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Original Research

Socioeconomic and migration-related disparities in prevalent young-onset type 2 diabetes: Data from the German National Cohort (NAKO)

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ABSTRACT

Objectives: Global prevalence of young-onset type 2 diabetes (YOT2D)— diagnosis age 20 – 45—is rising. While clinical drivers such as obesity are known, the role of socio-cultural factors in European high-income settings remain underexplored. We investigated the associations of socioeconomic position (SEP), migration background, and social networks with prevalent YOT2D within the German National Cohort (NAKO).
Study design: Matched case-control study within the NAKO baseline cohort (recruitment period 2014 – 2019).
Methods: We matched 808 YOT2D cases in 1:5 ratio to 4035 controls by sex, age, and study center. We applied conditional logistic regression to estimate odds ratios (ORs) and 95% confidence intervals (CIs), adjusting for parental diabetes, lifestyle factors, and body mass index (BMI). We also performed stratified analyses by BMI (cut-off 25 kg/m^2) to examine if associations varied across adiposity levels.
Results: In multivariable-adjusted analyses, low education (OR 2·13, 95%CI 1·44 – 3·15) and poverty-risk household income (OR 2·13, 95%CI 1·54 – 2·94) were associated with two-times higher odds of YOT2D compared to high-status counterparts. First-generation migrants showed higher odds of YOT2D (OR 1·61, 95%CI 1·27 – 2·04) relative to non-migrants. Notably, the association between low education and YOT2D was evident only among individuals with BMI ≥25 kg/m^2 (OR 1·76, 95%CI 1·46 – 2·11) but not among those with BMI <25 kg/m^2 (OR 0·94, 95%CI 0·70 – 1·27).
Conclusions: Our results highlight that YOT2D prevalence is associated with socioeconomic disadvantage and migration history. These findings emphasize the urgent need for targeted strategies that address health inequities faced by younger, socioeconomically vulnerable populations.

1. Introduction

Diabetes is a globally prevalent chronic disease that affected an estimated 485 million people aged 20 to 79 years worldwide in 2021, with approximately 96% of cases being type 2 diabetes (T2D).[1] A worrying trend of increasing T2D incidence among younger populations has been gaining recognition.[2,3] Young-onset type 2 diabetes is characterized by rapid β-cell function deterioration and a disproportionately high burden of microvascular and macrovascular complications.[4–8] Considering the mean diagnosis age in Germany was 61.0 ± 13·4 years[9] and to capture women of childbearing age,[8] young-onset T2D (YOT2D) is defined as T2D diagnosed between ages 20 – 45.

While risk profiles for later-onset T2D are well-explored,[10,11] existing gaps remain in research focusing on YOT2D. Current understanding points to family history and early-life obesity as key risk factors for YOT2D.[4,7] Overall, the drivers of YOT2D are expected to differ from later-onset phenotypes because early-life socioeconomic deprivation exposes individuals to intense environmental and nutritional stressors during critical developmental windows, accelerating metabolic decline before a lifetime risk exposure can accumulate. Less is known about the association between underlying socio-cultural factors traditionally linked to T2D in the general population.[12,13] In high-income countries, T2D has been suggested to disproportionately affect lower-income populations,[13,14] and a recent study demonstrated that these disproportions were heightened in YOT2D.[15] Most existing evidence have relied on linked secondary data from clinical and population registries[15–17] rather than primary population-based samples or utilized restricted indicators such as education and income within small study populations.[18]

Migrant populations exhibit a higher prevalence of T2D and typically develop the disease at younger ages than native-born populations.[19–21] Migrants frequently encounter challenges such as lower social integration, language barriers, and reduced social networks, which are linked to health inequalities and psychosocial stress.[20] Low SEP and social isolation are further associated with negative mental and physical health outcomes; specifically, lack of social support has been linked to higher T2D risks, including young adults.[22,23]

Furthermore, the pathways through which socio-cultural factors could be associated with YOT2D may vary by adiposity status.[24,25] In YOT2D, obesity is a critical driver of insulin resistance, with evidence suggesting that the duration of obesity and specific fat distribution are more significant in younger populations than in older cohorts.[3] This points to potential interactions between socio-cultural factors, adiposity, and onset age that has yet to be fully elucidated in large-scale studies.[26]

Given these knowledge gaps, we utilized data from the German National Cohort (NAKO)—a large, population-based study—to investigate the associations between SEP, migration background, social networks, and prevalent YOT2D. Additionally, we explored whether these associations are modified by adiposity indicators.

