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RESEARCH ARTICLE

Prevalence of Alzheimer's Disease and Cardiometabolic Multimorbidity in Older Adults Aged 60 and above in a Large-Scale Representative Sample in Türkiye: A Nationwide Population-Based Cross-Sectional Study

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Abstract

Background It is a well-established fact that Alzheimer's Disease (AD) is a growing public health challenge worldwide, with increasing prevalence among older adults. Cardiometabolic multimorbidity (CMM) and various sociodemographic and lifestyle factors are acknowledged to influence AD risk. This study aimed to estimate the prevalence of AD and investigate its association with CMM and related sociodemographic and behavioral factors in older adults aged 60 years and above in Türkiye.

Method This study was conducted using secondary data obtained from the Türkiye Health Survey, provided by the Turkish Statistical Institute (TÜİK). Data were derived from 4630 individuals (weighted sample of 11,331,239) aged 60 years and older. AD prevalence, CMM (hypertension, coronary heart disease, stroke, diabetes, hyperlipidemia), and relevant covariates were evaluated. Multivariable binary logistic regression models were used to identify independent predictors of AD.

Results The overall prevalence of AD was 3.8% (95% CI: 3.6–4.9%), slightly higher in females (4.1%, 95% CI: 3.8–5.7%) than males (3.5%, 95% CI: 2.8–4.7%). AD was more common among individuals who were single/divorced (6.4%), had lower education (4.1%), presented with CMM (5.9%), or led sedentary lifestyles (4.9%). In the model adjusted for age, sex, educational status, and marital status, the presence of CMM was significantly associated with increased odds of AD (aOR = 2.081; 95% CI: 1.522–2.844). In the further adjusted model for BMI, tobacco use, alcohol use, and activity during the day, CMM remained a significant predictor of AD (aOR = 1.975, 95% CI: 1.446–2.698).

Conclusions This large-scale study highlights a substantial burden of AD among older adults in Türkiye, strongly linked to CMM and modifiable social and behavioral factors. The findings of this study highlight the importance of integrated prevention strategies targeting vascular health, education, social support, and physical activity to reduce AD risk.

Keywords Alzheimer's disease · Cardiometabolic multimorbidity · Older adults · Risk factors · Population-based

1 Introduction

As populations age worldwide, the prevalence of dementia is rising to unprecedented levels [1, 2]. Alzheimer's disease (AD) is the most common cause of dementia, accounting for roughly 60–70% of cases [3, 4]. Dementia -predominantly due to AD- has become the seventh leading cause of death globally and was associated with approximately US$1.3 trillion in health expenditures in 2019 [5]. In the absence of disease-modifying treatments, the number of people living with dementia is projected to increase from about 57 million in 2019 to 153 million by 2050, with the fastest growth expected in rapidly aging regions such as North Africa and

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the Middle East [1]. Türkiye exemplifies this demographic trend: its population aged 65 years and above grew by 22.5% between 2015 and 2020 [5], and the number of people living with dementia in Türkiye is forecast to rise from ~0.8 million in 2019 to over 3.0 million by 2050 (a 277% increase) [1].

Cardiometabolic multimorbidity (CMM)– the co-occurrence of two or more cardiovascular or metabolic diseases in one individual– is another emerging challenge in aging populations [6–8]. Common components of CMM include hypertension, coronary heart disease, stroke, and diabetes mellitus, which are increasingly seen together in older adults [6]. The prevalence of such multimorbidity escalates with age; for example, an analysis reported that roughly half of people aged 60 years or older live with two or more chronic conditions [9]. This pattern of multiple cardiometabolic diseases poses a serious burden on clinical care and public health, as patients with CMM often experience higher disability and complex healthcare needs [6, 8]. Indeed, rising life expectancy means that more individuals are living longer with chronic cardiometabolic diseases, making CMM a major global health challenge for healthcare systems [6].

There is a growing body of evidence linking cardiometabolic health to late-life cognitive outcomes. Epidemiological studies have identified midlife hypertension, diabetes, stroke, and other cardiometabolic disorders as modifiable risk factors for cognitive impairment and dementia [1, 10]. Moreover, the coexistence of multiple cardiometabolic conditions appears to have an additive detrimental effect on brain health [11, 12]. In a recent multicohort study spanning several countries, individuals with two or more cardiometabolic diseases showed significantly accelerated cognitive decline compared to those with no cardiometabolic disease [11]. Likewise, a longitudinal study in Sweden reported that having at least two cardiometabolic conditions was associated with more than double the hazard of developing dementia relative to having none. These findings underscore that CMM may compound the risk of cognitive impairment and AD, highlighting the importance of integrated management of vascular and metabolic health to potentially mitigate dementia risk [10].

