DSX 19 (2025) 103331

Contents lists available at ScienceDirect

Diabetes & Metabolic Syndrome: Clinical Research & Reviews

journal homepage: www.elsevier.com/locate/dsx

Differential associations between smoking, e-cigarette use, and diabetes prevalence

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ARTICLE INFO

Keywords:
Diabetes
E-cigarettes
Cigarette smoking
Tobacco
Scotland
Cross-sectional study

ABSTRACT

Background: Cigarette smoking is a well-established risk factor for diabetes, but the relationship between e-cigarette use and diabetes remains uncertain. Evidence to date has been drawn almost entirely from North America and Asia, with little information from European populations.

Methods: We conducted a cross-sectional study of 17,854 adults aged 16 years and older from the 2017, 2018, 2019, and 2021 waves of the nationally representative Scottish Health Survey. Diabetes status was based on self-report of doctor-diagnosed diabetes. Participants were classified into six mutually exclusive categories of smoking and e-cigarette use: never users of either cigarettes or e-cigarettes, ex-smokers (former smokers who never used e-cigarettes), current exclusive cigarette smokers, current exclusive e-cigarette users, current dual users, and former e-cigarette users. Weighted prevalence estimates and survey-weighted binary logistic regression models were used to examine associations, adjusting for age group, sex, education, deprivation quintile, ethnicity, alcohol use, physical activity, and hypertension.

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https://doi.org/10.1016/j.dsx.2025.103331
Received 22 October 2025; Received in revised form 17 November 2025; Accepted 20 November 2025
Available online 21 November 2025

Results: Diabetes prevalence was highest among ex-smokers (11.3 %, 95 % CI: 10.1–12.5). Prevalence was 5.7 % (95 % CI: 5.2–6.2) among never users of either cigarettes or e-cigarettes, 6.2 % (95 % CI: 4.9–7.9) among current exclusive cigarette smokers, 4.9 % (95 % CI: 3.4–7.1) among current exclusive e-cigarette users, 8.3 % (95 % CI: 5.8–11.8) among current dual users, and 5.1 % (95 % CI: 4.1–6.3) among former e-cigarette users. In adjusted models, ex-smokers had 35 % higher odds of diabetes compared with never users of either cigarettes or e-cigarettes (OR = 1.35, 95 % CI = 1.14–1.60, $p < 0.001$), whereas current exclusive smokers (OR = 0.78, 95 % CI = 0.58–1.03, p = 0.084), current exclusive e-cigarette users (OR = 0.81, 95 % CI = 0.53–1.22, p = 0.309), current dual users (OR = 1.49, 95 % CI = 0.94–2.38, p = 0.091), and former e-cigarette users (OR = 1.00, 95 % CI = 0.78–1.29, p = 0.973) were not significantly different from never users. Sensitivity analyses restricting ex-smokers to those with ≥5 years since cessation and limiting the sample to adults aged ≥45 years reproduced the same pattern of results.

Conclusions: In this nationally representative study of Scottish adults, excess diabetes prevalence was observed among ex-smokers, a pattern that may reflect both reverse causation if individuals quit smoking after diagnosis and the lasting metabolic effects of cumulative smoking exposure. Neither current nor former e-cigarette use was associated with diabetes, and the observed variation in prevalence appeared linked to smoking history rather than e-cigarette use. However, because vaping is relatively recent, further longitudinal research is needed to clarify any long-term risks.

1. Introduction

Diabetes is a major global public health challenge, contributing to increased morbidity, premature mortality, and growing healthcare costs [1,2]. Worldwide, over 530 million people are estimated to be living with the condition, and prevalence continues to rise across high-income as well as low- and middle-income countries [3]. In the United Kingdom, diabetes poses a particularly pressing problem, with an estimated 4.3 million people currently affected and substantial inequalities in risk across socioeconomic groups [4]. Although both type 1 and type 2 diabetes contribute to this burden, the vast majority of adult cases are type 2, which is strongly influenced by lifestyle and environmental risk factors [5,6]. Cigarette smoking is one such factor: it is an established cause of diabetes, with evidence showing that both current and former smokers are at increased risk compared with never smokers [7–9]. Mechanistically, tobacco smoke promotes chronic inflammation, oxidative stress, and endothelial dysfunction, all of which impair glucose metabolism and insulin sensitivity [10–12]. Importantly, studies also suggest that the excess risk of diabetes persists even after cessation, indicating a lasting legacy of smoking exposure [13].

While the role of cigarette smoking in diabetes development is well established [10,11], far less is known about the association between e-cigarette use and diabetes. E-cigarettes have become increasingly popular in recent years, particularly in the UK, where they are now the most commonly used aid to smoking cessation [14,15]. Proponents argue that e-cigarettes offer a less harmful alternative to combustible tobacco and may reduce the risk of smoking-related disease if smokers switch completely [16–18]. However, concerns remain about their long-term health consequences, particularly because of exposure to nicotine and other constituents that could affect cardiometabolic health [19,20]. Evidence to date on e-cigarettes and metabolic outcomes has been limited and inconsistent [21–23]. Some studies suggest potential improvements in metabolic parameters among smokers who switch [24–26], whereas others highlight possible adverse effects, including increased insulin resistance [27]. Research specifically addressing the relationship between e-cigarette use and diabetes remains sparse, and findings are far from conclusive.