2. Methods

2.1. Study design and setting

The NAKO study is an ongoing, prospective population-based study investigating the etiology of major chronic diseases. Baseline assessment recruitment occurred in 2014 – 2019 across 18 study centers throughout Germany, and 205,414 participants aged 20 – 69 years were enrolled.[27] Participants were identified through random sampling from municipal population registries. The sampling strategy was stratified by sex (1:1) and age, with 10% of participants drawn from each 10-year age group between 20 and 39 years, and 26•7% from each 10-year age group between 40 and 69 years.[27,28]

2.2. Data collection

Baseline assessments followed standardized operating procedures (SOPs) across all sites. Data collection included face-to-face interviews, self-administered questionnaires covering lifestyle, and medical history, comprehensive medical tests, and biospecimen collection.[27]

2.3. Case-control study within the NAKO cohort

To optimize statistical efficiency and maximize data utilization within the NAKO cohort, this study was designed as a case-control study within the baseline assessments. This approach was selected over a full cross-sectional analysis of the entire cohort to address the severe group imbalance resulting from a low-prevalence outcome (~0·4%) within a large baseline population. In epidemiologic studies of rare outcomes, a 1:5 case-to-control ratio optimizes statistical power; increasing the number of controls beyond this threshold causes statistical power to plateau while introducing unnecessary background variance.[29,30] Furthermore, matching at the design stage creates an identical distribution of confounders (age, sex, and study center), thereby robustly preventing residual confounding and avoiding sparse-data bias during subsequent stratified sub-analyses.

Cases were matched without replacement to diabetes-free controls. Controls were randomly sampled from the underlying base cohort to ensure they represented the identical source population that generated the cases, thereby minimizing selection bias. Although three matched strata were incomplete (two cases with four controls and one case with two controls), they were retained in the analysis to maximize sample efficiency.

The selection framework for the analytical sample is illustrated in Fig. 1. Participants were eligible if they were aged 20 – 45 years at enrolment with a self-reported history of diabetes; pregnant women were excluded to eliminate potential gestational hyperglycaemia and unreliable source of HbA1c test results. Young-onset type 2 diabetes (YOT2D) was defined as a diagnosis established between ages 20 and 45.

To minimize differential misclassification of type 1 diabetes within the self-reported sample, an algorithm that combined age cut-off and time-to-insulin therapy was implemented. This combination of clinical features has been shown to correctly differentiate approximately 90% of type 1 from type 2 diabetes cases in young adults.[31] Consequently, we excluded individuals diagnosed before age 20, and those diagnosed between ages 20 and 45 who reported current insulin monotherapy initiated within two years of diagnosis. Participants with missing data regarding therapeutic regimens or age at diagnosis were also excluded to prevent the misclassification of other (gestational, secondary or rare) diabetes phenotypes.

Following these systematic exclusions, 808 participants (mean age: 39·2 years for females, 41·7 years for males) were classified as analytical cases. At baseline, their therapeutic regimens comprised insulin monotherapy initiated ≥2 years post-diagnosis, oral glucose-lowering medications alone or in combination with insulin, or diet and other unspecified therapies.

To exclude possible residual gestational diabetes among cases without current medicinal therapy and to ensure diagnostic robustness, we applied two refined YOT2D case definitions. These criteria incorporated: (1) baseline glycated haemoglobin (HbA1c ≥ 6.5%) and random blood glucose (RBG ≥200 mg/dL) concentrations; and (2) age-specific stratification, targeting a diagnosis between 30 and 45 years, or 6 – 29 years for individuals with a baseline BMI ≥25 kg/m^2 using non-insulin glucose-lowering medications (e.g., sulfonylureas) to differentiate from T1D (based on the NAKO Diabetes EG framework currently under revision).

2.4. *Exposure assessment*

2.4.1. *Socioeconomic position*

To assess SEP, we used several self-reported variables representing multiple dimensions of socio-economic status. Highest attained formal education was measured according to the International Standard of Classification 2011 (ISCED) and categorized into low (ISCED level ≤2), intermediate (ISCED level 3 – 5), and high (ISCED 6 – 8).[32] Household income was estimated from net monthly household income and size, then compared to the population median from the European Union Statistics on Income and Living Conditions (EU-SILC).[33] Income was categorized by its relative equivalent position, ranging from <60% (at risk of poverty) to >150% of the median. Employment status was categorized as employed (including self-employed, apprentices and employees on parental leave), unemployed (actively seeking employment), and inactive (including students and those not seeking employment).[34] Occupation type was grouped into: (1) employees and liberal professionals, (2) laborers and farmers (including self-employed farmers), (3) workers in crafts, trade or services, and (4) civil servants. Social classes according to the European Socioeconomic Classification (ESeC)[35] considered rather similar in employment terms, management

