Annals of Epidemiology 117 (2026) 110064

Contents lists available at ScienceDirect

Annals of Epidemiology

journal homepage: www.sciencedirect.com/journal/annals-of-epidemiology

The *revised*-FINDRISC: A tool for type 2 diabetes risk screening across diverse populations incorporating sociodemographic indicators

Dimitra-Irinna Vitoratou [a,b], Konstantina Dimakopoulou [a,c], Christina Mavrogianni [a], Eva Karaglani [a,b,d], Matzourana Argyropoulou [a,b], Greet Cardon [e], Natalya Usheva [f], Violeta Iotova [g], Tsvetalina Tankova [h], Natalia Giménez-Legarre [i,j], Luis A. Moreno [i,j], Florian Toti [k], Konstantinos Makrilakis [d], Ditila Doracaj [l], Rurik Imre [m], Péter Torzsa [m], Jaana Lindström [n,o], Demosthenes Panagiotakos [a], Yannis Manios [a,b,p,*]

[a] *Department of Nutrition and Dietetics, School of Health Science and Education, Harokopio University, Athens 17676, Greece*
[b] *European Centre for Obesity, Harokopio University, Athens 17676, Greece*
[c] *Department of Basic and Clinical Sciences, Medical School, University of Nicosia UNIC Athens, Athens 167 77, Greece*
[d] *1st Department on Propaedeutic Internal Medicine, National and Kapodistrian, University of Athens Medical School, Athens, Greece*
[e] *Department of Movement and Sports Sciences, Ghent University, Ghent, Belgium*
[f] *Department of Social Medicine and Health Care Organization, Faculty of Public Health, Medical University of Varna, Bulgaria*
[g] *Department of Pediatrics, Faculty of Medicine, Medical University of Varna, Bulgaria*
[h] *Division of Diabetology, Department of Endocrinology, Medical University of Sofia, Sofia, Bulgaria*
[i] *NUTRI-GENUD (B34_23R-Growth, Exercise, Nutrition and Development), Instituto Agroalimentario de Aragón (IA2), Instituto de Investigación Sanitaria Aragón (IIS Aragón), University of Zaragoza, Zaragoza, Spain*
[j] *Centro de Investigación Biomédica en Red de Fisiopatología de la Obesidad y Nutrición (CIBERObn), Instituto de Salud Carlos III, Madrid, Spain*
[k] *Department of Internal Medicine, University of Medicine of Tirana, Tirana, Albania*
[l] *Department of Biomedical and Experimental Sciences, University of Medicine Tirana, Tirana, Albania*
[m] *Department of Family Medicine, Semmelweis University, Budapest, Hungary*
[n] *Lifestyles and Living Environments Unit, Finnish Institute for Health and Welfare, Helsinki, Finland*
[o] *Institute of Public Health and Clinical Nutrition, University of Eastern Finland, Kuopio, Finland*
[p] *Institute of Agri-food and Life Sciences, Hellenic Mediterranean University Research Centre, Crete, Greece*

A R T I C L E I N F O

Keywords:
Type 2 diabetes
Risk
Epidemiology
Prevention
Screening

A B S T R A C T

Aim: To develop a revised version of the FINDRISC tailored to improve the identification of individuals at high risk for type 2 diabetes (T2D) across diverse populations.
Methods: The *revised*-FINDRISC was developed using pooled harmonized baseline data from the multinational Feel4Diabetes (NCT02393872; N = 3526) and DigiCare4You (NCT05648383; N = 2156) studies. Validation utilized data from the 20-year ATTICA cohort study in Greece. Original FINDRISC components were analyzed using Fisher's Linear Discriminant Analysis followed by supervised stepwise logistic regression to identify significant T2D cross-sectional predictors. The *revised*-FINDRISC was developed by re-scoring or excluding original items and incorporating new predictors, generating an integer-based score to enhance usability.
Results: The *revised*-FINDRISC significantly improved accuracy in identifying current T2D risk over the original, with an overall AUC of 0.911(95%CI: 0.901,0.922) versus 0.832(0.815,0.846). When stratified by country economic classification, the revised score outperformed the original across all groups: LMICs: 0.881(0.864,0.898) vs. 0.815(0.793,0.837), South European-HICs: 0.891(0.867,0.916) vs. 0.839(0.811,0.869), and North European-HICs: 0.921(0.872,0.971) vs. 0.844(0.742,0.949). A clinical threshold score of 13/24 in the *revised*-FINDRISC offers optimal sensitivity and specificity for identifying individuals at risk of T2D.
Conclusion: Enhanced with demographic, socio-economic, and clinical factors, the revised-FINDRISC potentially represents a substantive advancement in T2D screening, supporting early detection and targeted prevention.

* Correspondence to: El. Venizelou Ave, 70, GR - 176 76 Kallithea, Athens, Greece
E-mail address: manios@hua.gr (Y. Manios).

https://doi.org/10.1016/j.annepidem.2026.110064
Received 16 December 2025; Received in revised form 21 February 2026; Accepted 2 March 2026
Available online 5 March 2026

Introduction

Diabetes represents a critical global health concern, affecting 11.1% of the adult population, approximately one in nine individuals, with over 81% cases occurring in low- and middle-income countries (LMICs) [1]. Type 2 diabetes (T2D) constitutes the vast majority of diabetes cases, posing a significant economic burden, with global costs surpassing $1 trillion in 2024 [1]. Alongside the global rise in T2D, prediabetes or intermediate hyperglycemia [2], defined by impaired fasting glucose (IFG) and/or impaired glucose tolerance (IGT), is also rising, with IFG alone affecting 9.2% of the global population in 2024 [1]. This latent phase of dysglycemia often precedes T2D onset [3], with five-year cumulative incidence of T2D reaching 50% among individuals with IFG [2]. Both prediabetes and T2D frequently remain undiagnosed, due to their asymptomatic nature, limited healthcare access and inadequate health system capacity, allowing disease progression to occur silently resulting in delayed treatment, increased risk of complications and greater long-term healthcare costs [3,4].

Given this global health burden, early detection of T2D is critical, particularly through non-invasive, scalable screening tools, suitable for population-level use. Several diabetes risk scores based on simple, non-invasive indicators have therefore been developed and validated across diverse populations [5–7] and are recommended to guide decisions on further diagnostic testing [1,4,8]. Among these, the Finnish Diabetes Risk Score (FINDRISC) [9], is widely used in Europe for its simplicity, cost-effectiveness, and reasonable predictive accuracy. However, most early validation studies of FINDRISC were conducted in single-country settings, and often lacked socio-economic considerations, thus limiting the tool's generalizability. More recent evidence from a large, multi-country European cohort of early middle-aged adults from vulnerable groups showed that while FINDRISC effectively detected undiagnosed T2D, its performance in detecting broader dysglycaemia (prediabetes or T2D) was weaker and optimal cut-offs varied across settings [10].

These findings underscore the need to adapt diabetes risk scores to better reflect sociodemographic and healthcare system variability, particularly in populations with limited access to healthcare, low health literacy, and socio-economic disadvantages. As most diabetes cases now occur in LMICs [1], enhancing the sensitivity of such tools is crucial for timely intervention and effective prevention. To address this, the present study aims to develop a revised version of the FINDRISC tailored to improve accuracy in identifying individuals at high risk of T2D across various populations.

Methods

Study design

The *revised*-FINDRISC was developed using harmonized baseline data from two multicenter, multinational projects on T2D prevention: Feel4Diabetes (https://feel4diabetes-study.eu/), a community-based intervention, aiming to prevent T2D among families from vulnerable groups, and DigiCare4You (https://digicare4you.eu/), an effectiveness-implementation study aiming to empower individuals and integrate community care services for T2D prevention and management. Both studies were registered at clinicaltrials.gov (NCT02393872 and NCT05648383, respectively). A detailed description of each study has been described elsewhere [11,12].

External validation of the proposed risk tool was conducted using data from the ATTICA cohort. ATTICA is a population-based study, conducted in Greece, initiated in 2002 with a 20-year follow-up period (2002–2022). Details of the study can be found in previous publications [13].