Crucially, the small body of existing research on e-cigarettes and diabetes has been limited to cross-sectional analyses, drawn almost exclusively from the United States and Asia [28–33]. No studies from Europe have directly examined whether diabetes prevalence differs by e-cigarette use, despite the fact that smoking patterns, e-cigarette uptake, and health system contexts differ substantially across regions. This represents a significant gap in the international evidence base, particularly as European countries, including the UK, face a dual challenge of high diabetes burden and evolving patterns of nicotine product use.

In this study, we pooled data from four waves of the Scottish Health Survey (2017, 2018, 2019, and 2021) to investigate whether diabetes prevalence varies according to e-cigarette use status. We compared diabetes prevalence and odds across a comprehensive set of nicotine use categories, accounting for demographic, socioeconomic, behavioural, and clinical factors. By addressing this gap, our analysis contributes new evidence from a European context on the relationship between e-cigarette use and diabetes.

2. Methods

2.1. Study design, data source and study population

This study employed a cross-sectional design using data from the 2017, 2018, 2019, and 2021 waves of the Scottish Health Survey (SHeS). The SHeS is a nationally representative household survey commissioned by the Scottish Government to monitor the health and health-related behaviours of people living in Scotland [34]. It provides key evidence for health policy, trend monitoring, and evaluation of public health interventions. The survey uses a multistage, stratified probability sampling design based on the Postcode Address File to ensure representativeness across age, sex, socioeconomic status, and geography. Each annual wave is independently sampled, making the SHeS a repeated cross-sectional series rather than a longitudinal panel. The 2020 wave was excluded from the present analysis because the COVID-19 pandemic disrupted data collection methods, limiting comparability with other survey years [35].

In total, 25,128 individuals participated in the four survey years included: 5300 in 2017; 6790 in 2018; 6881 in 2019; and 6157 in 2021 [35]. Data collection was conducted through structured, interviewer-administered, computer-assisted personal interviews [34]. For sensitive topics such as smoking, alcohol use, and general health, participants were given the option of self-completing the questionnaire on the same electronic interface to enhance privacy and reporting accuracy. For the present analysis, harmonised End User Licence individual-level datasets were used, which ensured consistency in variable coding across years.

The analytic sample was restricted to adults aged ≥16 years, excluding 7161 children. After also excluding respondents with incomplete information on diabetes status, the final analytic sample comprised 17,854 adults across the four pooled survey waves.

2.2. Diabetes status

The outcome was self-reported, doctor-diagnosed diabetes, excluding gestational diabetes. Diabetes status was derived from the survey question asking participants whether they had ever been told by a doctor that they had diabetes. Response options were “Yes,” “No,” or “Don’t know.” Participants who answered “Don’t know” were excluded from the analysis. For the purposes of this study, diabetes was treated as a binary variable (yes/no), without distinguishing between type 1 and type 2 diabetes, although the majority of cases in adults are expected to be type 2. Self-reported diabetes has been shown to be a valid measure in epidemiological research, with studies reporting high agreement with medical records and practitioner validation (≥92 % reliability and ~95 % confirmation rates) [36–38].

2.3. Smoking and e-cigarette use

The primary exposures were cigarette smoking and e-cigarette use, derived from self-reported questions on current and past use. Using these responses, participants were classified into six mutually exclusive groups.

- Never users: never smoked cigarettes and never used e-cigarettes.
- Ex-smokers only: previously smoked cigarettes but never used e-cigarettes.
- Current exclusive cigarette smokers: currently smoke cigarettes and have never used e-cigarettes.
- Current exclusive e-cigarette users: currently use e-cigarettes but do not currently smoke cigarettes; this group included both never smokers and ex-smokers.
- Current dual users: currently use both cigarettes and e-cigarettes.
- Former e-cigarette users: previously used e-cigarettes but do not currently; this group included never smokers, ex-smokers, and current smokers.

These measures are widely used in national surveillance; however, the survey did not collect detailed information on vaping intensity, nicotine strength, device type or duration of use. Moreover, published validation of the e-cigarette questions is limited.

2.4. Covariates

We adjusted for a set of sociodemographic, behavioural, and clinical factors selected on the basis of prior evidence linking them to both nicotine use and diabetes [28–33]. Sociodemographic variables included age group (16–24, 25–34, 35–44, 45–54, 55–64, 65–74, 75+), sex (male, female), highest educational qualification (degree or higher, HNC/D or equivalent, higher grade or equivalent, standard grade or equivalent, other school level, none), deprivation quintile (Scottish Index of Multiple Deprivation, quintiles 1–5), and ethnicity (White, non-White). Behavioural variables comprised alcohol consumption (never, occasional, monthly–weekly, frequent [≥3 days/week]) and physical activity (low, moderate, meets recommended guidelines). Clinical covariates included hypertension status (doctor-diagnosed yes/no). All covariates were measured through self-report in the Scottish Health Survey. Missing values were retained as separate categories where relevant to preserve sample size. These covariates were included to account for demographic, socioeconomic, lifestyle, and clinical factors that may confound the association between nicotine use and diabetes.

2.5. Statistical analysis

All analyses accounted for the complex, multistage design of the Scottish Health Survey. We pooled the 2017, 2018, 2019, and 2021 adult survey waves and applied the individual survey person weights provided with each wave. Primary sampling units (PSUs) and strata were specified, and variances were estimated using Taylor series linearization, the default method for complex survey analysis. Weighted estimates therefore represent the non-institutionalised adult population of Scotland in the included years.