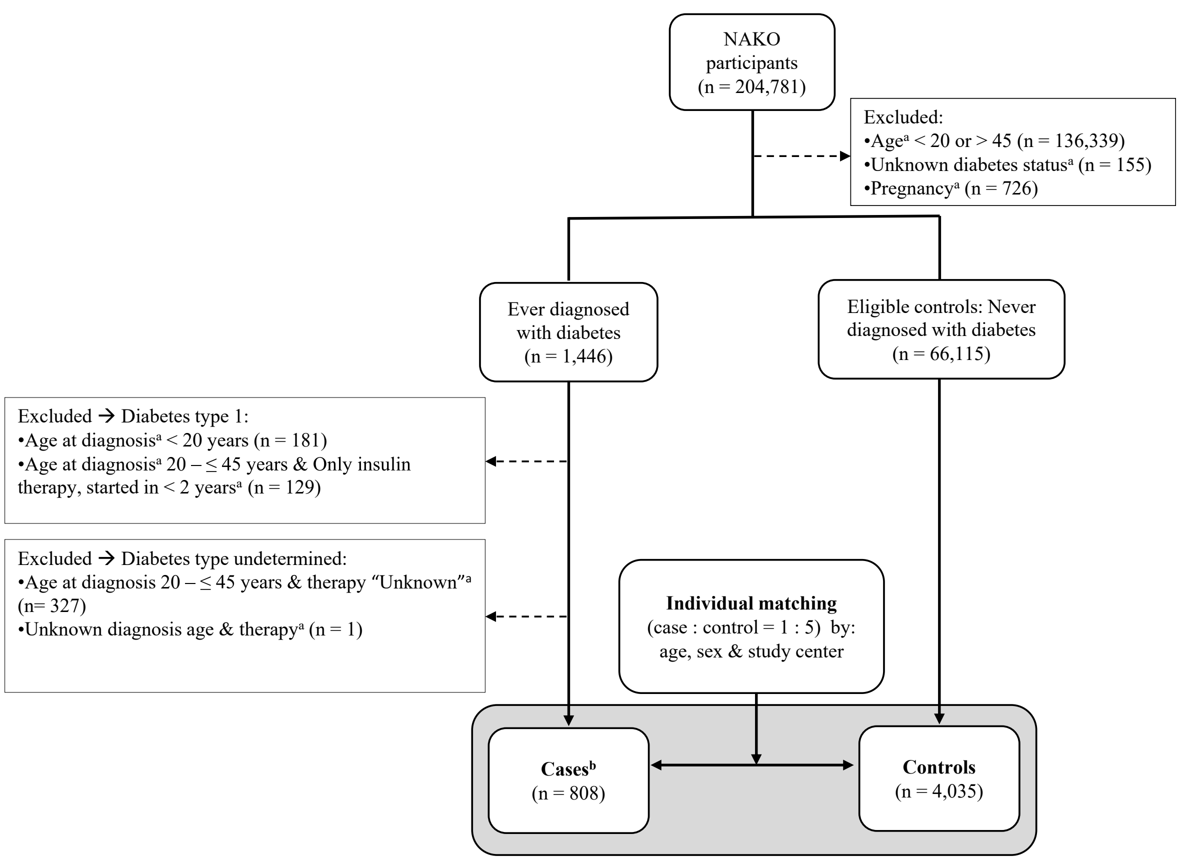

Fig. 1. Flowchart of the study population selection. [a] Self-reported [b] Participants with diabetes diagnosed age 20 – ≤ 45 years and being treated with: only insulin therapy, started ≥2 years (n = 15), insulin or oral therapy (n = 291), oral therapy with unknown diagnosis age (n = 1), diet or "other" therapy (n = 498), and participants with diabetes but unknown diabetes age and treated with "other" therapy (n = 3).

level, income, or work type (service or labor) were combined as: higher professionals (class 1), lower professionals (classes 2/3), small employers/self-employed (classes 4/5), lower grade white-collar workers (class 7), and higher and lower grade blue-collar workers (classes 6/8/9).[36]

2.4.2. Migration status

Migration status was categorized based on parental and own birth country region according to the United Nation's classification into: "non-migrants", "first generation migrants", further distinguished into the four most frequent regions in the dataset, and "other regions", and "second generation migrants". A detailed report on the classification process have been published elsewhere.[36]

2.4.3. Social network

The number and frequency of social contacts (spouse/partner, close relatives, friends, or membership in voluntary organizations) were summarized using the Social Network Index (SNI) developed by Berkman and Syme.[37] The index score comprised levels 1 ("social isolation") to 4 ("social integration"). For the analysis, levels 2 – 4 were combined to indicate "social integration".

2.5. Assessment of covariates

BMI was calculated from standardized height and weight measurements (via Bioelectric Impedance Analysis), manually verified, and categorized into "<25" (under-/normal weight), "25 – <30" (overweight), and "≥30" kg/m^2 (obese). Waist circumference (WC) was measured at a standardized location and defined as "low" (<94 cm males, <80 cm females) and "high" (≥94 cm males, ≥80 cm females) according to the International Diabetes Federation (IDF) definition.[38]

Self-reported current sedentary behavior, time spent sitting or resting on an ordinary day, was grouped into quartiles ("<4", "4 – 6", "6 – 9•3", and ">9•3" hours/day), and smoking behavior was categorized into current, former, or never smokers. Current alcohol consumption was estimated from self-reported type and average number of alcoholic beverage servings in the past 12 months and reported in grams/day. Parental diabetes history was categorized into none, one, or two affected parents.

2.6. Statistical analysis

Descriptive statistics are reported as absolute frequencies and percentages for cases and controls for all exposure variables and covariates, except for alcohol consumption, which was reported as mean (gram/day), standard deviation (SD) and minimum–maximum. Data in several categorical variables were missing in minimal amounts (less than or ~5%), except for SNI (11·5% missing) and parental diabetes of both parents (10·4% missing) and were incorporated as "unknown" category.

