <5% for Hba1c [15]. Participants were classified according to the American Diabetes Association (ADA) criteria in the following categories: normoglycemic (FPG <100 mg/dl; 5.6 mmol/l), prediabetics (FPG 100–125 mg/dl; 5.6–6.9 mmol/l) and having T2D (FPG ≥126 mg/dl; 7.0 mmol/l) [16] and this measurement was used in order to identify the study outcome.

2.7. Socio-demographic and behavioral characteristics

Standardized self-reported questionnaires were used in all study participants to gather information on basic socio-demographic characteristics (date of birth, ethnicity, education level, marital status, occupation) along with information about the person’s eating habits. Moreover, information concerning their drinking, eating, physical activity, sedentary behaviors, smoking, and sleep duration as well as their determinants, was self-reported using standardized questionnaires.

2.8. Statistical analysis

Continuous variables are presented as means ± standard deviations and categorical values as proportions (%). The normality of the distribution of variables was determined by the Kolmogorov − Smirnov test and histograms.

Multinomial logistic regression was employed to examine the univariate associations between several socio-demographic, anthropometric, clinical, and lifestyle indices (independent variables) and prediabetes or diabetes (dependent variables). Multinomial logistic regression was also performed to assess the multivariate associations of those socio-demographic, anthropometric, and lifestyle indices that were found to be associated with the dependent variables at the univariate level, with the risk of prediabetes or diabetes. In the multinomial logistic regression, every variable operates as the covariate of the other variables, thereby all the variables have been adjusted for multiple confounders. Statistical analysis was performed using the Statistical Package for Social Sciences (SPSS Inc., Chicago, IL, USA), version 25.0. The level of statistical significance was set at $p < 0.05$.

3. Results

Table 1 displays the main characteristics of the 2816 study participants enrolled with a mean age of 40.84 ± 5.64 years and a mean BMI of 28.45 ± 5.47 kg/m^2.

Table 2 presents the univariate associations of socio-demographic, anthropometric, and lifestyle indices with the prevalence of either prediabetes or T2DM in adults from “high-risk families”. Younger participants (<45 years of age) have a lower prevalence of prediabetes, while the prevalence is greater in men (OR, 95% C.I. 3.23 (2.22–4.70)) than in women. Normal weight people (OR, 95% C.I. 0.18 (0.09–0.35)) and those without abdominal obesity have an inverse association with prediabetes compared to overweight/obese and people with abdominal obesity. Concerning lifestyle factors, low red meat and low-fat dairy consumption, have negative associations with prediabetes, while medium weekly consumption of white meat and fish has a positive association with prediabetes compared to higher consumption, respectively. With regard to T2DM, men have a greater prevalence (OR, 95% C.I. 1.29 (1.03–1.61)) compared to women. People living in Northern and Southern Europe have a lower prevalence than those living in Eastern Europe, while adults with <12 years of education, unemployed or single have a positive association with T2DM.

Table 3 presents the multivariate associations of those socio-demographic, anthropometric, and lifestyle indices found to be associated with prediabetes or diabetes at the univariate level. Male gender is associated with higher prediabetes prevalence, while less than 45 years of age, low/medium waist circumference levels, consumption of up to 1 serving of low-fat dairy/day, and no coffee consumption have a negative association with prediabetes. Regarding prediabetes, men present with a higher prevalence (OR, 95% C.I. 2.77 (1.69–4.54)) compared to women. Conversely, people under 45 years old (OR, 95% C.I. 0.58 (0.37–0.92)) have a lower prevalence compared to those who are older. Waist circumference between 80 and 88 cm (women) and 94–102 cm (men) has a negative association compared to >88 cm or >102 cm, (OR, 95% C.I. 0.44 (0.22–0.89)), respectively. Consumption of 0–0.5 serving/day (OR, 95% C.I. 0.56 (0.33–0.94)) and 0.5–1 serving/day (OR, 95% C.I. 0.49 (0.24–0.96)) of low-fat dairy as well as no coffee consumption (OR, 95% C.I. 0.47 (0.25–0.89)) are associated with a lower prediabetes prevalence compared to >1 servings low-fat dairy/day and >1 cup of coffee/day, respectively.