We first described the distribution of characteristics by e-cigarette use status. These descriptive statistics were presented as unweighted counts and percentages to show the sample composition. Differences across groups were tested using χ^2 tests adjusted for the survey design.

Next, we estimated the weighted prevalence of diabetes across the six mutually exclusive smoking/vaping groups, with 95 % confidence intervals derived from survey-weighted procedures. Binary logistic regression models were then fitted to examine the association between smoking/vaping group and diabetes prevalence. We report odds ratios (ORs) and 95 % CIs from (i) unadjusted models and (ii) models adjusted for age group, sex, education, deprivation quintile, ethnicity, alcohol use, physical activity, and hypertension. The reference group in all models was never users (never smoked and never used e-cigarettes).

To further assess heterogeneity, we compared strata of current and former e-cigarette users by smoking history (never smoker, ex-smoker, current smoker), using never users of either product as the reference group and retaining them in the model.

Two prespecified sensitivity analyses were performed. First, the “ex-smoker only” category was restricted to individuals who had quit smoking ≥5 years prior to participation, in order to assess whether recency of quitting explained the observed association. Second, analyses were restricted to adults aged ≥45 years, the age group in which diabetes is most prevalent, to examine whether associations were consistent in this higher-risk population.

Missing values for covariates were retained as separate categories, ensuring that the analytic sample remained consistent across models. Outcome and exposure variables were complete after exclusions noted in the study population. For all logistic regression models we examined multicollinearity, overall model fit, and the influence of individual observations. All exposure and covariates were entered as categorical variables, so the assumption of linearity of continuous predictors in the logit did not apply. Multicollinearity was evaluated using variance inflation factors, which did not indicate any concerning collinearity. Overall model fit was assessed using survey-weighted goodness-of-fit statistics and pseudo R^2 measures, and inspection of influence statistics did not identify observations that materially altered the results. All tests were two-sided with a significance threshold of $\alpha = 0.05$, and no adjustments were made for multiple comparisons. Analyses were conducted in Stata version 18.

3. Results

Table 1 presents the characteristics of the study population by e-cigarette use status. Current and former e-cigarette users tended to be younger than never users, and both groups were more concentrated in the middle age bands. Females were slightly less represented among current and former e-cigarette users than among never users. Current and former e-cigarette users were marginally more likely to be White than never users. Never e-cigarette users were more likely to have degree-level qualifications and to live in less deprived areas, whereas current and former e-cigarette users were more often found in more deprived areas and had lower levels of formal education. Never e-cigarette users were predominantly never smokers or ex-smokers, while current and former e-cigarette users were much more likely to be current or ex-smokers. Alcohol use was common in all groups, with only small differences in drinking patterns. Current e-cigarette users were slightly more likely to report low physical activity than former or never users, and both current and former e-cigarette users were less likely to report hypertension than never e-cigarette users.

Fig. 1 shows the weighted prevalence of diabetes across smoking and vaping groups. Diabetes prevalence was lowest among current exclusive

Table 1
Characteristics of the study population by e-cigarette use status (N = 17,854).

Characteristic	Current e-cigarette users (n = 1116)	Former e-cigarette users (n = 1746)	Never e-cigarette users (n = 14,992)	Total (n = 17,854)	p-value
Age group, n (%)					<0.001
16–24	72 (6.5)	226 (12.9)	912 (6.1)	1210 (6.8)	
25–34	180 (16.1)	362 (20.7)	1637 (10.9)	2179 (12.2)	
35–44	204 (18.3)	314 (18.0)	1987 (13.3)	2505 (14.0)	
45–54	273 (24.5)	336 (19.2)	2421 (16.2)	3030 (17.0)	
55–64	230 (20.6)	281 (16.1)	2934 (19.6)	3445 (19.3)	
65–74	133 (11.9)	175 (10.0)	3003 (20.0)	3311 (18.5)	
75+	24 (2.2)	52 (3.0)	2098 (14.0)	2174 (12.2)	
Sex, n (%)					0.020
Male	495 (44.4)	805 (46.1)	6409 (42.8)	7709 (43.2)	
Female	621 (55.7)	941 (53.9)	8583 (57.3)	10,145 (56.8)	
Education, n (%)					<0.001
Degree or higher	250 (22.4)	395 (22.6)	6011 (40.1)	6656 (37.3)	
HNC/D or equivalent	184 (16.5)	254 (14.6)	1768 (11.8)	2206 (12.4)	
Higher grade/equivalent	162 (14.5)	313 (17.9)	2129 (14.2)	2604 (14.6)	
Standard grade/equiv.	272 (24.4)	397 (22.7)	2105 (14.0)	2774 (15.5)	
Other school level	50 (4.5)	55 (3.1)	800 (5.3)	905 (5.1)	
No qualifications	198 (17.7)	332 (19.0)	2179 (14.5)	2709 (15.2)	
Deprivation quintile, n (%)					<0.001
Most deprived	308 (27.6)	447 (25.6)	2074 (13.8)	2829 (15.9)	
2	304 (27.2)	452 (25.9)	2692 (18.0)	3448 (19.3)	
3	219 (19.6)	362 (20.7)	3202 (21.4)	3783 (21.2)	
4	156 (14.0)	289 (16.6)	3587 (23.9)	4032 (22.6)	
Least deprived	129 (11.6)	196 (11.2)	3437 (22.9)	3762 (21.1)	
Ethnicity, n (%)					<0.001
White	1104 (98.9)	1694 (97.0)	14,438 (96.3)	17,236 (96.5)	
Non-White	12 (1.1)	52 (3.0)	554 (3.7)	618 (3.5)	
Smoking status, n (%)					<0.001
Never	68 (6.1)	212 (12.1)	10,229 (68.2)	10,509 (58.9)	
Ex-smoker	620 (55.6)	388 (22.2)	3639 (24.3)	4647 (26.0)	
Current smoker	428 (38.3)	1146 (65.6)	1124 (7.5)	2698 (15.1)	
Alcohol use, n (%)					<0.001
Never	182 (16.3)	278 (15.9)	2589 (17.3)	3049 (17.1)	
Occasional (<monthly)	116 (10.4)	171 (9.8)	1295 (8.6)	1582 (8.9)	
Monthly–Weekly	282 (25.3)	470 (26.9)	3402 (22.7)	4154 (23.3)	
Frequent (3+ days/week)	536 (48.0)	827 (47.4)	7706 (51.4)	9069 (50.8)	
Physical activity, n (%)					0.013
Low	326 (29.2)	444 (25.4)	4110 (27.4)	4880 (27.3)	
Moderate	139 (12.5)	189 (10.8)	1597 (10.7)	1925 (10.8)	
Meets recommended	643 (57.6)	1098 (62.9)	9217 (61.5)	10,958 (61.4)	
Unknown/missing	8 (0.7)	15 (0.9)	68 (0.5)	91 (0.5)	
Hypertension, n (%)					<0.001
No condition	1065 (95.4)	1671 (95.7)	13,644 (91.0)	16,380 (91.7)	
Has condition	51 (4.6)	75 (4.3)	1348 (9.0)	1474 (8.3)	
Diabetes, n (%)					0.124
No condition	1043 (93.5)	1634 (93.6)	13,860 (92.5)	16,537 (92.6)	
Has condition	73 (6.5)	112 (6.4)	1132 (7.5)	1317 (7.4)	