To assess the association between exposures of interest and YOT2D, we employed conditional logistic regression, conditioned on matching strata and estimated odds ratios (ORs) and 95% confidence intervals (CIs). We performed multivariable-adjusted analyses using two sequential models, with potential confounders identified through a directed acyclic graph (Supplemental Fig. 1). Considering the assumed associations with SEP factors,[39] in Model 1, we adjusted for parental diabetes history and various socioeconomic factors, while excluding the specific exposure being studied; in Model 2, we refined the models by adding BMI, smoking, and sedentary behavior. Alcohol consumption was ultimately excluded from these models as it did not materially alter estimates.

We utilized unconditional logistic regression for sensitivity analyses and stratification by adiposity (BMI ≥25 kg/m^2 or IDF sex-specific WC cut-points[37]) to prevent the loss of statistical power that occurs when conditional models discard incomplete strata. In these specific sub-analyses, the original 1:5 matching protocol was broken. To maintain the integrity of the design and prevent selection bias, the original matching variables (age, sex, and study center) were explicitly included as adjustment covariates in all unconditional models. Stratified analyses were performed to explore potential interactions between the exposures and adiposity status. Due to limited sample sizes in stratified subgroups, education level was dichotomized into "low/intermediate" vs "high." Statistical significance for interactions was assessed using the Wald χ^2 test for cross-product terms.

To evaluate the robustness of the findings, several sensitivity analyses were conducted. First, the primary models were repeated using refined YOT2D definitions 1 and 2 (Supplementary Fig. S2 and S3, respectively). Second, the analysis was restricted to participants aged 20 – 40 (306 cases and 1525 controls). Finally, to account for the relatively high proportion of missing observations in the SNI variable, we performed a complete-case analysis for the primary models (621 cases and 3381 controls), as well as for the stratified and subsequent sensitivity analyses.

All analyses were performed using R version 2025.9.1.401.

3. Results

The present study included 808 cases and 4035 controls. Approximately 71% of YOT2D cases were female, and the mean age was 39·9 years (SD 5·2). A substantially higher proportion of cases (72%) was characterized by overweight and obesity (BMI ≥25 kg/m^2) compared to controls (46%). Markedly higher proportions of parental diabetes history were observed among cases compared with controls for one parent (32·5% vs 18·6%) and both parents (9·4% vs 2·2%) (Supplementary Table 1).

As shown in Table 1, approximately 54% of cases had intermediate-level education, whereas 54% of controls had high-level education. Household income <80% of the population median was reported by 42·7% of cases and 24·2% of controls. While the majority of participants were employed (82·5% of cases and 92·5% of controls), the proportion of those in the higher professional ESeC class was lower among cases (20·0%) than controls (31·7%). Approximately 22% of participants had a migration background (30·0% among cases and 20·9% among controls), the majority being first-generation migrants (23·0% vs 14·5%) originating from Eastern Europe (6·7% vs 5·7%). Social isolation was prevalent in approximately 12% of both groups.

In multivariable-adjusted analyses controlling for parental diabetes, lifestyle factors, and BMI (Table 2), low and intermediate education levels were associated with higher YOT2D odds (OR 2·13 95%CI [1·44–3·15] and 1·36 [1·14–1·63], respectively) compared with high education. Relative to employed participants, YOT2D odds were higher among the unemployed (OR 1·63 [1·10–2·44]) and occupationally inactive participants (OR 1·50 [1·06–2·13]). Participants with occupations as laborers or farmers had 1·41 times higher odds of YOT2D (95% CI 1·03–1·92) compared with those who were employees or liberal professionals. Furthermore, participants with low household income (<60% median) had a 2·13-fold higher YOT2D odds (95%CI 1·54–2·94) compared to those with high income. Within ESeC classes, blue-collar workers had higher odds of YOT2D (OR 1·64 [1·18–2·29]) than higher professionals. Compared with non-migrants, first-generation migrants showed elevated odds for YOT2D varying by region of origin: Eastern Europe (OR 1·43 [1·00–2·04]), West Asia (OR 2·04 [1·28–3·25]), and other regions (OR 1·99 [1·33–2·97]). No apparent association was observed for social isolation and YOT2D.

In stratified analyses, the association between low education and YOT2D was statistically significant among participants with high BMI ($p_{interaction}$ <0·01) and high WC ($p_{interaction}$ 0·02). Poverty-risk household income was associated with YOT2D exclusively among those with high WC ($p_{interaction}$ 0·03). Occupational associations (self-employed and civil servants vs. employees/liberal professionals) were only significant among those with low BMI (($P_{\text{interaction}}$ 0·03 and $P_{\text{interaction}}$ <0·01). Overall, certain socioeconomic patterns varied depending on whether

Table 1
Distribution of socio-economic factors, migration background and social network index by prevalent YOT2D status.