Despite the global relevance of this issue, data on AD and multimorbidity in the Turkish older population remain limited. Most estimates of dementia prevalence in Türkiye have come from localized studies with relatively small samples, yielding widely varying results [5]. For instance, prior community-based studies in different regions reported prevalence rates of late-life dementia ranging from under 10% to over 20%, with substantial discrepancies likely due to methodological and regional differences [5, 13, 14]. Overall, there is a lack of comprehensive, nationwide information on the burden of AD and its relationship with cardiometabolic conditions in Türkiye. Furthermore, the intersection of CMM and AD, and cognitive aging has been under-investigated in low- and middle-income countries, creating a knowledge gap in contexts like Türkiye. In light of the rapid demographic aging and rising burden of chronic disease in Türkiye, a clearer understanding of how AD prevalence interrelates with CMM is critically needed. Therefore, the present study aimed to investigate the prevalence of AD and CMM among Turkish adults aged 60 years and older and to identify the associated factors. By providing the first nationwide population-based data on these coexisting conditions and their correlates in Türkiye, this study seeks to address an important gap in the literature and inform targeted strategies for healthy aging and dementia prevention.

2 Methods

2.1 Study Design

The research was based on secondary data derived from the 2022 Türkiye Health Survey [15], conducted by the Turkish Statistical Institute (TÜİK) in 11,170 households chosen to represent the population at the national level. The primary objective was to collect essential health indicators—recognized as a major component among developmental measures that reflect a country's progress—and thereby address existing gaps in the available information. In addition to providing nationwide data, this survey is significant because it allows for international comparisons and informs national policy and planning needs. The Türkiye Health Survey aimed to collect a wide range of health indicators, encompassing the health status of infants, children, and adults. In addition, it assessed the extent of health service utilization among individuals aged 15 years and above, the level of difficulty encountered in performing daily activities, and lifestyle factors such as tobacco and alcohol use. Data were gathered through face-to-face interviews at the household level, employing three distinct questionnaires: (1) "basic characteristics of household members," (2) the "0–14 age group," and (3) the "15 + age group." Within the scope of this study, data of individuals aged 60 and over were obtained and used.

The geographic scope of the survey encompassed all settlements located within the borders of the Republic of Türkiye. Accordingly, the target population included all households residing in these settlements. However, the institutional population—defined as individuals residing permanently in military barracks, dormitories, prisons, hospitals, nursing homes, and similar facilities—was excluded. In addition, small settlements (e.g., small villages, "oba," "mezra," and similar locales) were omitted on the grounds

that it would not be feasible to achieve a sufficient number of sample households from these areas.

The study was conducted in accordance with the Declaration of Helsinki. The data employed in this research were of a secondary nature, drawn from the Türkiye Health Survey Research micro datasets provided by the Turkish Statistical Institute (TÜİK) [16]. These datasets are made available to researchers upon request and the payment of a specified fee. Since the data are anonymized, no personally identifiable details are revealed, thereby upholding participant confidentiality. As a result, this study utilized a pre-existing, publicly accessible secondary dataset, and did not necessitate any further consent or ethical approval. This practice aligns with earlier studies that used previous versions of the several dataset [17], where no additional research permissions or ethical committee approvals were required for producing scientific outputs.

2.2 Study Population and Sampling

This survey was designed to produce national-level estimates for Türkiye, with a total sample size of 11,170 household addresses. A stratified two-stage cluster sampling method was employed. For external stratification, settlements were classified as rural if their population was 20,000 or fewer, and urban if their population exceeded 20,000. In the first stage, primary sampling units were clusters (blocks) containing approximately 100 household addresses each. These blocks were randomly selected using probability proportional to size. In the second stage, systematic random sampling was conducted within each selected cluster to identify individual household addresses.

The sampling frame used in this study was the "National Address Database" (UAVT)—the basis for the Address-Based Population Registration System (ADNKS) established in 2007—updated as of August 2022. The first-stage sampling units were clusters (blocks) with an average of 100 household addresses, while the final sampling units were individual household addresses. From a total of 1,117 sampled blocks, 11,170 household addresses (10 per block) were selected.

In order to address the potential effects of survey design—particularly clustering and unequal selection probabilities—and to ensure representativeness of the non-institutionalized Turkish population, we employed a multi-stage weighting procedure encompassing design weights, nonresponse adjustments, and iterative calibration (FERTFAKTOR (INDIVIDUALFACTOR)). By aligning estimates with the national population distribution, this approach yielded nationally representative point estimates and corresponding 95% confidence intervals, thereby mitigating bias and enhancing the validity of the results. The weighting variable, "FERTFAKTOR (INDIVIDUALFACTOR)," was derived through a three-stage process. In the first stage, base weights were calculated as the inverse of each unit's final selection probability, incorporating both cluster and household-level probabilities; these weights were assigned at both household and individual levels. In the second stage, adjustments were made to compensate for sample attrition due to nonresponse. Finally, an Integrated Calibration method was applied, using population proportion estimates to iteratively refine the weights. Through this final calibration coefficient, the survey estimates were reconciled with the projected population (excluding institutionalized individuals) and the total number of households across Türkiye. A total of 4630 data of individuals aged 60 and over were analyzed, and the weighted total sample was defined to be 11,331,239 (Fig. 1).