Concerning T2DM, it was evidenced that people with low fruits and berries consumption and medium fish consumption presented with increased prevalence, while those who live in Southern Europe, with low legumes and low full-fat dairy consumption, have a decreased T2DM prevalence. More specifically, the consumption of 0–0.5 cups (OR, 95% C.I. 2.13 (1.16–3.91)) of fruits and berries/day had a positive association with T2DM compared to >0.5–3 cups/day. The consumption of 150–300 g of fish/week (OR, 95% C.I. 2.55 (1.01–6.41)) was related to higher T2DM prevalence in comparison with a greater consumption of >300 g/week. Conversely, people living in Southern Europe (OR, 95% C.I. 0.26 (0.11–0.57)) have a lower T2DM prevalence compared to those living in Eastern Europe. People that consume <1 cup/week of legumes (OR, 95% C.I. 0.55 (0.31–0.99)) have a negative association compared to those that consume ≥1 cup/week. Finally, the consumption of 0–0.5 serving/day (OR, 95% C.I. 0.34 (0.12–0.95)) as well as 0.5–1 serving/day (OR, 95% C.I. 0.37 (0.19–0.71)) of full-fat dairy is inversely associated with T2DM compared to >1 servings/day.

Table 1 Characteristics of the study population. The Feel4Diabetes study 2022.

	Total sample (n = 2816)	
	Mean	SD
Age (years)	40.84	5.64
BMI (kg/m^2)	28.45	5.47
Waist circumference (cm)	94.39	14.33
Total cholesterol (mg/dl)	195.05	38.29
LDL cholesterol (mg/dl)	120.85	33.40
HDL cholesterol (mg/dl)	53.46	14.30
Triglycerides (mg/dl)	109.47	85.85
Blood glucose (mg/dl)	93.81	14.75
HbA1c (%)	5.38	0.49
SBP (mmHg)	118.02	16.70
DBP (mmHg)	78.53	11.45

BMI: body mass index, HbA1c: hemoglobin A1c, SBP: systolic blood pressure, DBP: diastolic blood pressure

4. Discussion

The present study aimed to identify the predominant correlates of prediabetes and T2DM, among a variety of socio-demographic, anthropometric, and lifestyle indices, in a large sample of adults from families at high risk for T2DM from six European countries. It was evidenced that men have greater prediabetes prevalence while participants under 45 years old, with low/medium waist circumference levels as well as those who consume up to 1 serving of low-fat dairy daily and who do not consume coffee have lower prevalence. Concerning T2DM, people with low fruits/berries consumption and medium fish consumption presented with increased prevalence, while those who live in Southern Europe, with low legume and low full-fat dairy consumption, have decreased T2DM prevalence. Although obesity is a well-known risk factor for T2DM in the present study such an association was not observed, indicating that factors independently of weight status the adoption of a healthy lifestyle and balanced eating habits could be more significant for the reduction of T2DM risk. All these findings further enlighten the knowledge regarding population groups that are at greater risk of developing these life-threatening diseases and can facilitate the design of cost-effective future intervention programs, appropriate to the needs of these specific population subgroups aiming to prevent T2DM among those in higher need.

Concerning prediabetes, our findings revealed that men have a positive association compared to women. Previous literature has highlighted sex differences in developing prediabetes mainly due to biological factors such as differences in sex chromosomes, sex hormones, and their effects on body systems [17,18]. Men present with greater trunk and visceral fat (significant prediabetes predictor), upper extremity mass, and liver fat compared to women of the same age and BMI [19,20]. Meta-analyses have shown that women have higher leptin and adiponectin levels and therefore have better glucose, insulin and lipid regulation [21,22].