Characteristics	YOT2D Status	
	Controls (n = 4035)	Cases (n = 808)
Education level[a], n (%)		
High	2197 (54.4%)	301 (37.3%)
Intermediate	1721 (42.7%)	439 (54.3%)
Low	114 (2.8%)	68 (8.4%)
Unknown	3 (0.1%)	0 (0.0%)
Employment status, n (%)		
Employed	3732 (92.5%)	667 (82.5%)
Unemployed	110 (2.7%)	52 (6.4%)
Inactive	171 (4.2%)	81 (10.0%)
Unknown	22 (0.5%)	8 (1.0%)
Occupation, n (%)		
Employees and liberal professionals	3145 (77.9%)	575 (71.2%)
Laborers, farmers (including self-employed farmers) and apprentices	239 (5.9%)	90 (11.1%)
Self-employed in crafts, trade, industry, services	294 (7.3%)	62 (7.7%)
Civil servants	280 (6.9%)	43 (5.3%)
Unknown	77 (1.9%)	38 (4.7%)
Household income (% of population median)[b], n (%)		
<60% (poverty risk)	482 (11.9%)	215 (26.6%)
60 - <80%	497 (12.3%)	130 (16.1%)
80 - <100%	677 (16.8%)	116 (14.4%)
100 - <150%	1290 (32.0%)	199 (24.6%)
≥150%	872 (21.6%)	100 (12.4%)
Unknown	217 (5.4%)	48 (5.9%)
ESeC Class[c], n (%)		
Higher professionals	1279 (31.7%)	162 (20.0%)
Lower professionals	1539 (38.1%)	292 (36.1%)
Small employers/self-employed	156 (3.9%)	32 (4.0%)
Higher and lower grade blue-collar workers	357 (8.8%)	146 (18.1%)
Lower grade white-collar workers	510 (12.6%)	114 (14.1%)
Unknown	194 (4.8%)	62 (7.7%)
Migration status & birth region, n (%)		
Non-migrants	3192 (79.1%)	566 (70.0%)
1st generation migrants:	585 (14.5%)[a]	186 (23.0%)[a]
Eastern Europe	232 (5.7%)	54 (6.7%)
Southern Europe	66 (1.6%)	19 (2.4%)
West Asia	75 (1.9%)	45 (5.6%)
Central Asia	66 (1.6%)	19 (2.4%)
Other regions	146 (3.6%)	49 (6.1%)
2nd generation migrants	258 (6.4%)	56 (6.9%)
Social Network Index, n (%)		
Socially integrated	3131 (77.6%)	568 (70.3%)
Socially isolated	483 (12.0%)	102 (12.6%)
Unknown	421 (10.4%)	138 (17.1%)

YOT2D: young-onset type 2 diabetes.
[a] [1] Low = ISCED 0 – 2, intermediate = ISCED 3 – 5 and high = ISCED 6 - 8 according to the International Standard Classification of Education 2011 (ISCED 2011).[32]
[b] Household income categorized according to its relative position to the population median based on the European Union Statistics on Income and Living Conditions (EU-SILC).[33]
[c] ESeC = European Socioeconomic Classification.[35]

BMI or WC was used as the stratification variable, but did not differ significantly between stratum categories as visually confirmed by the overlapping confidence intervals in Fig. 2.

In sensitivity analyses utilizing the refined YOT2D definitions (Supplementary Table S2 and S3), the primary associations remained robust. Notably, these models revealed a statistically significant association between social isolation and YOT2D, yielding odds ratios of 1·87 (95% CI: 1·22–2·85) and 2·07 (95% CI: 1·41–3·02), respectively. When restricting the analysis to participants aged 20 – 40, the observed associations were similar to those in the primary analyses, albeit with wider confidence intervals; however, the association between first-generation migrant status (by country of birth) and YOT2D was no

Table 2
Odds ratios (ORs) and 95% confidence intervals (CIs) for the association between socioeconomic factors, migration background, and social network index and prevalent YOT2D.

