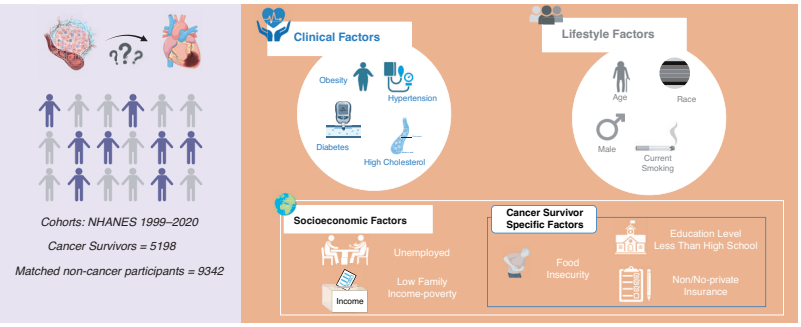
Cardiovascular Innovations and Applications

Vol. 11 (2026) 29
ISSN 2009-8618
DOI 10.15212/CVIA.2026.0016

RESEARCH ARTICLE

Socioeconomic, Lifestyle, and Clinical Factors Associated with Cardiovascular Events in the U.S. Cancer Population

Graphical Abstract



Highlights

- Adult cancer survivors had a high burden of prevalent cardiovascular disease (CVD).
- Socioeconomic vulnerability was strongly associated with CVD among cancer survivors.
- Food insecurity, limited education, and non-private insurance showed cancer-specific associations with CVD.

Authors

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In brief

Cancer survivors carry a substantial burden of prevalent cardiovascular disease. Beyond conventional clinical and lifestyle characteristics, socioeconomic disadvantage, including food insecurity, low educational attainment, and non-private or no insurance, showed additional associations with prevalent CVD in this population.

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Socioeconomic, Lifestyle, and Clinical Factors Associated with Cardiovascular Events in the U.S. Cancer Population

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Received: 13 November 2025; Revised: 9 February 2026; Accepted: 7 May 2026

Abstract

Background: Cardiovascular disease (CVD) is a leading cause of mortality among cancer survivors, yet the contributions of socioeconomic, lifestyle, and clinical factors to CVD remain unexplored.
Objective: This study was aimed at examining associations between these factors and prevalent CVD in adults with prior cancer and comparing them with those in a matched non-cancer cohort.
Methods: We analyzed 97,648 adults from the National Health and Nutrition Examination Survey. Associations of socioeconomic, lifestyle, and clinical factors with a composite endpoint of five self-reported cardiovascular events were assessed with multivariable logistic regression. Interaction analyses assessed differences by cancer status, and sensitivity analyses examined individual cardiovascular outcomes.
Results: We included 5584 cancer survivors and 9933 matched participants without cancer. Age, sex, unemployment, low income, current smoking, obesity, diabetes, hypertension, and hypercholesterolemia were associated with elevated odds of CVD prevalence in both groups. Among only cancer survivors, an absence of private insurance, or the presence of food insecurity or low educational attainment, was also independently associated with CVD prevalence. Sensitivity analyses indicated broadly consistent results across individual outcomes.
Conclusions: Socioeconomic, lifestyle, and clinical factors were associated with prevalent CVD among cancer survivors, with socioeconomic disadvantage contributing to disparities in CVD burden. Because the outcomes were self-reported, and the study was cross-sectional, the findings should be interpreted as associative rather than causal or predictive.

Keywords: cancer survivorship; cardiovascular disease; socioeconomic determinants; lifestyle factors; prevalent cardiovascular disease

Abbreviations: CI, Confidence Interval; CV, Cardiovascular; CVD, Cardiovascular Disease; NHANES, National Health and Nutrition Examination Survey; OR, Odds Ratio.

Introduction

The global population of cancer survivors has substantially increased and has surpassed 18 million individuals in the U.S. [1]. Although most adults with cancer become long-term survivors, cardiovascular disease (CVD) has emerged as the primary non-cancer cause of mortality [2, 3]. Previous studies have demonstrated an elevated prevalence of CV-associated factors among cancer survivors [4, 5]; however, the extent to which socioeconomic status (SES), lifestyle, and clinical factors are associated with greater survival in adults after cancer onset than adults without cancer remains unclear. Additionally, evidence suggests that traditional CV-associated factors might be associated with CVD prevalence among the population of survivors of childhood cancer [6, 7]. Zhu et al. have demonstrated racial and ethnic disparities in CVD outcomes [8]. Therefore, a more detailed understanding of SES-driven disparities is necessary to enable the development of timely and individualized management strategies for cancer survivors.