Table 2 Univariate associations of several socio-demographic, anthropometric, clinical, and lifestyle indices (independent variables) with prediabetes or diabetes (dependent variables). The Feel4Diabetes study 2022.

Independent variables	Cases (% of total)	Odds ratio (95% confidence interval)	
		Dependent variables	
		Prediabetes	Diabetes
Socio-demographic			
Age			
≥45 years	664 (23.6)	1	1
<45 years	2144 (76.4)	**0.50 (0.34–0.74)**	1.05 (0.81–1.35)
Sex			
Female	1875 (66.8)	1	1
Male	933 (33.2)	**3.23 (2.22–4.70)**	**1.29 (1.03–1.61)**
Region			
Easter Europe/LHMICs	804 (28.6)	1	1
Southern Europe/HICs under crisis	1250 (44.5)	1.53 (0.88–2.63)	**0.23 (0.18–0.30)**
Northern Europe/HICs	754 (26.9)	**2.54 (1.46–4.40)**	**0.33 (0.25–0.44)**
Education			
≥12 years	2100 (75.3)	1	1
<12 years	689 (24.7)	1.21 (0.80–1.83)	**1.41 (1.11–1.79)**
Occupation			
employed	2149 (77.1)	1	1
unemployed	640 (22.9)	0.79 (0.49–1.27)	**1.49 (1.17–1.90)**
Marital status			
married	2593 (92.9)	1	1
not married	198 (7.1)	0.61 (0.24–1.51)	**1.66 (1.16–2.39)**
Anthropometric			
Weight status			
≥30 kg/m^2	877 (36.0)	1	1
>25–30 kg/m^2	859 (35.2)	0.69 (0.47–1.03)	0.83 (0.51–1.35)
18.5–25 kg/m^2	701 (28.8)	**0.18 (0.09–0.35)**	0.57 (0.32–1.00)
Waist circumference			
>88 (women) or >102 (men)	1276 (52.5)	1	1
80-88 (women) or 94–102 (men)	604 (24.9)	**0.34 (0.19–0.59)**	0.74 (0.43–1.27)
<80 (women) or 94 (men)	550 (22.6)	**0.35 (0.19–0.62)**	0.81 (0.47–1.40)
Lifestyle			
Fruits and berries per day			
>0.5–3 cups	978 (35.3)	1	1
0–0.5 cups	1789 (64.7)	1.32 (0.89–1.97)	**1.88 (1.47–2.42)**
Veggies per day			
≥1 cup	1025 (37.1)	1	1
0-1 cup	1739 (62.9)	1.43 (0.96–2.12)	1.80 (1.41–2.29)
Legumes per week			
≥1 cup	1510 (55.1)	1	1
<1 cup	1229 (44.9)	1.40 (0.97–2.03)	**1.29 (1.03–1.61)**
Non whole grain cereals and bread per day (30g)			
>3 servings	685 (25.1)	1	1
0.5–3 servings	906 (33.2)	0.97 (0.56–1.67)	0.82 (0.62–1.08)
0–0.5 servings	1134 (41.6)	1.43 (0.88–2.33)	**0.61 (0.46–0.81)**
Whole grain cereals and bread per day (30g)			
>3 servings	674 (24.7)	1	1
0.5–3 servings	881 (32.3)	1.10 (0.68–1.78)	1.04 (0.77–1.40)
0–0.5 servings	1170 (42.9)	0.81 (0.50–1.32)	0.99 (0.75–1.31)
Red meat per week			
>300 g	1699 (62.0)	1	1
150–300 g	690 (25.2)	0.89 (0.58–1.37)	0.86 (0.65–1.13)
<150 g	351 (12.8)	**0.23 (0.87–0.65)**	**1.47 (1.08–1.98)**
White meat per week			
>400 g	891 (32.5)	1	1
200–400 g	992 (36.2)	**1.75 (1.12–2.73)**	**0.50 (0.39–0.66)**
<200 g	860 (31.4)	0.77 (0.44–1.32)	**0.49 (0.37–0.65)**
Fish per week			
>300 g	525 (19.2)	1	1
150–300 g	1060 (38.7)	**1.71 (1.01–2.89)**	**1.58 (1.16–2.15)**
<150 g	525 (19.2)	0.86 (0.48–1.53)	0.88 (0.63–1.24)
Nuts and seeds portions per week (30g)			
≥90gr	688 (25.0)	1	1
up to 90gr	725 (26.4)	1.47 (0.88–2.46)	**1.46 (1.09–1.96)**