Exposure	Cases (n = 808)/ Controls (n = 4035)	OR (95%CI)		
		Univariable	Multivariable model 1	Multivariable model 2[a]
Education level[b,c]				
High	301/2197	Ref.	Ref.	Ref.
Intermediate	439/1721	1.91 (1.62 – 2.24)	1.69 (1.43 – 2.00)	1.36 (1.14 – 1.63)
Low	68/114	4.34 (3.14 – 6.00)	2.85 (1.98 – 4.10)	2.13 (1.44 – 3.15)
Employment status[d]				
Employed	667/3732	Ref.	Ref.	Ref.
Unemployed	52/110	2.59 (1.84 – 3.64)	1.81 (1.25 – 2.62)	1.63 (1.10 – 2.44)
Inactive	81/171	2.71 (2.04 – 3.60)	2.00 (1.46 – 2.75)	1.50 (1.06 – 2.13)
Occupation[d]				
Employees and liberal professionals	575/3145	Ref.	Ref.	Ref.
Laborers and farmers (including self-employed farmers)	90/239	2.16 (1.65 – 2.82)	1.50 (1.12 – 2.02)	1.41 (1.03 – 1.92)
Self-employed in crafts, trade, industry, services	62/294	1.18 (0.88 – 1.59)	1.25 (0.92 – 1.70)	1.34 (0.96 – 1.86)
Civil servants	43/280	0.85 (0.61 – 1.19)	1.16 (0.81 – 1.65)	1.31 (0.90 – 1.90)
Household income (of population median)[e]				
≥ 150%	100/872	Ref.	Ref.	Ref.
100 – <150%	199/1290	1.36 (1.05 – 1.76)	1.21 (0.92 – 1.58)	1.11 (0.84 – 1.48)
80 – <100%	116/677	1.55 (1.16 – 2.07)	1.31 (0.96 – 1.78)	1.15 (0.83 – 1.59)
60 – <80%	130/497	2.40 (1.79 – 3.20)	1.68 (1.22 – 2.30)	1.52 (1.09 – 2.13)
<60% (poverty risk)	215/482	4.04 (3.09 – 5.28)	2.63 (1.94 – 3.56)	2.13 (1.54 – 2.94)
ESeC Class[d,f]				
Higher professionals	162/1279	Ref.	Ref.	Ref.
Lower professionals	292/1539	1.49 (1.21 – 1.84)	1.18 (0.94 – 1.49)	1.20 (0.94 – 1.53)
Small employers/ self-employed	32/156	1.67 (1.10 – 2.54)	1.31 (0.84 – 2.03)	1.19 (0.74 – 1.91)
Higher & lower grade blue-collar workers	146/357	3.45 (2.65 – 4.49)	1.91 (1.41 – 2.60)	1.64 (1.18 – 2.29)
Lower grade white-collar workers	114/510	1.75 (1.34 – 2.27)	1.17 (0.87 – 1.59)	1.06 (0.77 – 1.46)
Migration background & birth region[c]				
Non-migrants	566/3192	Ref.	Ref.	Ref.
1st generation migrants[g]	186/585	1.89 (1.55 – 2.30)	1.49 (1.19 – 1.86)	1.61 (1.27 – 2.04)
Eastern Europe	54/232	1.38 (1.00 – 1.89)	1.23 (0.88 – 1.72)	1.43 (1.00 – 2.04)
Southern Europe	19/66	1.75 (1.04 – 2.93)	1.32 (0.77 – 2.28)	1.14 (0.64 – 2.03)
West Asia	45/75	3.53 (2.41 – 5.19)	1.86 (1.21 – 2.87)	2.04 (1.28 – 3.25)
Central Asia	19/66	1.72 (1.02 – 2.89)	1.61 (0.93 – 2.78)	1.63 (0.91 – 2.91)
Other regions (e.g. Sub-Saharan	49/146	1.98 (1.41 – 2.79)	1.72 (1.19 – 2.48)	1.99 (1.33 – 2.97)

(continued on next page)

Table 2 (*continued*)

Exposure	Cases (n = 808)/ Controls (n = 4035)	OR (95%CI)		
		Univariable	Multivariable model 1	Multivariable model 2[a]
Africa, South Asia)				
2nd generation migrants	56/258	1.29 (0.95 – 1.76)	1.07 (0.77 – 1.49)	0.96 (0.68 – 1.38)
Social Network Index[h]				
Socially integrated	568/3131	Ref.	Ref.	Ref.
Socially isolated	102/483	1.17 (0.92 – 1.47)	1.04 (0.82 – 1.33)	0.97 (0.74 – 1.26)

YOT2D: young-onset type 2 diabetes.
[a] Models additionally adjusted for BMI, sedentary behavior, and smoking.
[b] Low = ISCED 0 – 2, intermediate = ISCED 3 – 5 and high = ISCED 6 - 8 according to the International Standard Classification of Education 2011 (ISCED 2011).[32]
[c] Multivariable model adjusted for parental diabetes and mutually adjusted for education and migration background.
[d] Multivariable model adjusted for parental diabetes and education.
[e] Household income categorized according to its relative position to the population median based on the European Union Statistics on Income and Living Conditions (EU-SILC).[33] Multivariate model adjusted for parental diabetes education, occupation and migration background.
[f] ESeC = European Socioeconomic Classification.[35]
[g] Estimates for 1st generation migrants from all birth regions compared to non-migrants.
[h] Multivariable model adjusted for parental diabetes, education and migration background.

longer present (Supplementary Table S4). Finally, the complete-case analysis for SNI demonstrated that despite minor variations in point estimates—expected due to the restricted dataset—the results remained highly consistent with our primary findings in both direction and magnitude, further confirming their robustness (Supplementary Table S5–S9).

4. Discussion

In this large population-based study of the German population, we observed robust associations between multiple socioeconomic indicators and the odds of YOT2D. Our findings reveal that the prevalence of YOT2D is disproportionately concentrated among individuals with lower educational level, lower household income, employment in blue-collar ESeC classes, and first-generation migrant status. Notably, the statistical associations persisted independently of parental history and established lifestyle risk factors, suggesting that structural and environmental factors intertwined with an individual's social position may represent key correlates of early disease onset.