Current e-cigarette users (n = 1116) include both exclusive e-cigarette users and dual users who also currently smoke cigarettes. Former e-cigarette users (n = 1746) are past e-cigarette users regardless of smoking history. Never e-cigarette users (n = 14,992) include individuals who never used e-cigarettes; this group comprises never users of any nicotine product, ex-smokers only, and current exclusive cigarette smokers.

e-cigarette users (4.9 %, 95 % CI: 3.4–7.1) and former e-cigarette users (5.1 %, 95 % CI: 4.1–6.3), closely comparable to never users of either product (5.7 %, 95 % CI: 5.2–6.2). In contrast, ex-smokers had the highest prevalence (11.3 %, 95 % CI: 10.1–12.5), nearly double that observed in never users. Current exclusive cigarette smokers had a prevalence of 6.2 % (95 % CI: 4.9–7.9), only slightly above that of never users. Dual users of cigarettes and e-cigarettes exhibited an intermediate prevalence of 8.3 % (95 % CI: 5.8–11.8). The overall weighted prevalence of diabetes in our survey sample is 6.7 % (95 % CI: 6.3 %–7.1 %).

Table 2 presents crude and adjusted odds ratios for diabetes by smoking and vaping status. In crude models, ex-smokers had more than double the odds of diabetes compared with never users (OR 2.11, 95 % CI: 1.81–2.46, $p < 0.001$). This association was attenuated but remained significant after adjustment for age group, sex, education, deprivation quintile, ethnicity, alcohol use, physical activity, and hypertension (adjusted OR 1.35, 95 % CI: 1.14–1.60, $p < 0.001$). Current exclusive cigarette smokers did not differ significantly from never users in crude models (OR 1.11, 95 % CI: 0.84–1.45, p = 0.465) and showed a nonsignificant trend toward lower odds after adjustment (adjusted OR 0.78, 95 % CI: 0.58–1.03, p = 0.084). Similarly, current exclusive e-cigarette users had no elevated odds in crude (OR 0.86, 95 % CI: 0.58–1.28, p = 0.468) or adjusted models (adjusted OR 0.81, 95 % CI: 0.53–1.22, p = 0.309). Dual users exhibited significantly higher crude odds of diabetes compared with never users (OR 1.51, 95 % CI: 1.01–2.25, p = 0.046), although this association was attenuated and no longer significant after adjustment (adjusted OR 1.49, 95 % CI: 0.94–2.38, p = 0.091). Former e-cigarette users showed no difference in diabetes odds compared with never users in either crude (OR 0.89, 95 % CI: 0.70–1.14, p = 0.351) or adjusted models (adjusted OR 1.00, 95 % CI: 0.78–1.29, p = 0.973).