(*continued on next page*)

Table 2 (*continued*)

Independent variables	Cases (% of total)	Odds ratio (95% confidence interval)	
		Dependent variables	
		Prediabetes	Diabetes
no consumption	1338 (48.6)	1.16 (0.72–1.87)	**1.70 (1.24–2.34)**
Salty snacks per week (40g)			
>3 portions	521 (18.9)	1	1
0.5–3 portions	759 (27.5)	1.50 (0.80–2.82)	**1.42 (1.01–1.98)**
<0.5 portions	1476 (53.6)	1.75 (0.99–3.10)	1.26 (0.92–1.71)
Sweet snacks per week (40g)			
>3 portions	1425 (51.5)	1	1
0.5–3 portions	704 (25.4)	1.24 (0.78–1.95)	**1.30 (1.01–1.68)**
<0.5 portions	638 (23.1)	**1.57 (1.01–2.43)**	1.13 (0.86–1.49)
Dairy low fat per day (240 ml)			
>1 servings	537 (19.8)	1	1
0.5–1 servings	492 (18.1)	**0.43 (0.23–0.78)**	0.84 (0.58–1.21)
0–0.5 servings	1686 (62.1)	**0.49 (0.32–0.75)**	0.93 (0.70–1.24)
Dairy full fat per day (240 ml)			
>1 servings	2174 (80.1)	1	1
0.5–1 servings	305 (11.2)	0.79 (0.33–1.91)	0.70 (0.44–1.11)
0–0.5 servings	236 (8.7)	0.94 (0.48–1.84)	**0.57 (0.40–0.81)**
Coffee per day (250 ml)			
>1 cup	1035 (36.9)	1	1
Up to 1 cup	797 (28.4)	0.70 (0.45–1.07)	**1.86 (1.40–2.47)**
0 cups	976 (34.8)	**0.39 (0.24–0.63)**	**1.89 (1.44–2.47)**
Soft drinks with sugar per day (250 ml)			
consumption	1023 (36.4)	1	1
no consumption	1785 (63.6)	1.45 (0.96–2.18)	0.84 (0.67–1.05)
Soft drinks without sugar per day (250 ml)			
consumption	845 (30.1)	1	1
no consumption	1963 (69.9)	0.83 (0.56–1.23)	1.02 (0.81–1.29)
Alcohol per sex per week			
>7 g or >14 g for men and women	176 (18.9)	1	1
Up to 7 g or 14 g for men and women	757 (81.1)	0.63 (0.36–1.10)	1.13 (0.70–1.83)
MPA per day			
≥30 min	985 (38.6)	1	1
<30min	1565 (61.4)	0.97 (0.66–1.43)	1.02 (0.81–1.29)
Walking per day			
≥30 min	575 (26.5)	1	1
<30min	1593 (73.5)	1.60 (0.94–2.74)	0.93 (0.70–1.23)
Total screen time per day			
≥2 h	1419 (52.2)	1	1
<2 h	1299 (47.8)	0.75 (0.52–1.10)	0.98 (0.79–1.23)
Sleep hours			
≥7 h	1869 (68.5)	1	1
<7 h	858 (31.5)	1.34 (0.91–1.96)	1.09 (0.86–1.38)

HOMA-IR: homeostatic model assessment insulin resistance, MPA: moderate physical activity
Bold font indicates statistically significant OR ($P < 0.05$).