2.3 Identification of Data

The data included a range of demographic, socioeconomic, and health-related variables in this study. Age was identified as a continuous variable representing each participant's chronological age in years at the time of survey administration, and it is reported as mean ± standard deviation with the observed range specified. Sex was defined by self-report and dichotomized as "male" or "female" according to the respondent's identification at the time of data collection. Marital status was derived from participants' responses to a questionnaire and subsequently categorized into two groups: "married" and "single or divorced" (including never-married, widowed, separated, or legally divorced respondents). Educational status was determined based on the highest level of formal schooling completed and divided into "high school and below" (participants whose highest attained degree was primary, middle, or high school, including vocational high school) and "university and above" (participants who reported completion of a bachelor's, master's, or doctoral degree). AD status was identified as yes or no from a physician's diagnosis, but no clinical or neuropsychological assessments or biomarker confirmations were available. CMM was defined as having at least two physician-diagnosed cardiometabolic conditions: hypertension, coronary heart disease, stroke, diabetes mellitus (type 1 or type 2), and hyperlipidemia. Information on disease severity, duration, and level of control was not captured in the data instrument. Tobacco use was recorded as "yes" for individuals reporting current use of any combustible tobacco product (e.g., cigarettes, cigars, or pipes) and "no or quit" for those who had never smoked regularly or who had ceased smoking before survey administration. Alcohol use was defined as a binary variable in which participants were classified as "yes" if they reported any alcohol consumption (beer, wine, or spirits) within the preceding year and "no"