Herein, we aimed primarily to examine the associations of socioeconomic, lifestyle, and clinical factors with prevalent CVD among U.S. cancer survivors. In a secondary analysis, we compared these associations with those observed in an age-, sex-, and race-matched cohort without cancer to assess whether the association strength differed by cancer status.

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Methods

Study Population

NHANES, a cross-sectional survey using a stratified four-stage probability sampling design to sample noninstitutionalized U.S. adults in 2-year cycles since 1999, is conducted by the National Center for Health Statistics. Herein, we conducted association analyses on data from 11 survey cycles spanning 1999–2023. The participants included in our analyses were restricted to a study sample of individuals 20 years or older with a history of cancer diagnosis (n = 5584) and a matched comparison group without cancer, thus ensuring access to adequate information to determine cardiovascular (CV) status and associated factors. For etiologic comparison, participants without a reported cancer diagnosis were frequency-matched to the cancer analytic sample by age, sex, and race/ethnicity (1:1.8 ratio; n = 9933) [6] to create a non-cancer comparison group. This comparator study sample was used to benchmark the magnitudes and patterns of associations of socioeconomic, lifestyle, and clinical factors with CVD events. NHANES protocols were approved by the institutional review board of the National Center for Health Statistics, and all study participants provided written informed consent. This research adhered to the Strengthening the Reporting of Observational Studies in Epidemiology reporting guidelines.

Data Collection

In each 2-year survey cycle, participants underwent in-home interviews and attended mobile examination centers. At these centers, they completed supplementary questionnaires, underwent a physical examination, and provided biological samples for further analysis.

In the initial survey cycles of NHANES, Asians of non-Hispanic origin were not included in the response options for the self-reported race and ethnicity question. Consequently, we reclassified participants into four mutually exclusive categories: non-Hispanic White, non-Hispanic Black, Hispanic, and others. We identified social determinants of health variables, such as employment status, family income-poverty ratio, health insurance status, food security, education level, and relationship status [9],

that were available in the NHANES 1999–2023 questionnaires (Table S1). All participants were asked what type of work they had done in the past week. Except for students, retirees, and family caregivers, we classified participants who were looking for work and those who had not worked at a job in the previous week as unemployed. Family income-to-poverty ratio, defined as the ratio of family income relative to a family size-specific poverty threshold [10], is provided as an NHANES demographic variable. Household food security was measured with the ten-item U.S. Food Security Survey Module [11], with full food security defined as zero affirmative responses, and food insecurity defined as one or more affirmative responses to the ten survey items [12]. Participants reported their highest education level in the demographic section of the survey. Health insurance status was determined by participants' responses to items asking about health insurance status and type. Participants were asked whether they were married, widowed, divorced, separated, never married, or living with a partner. We grouped those who were married or living with a partner, and compared them with those currently living without a spouse or partner.

Additional demographic and behavioral variables were identified according to interview items. In NHANES 2001–2004, the physical activity level in daily activities during the past 30 days was assessed with an interviewer-administered questionnaire [13]. In NHANES 2005–2023, usual levels of physical activity at work or during leisure time in a typical week were evaluated with the Global Physical Activity Questionnaire [14]. Individuals without moderate or vigorous activity in work and leisure were considered physically inactive. Current smoking status was determined according to participants' responses to questions regarding whether they had smoked ≥100 cigarettes over their lifetime and their current tobacco product consumption. Heavy drinking was assessed with NHANES questions regarding self-reported average weekly alcohol consumption. Health conditions and measures relevant to CV events were obtained from both mobile examination centers' extracted examination results and participants' responses to questionnaire items (history of congestive heart failure, coronary heart disease, angina, heart attack, and stroke). Weight and height were measured at the time of the physical examination. Obesity was defined as a body mass index of ≥30 kg/m^2, and central obesity was defined as a waist circumference of at least 102 cm in men or 88 cm in women [15]. Hypertension, hypercholesterolemia, and diabetes mellitus status were obtained through self-reporting of physician-diagnosed conditions. We did not categorize participants according to specific measurement thresholds. The composite of CVD events was defined as a self-reported history of any of the following: congestive heart failure, coronary heart disease, angina/angina pectoris, heart attack, or stroke.