The findings showed that people under 45 years have a negative prediabetes association compared to older ones. Although in the present study the age range is limited we disclosed a key association as the age of 45 may be critical for the development of this disease. The Global Health Observatory data repository of the WHO has also revealed that prediabetes prevalence tends to increase rapidly after the age of 45 years [23]. Another cross-sectional survey conducted on 1451 individuals 25–64 years old, disclosed that the prevalence of prediabetes between 45 and 54 years of age is 35.9% for men and 21.5% for women, while these percentages increase up to 44.1% and 30.6%, respectively, between 55 and 64 years of age [24]. Human aging is associated with the development of insulin resistance (IR), β-cell dysfunction, and glucose intolerance. The age-related alterations in chronic inflammation, hormone signaling, mitochondrial dysfunction as well as lipid metabolism dysregulation can lead to prediabetes [25,26].

In the present study, people with low/medium waist circumference values had lower prediabetes prevalence compared to those with abdominal obesity. Waist circumference as an abdominal adiposity measure predicts fat distribution and visceral adiposity which is a more accurate prediabetes determinant than overall adiposity [27]. A cross-sectional study of 2230 adults (≥50 years old) revealed a strong association of abdominal obesity with prediabetes [28] as it leads to a deficient expansion of the subcutaneous fat depot, promoting lipotoxicity and IR in

Table 3 Multivariate associations of socio-demographic, anthropometric, clinical and lifestyle indices (independent variables) with prediabetes or diabetes (dependent variables). The Feel4Diabetes study 2022.

Independent variables	Cases (% of total)	Odds ratio (95% confidence interval)	
		Dependent variables	
		Prediabetes	Diabetes
Socio-demographic	664 (23.6)	1	1
Age			
≥45 years			
<45 years	2144 (76.4)	**0.58 (0.37–0.92)**	0.74 (0.43–1.29)
Gender			
Female	1875 (66.8)	1	1
Male	933 (33.2)	**2.77 (1.69–4.54)**	1.50 (0.86–2.63)
Region			
Eastern Europe/LHMICs	804 (28.6)	1	1
Southern Europe/HICs under crisis	1250 (44.5)	1.80 (0.86–3.78)	**0.26 (0.11–0.57)**
Northern Europe/HICs	754 (26.9)	1.85 (0.87–3.91)	2.00 (0.96–4.12)
Education			
≥12 years	2100 (75.3)	1	1
<12 years	689 (24.7)	0.98 (0.57–1.67)	0.95 (0.51–1.80)
Occupation			
employed	2149 (77.1)	1	1
unemployed	640 (22.9)	1.15 (0.65–2.04)	0.81 (0.41–1.60)
Marital status			
married	2593 (92.9)	1	1
not married	198 (7.1)	0.80 (0.28–2.31)	1.53 (0.61–3.79)
Anthropometric			
Weight status			
≥30 kg/m^2	877 (36.0)	1	1
>25–30 kg/m^2	859 (35.2)	0.91 (0.54–1.53)	0.67 (0.34–1.32)
18.5–25 kg/m^2	701 (28.8)	0.38 (0.14–1.06)	0.61 (0.23–1.59)
Waist circumference			
>88 cm (women) or >102 cm (men)	1276 (52.5)	1	1
80–88 cm (women) or 94–102 cm (men)	604 (24.9)	**0.44 (0.22–0.89)**	1.11 (0.53–2.32)
<80 cm (women) or 94 cm (men)	550 (22.6)	0.74 (0.32–1.69)	1.08 (0.43–2.71)
Lifestyle			
Fruits and berries per day			
>0.5–3 cups	978 (35.3)	1	1
0–0.5 cups	1789 (64.7)	1.16 (0.70–1.92)	**2.13 (1.16–3.91)**
Veggies per day			
≥1 cup	1025 (37.1)	1	1
0-1 cup	1739 (62.9)	1.06 (0.65–1.74)	0.71 (0.41–1.23)
Legumes per week			
≥1 cup	1510 (55.1)	1	1
<1 cup	1229 (44.9)	1.12 (0.67–1.87)	**0.55 (0.31–0.99)**
Non whole grain cereals and bread per day (30g)			
>3 servings	685 (25.1)	1	1
0.5–3 servings	906 (33.2)	1.17 (0.63–2.18)	1.07 (0.55–2.10)
0–0.5 servings	1134 (41.6)	1.61 (0.88–2.93)	0.72 (0.37–1.41)
Red meat per week			
>300 g	1699 (62.0)	1	1
150–300 g	690 (25.2)	1.08 (0.65–1.79)	1.32 (0.73–2.37)
<150 g	351 (12.8)	0.32 (0.09–1.09)	0.99 (0.39–2.52)
White meat per week			
>400 g	891 (32.5)	1	1
200–400 g	992 (36.2)	1.02 (0.59–1.77)	0.80 (0.43–1.50)
<200 g	860 (31.4)	0.72 (0.37–1.39)	0.71 (0.35–1.43)
Fish per week			
>300 g	525 (19.2)	1	1
150–300 g	1060 (38.7)	1.06 (0.57–1.96)	**2.55 (1.01–6.41)**
<150 g	525 (19.2)	0.95 (0.47–1.89)	2.02 (0.76–5.35)
Nuts and seeds portions per week (30g)			
≥90gr	688 (25.0)	1	1
up to 90gr	725 (26.4)	1.53 (0.85–2.75)	1.37 (0.68–2.78)
no consumption	1338 (48.6)	0.99 (0.56–1.75)	1.49 (0.76–2.92)
Salty snacks per week (40g)			
>3 portions	521 (18.9)	1	1
0.5–3 portions	759 (27.5)	1.15 (0.58–2.29)	1.29 (0.59–2.83)