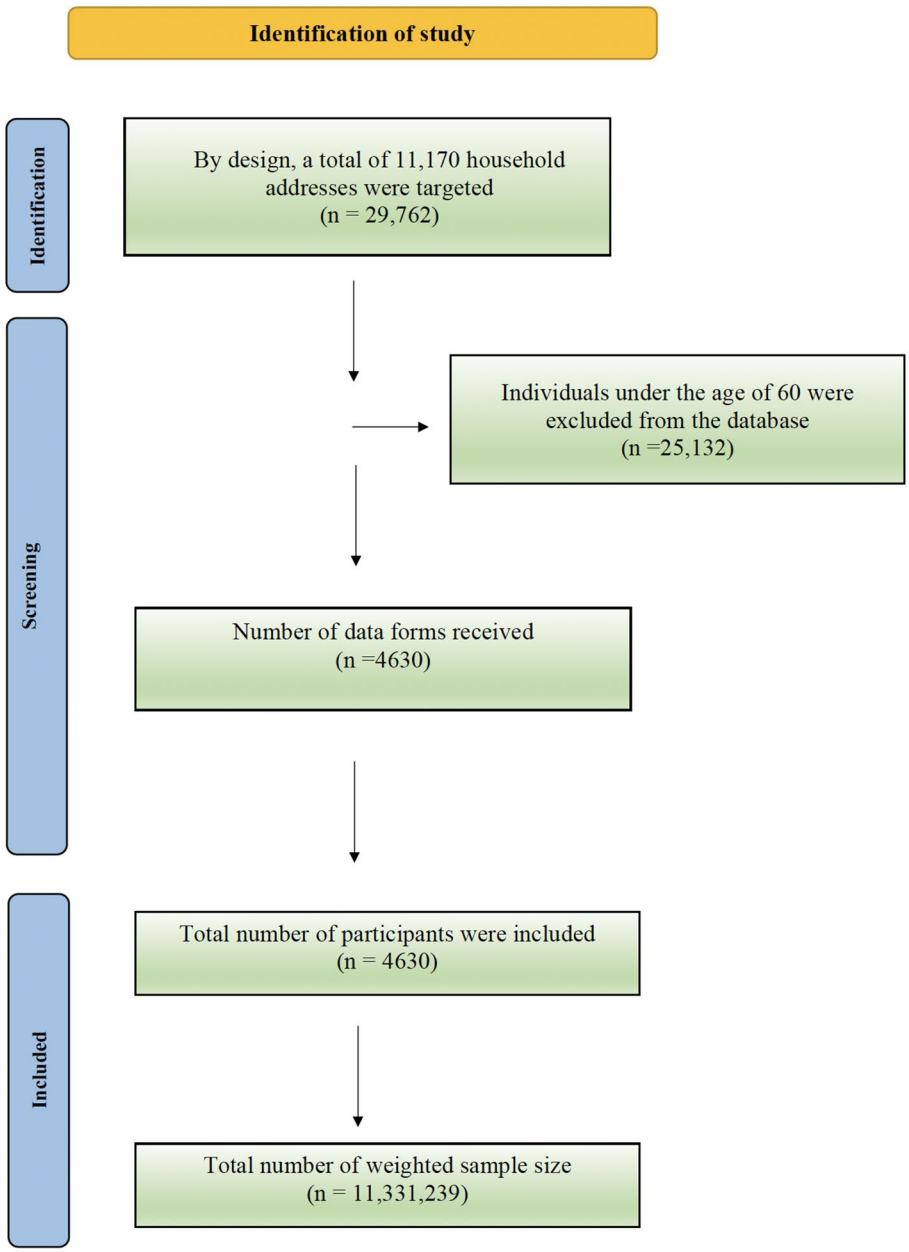


Fig. 1 A flow diagram depicting the selection process of individuals aged 60 and above in the population-based study

if they abstained during that period. Daytime activity level was classified as mostly sitting or less mobile versus requiring moderate or greater force. The regions were classified and presented as 12 regions according to The Nomenclature of Territorial Units for Statistics (NUTS) [15].

2.4 Statistical Analysis

Prior to conducting parametric tests, the distribution of continuous variables was assessed for normality via Kolmogorov–Smirnov tests. Where applicable, the data were weighted to reflect population-level parameters, and all subsequent analyses accounted for these sampling weights. Descriptive statistics are presented as mean ± standard deviation for continuous variables or as frequencies and percentages for categorical variables. To compare proportions across different subgroups, chi-squared tests were conducted. Following a significant Pearson chi-square test of independence, Bonferroni-adjusted post hoc pairwise comparisons of column proportions were conducted to identify which regional contrasts differed significantly. The association between AD and key variables of interest was examined through three multivariable binary logistic regression models. Model 1 was unadjusted, and covariates listed were included as independent variables in multivariable logistic regression models predicting the binary outcome of interest.

In Model 2, estimates were adjusted for baseline sociodemographic factors such as age (continuous), sex (male vs. female), educational status (high school and below vs. university and above), and marital status (married vs. single or divorced). In Model 3, the adjustment cluster was further expanded to include key lifestyle and health-related characteristics, namely BMI (continuous), tobacco use (yes vs. no or quit), alcohol use (yes vs. no), and daily physical activity—in addition to all covariates included in Model 2. The backward stepwise likelihood ratio (LR) method was employed to arrive at the final models, and odds ratios (ORs) and adjusted odds ratios (aORs) with 95% confidence intervals (CIs) were generated to quantify the effect sizes. For Model 2 and 3, the constant coefficient (β) and its standard error (SE) were also calculated, providing a baseline term in the logistic regression equation. We also assessed goodness of fit utilizing the Hosmer–Lemeshow test for binary logistic regression analysis for Model 2 and Model 3. All analyses and visualization were carried out using STATA software (v.18, College Station, TX, USA), R (v.4.2, R Foundation for Statistical Computing, Vienna, Austria) using packages such as ggplot2 and dplyr, and the SPSS (v30.0) package program. All tests were two-sided, and *p*-values less than 0.05 were considered indicative of statistical significance.

Table 1 Baseline descriptive and socio-demographic characteristics of the population ($n=4630$)

Variables	Total (n=4630)
Age, mean ± SD, years	69.1 ± 7.3 (min-max: 60–102)
Sex, n (%)	
Male	2162 (46.7)
Female	2468 (53.3)
Marital status, n (%)	
Married	3327 (71.9)
Single or divorced	1303 (28.1)
Educational status, n (%)	
High school and below	4234 (91.4)
University and above	396 (8.6)
Alzheimer's Disease, n (%)	
No	4452 (96.2)
Yes	178 (3.8)
Cardiometabolic multimorbidity, n (%)*	
No	2833 (61.2)
Yes	1797 (38.8)
Tobacco use, n (%)	
No or quit	3765 (81.3)
Yes	865 (18.7)
Alcohol use, n (%)	
No	3892 (84.1)
Yes	738 (15.9)
Activity during the day, n (%)	
Mostly sitting or less mobile	3134 (67.7)
Requiring moderate or greater force	1496 (32.3)

*Cardiometabolic multimorbidity was considered as having at least two of the following five diseases, which was classified as multimorbidity present: hypertension, coronary heart disease, stroke, diabetes mellitus, and hyperlipidemia. SD: standard deviation

3 Results

The baseline characteristics of the research group are summarized in Table 1. Accordingly, the sample included 4630 individuals (weighted sample of 11,331,239) with a mean age of 69.1 ± 7.3 years (range 60–102). Of this population, 46.7% ($n=2162$) were male and 53.3% ($n=2468$) were female. Nearly seven in ten participants (71.9%, $n=3327$)) were married, while 28.1% were single or divorced. With respect to educational attainment, 91.4% had a high school education or below, whereas 8.6% ($n=396$) had completed university-level studies. Based on the analysis, the overall prevalence of AD was estimated at 3.8% (95% CI: 3.6–4.9%), slightly higher in females (4.1%, 95% CI: 3.8–5.7%) than males (3.5%, 95% CI: 2.8–4.7%), and 38.8% exhibited CMM among all participants. Furthermore, Fig. 2 illustrates the regional prevalence of AD. Notably, the Aegean region exhibited the lowest prevalence of AD (1.7%) among all twelve regions. Additionally, 18.7% ($n=865$) of individuals reported using tobacco, and 15.9% ($n=738$) reported consuming alcohol. Regarding daily activity, 67.7% ($n=3134$) engaged in mostly sedentary or minimally active routines, and 32.3% ($n=1496$) performed activities requiring moderate or greater force.