Table 3 examines the association between diabetes and smoking history among current and former e-cigarette users. Compared with never users of any nicotine product, current exclusive e-cigarette users who had never smoked cigarettes had markedly lower crude odds of

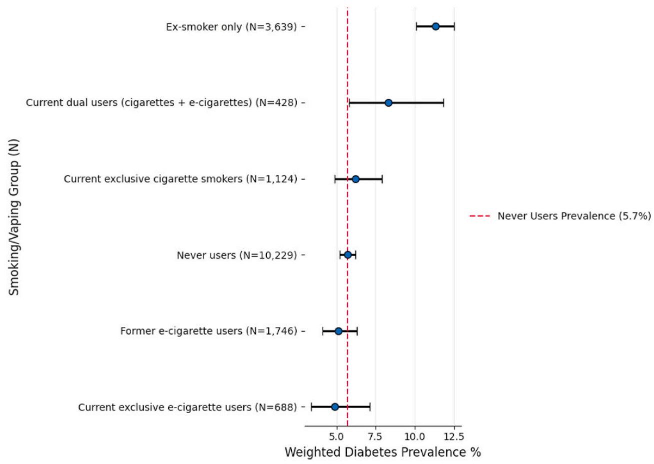

Fig. 1. Weighted prevalence of diabetes by smoking/vaping group (N = 17,854)
Values represent the weighted prevalence of diabetes within each smoking/vaping group, with 95 % confidence intervals derived from survey-weighted estimates. N = unweighted sample size.

diabetes (OR 0.24, 95 % CI: 0.05–1.25, p = 0.090), though this association was not statistically significant after adjustment (adjusted OR 0.45, 95 % CI: 0.08–2.50, p = 0.363). Similarly, current exclusive e-cigarette users who were ex-smokers did not differ significantly from never users in crude (OR 0.95, 95 % CI: 0.64–1.43, p = 0.816) or adjusted analyses (adjusted OR 0.82, 95 % CI: 0.53–1.26, p = 0.362). Former e-cigarette users who had never smoked showed significantly lower crude odds of diabetes (OR 0.17, 95 % CI: 0.06–0.53, p = 0.002), but this association was no longer evident after covariate adjustment (adjusted OR 0.67, 95 % CI: 0.21–2.19, p = 0.509). Neither former e-cigarette users who were ex-smokers (adjusted OR 1.22, 95 % CI: 0.77–1.93, p = 0.394) nor those who continued to smoke cigarettes (adjusted OR 0.92, 95 % CI: 0.68–1.24, p = 0.582) differed from never users.

Table 4
Adjusted odds of diabetes among ex-smokers, excluding recent quitters (<5 years since cessation).

Nicotine use group	N	Adjusted OR (95 % CI)	p-value
Never users (neither cigarettes nor e-cigarettes)	10,229	1.00 (ref)	–
Ex-smokers only (all)	3639	1.35 (1.14–1.60)	<0.001
Ex-smokers only (≥5 years since cessation)	2034	1.28 (1.06–1.55)	0.009

Adjusted for age group, sex, education, deprivation quintile, ethnicity, alcohol use, physical activity and hypertension.
The "Ex-smokers only (all)" and "Ex-smokers only (≥5 years since cessation)" rows are from separate models, both using never users as the reference group.

Sensitivity analysis

Table 4 presents a sensitivity analysis excluding recent quitters to assess whether the association between smoking cessation and diabetes was driven by reverse causality. Compared with never users, ex-smokers overall had significantly higher odds of diabetes (adjusted OR 1.35, 95 % CI: 1.14–1.60, p < 0.001). When restricting the analysis to those who had quit smoking at least five years earlier, the association persisted, although it was modestly attenuated (adjusted OR 1.28, 95 % CI: 1.06–1.55, p = 0.009).

Table 5 shows adjusted associations between smoking/vaping status and diabetes among adults aged 45 years and older, the age group at greatest risk of developing diabetes. Compared with never users, ex-smokers continued to exhibit significantly higher odds of diabetes (adjusted OR 1.42, 95 % CI: 1.20–1.68, p < 0.001). In contrast, current exclusive cigarette smokers (adjusted OR 0.75, 95 % CI: 0.56–1.02, p = 0.064) and current exclusive e-cigarette users (adjusted OR 0.70, 95 % CI: 0.44–1.10, p = 0.120) both showed nonsignificant trends toward lower odds. Dual users of cigarettes and e-cigarettes (adjusted OR 1.19,

Table 2
Crude and adjusted odds ratios for diabetes by smoking and vaping status (N = 17,854).

Nicotine use group	N	Crude OR (95 % CI), p-value	Adjusted OR (95 % CI), p-value[a]
Never users (neither cigarettes nor e-cigarettes)	10,229	1.00 (ref)	1.00 (ref)
Ex-smokers only	3639	2.11 (1.81–2.46), <0.001	1.35 (1.14–1.60), <0.001
Current exclusive cigarette smokers	1124	1.11 (0.84–1.45), 0.465	0.78 (0.58–1.03), 0.084
Current exclusive e-cigarette users	688	0.86 (0.58–1.28), 0.468	0.81 (0.53–1.22), 0.309
Current dual users (cigarettes + e-cigarettes)	428	1.51 (1.01–2.25), 0.046	1.49 (0.94–2.38), 0.091
Former e-cigarette users	1746	0.89 (0.70–1.14), 0.351	1.00 (0.78–1.29), 0.973

Never user: never smoked cigarettes and never used e-cigarettes. Ex-smoker only: formerly smoked cigarettes, never used e-cigarettes. Current exclusive cigarette smoker: currently smokes cigarettes, does not use e-cigarettes. Current exclusive e-cigarette user: currently uses e-cigarettes, does not smoke cigarettes. Current dual user: currently smokes cigarettes and uses e-cigarettes. Former e-cigarette user: previously used e-cigarettes, but does not currently; this group includes never smokers, ex-smokers, and current smokers.
[a] Adjusted for age group, sex, education, deprivation quintile, ethnicity, alcohol use, physical activity, and hypertension.