Sample and sampling procedures

The Feel4Diabetes and DigiCare4You interventions targeted free-living adults (≥20 years), for the prevention of cardiometabolic disorders, including T2D. Recruitment followed a standardized, multi-stage sampling procedure in selected provinces, resulting in the inclusion of 3526 participants in Feel4Diabetes, and 2156 in DigiCare4You. Of the 5682 individuals recruited, 5164 with full data were included in the analyses. The Feel4Diabetes was implemented in Belgium, Bulgaria, Finland, Greece, Hungary, and Spain, with baseline data collected in 2016, while DigiCare4You took place in Albania, Bulgaria, Greece, and Spain, with baseline data collected between 2022 and 2023 (Figure S1). In Feel4Diabetes, primary schools in selected municipalities were community entry-points, and parents of children in the first three grades completed the FINDRISC and a brief lifestyle questionnaire. If at least one parent met the country-specific FINDRISC cut-off (in most countries, ≥9), both parents were invited for a brief medical check-up, resulting in a cohort with a broad distribution of FINDRISC values. Similarly, DigiCare4You applied a two-stage screening process, where parents completed the FINDRISC, and those scoring ≥ 10 were invited to undergo a brief medical check-up.

The ATTICA study consisted of 3042 participants from Greece, that were randomly selected from the general population (aged 18 +), enrolled in the study in 2002 and followed up for 20 years (2002–2022). Outcomes of interest were the development of cardiovascular disease, T2D and other metabolic disorders.

Measurements

Participants in all three studies completed the FINDRISC, which consists of eight scored items: age, body mass index (BMI), waist circumference (WC), daily physical activity (PA), daily consumption of vegetables and fruits/berries, use of antihypertensive medication, history of high blood glucose (BG), and family history of diabetes [9]. The total score ranges from 0 to 26, with ≥ 15 indicating a high 10-year risk of developing T2D.

Moreover, fasting glycemia and lipid profile testing, along with anthropometric and blood pressure measurements were conducted at local community health centers or general practitioners' offices by trained research assistants or healthcare personnel, using standardized protocols and calibrated equipment. Lipid profile measurements included total cholesterol (TC), LDL, HDL, and triglycerides (TG). Fasting BG levels were measured, and participants were classified based on ADA criteria [8] as normoglycemic (fasting BG, FBG<100mg/dL), as having IFG (FBG 100–125mg/dL) and as having T2D (FBG≥126mg/dL or having been diagnosed with T2D in the past). Detailed categorization of these variables are provided in Supplementary Material 1.*Development of the revised-FINDRISC*

Detailed methodological procedures are provided in Supplementary Material 1. Briefly, the contribution of original FINDRISC items was first examined using Fisher's Linear Discriminant Analysis (LDA), overall and stratified by country economic classification (CEC), to assess their contribution to distinguishing individuals with and without T2D at baseline [14]. The resulting discriminant loadings guided the re-scoring and selection of items for the revised-FINDRISC. Subsequently, supervised stepwise logistic regression models were applied in the harmonized Feel4Diabetes and DigiCare4You dataset to identify predictors of existing T2D, informed by both statistical criteria and clinical relevance [15,16]. Models were sequentially adjusted for key sociodemographic and clinical covariates, retaining variables that improved model fit and discrimination. The revised-FINDRISC was developed by re-weighting or excluding original items and incorporating additional predictors. Regression coefficients were transformed into an integer-based scoring system [17], to enhance clinical usability. The total revised-FINDRISC score ranges from 0 to 24 and was designed to identify high-risk individuals without diagnosed T2D who would benefit from careful

monitoring.

Statistical analysis

Categorical variables are presented as frequencies (n) and percentages (%). Continuous variables are described using means or medians and dispersion (Standard Deviation; SD or Inter-Quartile-Range; IQR). Comparisons of demographic and clinical characteristics between T2D status and CEC groups were performed using chi-square test (categorical variables), independent samples *t*-tests or one-way analysis of variance with Bonferroni correction (normally distributed continuous variables), and Mann–Whitney U or Kruskal–Wallis tests (skewed data). To evaluate the classification performance of the original and *revised*-FINDRISC, logistic regression models were applied with T2D status at baseline as the outcome variable assessed at baseline (cross-sectional analysis). A stepwise modeling approach was employed to assess the incremental value of additional demographic and clinical predictors. Model performance was assessed using multiple statistical criteria: a. model fit was evaluated via likelihood ratio (LR) tests, Akaike Information Criterion (AIC), and Bayesian Information Criterion (BIC), with lower AIC/BIC and higher LR values indicating better fit and parsimony; b. discriminative ability was assessed using Harrell's C-index and the area under the receiver operating characteristic curve (AUC); c. sensitivity, specificity, percentage of correctly classified cases were estimated; and d. the Net Reclassification Improvement (NRI) and Integrated Discrimination Improvement (IDI) indices were used to quantify improvements in classification performance. Moreover, calibration plots and the Hosmer–Lemeshow (H–L) test were used to evaluate calibration. Finally, Decision Curve Analysis (DCA) was performed to evaluate clinical usefulness of the *revised*-FINDRISC. The final logistic regression model was applied to the ATTICA dataset without modification to assess generalizability. No recalibration or re-estimation of model coefficients was performed in the validation dataset. AUC values were calculated overall and stratified by CEC and by sex. The performance was evaluated in terms of sensitivity, specificity, and overall correct classification rate. To assess potential information loss from coefficient rounding, we compared the discrimination of the original logistic regression model with that of the integer-based revised-FINDRISC using DeLong's test. A p-value < 0.05 was considered statistically significant.

All analyses were performed in STATA (StataCorp. 2015. Stata: Release 15. Statistical Software).

Results

Descriptive characteristics of the harmonized and validation samples

Table 1 presents selected demographic, lifestyle and clinical factors, stratified by T2D status. T2D was reported by 16.4% of the participants (849/5164). Compared to those without T2D, individuals with T2D were more likely to be male, older, have lower education levels, be unemployed, and reside in LMICs (all $p < 0.001$). Moreover, they also exhibited higher BMI, WC, and TG levels, as well as lower HDL and LDL levels ($p < 0.001$). Participants with T2D additionally reported less frequent PA and fruit/vegetable intake, lower alcohol consumption and higher prevalence of high blood glucose and family history of T2D. Additional results stratified by country economic status are available in Supplementary Material 1.

Characteristics of the ATTICA cohort used for external validation have been reported previously [13]. Briefly, during the 20-year follow-up period (2002–2022), 526 incident T2D cases occurred among 2000 participants (i.e., 26.3% cumulative incidence, 95%CI [24.4%, 28.3%]), with higher incidence in men than women (31.4% vs21.4%). Baseline FINDRISC score was significantly higher among those who developed T2D during the follow-up period as compared to those who did not (11.1(5.06) vs. 6.6(4.2), p < 0.001). This difference was more pronounced when the *revised*-FINDRISC was applied, i.e., 13.2

Table 1
Distribution of demographic, lifestyle and clinical factors, by T2D in all countries.