The distribution of AD prevalence according to various baseline characteristics among individuals is summarized in Table 2. The prevalence of AD was significantly higher among individuals with CMM (5.9%) compared to those without (2.5%) ($p<0.001$). Marital status also showed a significant association; individuals who were single, divorced, or widowed had a significantly higher prevalence of AD (6.4%) compared to married participants (2.9%) ($p<0.001$). Regarding physical activity, participants who were mostly sitting or less mobile had a higher AD prevalence (4.9%) compared to those engaged in activities requiring moderate or greater force (1.7%) ($p<0.001$). Individuals who reported no alcohol use had a higher prevalence of AD (4.2%) than those who consumed alcohol (2.0%) ($p=0.005$). No significant differences were observed in AD prevalence based on sex ($p=0.275$) or tobacco use ($p=0.303$).

Table 3 presents the findings of three multivariable binary logistic regression models investigating the associations among AD, CMM, and several sociodemographic and lifestyle factors. In Model 1 (the unadjusted model), the presence of CMM is associated with a more than two fold increase in the odds of AD (OR=2.404, 95% CI=1.771–3.262, $p<0.001$). Model 2 was adjusted for age,

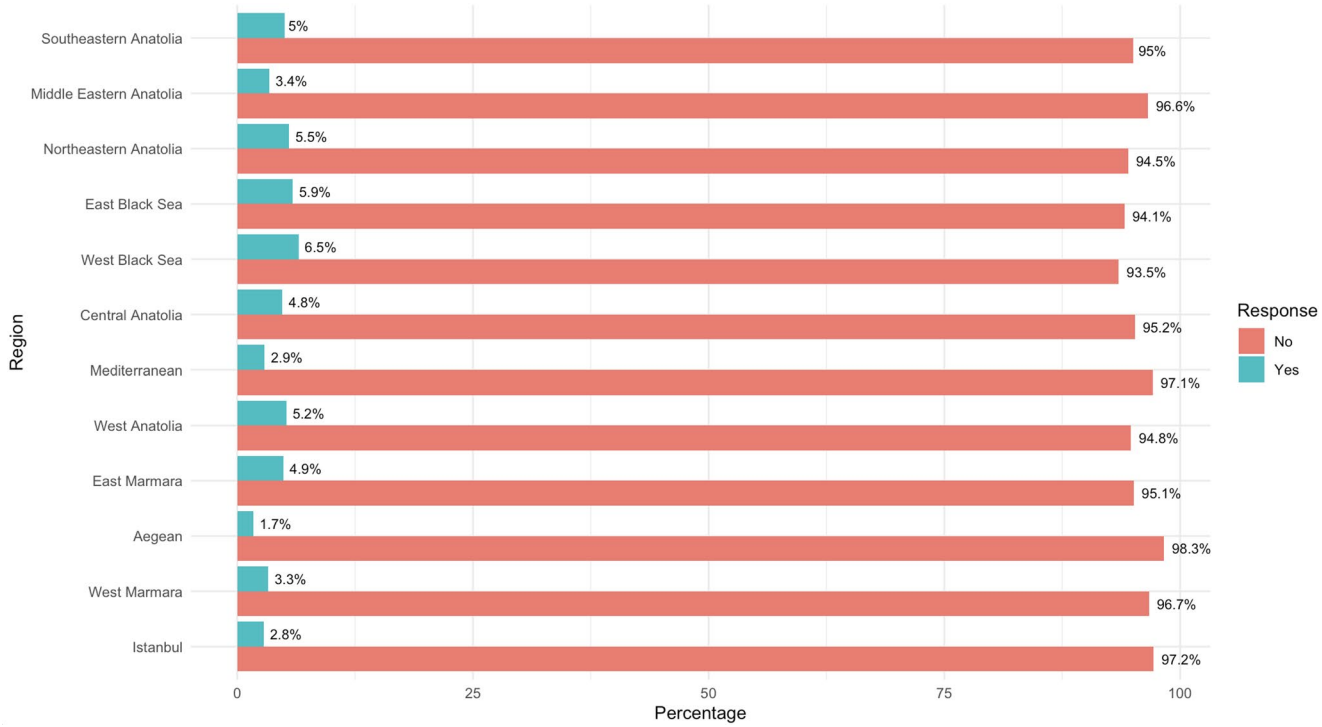


Fig. 2 Prevalence of Alzheimer's disease by region in those 60 and above in the population-based study. A significant association between geographic region and AD was observed ($p<0.001$). Bonferroni-adjusted post hoc comparisons of column proportions showed that only East Marmara, Central Anatolia, and Southeastern Anatolia did not differ significantly from one another in the percentage without AD, whereas every other interregional contrast reached significance