Table 3
Crude and adjusted odds of diabetes by smoking history among current and former e-cigarette users (N = 12,663).

Nicotine use group	N	Crude OR (95 % CI), p-value	Adjusted OR (95 % CI), p-value[a]
Never users (neither cigarettes nor e-cigarettes)	10,229	1.00 (ref)	1.00 (ref)
Current exclusive e-cigarette users: never smoker	68	0.24 (0.05–1.25), 0.090	0.45 (0.08–2.50), 0.363
Current exclusive e-cigarette users: ex-smoker	620	0.95 (0.64–1.43), 0.816	0.82 (0.53–1.26), 0.362
Former e-cigarette users: never smoker	212	0.17 (0.06–0.53), 0.002	0.67 (0.21–2.19), 0.509
Former e-cigarette users: ex-smoker	388	1.08 (0.69–1.68), 0.730	1.22 (0.77–1.93), 0.394
Former e-cigarette users: current smoker	1146	1.02 (0.77–1.35), 0.915	0.92 (0.68–1.24), 0.582

Never user: never smoked cigarettes and never used e-cigarettes. Current exclusive e-cigarette user, never smoker: currently uses e-cigarettes and has never smoked cigarettes. Current exclusive e-cigarette user, ex-smoker: currently uses e-cigarettes and is a former cigarette smoker. Former e-cigarette user, never smoker: previously used e-cigarettes but has never smoked cigarettes. Former e-cigarette user, ex-smoker: previously used e-cigarettes and is a former cigarette smoker. Former e-cigarette user, current smoker: currently smokes cigarettes and previously used e-cigarettes, but no longer vapes.
[a] Adjusted for age group, sex, education, deprivation quintile, ethnicity, alcohol use, physical activity, and hypertension.

Table 5
Adjusted odds of diabetes by smoking/vaping group among adults aged ≥45 years (N = 11,960).

Nicotine use group	N	Adjusted OR (95 % CI)	p-value
Never users (neither cigarettes nor e-cigarettes)	6656	1.00 (ref)	–
Ex-smokers only	3081	1.42 (1.20–1.68)	<0.001
Current exclusive cigarette smokers	719	0.75 (0.56–1.02)	0.064
Current exclusive e-cigarette users	415	0.70 (0.44–1.10)	0.120
Current dual users (cigarettes + e-cigarettes)	245	1.19 (0.78–1.81)	0.428
Former e-cigarette users	844	1.01 (0.77–1.31)	0.961

Adjusted for age group, sex, education, deprivation quintile, ethnicity, alcohol use, physical activity and hypertension.

95 % CI: 0.78–1.81, p = 0.428) and former e-cigarette users (adjusted OR 1.01, 95 % CI: 0.77–1.31, p = 0.961) did not differ from never users.

4. Discussion

In this large, nationally representative study of adults in Scotland, diabetes prevalence differed across smoking and e-cigarette use groups. The excess burden was concentrated among ex-smokers, who had substantially higher odds of diabetes compared with never users, even after adjustment for demographic, socioeconomic, behavioural, and clinical characteristics. By contrast, current exclusive cigarette smokers and current exclusive e-cigarette users did not have statistically significantly higher odds of diabetes, and former e-cigarette users were indistinguishable from never users. Dual users of cigarettes and e-cigarettes displayed elevated crude odds of diabetes, but this association was no longer statistically significant following adjustment, suggesting that differences in age, socioeconomic status, and related factors accounted for much of the crude variation.

Stratified analyses further indicated that among current and former e-cigarette users, observed variation in diabetes prevalence was primarily attributable to smoking history rather than vaping. These findings are consistent with U.S. evidence from NHANES, which reported no independent association between current e-cigarette use and diabetes or prediabetes [28]. They also align with analyses of BRFSS data, which found that sole e-cigarette use was not significantly associated with diabetes but was linked to greater odds of prediabetes [30]. Orimoloye et al. conducted parallel animal and human analyses and found that neither experimental e-cigarette exposure in mice nor sole e-cigarette use in U.S. adults was associated with insulin resistance after adjustment [39]. Together, the Scottish data add European evidence to a growing body of studies indicating that exclusive e-cigarette use is not linked to excess diabetes prevalence, though questions remain about possible associations with subclinical outcomes such as insulin resistance, and it is important to recognise that the observational timeframe for vaping is considerably shorter than for smoking at the time of this analysis.

The sensitivity analyses supported these results. Restricting the ex-smoker category to individuals who had quit smoking at least five years earlier reduced the magnitude of the association with diabetes, but the odds remained significantly higher compared with never users. This pattern is consistent with longstanding evidence that diabetes risk remains elevated for many years after smoking cessation, even though it diminishes over time. Age-restricted analyses yielded similar results: ex-smokers had higher odds of diabetes, whereas current smokers, exclusive e-cigarette users, dual users, and former e-cigarette users did not differ significantly from never users. These findings contrast somewhat with recent U.S. studies that identified higher odds of prediabetes among e-cigarette users [29,40] and with NHANES analyses suggesting greater insulin resistance among former e-cigarette users who previously smoked [28]. A review of metabolic outcomes also reported inconsistent associations between e-cigarette use and glucose regulation, blood pressure, and adiposity [21]. The absence of a significant association in the present analysis may reflect differences in population characteristics, device types, usage intensity, or healthcare systems across settings. Nevertheless, the consistency across multiple sensitivity checks in this study reinforces the conclusion that smoking history, rather than e-cigarette use, is currently the dominant factor linked with diabetes prevalence.