Overall, these results are consistent with prior reports documenting associations between lower SEP, migration status, and T2D risk in Western countries.[12,13] The persistent link between low education and YOT2D after controlling for plausible confounders, highlights education as a key correlate of early-onset disease. This finding supports the notion that longer duration of schooling was beneficial for survival, more so in younger populations.[40] Educational level may indicate a person's cognitive capacity for processing health information, thereby relating to health literacy—an important skill correlated with healthy behavior, healthcare utilization, and self-management in therapy.[41–43]

Our data further revealed that the association between lower education and YOT2D was more pronounced in the presence of higher BMI and abdominal obesity. This finding complements previous reports of exacerbated links between adiposity and incident T2D among older adults with low vs. higher education levels.[25] While this association might not stem solely from cognitive factors, but also from psychological factors, unhealthy behaviors, and poorer living conditions, the observed lower educational achievement is linked to socioeconomic inequality and subsequent health outcomes.[44,45]

In our analyses, individuals who reported being unemployed/inactive in the labor market had higher odds for YOT2D compared to their employed counterparts. This finding complements prior studies showing an association between unemployment and T2D,[16,17,46] particularly when unemployment was prolonged.[47,48] While we controlled for lifestyle behaviors, we did not account for inherent psychological factors, such as status anxiety and chronic stress, which may be intertwined with these findings and require further exploration.[49,50]

In accordance with our findings, recent studies have observed disadvantageous effects of low parental and offspring's income on obesity or diabetes risk in later life.[51] Moreover, the association between households at poverty risk (income <60% population median) and YOT2D was augmented by abdominal obesity in our study. Abdominal obesity could have a different physiological mechanism than general obesity (BMI)[52] in increasing the risk of metabolic diseases such as T2D, and it can be linked to limited access to healthy food, less physical activity, and other lifestyle factors prevalent in low-income communities.[53] On the other hand, reverse causality between obesity and low income has also been reported, as people with obesity might experience labor-market discrimination and social stigmatization leading to having low-income jobs.[54]

Regarding migration background, 1st generation migrants showed higher YOT2D odds than the native population, substantiating reports of varying risk levels based on birth country or ethnicity.[15,20,21] This diversity may be linked to genetic predispositions or environmental shifts, such as changes in social support systems and exposure to "Western--diet" characterized by highly processed, calorie-dense foods.[55]

Additionally, our sensitivity analyses indicated that social isolation was associated with higher YOT2D odds, reinforcing observations that limited social networks correlate with diabetes risk in young adults.[22] This finding highlights the role of social isolation in YOT2D cases that were clinically characterized with either treated with prescribed medicine or increased HbA1c levels. However, this relationship may be bidirectional; for example, obesity in young adults is often associated with social withdrawal, which may further contribute to isolation and loneliness.[56]

4.1. Strengths and limitations

To our knowledge, this study is the first to investigate the associations between various socioeconomic indicators, migration, and social networks concerning YOT2D in a socio-culturally diverse European population. By assessing multiple SES indicators concurrently, we gained insight into the roles of each indicator, as they are not entirely interchangeable. However, several limitations should be noted. The YOT2D outcome was based on self-reported diagnosis and clinical characteristics, which may limit the certainty of T2D classification. Nevertheless, we applied stringent criteria to distinguish T2D from T1D, and any remaining misclassification is expected to be non-differential. There was also a larger proportion of females in our primary analysis. However, our study sample was matched by sex so that our estimates were independent of this distribution. Next, because we utilized cross-sectional baseline data, we cannot ascertain the temporal sequence of events or infer causality. However, some factors, such as educational level and migration background, likely preceded the diagnosis. Additionally, the NAKO cohort may involve selection bias, as the prerequisite German language skills and official residency registration[27] meant that recruited 1st generation migrant participants may experience fewer disadvantages than other migrants.[28] Moreover, the relatively small number of migrant participants and notable proportion of unknown parental diabetes among them warrant cautious interpretation of observed associations between particular origin countries and YOT2D. Finally, the use of prevalence odds ratios may provide higher estimates