sex, educational status, marital status, and physical activity during the day. In this model, CMM was significantly associated with increased odds of AD (aOR = 2.081; 95% CI: 1.522–2.844, $p<0.001$). Model 3 was further adjusted for BMI, tobacco use, alcohol use, and activity during the day. The association between CMM and AD remained significant but was slightly decreased (aOR = 1.975; 95% CI: 1.446–2.698, $p<0.001$). The Hosmer–Lemeshow goodness-of-fit test results indicated acceptable model fits, with p-values of 0.184 for Model 2 and 0.307 for Model 3.

4 Discussion

This study, conducted on 4630 older adults (weighted sample of over eleven million), aimed to clarify the interplay among sociodemographic variables, cardiometabolic conditions, and the occurrence of AD. The findings indicated an overall AD prevalence of 3.8% (95% CI: 3.6–4.9%) which was slightly higher among female than male, and significantly elevated in individuals who were single, divorced, or widowed compared to those who were married. Additionally, low educational attainment emerged as a potential risk indicator, aligning with the well-established concept of cognitive reserve. Of particular importance, CMM was strongly associated with increased odds of AD, emphasizing the influence of vascular and metabolic health on late-life cognitive outcomes. Finally, a more sedentary lifestyle corresponded to heightened disease prevalence, suggesting that routine physical activity may play a protective role.

Our analysis found an overall AD prevalence of approximately 3.8% in adults aged 60+, which is consistent with epidemiological surveys. For example, a national study in Iran reported about 7.9% dementia prevalence in this age group [18]. Notably, AD was more common in females than males in our cohort, mirroring the well-documented pattern that roughly two-thirds of dementia cases occur in females—largely because female, on average, may live longer into the high-risk age ranges [19, 20]. This longevity-driven disparity aligns with prior reports and helps explain the higher AD burden observed in females.

Marital status emerged as an important determinant of AD risk. Being married was associated with substantially lower odds of AD compared to being unmarried. Indeed, meta-analytic evidence shows that lifelong single and widowed individuals have significantly higher AD risk than married peers [21]. The elevated prevalence of AD among single/divorced seniors in our study (6.4% vs. 2.9% in married seniors) may reflect the impact of social isolation; epidemiologic data indicate that social isolation is independently associated with about a 1.3-fold increase in dementia risk in older adults [22–24]. These findings support the view

Table 2 Distribution of alzheimer's disease prevalence according to baseline variables ($n=4630$)

Variables	Alzheimer's Disease		*P*-value*
	No, n (%)	Yes, n (%)	
Cardiometabolic multimorbidity**			<0.001†
No	2761 (97.5)	72 (2.5)	
Yes	1691 (94.1)	106 (5.9)	
Sex			0.275
Male	2086 (96.5)	76 (3.5)	
Female	2366 (95.9)	102 (4.1)	
Marital status			<0.001†
Married	3232 (97.1)	95 (2.9)	
Single, divorced or widowed	1220 (93.6)	83 (6.4)	
Educational status			0.005†
High school and below	4061 (95.9)	173 (4.1)	
University and above	391 (98.7)	5 (1.3)	
Tobacco use			0.303
No or quit	3615 (96.0)	150 (4.0)	
Yes	837 (96.8)	28 (3.2)	
Alcohol use			0.005†
No	3729 (95.8)	163 (4.2)	
Yes	723 (98.0)	15 (2.0)	
Activity during the day			<0.001†
Mostly sitting or less mobile	2982 (95.1)	152 (4.9)	
Requiring moderate or greater force	1470 (98.3)	26 (1.7)	

*Chi-squared (χ^2) test. **Cardiometabolic multimorbidity was considered as having at least two of the following five diseases, which was classified as multimorbidity present: hypertension, coronary heart disease, stroke, diabetes mellitus, and hyperlipidemia. † Statistically significant

Table 3 Multivariable binary logistic regression analyses of the association between alzheimer's disease, cardiometabolic multimorbidity, and associated factors ($n=4630$)