(*continued on next page*)

Table 3 (*continued*)

Independent variables	Cases (% of total)	Odds ratio (95% confidence interval)	
		Dependent variables	
		Prediabetes	Diabetes
<0.5 portions	1476 (53.6)	1.18 (0.61–2.49)	1.70 (0.79–3.63)
Sweet snacks per week (40g)			
>3 portions	1425 (51.5)	1	1
0.5–3 portions	704 (25.4)	1.31 (0.78–2.20)	1.32 (0.72–2.42)
<0.5 portions	638 (23.1)	1.67 (0.96–2.87)	1.73 (0.93–3.21)
Dairy low fat per day (240 ml)			
>1 servings	537 (19.8)	1	1
0.5–1 servings	492 (18.1)	**0.49 (0.24–0.96)**	0.78 (0.43–1.42)
0–0.5 servings	1686 (62.1)	**0.56 (0.33–0.94)**	0.51 (0.16–1.62)
Dairy full fat per day (240 ml)			
>1 servings	2174 (80.1)	1	1
0.5–1 servings	305 (11.2)	1.02 (0.37–2.78)	**0.37 (0.19–0.71)**
0–0.5 servings	236 (8.7)	1.08 (0.49–2.40)	**0.34 (0.12–0.95)**
Coffee per day (250 ml)			
>1 cup	1035 (36.9)	1	1
Up to 1 cup	797 (28.4)	1.13 (0.67–1.91)	0.98 (0.53–1.79)
0 cups	976 (34.8)	**0.47 (0.25–0.89)**	0.93 (0.49–1.75)

HOMA-IR: homeostatic model assessment insulin resistance
Bold font indicates statistically significant OR ($P < 0.05$).

muscle, liver, and pancreatic β-cells, thus leading to plasma glucose levels elevation and prediabetes [29,30].