The observation that ex-smokers, but not current smokers, had elevated odds of diabetes is also in line with epidemiological expectations. Although current exclusive smokers showed slightly lower odds of diabetes, this finding was not statistically significant and is unlikely to reflect a protective effect. Instead, it likely reflects the combined influence of age structure, reverse causation, and selection effects: current smokers in cross-sectional surveys tend to be younger, individuals diagnosed with diabetes are often advised to quit smoking (inflating the ex-smoker category), and those who continue smoking may represent a healthier subset without diagnosed metabolic disease. These processes help reconcile our cross-sectional findings with prospective evidence demonstrating that smoking increases the risk of incident diabetes [8,9]. Biologically, smoking is associated with systemic inflammation, oxidative stress, and impaired pancreatic β-cell function [41], which together contribute to insulin resistance and subsequent diabetes onset after sustained exposure [10–12]. By contrast, neither current nor former e-cigarette users showed higher odds of diabetes in this analysis. While nicotine can induce short-term insulin resistance [42,43], e-cigarettes contain substantially fewer toxicants than combustible tobacco, particularly those implicated in chronic inflammation and endothelial dysfunction [44]. This reduced toxicant exposure, alongside a shorter duration of use compared to smoking, may contribute to the absence of an observable association between e-cigarette use and diabetes in the present data.

The results carry several implications for public health. The findings underline the importance of preventing smoking initiation, given that elevated diabetes prevalence was most pronounced among ex-smokers, suggesting a lasting legacy of prior combustible tobacco exposure. The absence of an association between e-cigarette use and diabetes prevalence in this representative European sample is notable. Although causality cannot be inferred, the findings suggest that exclusive e-cigarette use does not add to the diabetes burden beyond that linked with smoking history at the time of this analysis. This may provide some reassurance in the harm reduction debate, indicating that switching from cigarettes to e-cigarettes is not associated with higher diabetes prevalence. However, the wide confidence intervals observed in smaller subgroups highlight the need for larger studies, and only longitudinal data can clarify whether long-term e-cigarette use is linked to incident diabetes. These wider intervals indicate reduced statistical precision in the exclusive e-cigarette and dual-use groups, meaning that modest associations cannot be ruled out despite null point estimates, and reinforcing that the findings for these subgroups should be interpreted with caution. Importantly, these results also highlight the necessity of accounting for smoking history when examining e-cigarette use and health outcomes; failure to do so risks attributing the consequences of past smoking to vaping [45,46].

This study has notable strengths and limitations. Strengths include the use of four recent, nationally representative surveys pooled to provide adequate statistical power, and the ability to classify nicotine use into exclusive smoking, exclusive vaping, dual use, and former use categories. The survey data included detailed sociodemographic, behavioural, and clinical measures, allowing for robust adjustment, and the analysis incorporated prespecified sensitivity checks that confirmed the main findings.

Limitations include the cross-sectional design, which prevents establishing temporality and therefore precludes causal inference [47]. This also raises the possibility of reverse causation, particularly among ex-smokers who may have quit smoking after a diabetes diagnosis, inflating diabetes prevalence in this group. Because exposure and outcome were measured at the same time, it is not possible to determine whether nicotine-use patterns preceded or followed diabetes. Diabetes was self-reported and not clinically verified, and the survey did not distinguish between type 1 and type 2, although most cases in adults are likely to be type 2. Residual confounding remains possible, especially from unmeasured factors such as BMI/obesity, dietary patterns, and family history of diabetes, which could influence both nicotine use trajectories and diabetes risk. In addition, the survey did not capture heterogeneity in e-cigarette use, including device type, nicotine concentration, intensity or frequency of use, duration of vaping, or switching and relapse patterns. This limited granularity may result in exposure misclassification and obscure differences between vaping behaviours. Finally, although the overall sample was large, numbers in the exclusive e-cigarette and dual-use groups were small, leading to wide confidence intervals for these estimates.

Future research should prioritise longitudinal studies that can establish temporality and investigate whether e-cigarette use is associated with incident diabetes, with adequate control for overweight and obesity, which are major determinants of diabetes risk. Prospective European cohorts are particularly needed, as existing evidence is drawn almost entirely from cross-sectional studies conducted in U.S. populations. Future work should also distinguish exclusive e-cigarette use from dual use and smoking cessation pathways, while incorporating measures of use intensity, device type, and duration of exposure. The inclusion of objective biomarkers of metabolic health, such as insulin resistance, glucose tolerance, and adiposity, alongside self-reported diagnoses, would provide deeper insight into potential subclinical effects. Integrating biological and epidemiological approaches will be essential to determine whether any long-term metabolic consequences are attributable to e-cigarette use itself or are instead the residual effects of prior combustible tobacco smoking.