Variables	Model 1 [a]	Model 2 [b]	Model 3 [c]
	OR [95% CI]	aOR [95% CI] **	aOR [95% CI] **
Cardiometabolic multimorbidity*			
No	Ref	Ref	Ref
Yes	2.404 [1.771–3.262]	2.081 [1.522–2.844]	1.975 [1.446–2.698]
P-value	<0.001†	<0.001†	<0.001†
		Constant β = -9.218 (SE = 0.940), *p* < 0.001	Constant β = -10.224 (SE = 0.774), *p* < 0.001
		Hosmer–Lemeshow test: χ^2 = 11.327, *p* = 0.184	Hosmer–Lemeshow test: χ^2 = 9.435, *p* = 0.307

[a] Model 1 is the unadjusted model. [b] Model 2 was adjusted by age, sex, educational status, and marital status. [c] Model 3 was further adjusted by BMI, tobacco use, alcohol use, and activity during the day, in addition to the variables in Model 2. aOR: Adjusted odds ratio. OR: odds ratio, CI: confidence interval. SE: standard error. BMI: Body Mass Index. *Cardiometabolic multimorbidity was considered as having at least two of the following five diseases, which was classified as multimorbidity present: hypertension, coronary heart disease, stroke, diabetes mellitus, and hyperlipidemia. **Multivariable logistic regression analysis calculated by using the backward stepwise likehood ratio (LR) method.: χ^2: Chi-squared. † Statistically significant

that social engagement and partner support can be protective factors for cognitive health in late life.

Of note, consistent with the cognitive reserve hypothesis, lower educational attainment was linked to higher AD prevalence in our sample. Individuals with less education tend to have a greater risk for dementia—a meta-analysis found that low education is associated with roughly double the odds of developing dementia compared to higher education levels [25–27]. In fact, inadequate education in early life has been highlighted as one of the most important risk factors for later-life dementia; the Lancet Commission reported that having less education in youth confers a notably elevated risk of dementia in old age [28]. These observations highlight the protective effect of education and lifelong learning on brain resilience.

Our findings identified CMM as a strong predictor of AD. Several studies suggest that seniors with co-occurring cardiometabolic diseases such as diabetes, heart disease, or stroke had a significantly higher likelihood of AD [10, 29–31]. Prior study, a large cohort study, reported that having two or more of these diseases more than doubled the hazard of developing dementia (HR ~ 2.10) [10]. Notably, this association persists even after adjusting for other factors, emphasizing that cardiometabolic burden itself independently contributes to cognitive decline. Public health research suggests that targeting CMM could help reduce dementia risk at the population level [32–35], highlighting the importance of managing vascular risk factors to potentially mitigate AD incidence.

A sedentary lifestyle was significantly associated with higher AD prevalence in our study (4.9% in inactive individuals vs. 1.7% in the physically active). This trend is in line with extensive evidence that regular physical activity is protective against dementia. Large meta-analyses show that greater physical activity is linked to lower incidence of both all-cause dementia and AD, supporting exercise as a modifiable protective factor for brain health [36]. Correspondingly, health agencies recommend exercise as a key preventive measure—for instance, the World Health Organization [37] advises that people can reduce their risk of dementia by engaging in routine physical exercise along with other healthy lifestyle behaviors [38–42]. These converging findings and reports support the role of an active lifestyle in promoting cognitive resilience in older age.

Our bivariate analysis indicated that alcohol use was associated with a significantly lower prevalence of AD. This finding aligns with numerous observational studies reporting reduced dementia risk in light-to-moderate consumers. A meta-analysis has shown roughly a 20–30% lower risk of AD in moderate alcohol consumption compared to non-consumption [43]. This study found a pooled relative risk of ~0.72 for AD among light/moderate drinkers, suggesting a protective correlation [43]. Similarly, a recent review suggested that many studies support a J-shaped relationship with moderate drinking linked to lower AD risk [44]. But methodological limitations, such as confounding biases, mean we cannot assume causation. In summary, our alcohol finding is in line with prior research, but the direction of causality remains uncertain. In contrast, tobacco use showed no statistically significant association with AD in our data. This result appears to diverge from the majority of existing literature, which identifies smoking as a risk factor for dementia. Large prospective studies and meta-analyses have consistently found that current smokers have a higher incidence of AD than never-smokers [45]. The absence of a significant effect in our study could stem from limited power or the cross-sectional design. It may also reflect survivor bias in an elderly cohort: smokers tend not to live as long, so fewer smokers survive into the age range of AD diagnosis, potentially leaving a group of unusually healthy smokers in late life. This can produce an illusion of no harm or even a protective effect in older samples. The weight of evidence indicates smoking is associated with greater dementia risk, and our null finding could be due to reverse causality (e.g. patients with cognitive decline quitting smoking) or biases in who remains in the sample at older ages.