Demographic and lifestyle factors	Total (N = 5164)	T2D status		p-value
		No (N = 4315)	Yes (N = 849)	
Sex; %male	35%	32.1%	49.7%	< 0.001 *
Age group, years; %				
< 45	56.4%	62.7%	24.3%	< 0.001 *
45–54	31.1%	30.4%	34.6%	
55–64	7.4%	4.8%	20.6%	
64 +	5.1%	2.1%	20.5%	
Educational level; % < 12 years	29.5%	27.1%	41.4%	< 0.001 *
Smoking habits; % Current	25.9%	26.1%	25.2%	0.611*
Physical Activity; % not regular	36%	38.1%	25.3%	< 0.001 *
Fruit/Vegetables; % not frequent	38%	34%	20%	< 0.001 *
Alcohol, servings/ week; median (IQR)	1 (3)	1 (3)	0 (2)	< 0.001†
Marital status; % married or cohabiting	91.3%	91.9%	88.1%	0.003*
Occupation status; % unemployed	27.5%	25.8%	35.6%	< 0.001 *
Clinical factors				
BMI, kg/m$^{\dagger;}$ %				
< 25	26.4%	29.1%	13%	< 0.001 *
25–30	37.5%	38%	34.6%	
30 +	36.1%	32.9%	52.4%	
Waist circumference, cm; %				
F< 80, M< 94	12.8%	13.3%	10.6%	< 0.001 *
F 80–88, M 94–102	29.2%	30.8%	21.1%	
F> 88, M> 102	58%	55.9%	68.3%	
History of high blood glucose; %yes	42.3%	32.6%	91.5%	< 0.001 *
T2D family history; %				
No	30.2%	31.1%	25.4%	0.004*
Yes, 1st degree	41.0%	40.4%	43.9%	
Yes, 2nd degree	28.9%	28.5%	30.6%	
Use of antihypertensive medication; %yes	23.2%	17.6%	51.6%	< 0.001 *
Total cholesterol, mg/ dL; mean (SD)	195 (38.2)	196 (38.2)	191 (38.4)	< 0.001‡
LDL, mg/dL; mean (SD)	120 (33.9)	121 (33.3)	113 (35.7)	< 0.001‡
HDL, mg/dL; mean (SD)	53 (13.9)	54 (14.1)	49 (12.0)	< 0.001‡
TG, mg/dL; mean (SD)	119 (90.0)	112 (79.6)	159 (123.7)	< 0.001‡
Country economic classification^{+},%				
LMICs	35.7%	29.5%	67.5%	< 0.001 *
SE-HICs	47.8%	51.4%	29.5%	
NE-HICs	16.5%	19.1%	3.1%	

T2D: Type 2 Diabetes defined as FBG≥ 126mg/dL or being previously diagnosed; SD: Standard Deviation; IQR: Inter-quartile range, TG: Triglycerides, LMICs: Low- and Middle- Income Countries, SE-HICs: South European-High-Income Countries, NE-HICs: and North European-High-Income Countries

+Classified according to World Bank 2012; LMICs: Albania, Bulgaria, Hungary; SE-HICs: Greece, Spain; NE-HICs: Belgium, Finland

* Chi-square;

† Mann-Whitney U-test;

‡ Indepedent samples *t*-test

(4.86) vs. 6.9(3.1) ($p < 0.001$).

Discrimination analysis

Table 2 shows the contributions of the original FINDRISC items using LDA. Overall, history of high blood glucose was the strongest contributor to FINDRISC discrimination, followed by age, antihypertensive medication use, BMI, and family history of T2D. When analyses were stratified by CEC it was revealed that across all country groups, high BG history was the strongest contributor, accounting for nearly half of its discriminative power overall (48.7%) and even more in LMICs (52.4%) and SE-HICs (55.2%). Age consistently ranked second, with contributions ranging from 13.2% to 25.7%. Antihypertensive medication and BMI showed moderate contributions, particularly in SE-HICs and NE-HICs. Family history of T2D contributed modestly, while lifestyle factors, such as PA and fruit/vegetable intake had minimal or slightly negative standardized loadings. WC consistently showed very low contribution across all country groups. Sex-specific analyses indicated variability in the contribution of certain metabolic risk factors (Supplementary material 1).

Additional factors improving classification performance of revised-FINDRISC

To enhance the classification ability of FINDRISC, several demographic and clinical factors were sequentially added (Model 1, Table 3**)**. using a stepwise approach to retain variables that improved model fit and discrimination, rather than forcing all covariates into the model. These factors were sex and educational level, with female sex and higher education associated with lower diabetes odds, suggesting important sociodemographic influences beyond traditional clinical risk factors. Moreover, TG emerged as a significant clinical predictor. Conversely, variables such as WC, PA, fruit/vegetable consumption, smoking, and occupational status were excluded at this stage, indicating that their predictive power was either weaker or accounted for by other included variables**.** Model fit (Table 4) improved progressively from Model 0 through Model 3, as demonstrated by increasing LR statistics and decreasing AIC and BIC values, indicating better explanatory power and parsimony with additional variables. Discrimination metrics also showed incremental gains: Harrell's C and AUC increased, reflecting enhanced accuracy in distinguishing individuals with and without T2D. Sensitivity improved modestly across models (49.5%-55%), while specificity remained consistently high (>95%). The overall percentage of correctly classified individuals reached 88.3% in Model 3. Reclassification measures demonstrated significant improvement when adding sex, educational level, and TG. The NRI was positive and significant for Models 2 and 3, indicating better risk stratification beyond the baseline model. Similarly, IDI showed significant enhancement, underscoring improved predictive performance with the inclusion of demographic and clinical factors. The calibration plot (Fig. 1) demonstrated good agreement between predicted and observed probabilities for T2D. The points aligned closely with the 45-degree reference line across the range of predicted risks, indicating that the model is well-calibrated. This visual finding supports the Hosmer–Lemeshow test result ($p = 0.074$), which also suggested no significant lack of fit.

Sensitivity analyses by socio-economic classification and sex

Based on these analyses, the revised-FINDRISC is presented in Table 5. Key modifications included adjusting the weighting of the key items: age categories 55–64 and 64 + received increased points (from 3 to 4, and 4–6, respectively), reflecting stronger age-related risk. The high BG history was raised substantially from 5 to 8 points. BMI weighting was slightly reduced for the highest category (30 + from 3 to 2 points). Family history points were equalized for 1st and 2nd degree relatives, both reduced to 2 points from 5 and 3. WC, PA, and fruit/

Table 2
Contributions of original FINDRISC items to the discriminant function derived from Fisher's Linear Discriminant Analysis (LDA). Loadings indicate the relative weight of each variable in distinguishing individuals with versus without type 2 diabetes in the development dataset. Higher absolute values reflect stronger contributions to group separation and informed the re-weighting or selection of items in the revised-FINDRISC.

	FINDRISC item	Loading (Standardized)	Contribution	Interpretation
Overall	History of High Blood Glucose	0.698	48.7%	Strongest predictor, nearly half of the discriminative power
	Age	0.47	22.1%	Key predictors
	Use of antihypertensive medication	0.291	8.5%	
	BMI	0.224	5.0%	Moderate
	T2D family history	0.105	1.1%	predictors
	Physical Activity	-0.106	1.1%	Factors that
	Fruit/Vegetable consumption	-0.093	0.9%	reduce diabetes risk slightly
	Waist circumference	-0.024	0.1%	Low contributor
LMICs	History of High Blood Glucose	0.724	52.4%	Strongest contributors,
	Age	0.507	25.7%	dominate the predictive power
	BMI	0.168	2.8%	Moderate
	Use of antihypertensive medication	0.138	1.9%	predictors
	T2D family history	0.071	0.5%	Low contribution
	Fruit/Vegetable consumption	-0.068	0.5%	
	Physical Activity	-0.062	0.4%	
	Waist circumference	0.005	0.0%	Negligible contribution after adjusting for other factors
SE-HICs	History of High Blood Glucose	0.743	55.2%	Strongest discriminator, separates diabetes best
	Age	0.363	13.2%	Strong
	Use of antihypertensive medication	0.357	12.7%	contribution
	BMI	0.271	7.3%	Moderate
	T2D family history	0.237	5.6%	contribution
	Waist circumference	0.064	0.4%	Low unique contribution
	Fruit/Vegetable consumption	-0.029	0.1%	Negligible contribution
	Physical Activity	-0.018	0.0%	after adjusting for other factors
NE-HICs	History of High Blood Glucose	-0.621	38.6%	Strongest discriminators
	Age	-0.506	25.6%	
	BMI	-0.363	13.2%	Moderate
	Use of antihypertensive medication	0.321	10.3%	contributors
	T2D family history	-0.3	9.0%	
	Fruit/Vegetable consumption	0.172	3.0%	Minor contribution
	Physical Activity	0.112	1.3%	
	Waist circumference	0.078	0.6%	Negligible contribution