Regarding diet indices, in the present study, consumption of up to 1 serving (240 ml) of low-fat dairy daily had a negative prediabetes association compared to higher consumption. Conversely, the majority of previous studies suggest that increased dairy consumption (2–3 servings/day), particularly fermented dairy products, cheese, and low-fat dairy, especially yogurt, are associated with lower risk [31–33]. Another cross-sectional study conducted on 167,729 individuals showed inverse associations of skimmed and fermented dairy products and low-fat cheese with prediabetes. Each 100 g increase in the low-fat dairy product leads to a 2% lower risk. These benefits may be explicated by the presence of calcium and protein (whey and casein) and their favorable influence on energy balance, body weight maintenance, lipid metabolism, and insulin secretion [34,35]. A possible explanation for this discrepancy is due to the recording of milk intake alone, as other dairy products (yogurt, cheese) were not evaluated in the present study. Moreover, our study showed that no coffee consumption leads to a lower prediabetes prevalence compared to consumption of >1 cup/day. In contrast to our results, previous studies have indicated that coffee has a protective effect on prediabetes development suggesting that magnesium, chlorogenic acid, and caffeine have beneficial effects on insulin sensitivity and β-cell function [36–38] in a dose of 3–4 cups of coffee/day.

As regards T2DM risk factors it was shown that people from Southern Europe (countries under economic crisis) have a negative T2DM association compared to people from Eastern Europe (middle- and low-income countries). A large French survey (32,435 men and 16,378 women, 35–80 years old) that investigated the association between T2DM and SES, showed higher risk among deprived men and women compared to non-deprived, even after accounting for confounding variables [39]. Some studies have suggested that the presence of SES-related inequalities in T2DM are affected by the unequal distribution of risk factors for T2DM such as obesity, physical inactivity, and unhealthy diet, which are most prevalent among those with the lowest SES, accounting for 33–50% of this association [40–42].

Concerning the diet indices, it is well established that lifestyle intervention, including weight management and adopting healthy eating patterns, reduce T2DM risk; however, the impact of specific foods and nutrients remain the subject of ongoing research. Concretely, the present study disclosed that low fruit/berries consumption (0–0.5 cups/day) increases the T2DM prevalence in comparison with higher consumption of >0.5–3 cups/day. In agreement with our results are previous systematic reviews and meta-analyses of prospective cohort studies [43–45]. A recent meta-analysis revealed that a 1 serving/day increment of fruit intake was associated with a 6% lower T2DM risk. The lowest relative risk was observed for consumption between 2 and 2.6 servings/day [45]. Another meta-analysis on berries intake showed that their consumption was associated with an 18% reduction in T2DM risk [43]. Fruit and berries are rich in fiber, flavonoids, anthocyanins, antioxidants, folate, and potassium that could decode their protective effects on T2DM. Dietary fibers are associated with insulin sensitivity and delay of carbohydrates absorption and therefore can lower postprandial blood glucose and insulin levels [46,47].

Moreover, regarding fish consumption, it was shown that 150–300 g of fish/week can increase the T2DM prevalence compared to higher consumption of >300 g/week. This association has been investigated in several prospective cohort studies, systematic reviews, and meta-analyses [48,49] but the conclusions are still inconsistent. A meta-analysis disclosed a significant protective effect of high oily fish intake (80 g/day) on T2DM risk though lean fish intake had no significant effect [48]. Another meta-analysis of 16 studies with 45,029 T2DM cases with an overall intake range between 0 and 225 g/day showed no significant association for the highest versus lowest fish intake category and for each additional 100 g/day [43]. Fish types, cooking methods, selenium, mercury, and other environmental contaminants in fish may affect the results though ethnicity may be partially contributing to high heterogeneity as studies in Asian populations have reported protective effects, while studies in western populations showed opposite results [48–50]. Differences in overall dietary patterns or genetic backgrounds between eastern and western populations may contribute to these differences [48].

Additionally, consumption of <1 cup of legumes per week may decrease the T2DM prevalence compared to ≥1 cup/week. The results from previous studies remain controversial due to the inconsistency in the definition of legumes and legume subtypes. Previous systematic reviews and meta-analyses showed that legume consumption was not significantly associated with T2DM incidence [43,51], while in agreement with our results is a recent meta-analysis which disclosed that in Europe 140 g/day of legume consumption could increase by 17% the T2DM risk [52]. This positive association may be due to the co-consumption of other dietary components with legumes. In the current study, we could not control the methods of preparation and therefore confounding due to cooking methods or other ingredients consumed alongside legumes. Our findings suggest that dietary contexts of legume consumption are important and this may be a plausible explanation for the inconsistency of findings in the existing literature.