5. Conclusion

In this nationally representative study of adults in Scotland, adjusted analyses showed higher odds of diabetes among ex-smokers (former cigarette smokers who never used e-cigarettes), but not among current smokers, exclusive e-cigarette users, dual users, or former e-cigarette users, when each group was compared with adults who had never used either cigarettes or e-cigarettes. Sensitivity analyses confirmed that these associations were robust to smoking duration and age restrictions, suggesting that the excess burden of diabetes in this population is primarily associated with past smoking rather than e-cigarette use. Future longitudinal studies are needed to establish temporality, disentangle the metabolic consequences of different nicotine use trajectories while controlling for overweight and obesity, and clarify whether long-term e-cigarette use carries risks distinct from those of combustible tobacco.

Ethics approval

This was a secondary analysis of publicly available, anonymized data. No ethical approval was sought. To download the dataset used in the analyses, please visit https://ukdataservice.ac.uk/find-data/browse/health/

CRediT authorship contribution statement

Yusuff Adebayo Adebisi: Conceptualization, Investigation, Methodology, Formal analysis, Data curation, Writing – original draft, Writing – review & editing, Visualization, Project administration, Supervision. Chimwemwe Ngoma: Conceptualization, Writing – review & editing. Davide Campagna: Conceptualization, Writing – review & editing. Antonio Ceriello: Writing – review & editing, Validation. Najim Z. Alshahrani: Conceptualization, Writing – review & editing. Anoop Misra: Writing – review & editing, Validation. Abdul Basit: Writing – review & editing. Cristina Russo: Writing – review & editing. Tadej Battelino: Writing – review & editing. Noel Somasundaram: Writing – review & editing. Muhammad Yazid Jalaludin: Writing – review & editing. Phuong Le Dinh: Writing – review & editing. Yoshifumi Saisho: Writing – review & editing. Magdalena Walicka: Writing – review & editing. Venera Tomaselli: Writing – review & editing. Giulio Cantone: Writing – review & editing. Othmar Moser: Writing – review & editing, Visualization. Riccardo Polosa: Conceptualization, Supervision, Writing – review & editing.

Human and animal rights and informed consent

As this study involved secondary data analysis, no ethical approval or informed consent was required by the authors for this research, as it qualifies for exemption from human subjects research.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. The open-access publication fee was covered by the University of Glasgow through their agreement with Elsevier.

Declaration of Competing interest

Yusuff Adebayo Adebisi has previously received funding through the Tobacco Harm Reduction Scholarship and the Kevin Molloy Fellowship, both awarded by Knowledge-Action-Change (KAC), an independent public health organization based in the UK that is funded by Global Action to End Smoking (GA), an independent US non-profit 501(c) (3) grant-making organization. Chimwemwe Ngoma is a consultant to KAC. Magdalena Walicka has received honoraria for lectures from Sanofi, AstraZeneca, Teva, and Eli Lilly, and has received support for attending meetings from Sanofi, Novo Nordisk, and Berlin Chemie. Othmar Moser received clinical trial support from Sêr Cymru II COFUND Fellowship/ European Union, Novo Nordisk A/S, Novo Nordisk AT, Abbott Diabetes Care, Sanofi, Dexcom, Team Novo Nordisk, SAIL, Maisel's Brauerei, Medtronic AT, EFSD/EASD, Falke, Federal Institute of Sport Science (BISp), Perfood, Ypsomed, and Sinocare. He received presenters' honoraria from Medtronic AT, Medtronic Int., Eli Lilly, Novo Nordisk, Sanofi, TAD Pharma, ADA, Diatec, Berufsverband Deutscher Internist*innen, Dexcom, AstraZeneca, Ypsomed, Insulet, Diabetologen Hessen, and Abbott Diabetes Care. He received conference travel support from Novo Nordisk A/S, Novo Nordisk AT, Novo Nordisk UK, Medtronic AT, Sanofi, EASD, OEDG, and DDG. He is a member of the advisory board of Sanofi, TAD Pharma, Dexcom, Perfood, and Medtronic. Riccardo Polosa is a full tenured Professor of Internal Medicine at the University of Catania (Italy) and Medical Director of the Institute for Internal Medicine and Clinical Immunology at the same university. He has received grants from multiple public, private, and non-profit sources, including U-BIOPRED, AIR-PROM, Integral Rheumatology & Immunology Specialists Network (IRIS), the Foundation for a Global Action to End Smoking, Pfizer, GlaxoSmithKline, CV Therapeutics, NeuroSearch A/S, Sandoz, Merk Sharp & Dohme, Boehringer Ingelheim, Novartis, Arbi Group Srl., Duska Therapeutics, Forest Laboratories, and from ministerial grants funded by NextGenerationEU of the European Union. He is the founder of the Center for Tobacco Prevention and Treatment (CPCT) and the Center of Excellence for the Acceleration of Harm Reduction (CoEHAR) at the University of Catania. He has received consultancy fees from Pfizer, Boehringer Ingelheim, Duska Therapeutics, Forest Laboratories, CV Therapeutics, Sermo Inc., GRG Health, Clarivate Analytics, Guidepoint Expert Network, and GLG Group, receives textbook royalties from Elsevier, and is involved in a patent application for ECLAT Srl. He serves as a pro bono scientific advisor for Lega Italiana Anti Fumo (LIAF) and the International Network of Nicotine Consumers Organizations (INNCO), is Chair of the European Technical Committee for Standardization on "Requirements and test methods for emissions of electronic cigarettes" (CEN/TC 437; WG4), and is scientific advisor of the non-profit Foundation RIDE2Med. All other authors declare no conflicts of interest.

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