BMI: Body Mass Index
LMICs: Low- and Middle- Income Countries, SE-HICs: South European-High-Income Countries, NE-HICs: and North European-High-Income Countries
+Classified according to World Bank 2012; LMICs: Albania, Bulgaria, Hungary; SE-HICs: Greece, Spain; NE-HICs: Belgium, Finland

vegetable consumption were removed from the score. New variables were added: sex (male: 2 points), educational level (≤12 years: 1 point), and history of elevated TG > 150mg/dL (1 point). The *revised*-FINDRISC showed significant improvement in the correct classification ability as compared to the original (Fig. 2). In particular, the *revised*-FINDRISC demonstrated overall superior discrimination with an AUC of 0.911 (95%CI: 0.901–0.922), compared to 0.832 (95%CI:0.818–0.846) for the original FINDRISC. When stratified by CEC, the revised score consistently outperformed the original across all groups: LMICs (0.881 vs. 0.815), SE-HICs (0.891 vs. 0.839), and NE-HICs (0.921 vs. 0.844). Similarly, the *revised*-FINDRISC showed improved predictive accuracy for both males (0.910 vs. 0.826) and females (0.902 vs. 0.845). Moreover, for clinical practice it is revealed that a threshold of 13 (out of a maximum score of 24) in the *revised*-FINDRISC tool has the optimal sensitivity and specificity in correctly identifying the potential candidate for T2D (Tables S3, S4).

To further evaluate the tool's performance in populations without access to clinical measurements, we reduced the *revised*-FINRISC by excluding information related to knowledge of BG and TG levels. In place of these variables, we incorporated fruit/vegetable consumption

Table 3
FINDRISC items identified as significant predictors using supervised stepwise logistic regression models.

	OR (95%CI)		
FINDRISC Items	**Model 1**	**Model 1 + demographic factors**	**Model 1 + demographic + clinical factors**
Age, years			
< 45	Reference category		
45–54	2.64 (2.09–3.35)	2.14 (1.68–2.74)	2.13 (1.67–2.72)
55–64	6.60 (4.77–9.13)	5.03 (3.60–7.04)	5.17 (3.69–7.25)
64 +	12.18 (8.00–18.56)	10.97 (7.15–16.84)	10.83 (7.06–16.63)
History of High Blood Glucose			
Yes vs No	22.26 (16.57–29.90)	26.53 (19.58–35.95)	26.93 (19.84–36.55)
BMI, kg/m^2			
< 25	Reference category		
25–30	2.12 (1.56–2.88)	1.69 (1.23–2.33)	1.60 (1.16–2.21)
30 +	3.45 (2.56–4.66)	2.90 (2.12–3.96)	2.63 (1.92–3.61)
Use of antihypertensive medication			
Yes vs No	2.14 (1.70–2.69)	2.10 (1.66–2.66)	1.98 (1.56–2.52)
T2D family history			
No	Reference category		
Yes, 2nd degree	2.00 (1.52–2.62)	1.91 (1.44–2.52)	1.93 (1.46–2.56)
Yes, 1st degree	1.81 (1.40–2.34)	1.93 (1.48–2.52)	1.90 (1.45–2.48)
Waist circumference, cm	Excluded	Excluded	Excluded
F< 80, M< 94	Reference category		
F 80–88, M 94–102	-	-	-
F> 88, M> 102	-	-	-
Physical Activity	Excluded	Excluded	Excluded
30minPA; not everyday vs 30minPA; everyday	-	-	-
Fruits & Vegetables consumption	Excluded	Excluded	Excluded
Not everyday vs Everyday	-	-	-
Sex	-	-	-
Female vs male	-	0.35 (0.28–0.44)	0.37 (0.30–0.46)
Smoking habits	-	Excluded	Excluded
Current vs never/former	-	-	-
Educational level	-		
> 12 years vs ≤ 12 years	-	0.71 (0.57–0.88)	0.71 (0.57–0.88)
Occupational status	-	Excluded	Excluded
Employed vs unemployed	-	-	-
TG, mg/dL	-	-	
> 150 vs ≤ 150	-	-	1.73 (1.37–2.20)
Total cholesterol, mg/dL	-	-	Excluded
> 200 vs ≤ 200	-	-	-
HDL, mg/dL	-	-	Excluded
M< 40, F< 50 vs other	-	-	-
LDL, mg/dL	-	-	Excluded
> 190 vs ≤ 190	-	-	-
Model performance metrics	Model 1	Model 2	Model 3
LR statistic	1512.50	1576.95	1597.19
AIC	2363.338	2294.885	2276.641
BIC	2452.274	2371.115	2359.224
Harrell C-index	0.9053	0.9100	0.9127
AUC	0.9053	0.9100	0.9127
Sensitivity (%)	50.91%	53.43%	54.97%
Specificity (%)	95.58%	95.18%	95.07%
PPV (%)	70.00%	69.20%	69.31%
Correctly classified (%)	88.05%	88.14%	88.30%
NRI	-	0.05676 ($p < 0.001$)	0.02159 ($p = 0.026$)
IDI	-	0.3683 ($p < 0.001$)	0.38769 ($p < 0.001$)

OR: Odds Ratio; CI: Confidence Interval, BMI: Body Mass Index, T2D: Type 2 Diabetes, F: Female, M: Male, TG: Triglycerides, HDL: High density Lipoproteins, LDL: Low Density Lipoproteins; AIC: Akaike Information Criterion; BIC: Bayesian Information Criterion; LR: Likelihood Ratio statistic; AUC: Area Under the Receiver Operating Characteristic Curve; PPV: Positive Predictive Value; NRI: Net Reclassification Improvement; IDI: Integrated Discrimination Improvement.

Table 4
Measures of model fit, discrimination, and calibration of risk models with or without FINDRISC items and other potential demographic and clinical factors in the prediction of type 2 diabetes.

	Model 0	Model 1	Model 2	Model 3
Model fit				
Likelihood Ratio	1480.54	1512.50	1576.95	1597.19
Akaike's information criterion	2387.291	2363.338	2294.885	2276.641
Bayesian information criterion	2450.816	2452.274	2371.115	2359.224
LR test, *p*-value	-	-	96.41$p < 0.001$	20.24$p < 0.001$
Discrimination				
Harrell's C	0.9023	0.9053	0.9100	0.9127
AUC[d]	0.9023	0.9053	0.9100	0.9127
Sensitivity %	49.51%	50.91%	53.43%	54.97%
Specificity %	95.29%	95.58%	95.18%	95.07%
PPV %	68.08%	70.00%	69.20%	69.31%
Correctly classified (%)	87.57%	88.05%	88.14%	88.30%
Reclassification				
Continuous net reclassification improvement*p*-value	-	-	0.05676$p < 0.001$	0.02159$p = 0.026$
integrated discrimination index*p*-value	-	-	0.3683$p < 0.001$	0.38769$p < 0.001$

AUC: area under the receiver operating characteristic curve.
Model 0: History of high blood glucose + Age + Use of antihypertensive medication +Family history of diabetes + Physical activity + Fruit/vegetable consumption + Waist circumference;
Model 1: History of high blood glucose + Age + Use of antihypertensive medication +Family history of diabetes + Physical activity
Model 2: Model 1 + sex + educational level
Model 3: Model 2 + Triglycerides (TG)