Last but not least, the consumption of ≤1 (240 ml) of full-fat dairy daily was associated with lower T2DM prevalence compared to >1 serving/day. A previous meta-analysis showed that each additional 200 g/day of dairy products was inversely associated with T2DM risk although this inverse association was observed only in Asian and Australian populations, not for American and European ones, as well as for people ≥50 years old. Moreover, low-fat dairy products showed a borderline inverse association, whereas no association could be observed for high-fat dairy products [43]. In agreement with our results is a recent cohort study conducted on 167,729 people (25-50-year-olds) that showed significant positive associations between full-fat dairy and T2DM. In detail, it was revealed that the consumption of 240 ml full-fat dairy/day is associated with a 13% higher T2DM risk, while this percentage can reach 18% and 35% for the consumption of 240–400 ml/day and >400 ml/day, respectively [34]. This could be explained by the fact that full-fat dairy products have a higher energy and lipid content and hence may contribute to weight gain and thereby glucose intolerance.

The present study has some strengths and limitations. An important strength is its large sample conducted in more than 12,000 participants, including more than 2000 families at high risk for developing T2DM, from six European countries. Additionally, the standardized protocols and procedures followed across all centers, and the objectively collected data regarding biochemical and anthropometric indices, and clinical and lifestyle data safeguard the more objective and reliable assessment and increase the generalizability of findings. Its limitation is that the cross-sectional study design could not support conclusions on the risk of the disease because the temporal link between the outcome and the exposure cannot be determined as both are examined at the same time. Moreover, part of the collected data is self-reported due to the use of self-reported questionnaires. Although the validity and reliability of the relevant questionnaires were tested before the start of the intervention, this approach is prone to recall bias and social desirability.

The results of the current study add to the present literature with data retrieved from families from six European countries in a large-scale European study and provide novel information on the predominant correlates of these diseases, among a variety of socio-demographic, anthropometric and lifestyle indices. Our results indicate that men, young adults (above 45 years of age), with high waist circumference and poor dietary habits have higher prediabetes prevalence. Furthermore, people living in LMICs, with poor dietary habits have an increased T2DM prevalence. These findings indicate the need for diabetes prevention measures targeting young adults and especially men, above 45 years of age, with central obesity and poor dietary habits and prioritize vulnerable groups and populations living in LMICs.

Data availability

The datasets generated and/or analyzed during the current study are not publicly available, since the data used is confidential based on Feel4Diabetes publication rules, but are available from the corresponding author upon reasonable request.

Ethics approval

The Feel4Diabetes-study adhered to the Declaration of Helsinki and the conventions of the Council of Europe on human rights and biomedicine. All participating countries obtained ethical clearance from the relevant ethical committees and local authorities. More specifically, in Belgium, the study was approved by the Medical Ethics Committee of the Ghent University Hospital (ethical approval code: B670201524437); in Bulgaria, by the Ethics Committee of the Medical University of Varna (ethical approval code: 52/10-3-2016r) and the municipalities of Sofia and Varna, as well as the Ministry of Education and Science local representatives; in Finland, by the hospital district of Southwest Finland ethical committee (ethical approval code: 174/1801/2015); in Greece, by the Bioethics Committee of Harokopio University (ethical approval code: 46/3-4-2015) and the Greek Ministry of Education; in Hungary, by the National Committee for Scientific Research in Medicine (ethical approval code: 20095/2016/EKU); and in Spain, by the Clinical Research Ethics Committee and the Department of Consumers' Health of the Government of Aragón (ethical approval code:CP03/2016). Consent to participate All participants gave their written informed consent prior to their enrolment in the study.

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Declaration of competing interest

The authors declare no competing interests.

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