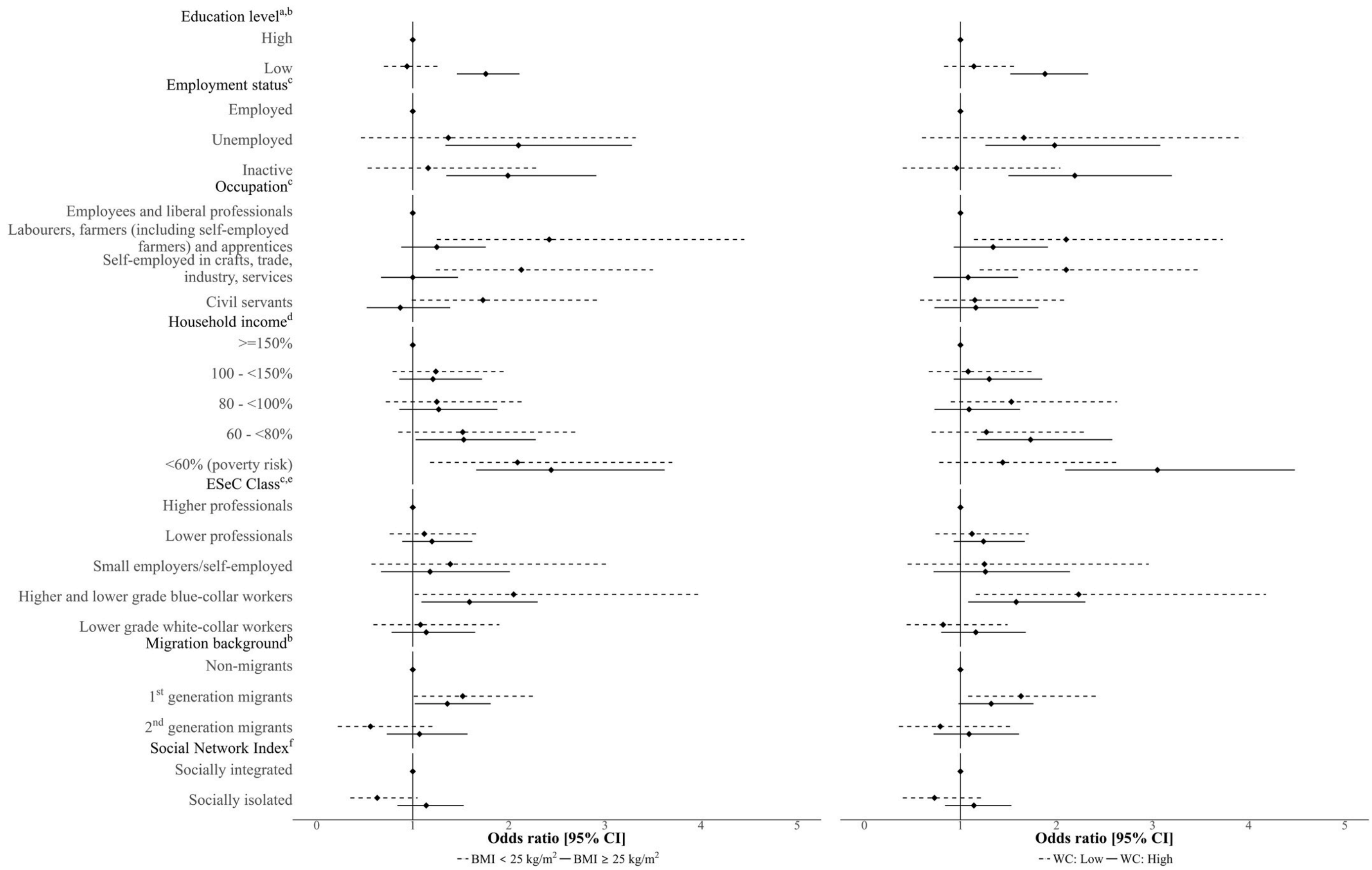

Fig. 2. Multivariable-adjusted odds ratios (ORs) and 95% confidence intervals (CIs) for the association between socioeconomic factors, migration background and social network index and prevalent YOT2D according to BMI status and WC according to IDF criteria.[38] All models adjusted for age, sex, study center, sedentary behavior, smoking and parental diabetes. [a] Low = ISCED 0 –5 and high = ISCED 6 - 8 according to the International Standard Classification of Education 2011 (ISCED 2011).[32] [b] Model mutually adjusted for education and migration background. [c] Model additionally adjusted for education. [d] Household income categorized according to its relative position to the population median based on the European Union Statistics on Income and Living Conditions (EU-SILC).[33] Multivariate model additionally adjusted for education, occupation and migration background. [e] ESeC = European Socioeconomic Classification.[35] [f] Model additionally adjusted for education and migration background. $p_{interaction}$ <0.01 for low education level and high BMI, and $p_{interaction}$ <0.01 and 0.03 for civil servants and self-employed in crafts, trade, industry, services occupation categories and low BMI; $p_{interaction}$ 0.02 for low education level and 0.03 for poverty-risk household income and high WC. YOT2D: young-onset type 2 diabetes; BMI: body mass index; WC: waist circumference.

of association than prevalence ratios, though this is less pronounced in outcomes with low prevalence, such as YOT2D.[57]

4.2. Conclusion

These findings highlight that YOT2D prevalence in a high-income country setting like Germany was associated with socioeconomic disparities and migration history. The exacerbation of metabolic vulnerability in socioeconomically deprived populations further underscores the need for effective public health policy and secondary prevention strategies that prioritize health inequities faced by younger, socioeconomically disadvantaged and diverse populations in high-income countries.

Ethical approval

The German National Cohort (NAKO) study is performed with the approval of the relevant ethics committees, and is in accordance with national law and with the Declaration of Helsinki of 1975 (in the current, revised version). All participants provided written informed consent.

Data sharing statement

The NAKO Study data are available for application at https://nako.de/en/research/.

Author contributions

JT and KA developed the research question. JT prepared the data for analysis, performed the data analysis, and drafted the manuscript. RN, HP and KG contributed to the data preparation and analysis. JT and KA contributed to the interpretation of the data. KA supervised the manuscript writing. All authors except JT, HP, RN and KA were involved in the NAKO study design, funding acquisition, and data collection. All authors revised the manuscript and approved the submitted version.

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Declaration of competing interest

The authors declare no conflict of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.puhe.2026.106425.

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