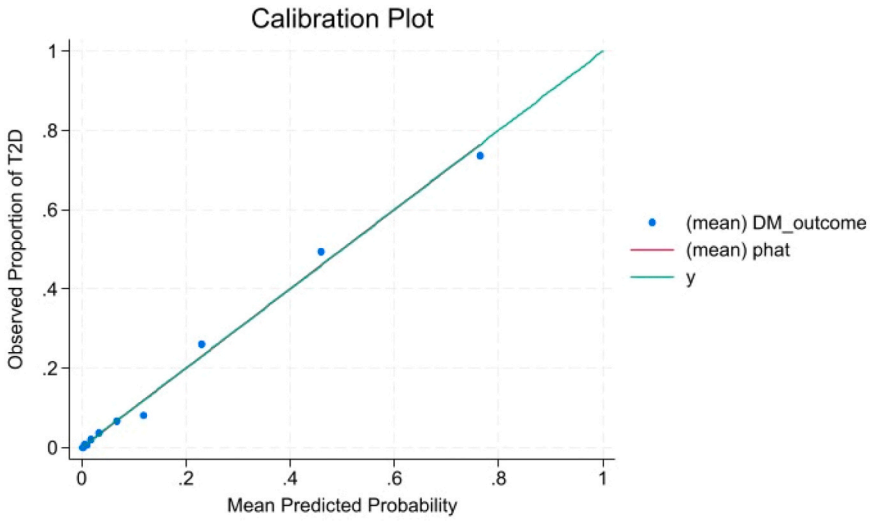

Fig. 1. Calibration plot assessing predicted probabilities of T2D from the logistic regression model.

and PA. Thus, the "eliminated" *revised*-FINFRISC included 8 items: age, BMI, antihypertensive medication, T2D family history, fruit/vegetable consumption, PA, sex and educational level. The accuracy of the "eliminated" *revised*-FINDRISC was 84.12%. The AUC (95%CI) was 0.678(0.647–0.710) for males and 0.792 (0.768–0.816) for females. In addition, AUC (95%CI) for the "eliminated" *revised*-FINDRISC by CEC was: 0.765(0.743–0.787), 0.740(0.702–0.778) and 0.777(0.693–0.861) for LMICs, SE-HICs and NE-HICs, respectively. For clinical use, optimal cut-off points (out of a maximum score of 18) were ≥ 7 for LMICs, ≥ 9 for SE-HICs, ≥ 6 for NE-HICs, and ≥ 7 overall. Results from the decision curve analysis are provided in Supplementary Material 1. Discrimination was nearly identical between the full model (AUC 0.9130) and the integer-based score (AUC 0.9113; ΔAUC = 0.0017).

Validation analysis

Validation of the *revised*-FINDRISC was further undertaken in a population-based cohort, the ATTICA study (Table 6). The original FINDRISC yielded an AUC of 0.758, 95%CI(0.724, 0.792), whereas the *revised*-FINDRISC demonstrated a significant improvement with an AUC of 0.890, 95%CI(0.878, 0.902). Moreover, comparable discrimination was observed across sexes (males: 0.895, 95%CI(0.872, 0.918); females: 0.880, 95%CI(0.870, 0.901)). The threshold of 13 out of 24 was confirmed in the validation sample, with sensitivity 81.82%, specificity 84.77%, and correct classification of 83.77% of the ATTICA study participants by T2D status.

Discussion

The aim of this study was to develop a revised version of the FINDRISC, to improve the identification of individuals at high risk of T2D in various populations, supporting early detection and targeted monitoring. Modifications were guided by the need to enhance its relevance and performance across varying population subgroups. Although the original FINDRISC was designed to estimate 10-year risk of developing T2D, rather than detect existing cases, it has shown reasonable accuracy in identifying undiagnosed T2D. Building on this foundation, the *revised*-FINDRISC seeks to enhance the identification of individuals at high-risk of T2D who may benefit from careful monitoring across diverse demographic and socio-economic contexts, while retaining practicality for

Table 5
The *revised*-FINDRISC score. A tool for screening for T2D at population level.

Item	Scoring system		
	FINDRISC	*revised*-FINDRISC	'eliminated'-revised-FINDRISC
Age, years:			
< 45;	0	0	0
45–54;	2	2	2
55–63;	3	4	4
64 +	4	6	6
History of High Blood Glucose			
No	0	0	-
Yes	5	8	-
BMI, kg/m^2			
< 25	0	0	0
25–30	1	1	1
30 +	3	2	2
Use of antihypertensive medication			
No	0	0	0
Yes	2	2	2
T2D family history:			
no	0	0	0
yes, 1st degree	5	2	2
yes, 2nd degree	3	2	2
WC, cm:			
F< 80, M< 94	0	-	-
F 80–88, M 94–102	3	-	-
F> 88, M> 102	4	-	-
Physical Activity:			
Regular (30min/day)	0	-	0
Not regular	2	-	2
Fruits & Vegetables consumption			
Everyday	0	-	0
Not everyday	1	-	1
Additional factors			
Sex			
Female	-	0	0
Male	-	2	2
Educational level, years			
> 12	-	0	0
≤ 12	-	1	1
History of high TG			
≤ 150 mg/dL	-	0	-
> 150 mg/dL	-	1	-
Max total score	26	24	18

scaling factor: ln(odds)/0.4 [16]
BMI: Body mass index, T2D: Type 2 Diabetes, TG: Triglycerides, WC: Waist circumference

population-level screening and intervention.

While the original tool has been widely used in European settings, accumulating evidence indicates that socio-economic, demographic, and clinical risk factors vary across regions and population subgroups [4,10]. Accordingly, incorporating sex, education level and history of high TG in the *revised*-FINDRISC represents a substantial enhancement. These variables have strong and well-established associations with T2D. Lower educational attainment has been consistently linked to higher diabetes risk, partly through low health literacy and limited healthcare access [18]. Male sex is associated with elevated T2D incidence, earlier onset, and diagnosis at lower BMI compared to females [19]. Elevated TG levels are an established marker of insulin resistance, predicting T2D development independently [20], and alongside FBG [21]. The original FINDRISC prioritized non-invasive, easily obtained variables to serve as a "mini-intervention," deliberately excluding sex, education, and TG due to their non-modifiable or less accessible nature. Nowadays, however, TG measurements are now routinely available in cardiovascular risk assessment, supporting their inclusion in contemporary screening tools. Including TG alongside BG offers additional predictive value and is aligned with the need to encourage proactive screening.

Notably, self-reported PA, fruit/vegetable consumption, and WC were excluded in the *revised*-FINDRISC. In the original tool, dietary and PA components were included primarily for awareness-raising rather than predictive purposes [9]. Their exclusion does not imply a diminished role in T2D prevention but reflects their limited added value in risk discrimination when combined with other clinical and sociodemographic predictors. Although PA and dietary habits are behavioral variables prone to reporting bias [22,23], both remain central to T2D prevention strategies and should continue to be prioritized in clinical and public health interventions [24]. Waist circumference, although clinically relevant, is prone to measurement error when self-reported or inconsistently assessed [25,26] and appears to be a weaker predictor of insulin resistance and T2D in men [19]. Consistent with this, it has been excluded from a shorter FINDRISC version [27].

Building on the original FINDRISC, the *revised*-FINDRISC enhances screening accuracy while preserving core strengths including simplicity, non-invasive nature, and ease of use in clinical and community settings. The original tool has played a pivotal role in population-level diabetes screening throughout Europe and beyond. However, as understanding of T2D risk has evolved to encompass a broader set of sociodemographic and metabolic factors [28,29], there is increasing demand for tools that reflect this complexity. The *revised*-FINDRISC addresses this need by refining variable selection and weighting to improve sensitivity and contextual relevance, across diverse populations, while retaining an integer-based structure that supports scalability and implementation in primary care and community settings.

These refinements translated into a strong performance of the *revised*-FINDRISC in identifying individuals at high risk for T2D, a key public health objective. Given the often-asymptomatic nature of prediabetes and early-stage diabetes, early identification is essential for initiating lifestyle interventions and preventing disease progression [4]. The tool's applicability in populations with low health literacy further supports its use as a frontline screening instrument. Notably, the *revised*-FINDRISC performed well even when surrogate markers for T2D development, i.e., BG and TG-levels, were excluded in the "eliminated" tool. Accordingly, the *revised*-FINDRISC represents a valuable resource for public health campaigns, mobile health programs, and primary care workflows aiming to close gaps in diabetes prevention and care. To facilitate implementation, an informational brochure was developed (Supplementary Material 2), including a user-friendly scoring table tailored for use by clinicians and public health professionals with potential for adaptation into electronic or mobile health platforms.