Of note, the regional disparities in AD prevalence likely reflect a confluence of socioeconomic and healthcare factors. Population-based surveys from Eastern Anatolia demonstrate that lower educational attainment and higher comorbidity burden are associated with both an increased risk of AD and delayed diagnosis in disadvantaged communities [46, 47]. Taken together, the availability of memory clinics and specialist neurologists is concentrated in larger, more industrialized cities—regions with higher insurance coverage and population density exhibit greater utilization of AD-specific services, whereas rural provinces remain underserved [48, 49]. Moreover, persistent stigma surrounding dementia in certain cultural contexts can hinder care-seeking behaviors and underreporting of symptoms, further skewing self-reported prevalence data in some regions [50]. These findings emphasize the need for targeted interventions to improve diagnostic infrastructure, broaden health insurance access, and implement region-specific education campaigns to reduce stigma and address the underlying social determinants of AD.

This research had several limitations that should be emphasized. This study's cross-sectional design precludes definitive causal inference between CMM and AD, as temporal relationships cannot be conclusively established. Additionally, reliance on self-reported data for lifestyle factors may introduce recall bias or inaccuracies in the assessment of exposure variables. Although we defined CMM as the co-occurrence of two or more conditions (hypertension, diabetes, stroke, coronary heart disease, or hyperlipidemia), we lacked data on disease severity, duration, or level of control, which could substantially modify the observed associations. Furthermore, regional differences in health literacy and stigma could exacerbate these inaccuracies: areas with greater awareness and access to specialist care may yield more accurate self-reports, whereas underresourced or more conservative communities might understate cognitive symptoms. Although the large weighted sample enhances generalizability, regional variations in healthcare access and diagnostic practices may affect the uniformity of AD detection across diverse settings. In addition, the exclusion of small settlements may limit the generalizability of our findings, since these communities often differ from larger urban and peri-urban areas in socioeconomic status, healthcare access, and disease risk profiles, which could introduce selection bias and under- or overestimate the true prevalence of AD and CMM in the overall population. Moreover, potential residual confounding arising from unmeasured variables such as dietary habits or genetic predispositions cannot be fully excluded, highlighting the need for further longitudinal and biomarker-validated studies. The cross-sectional design of our study precludes causal inference regarding the associations between alcohol or tobacco use and AD, and raises the possibility of reverse causation (i.e., changes in substance use following cognitive decline). Additionally, survival bias may have influenced the observed associations, particularly for tobacco use, as individuals who engage in high-risk behaviors may be underrepresented in the older population due to premature mortality. Moreover, external validation in independent cohorts is warranted to confirm the stability and reproducibility of our findings. Of note, although our model fit and discrimination statistics met standard thresholds, the Hosmer–Lemeshow test can be sensitive to sample size, and AUC does not capture clinical decision thresholds.

5 Conclusion

In summary, our results underline the multifactorial nature of AD risk, involving a combination of non-modifiable factors and modifiable health and lifestyle factors. Numerous modifiable determinants, including cardiovascular/

metabolic health, social and cognitive engagement, and lifestyle habits, independently affect an individual's likelihood of developing AD. Notably, many of the risk factors observed in this study, such as lower education, being unmarried/socially isolated, cardiometabolic disease burden, and physical inactivity, overlap with those identified by expert consensus as key contributors to dementia risk [51] . This alignment with the broader literature strengthens the evidence that addressing cardiometabolic conditions and promoting higher education, social connectedness, and regular exercise in the population could help reduce the odds of AD, or at least delay its onset, at the public health level. Each of these factors describes a modifiable target for public health interventions aimed at mitigating the rising burden of AD in aging populations.

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Author Contributions MEA: Conceptualization, Methodology, Software, Writing-Original draft preparation, Writing-Reviewing and Editing, Critical Review, and Data analysis. MEA and AK: Writing-Original draft preparation, Writing-Reviewing and Editing, Critical Review. The final manuscript was reviewed and approved by all authors.

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Data Availability The data used in this study were obtained from the publicly available Turkey Health Survey conducted by the Turkish Statistical Institute (TÜİK). The survey datasets can be accessed through the official TÜİK website upon request: https://www.tuik.gov.tr. Since the data are anonymized, no personally identifiable details are revealed, thereby upholding participant confidentiality. Researchers can apply for access via the "Microdata Access" portal, subject to institutional approval and data use agreements.

Declarations

Ethics Approval and Consent to Participate The study was conducted in accordance with the Declaration of Helsinki. The data employed in this research were of a secondary nature, drawn from the Turkish Türkiye elderly Profile Research micro datasets provided by the Turkish Statistical Institute (TÜİK). These datasets are made available to researchers upon request and the payment of a specified fee. Since the data are anonymized, no personally identifiable details are revealed, thereby upholding par-ticipant confidentiality. As a result, this study utilized a pre-existing, publicly accessible secondary dataset, and did not necessitate any further consent or ethical approval. This practice aligns with earlier studies that used previous versions of the several dataset [17], where no additional re-search permissions or ethical committee approvals were required for producing scientific outputs. All participants provided informed consent prior to participating in the study.

Consent for Publication Not Applicable.

Competing Interests The authors declare no competing interests.

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