Strengths and limitations

A major strength of the present study is the use of data from a large, pan-European sample across seven countries, collected by well-trained health professionals using standardized protocols across all centers. Our approach further benefits from a well-characterized validation sample from the ATTICA cohort [13]. This concordance in performance supports the generalizability of our findings and sets a foundation for future replication and external validation.

Nonetheless, it is essential to acknowledge certain limitations. Firstly, although the development of the *revised*-FINDRISC is based on community-based cohorts, these are not representative of the general population, as both Feel4Diabetes and DigiCare4You focused on individuals from vulnerable or high-risk groups, which may limit generalizability. However, to address this, its validation performance was also evaluated in a general population-based cohort study with an extensive, 20-year follow-up period. The external validation in the independent ATTICA cohort represents a single-country setting and may not fully capture performance across different country economic classifications. Although robust discrimination and calibration were confirmed, future studies could consider derivation–validation splits across countries to further evaluate generalizability. Secondly, although the inclusion of socio-economic indicators improved model sensitivity, the availability

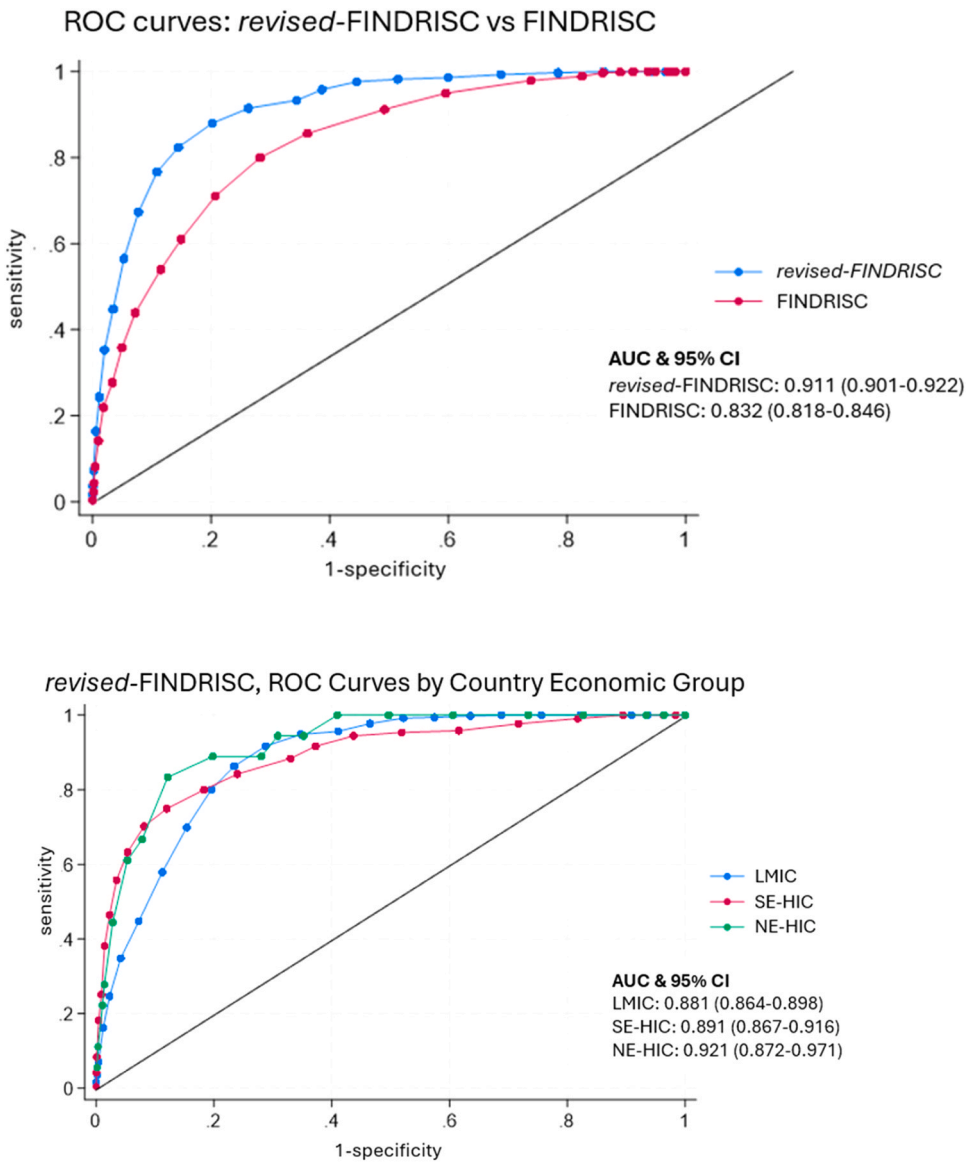

Fig. 2. Receiver Operating Characteristic curves for FINDRISC and *revised*-FINDRISC, overall (upper plot), and by socio-economic indicators (lower plot).

Table 6
External Validation Performance of the Original and Revised FINDRISC Models in the ATTICA Cohort.

Model	AUC (95% CI)	Sensitivity	Specificity	Correctly classified (%)
Original FINDRISC	0.758 (0.724–0.792)	–	–	–
Revised-FINDRISC	0.890 (0.878–0.902)	81.82%	84.77%	83.77%

and quality of such data may vary across healthcare settings and regions, potentially limiting the tool's scalability. Moreover, the inclusion of variables such as a history of high BG or TG levels may limit feasibility in some settings, as these indicators require prior laboratory testing. Thirdly, although the *revised*-FINDRISC effectively identified T2D, its capability to detect prediabetes as a separate outcome was not independently evaluated. Finally, the simplified scoring system, though practical, may reduce predictive precision compared with full regression models.

As such, the *revised*-FINDRISC should be considered a supportive screening instrument rather than a substitute for clinical judgment or diagnostic testing. Future research should assess its effectiveness in detecting earlier stages of dysglycemia and it applicability across diverse healthcare contexts.

Conclusion

The *revised*-FINDRISC integrates demographic, socio-economic, and clinical indicators while preserving usability, potentially representing a substantive advancement in diabetes risk screening. Its deployment could facilitate early detection and targeted prevention, including socio-economically disadvantaged and health-resource-limited populations.

Bioethics

All studies 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 Ethics Committees and local authorities. All participants were informed about the study objectives and procedures and provided their written consent to participate.

Funding

The Feel4diabetes and DigiCare4You studies have received funding from the European Union's Horizon 2020 research and innovation program under grant agreement Nº643708 and 945246, respectively. The content of this article reflects only the authors' views, and the European Union is not liable for any use that may be made of the information contained therein. The ATTICA study was funded by research grants from the Hellenic Cardiological Society [HCS2002] and the Hellenic Atherosclerosis Society [HAS2003].

CRediT authorship contribution statement

Christina Mavrogianni: Writing – review & editing, Writing – original draft, Investigation. **Florian Toti:** Writing – review & editing, Investigation. **Dimitra - Irinna Vitoratou:** Writing – review & editing, Writing – original draft, Visualization, Conceptualization. **Konstantinos Makrilakis:** Writing – review & editing, Investigation. **Konstantina Dimakopoulou:** Writing – review & editing, Writing – original draft, Visualization, Formal analysis. **Natalia Giménez-Legarre:** Writing – review & editing, Investigation. **Luis A. Moreno:** Writing – review & editing, Investigation. **Yannis Manios:** Writing – review & editing, Project administration, Conceptualization. **Violeta Iotova:** Writing – review & editing, Investigation. **Tsvetalina Tankova:** Writing – review & editing, Investigation. **Jaana Lindström:** Writing – review & editing, Investigation. **Greet Cardon:** Writing – review & editing, Investigation. **Demosthenes Panagiotakos:** Writing – review & editing, Validation, Formal analysis, Conceptualization. **Natalya Usheva:** Writing – review & editing, Investigation. **Rurik Imre:** Writing – review & editing, Investigation. **Eva Karaglani:** Writing – review & editing, Investigation. **Péter Torzsa:** Writing – review & editing, Investigation. **Matzourana Argyropoulou:** Writing – review & editing, Investigation. **Ditila Doracaj:** Writing – review & editing, Investigation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The authors would like to thank the members of the Feel4Diabetes, DIgiCare4You and ATTICA-study groups:

Feel4Diabetes: Coordinator: Yannis Manios, Steering Committee: Yannis Manios, Greet Cardon, Jaana Lindström, Peter Schwarz, Konstantinos Makrilakis, Lieven Annemans, Winne Ko, Harokopio University (Greece): Yannis Manios, Kalliopi Karatzi, Odysseas Androutsos, George Moschonis, Spyridon Kanellakis, Christina Mavrogianni, Konstantina Tsoutsoulopoulou, Christina Katsarou, Eva Karaglani, Irini Qira, Efstathios Skoufas, Konstantina Maragkopoulou, Antigone Tsiafitsa, Irini Sotiropoulou, Michalis Tsolakos, Effie Argyri, Mary Nikolaou, Eleni-Anna Vampouli, Christina Filippou, Kyriaki Apergi, Amalia Filippou, Gatsiou Katerina, Efstratios Dimitriadis, Finnish Institute for Health and Welfare (Finland): Jaana Lindström, Tiina Laatikainen, Katja Wikström, Jemina Kivelä, Päivi Valve, Esko Levälahti, Eeva Virtanen, Tiina Pennanen, Seija Olli, Karoliina Nelimarkka, Ghent University (Belgium), Department of Movement and Sports Sciences: Greet Cardon, Vicky Van Stappen, Nele Huys, Department of Public Health: Lieven Annemans, Ruben Willems, Department of Endocrinology and Metabolic Diseases: Samyah Shadid, Technische Universität Dresden (Germany): Peter Schwarz, Patrick Timpel, University of Athens (Greece): Konstantinos Makrilakis, Stavros Liatis, George Dafoulas, Christina-Paulina Lambrinou, Angeliki Giannopoulou, International Diabetes Federation European Region (Belgium): Winne Ko, Ernest Karuranga, Universidad De Zaragoza (Spain): Luis Moreno, Fernando Civeira, Gloria Bueno, Pilar De Miguel-Etayo, Esther Mª Gonzalez-Gil, María L. Miguel-Berges, Natalia Giménez-Legarre, Paloma Flores-Barrantes, Alelí M. Ayala-Marín, Miguel Seral-Cortés, Lucia Baila-Rueda, Ana Cenarro, Estíbaliz Jarauta, Rocío Mateo-Gallego, Medical University of Varna (Bulgaria): Violeta Iotova, Tsvetalina Tankova, Natalia Usheva, Kaloyan Tsochev, Nevena Chakarova, Sonya Galcheva, Rumyana Dimova, Yana Bocheva, Zhaneta Radkova, Vanya Marinova, Yuliya Bazdarska, Tanya Stefanova, University of Debrecen (Hungary): Imre Rurik, Timea Ungvari, Zoltán Jancsó, Anna Nánási, László Kolozsvári, Csilla Semánova, Éva Bíró, Emese Antal, Sándorné Radó: Extensive Life Oy (Finland): Remberto Martinez, Marcos Tong.

DigiCare4You: Coordinator: Yannis Manios, Harokopio University (Greece); Steering Committee: Yannis Manios, Chiara Seghieri, Djordje Djokic, Konstantinos Votis, Konstantinos Makrilakis, Lieven Annemans/Ruben Willems, Rajesh Vedanthan, Sabine Dupont; Baker Heart and Diabetes Institute (Australia): Brian Oldenburg. Centre for Research & Technology Hellas (Greece): Konstantinos Votis, Andreas Triantafyllidis, Sofia Segkouli, Anastasios Alexiadis, Aggeliki Spyrou, Panagiotis Petridis, Katerina Skoumpourdi. Ghent University (Belgium): Lieven Annemans, Ruben Willems, Delfien Gryspeerdt. Harokopio University (Greece): Yannis Manios, Costas Anastasiou, Konstantinos Tserpes, Christos Diou, Constantine Tsigos, Christina Mavrogianni, Eva Karaglani, Agathi Ntzouvani, Katerina Kontochristopoulou, Rafaela Makri, Matzourana Argyropoulou, Amalia Filippou, Maria Chrysini, Katerina Vervesou, Renos Roussos, Niovi Chrysanthakopoulou, Thalia Lampidi, Irene Rifioti, Olga Voureka, Renia Terzaki, Christina Pelekanou, Panayiota Kostarellou, Christina Patmiou. International Diabetes Federation European Region (Belgium): Sabine Dupont, Elizabeth Dupont, Izabell Thunström. International Foundation for Integrated Care (UK): Alejandro Gil-Salmerón. La Trobe University (Australia): George Moschonis, George Siopis. Meteda (Italy): Sandro Girolami, Giacomo Vespasiani, Teresa Almonti, Nazzareno Pierantozzi, Eric Notts, Giorgia Stoppaccioli, Claudia D'Antonio. Monash University (Australia): Helen Skouteris. National and Kapodistrian University of Athens (Greece): Konstantinos Makrilakis, George Stergiou, Stavros Liatis, George Karamanakos, Chrysi Koliaki, Anastasios Kollias, Eva Zikou, Haris Dimosthenopoulos. New York University Grossman School of Medicine (USA): Rajesh Vedanthan, Keng-Yen Huang, Samrachana Adhikari, Jessica Gjonaj. Privanova (France): Farhan Sahito, Djordje Djokic, Arzoo Sahito, Gisella Battalova, Anastasiya Kiseleva. Sant'Anna School of Advanced Studies (Italy): Chiara Seghieri, Tallys Feldens, Francesca Ferre. Medical University of Varna (Bulgaria): Violeta Iotova, Natalya Usheva, Tanya Zlateva, Kaloyan Tzochev, Yoto Yotov, Rosiitsa Chamova, Anna Kozhuharova, Vesela Todorova, Alexander Mitev, Ralitsa Marinova, Donika Kandilarova, Sonya Nedelcheva, Petya Boncheva, Martin Mirchev. Universidad De Zaragoza (Spain): Luis Moreno Aznar, Rosa Magallón Botaya, Gloria Bueno Lozano, Natalia Giménez-Legarre, Ivie Maneschy, Maria L. Miguel-Berges, Paloma Flores-Barrantes, Esther Ma Gonzalez-Gil, Pilar De Miguel-Etayo, Bárbara Oliván Blázquez, Susana Pérez. University of Medicine, Tirana (Albania): Florian Toti, Ditila Doracaj, Ergita Nelaj, Skerdi Prifti, Luftime Bruka, Adriana Lapardhaja, Ornela Laze, Marilda Hysa, Dorina Minxuri, Tea Shehu.

ATTICA-Study: Principal investigators: Christos Pitsavos, Demosthenes Panagiotakos, Christina Chrysohoou; Contributors: Eva Damigou, Elpiniki Vlachopoulou, Christina Vafia, Konstantina Kyrili, Georgia Anastasiou, Amalia Despoina Koutsogianni, Evangelinos Michelis, Manolis Kambaxis, Kyriakos Dimitriadis, Ioannis Andrikou, Amalia Sofianidi, Natalia Sinou, Aikaterini Skandali, Christina Sousouni, Ekavi N. Georgousopoulou, Natassa Katinioti, Labros Papadimitriou, Konstantina Masoura, Spiros Vellas, Yannis Lentzas, Manolis Kambaxis, Konstantina Palliou, Vassiliki Metaxa, Agathi Ntzouvani, Dimitris Mpougatsas, Nikolaos Skourlis, Christina Papanikolaou, Georgia-Maria Kouli, Aimilia Christou, Adella Zana, Maria Ntertimani, Aikaterini Kalogeropoulou, Evangelia Pitaraki, Alexandros Laskaris, Mihail Hatzigeorgiou and Athanasios Grekas, Efi Tsetsekou, Carmen Vassiliadou, George Dedoussis, Marina Toutouza-Giotsa, Konstantina

Tselika, Sia Poulopoulou and Maria Toutouza for their assistance in the baseline and follow-up evaluations.

Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.annepidem.2026.110064.

References

[1] International Diabetes Federation. IDF Diabetes atlas. 11th ed. Brussels: International Diabetes Federation; 2025. ⟨https://diabetesatlas.org⟩.

[2] Richter B, Hemmingsen B, Metzendorf MI, Takwoingi Y. Development of type 2 diabetes mellitus in people with intermediate hyperglycaemia. Cochrane Database Syst Rev 2018;10:CD012661. https://doi.org/10.1002/14651858.CD012661.pub2.

[3] Echouffo-Tcheugui JB, Selvin E. Prediabetes and what it means: the epidemiological evidence. Annu Rev Public Health 2021;42:59–77. https://doi.org/10.1146/annurev-publhealth-090419-102644.

[4] Chan JCN, Lim LL, Wareham NJ, Shaw JE, Orchard TJ, Zhang P, et al. The Lancet Commission on diabetes: using data to transform diabetes care and patient lives. Lancet 2021;396(10267):2019–82. https://doi.org/10.1016/S0140-6736(20)32374-6.

[5] Abbasi A, Peelen LM, Corpeleijn E, van der Schouw YT, Stolk RP, Spijkerman AMW, et al. Prediction models for risk of developing type 2 diabetes: systematic literature search and independent external validation study. BMJ 2012;345:e5900. https://doi.org/10.1136/bmj.e5900.

[6] Brown N, Critchley J, Bogowicz P, Mayige M, Unwin N. Risk scores based on self-reported or available clinical data to detect undiagnosed type 2 diabetes: a systematic review. Diabetes Res Clin Pract 2012;98(3):369–85. https://doi.org/10.1016/j.diabres.2012.09.005.

[7] Noble D, Mathur R, Dent T, Meads C, Greenhalgh T. Risk models and scores for type 2 diabetes: systematic review. BMJ 2011;343:d7163. https://doi.org/10.1136/bmj.d7163.

[8] American Diabetes Association Professional Practice Committee. 2. Diagnosis and classification of diabetes: standards of care in diabetes—2025. Diabetes Care 2025;48(1):S27–49. https://doi.org/10.2337/dc25-S002.

[9] Lindström J, Tuomilehto J. The diabetes risk score: a practical tool to predict type 2 diabetes risk. Diabetes Care 2003;26(3):725–31. https://doi.org/10.2337/diacare.26.3.725.

[10] Mavrogianni C, Lambrinou CP, Androutsos O, Lindström J, Kivelä J, Cardon G, et al. Evaluation of the Finnish diabetes risk score as a screening tool for undiagnosed type 2 diabetes and dysglycaemia among early middle-aged adults in a large-scale European cohort: the Feel4Diabetes-study. Diabetes Res Clin Pract 2019;150:99–110. https://doi.org/10.1016/j.diabres.2019.02.017.

[11] DigiCare4You. Improving early prevention and management of type 2 diabetes and hypertension. https://digicare4you.eu/; [accessed 27 Aug 2025].

[12] Manios Y, Androutsos O, Lambrinou CP, Cardon G, Lindström J, Annemans L, et al. A school- and community-based intervention to promote healthy lifestyle and prevent type 2 diabetes in vulnerable families across Europe: design and implementation of the Feel4Diabetes-study. Public Health Nutr 2018;21(17):3281–90. https://doi.org/10.1017/S1368980018002136.

[13] Kechagia I, Barkas F, Liberopoulos E, Chrysohoou C, Sfikakis PP, Tsioufis C, et al. Association between simple, combined lipid markers and 20-year cumulative incidence of type 2 diabetes: the ATTICA cohort study (2002–2022). Lipids Health Dis 2024;23(1):413. https://doi.org/10.1186/s12944-024-02383-8.

[14] Zhao S, Zhang B, Yang J, et al. Linear discriminant analysis (Article) Nat Rev Methods Prim 2024;4:70. https://doi.org/10.1038/s43586-024-00346-y.

[15] Harrell FE. Regression Modeling Strategies. 2nd ed. New York: Springer; 2015. https://doi.org/10.1007/978-3-319-19425-7.

[16] Steyerberg EW. Clinical Prediction Models: A Practical Approach to Development, Validation, and Updating. 2nd ed. New York: Springer; 2019. https://doi.org/10.1007/978-3-030-16399-0.

[17] Sullivan LM, Massaro JM. D'Agostino RB. Presentation of multivariate data for clinical use: the Framingham study risk score functions. Stat Med 2004;23(10):1631–40. https://doi.org/10.1002/sim.1742.

[18] Hill-Briggs F, Adler NE, Berkowitz SA, Chin MH, Gary-Webb TL, Navas-Acien A, et al. Social determinants of health and diabetes: a scientific review. Diabetes Care 2020;44(1):258–79. https://doi.org/10.2337/dci20-0053.

[19] Kautzky-Willer A, Leutner M, Harreiter J. Sex differences in type 2 diabetes. Diabetologia 2023;66(6):986–1002. https://doi.org/10.1007/s00125-023-05891-x.

[20] Zhao J, Zhang Y, Wei F, Song J, Cao Z, Chen C, et al. Triglyceride is an independent predictor of type 2 diabetes among middle-aged and older adults: a prospective study with 8-year follow-ups in two cohorts. J Transl Med 2019;17(1):403. https://doi.org/10.1186/S12967-019-02156-3.

[21] Kurniawan LB. Triglyceride-glucose index as a biomarker of insulin resistance, diabetes mellitus, metabolic syndrome, and cardiovascular disease: a review. EJIFCC 2024;35(1):44–51.

[22] Hebert JR, Clemow L, Pbert L, Ockene IS, Ockene JK. Social desirability bias in dietary self-report may compromise the validity of dietary intake measures. Int J Epidemiol 1995;24(2):389–98. https://doi.org/10.1093/ije/24.2.389.

[23] Prince SA, Adamo KB, Hamel ME, Hardt J, Gorber SC, Tremblay M. A comparison of direct versus self-report measures for assessing physical activity in adults: a systematic review. Int J Behav Nutr Phys Act 2008;5:56. https://doi.org/10.1186/1479-5868-5-56.

[24] Ibrahim M, Tuomilehto J, Aschner P, Beseler L, Cahn A, Eckel RH, et al. Global status of diabetes prevention and prospects for action: a consensus statement. Diabetes Metab Res Rev 2018;34(6):e3021. https://doi.org/10.1002/dmrr.3021.

[25] Carranza Leon BG, Jensen MD, Hartman JJ, Jensen TB. Self-measured vs professionally measured waist circumference. Ann Fam Med 2016;14(3):262–6. https://doi.org/10.1370/afm.1896.

[26] Verweij LM, Terwee CB, Proper KI, Hulshof CT, van Mechelen W. Measurement error of waist circumference: gaps in knowledge. Public Health Nutr 2013;16(2):281–8. https://doi.org/10.1017/S1368980012002741.

[27] Li J, Bergmann A, Reimann M, Bornstein SR, Schwarz PE. A more simplified Finnish diabetes risk score for opportunistic screening of undiagnosed type 2 diabetes in a German population with a family history of the metabolic syndrome. Horm Metab Res 2009;41(2):98–103. https://doi.org/10.1055/s-0028-1087191.

[28] Singh S, Kriti M, KS A, Sarma DK, Verma V, Nagpal R, et al. Deciphering the complex interplay of risk factors in type 2 diabetes mellitus: a comprehensive review. Metab Open 2024;22:100287. https://doi.org/10.1016/j.metop.2024.100287.

[29] Bijlsma-Rutte A, Rutters F, Elders PJM, Bot SDM, Nijpels G. Socio-economic status and HbA1c in type 2 diabetes: a systematic review and meta-analysis. Diabetes Metab Res Rev 2018;34(6):e3008. https://doi.org/10.1002/dmrr.3008.