Statistical Analysis

In the primary analysis, a machine learning algorithm (MissForest) was applied to impute non-systematically missing data among participants. The MissForest algorithm, a random forest algorithm that averages data over many unpruned regression trees to impute missing data, outperforms other available imputation methods, such as the multiple imputation by chained equations method, the k-Nearest Neighbors algorithm, and the Missing Pattern Alternating Lasso algorithm [16]. We assumed that data were missing at random [17]. The outcome variable and all covariates (age; sex; race and ethnicity; and social, individual, and clinical factors) were included for imputation. A complete-case analysis was conducted as an additional sensitivity analysis. Social, individual, and clinical factors were dichotomized according to conventional cut points and definitions provided by public health authorities. Further sensitivity analysis was performed to assess associations between the included factors and major individual CV outcomes, including heart failure, coronary heart disease, myocardial infarction, and stroke. These analyses were conducted with multivariable logistic regression models with the same covariates as in the primary analysis among cancer survivors. Potential multicollinearity among the included factors, particularly socioeconomic factors, was assessed with a pairwise correlation matrix (Figure S1). Variables were retained in the multivariable model according to their clinical significance [18, 19] and the absence of high mutual correlation (all coefficients $|r| < 0.5$). Pairwise correlations among dichotomous candidate factors were assessed with Cramer's V [20].

We present age- and sex-adjusted odds ratios (ORs) for each candidate factor regarding CV events in both the cancer survivor study sample and the matched non-cancer comparison group. Independent associations of social, individual, and clinical factors with CV events in this population were examined by simultaneous inclusion of these factors in a multivariate logistic regression model, after demographic covariates were accounted for. Additionally, the dose-response relationships of the number of social, individual, and clinical factors vs the occurrence of CV events were assessed.

To evaluate whether associations between the investigated factors and CVD outcomes differed by cancer status, we fit logistic regression models including an indicator of cancer vs non-cancer, and multiplicative interaction terms between cancer status and each socioeconomic, lifestyle, and clinical factor. Stratified ORs, as well as interaction ORs and 95%, are reported with confidence intervals (CIs) (Supplementary Table S7). These analyses were designed to formally test whether selected factors were associated with CVD prevalence among cancer survivors vs the matched cohort without cancer.

All analyses were conducted in R software, version 4.5.1 (R Foundation, Vienna, Austria), and survey analysis procedures were used, given the complex survey design. Use of survey examination weights helped achieve estimates that were nationally representative, in line with recommendations provided by the National Center for Health Statistics. All statistical tests were two-sided, and P values < 0.05 were deemed statistically significant.

Results

Study Population

The interview samples of the 1999–2023 NHANES survey cycles included 58,744 participants older than 20 years, of whom 5584 adults reporting a positive cancer history and 9933 matched adults without cancer were included in our analysis. Among the included participants with cancer, the median age was 70 years, 47.2% were men, and 68.7% were non-Hispanic White (Table 1). The population's SES, lifestyle, and clinical baseline characteristics are listed in Table 1. The number of CVD events by individual cancer type is shown in Table S2. Participants with bladder cancer, kidney cancer, or more than three cancer types had higher ratios of positive CVD events.

Associations of SES, Lifestyle, and Clinical Factors with CVD Events

Figure 1 illustrates the associations of various factors and CVD events in cancer survivors and the matched non-cancer study sample. Pairwise correlation analysis suggested modest correlations among most SES factors (Figure S1). After adjusting for age and sex, we observed consistent trends in the cancer survivor group (Figure 1A, Table S3) and matched non-cancer group (Figure 1B, Table S4). In both cohorts, a range of SES, lifestyle, and clinical factors were independently associated with elevated CV event rates.

Adjusted multivariable logistic analyses (cancer survivor group in Table S5, Figure 1A; matched non-cancer group in Table S6, Figure 1B) revealed that the included factors (unemployed status; current smoker status; and history of diabetes, hypertension, and hyperlipidemia) were generally consistent across groups (Figure 1A and B). Notably, the family income-poverty ratio (OR: 1.28, 95% CI 1.09–1.50 vs OR: 1.12, 95% CI 0.99–1.27, interaction OR: 1.26, 95% CI 1.06–1.51) showed a significant association only among cancer survivors (Table S7). The negative associations of those factors were additive; i.e., the more SES, lifestyle, and clinical factors present, the greater the odds of prevalent CVD events (Figure 2).

To perform the sensitivity analysis among cancer survivors, we used various cut points to assess the associations of factors with adverse CV outcomes (Table S8). The results were consistent with the main findings. The associations of various factors with CV events were also examined after multivariable adjustment in the complete-case analysis. Although the magnitude and precision of some estimates exhibited modest fluctuations due to the decreased sample size, the direction and significance of the overall findings remained consistent with those in the primary analysis (Table S9). Therefore, our findings were deemed robust and not artifacts of the imputation process. In sensitivity analyses using individual CV outcomes, the

Table 1 Characteristics of Adult Cancer Survivors and a Matched Non-cancer Population Comparison Group.

Characteristic, n (%)	Cancer Cohort	Matched Non-Cancer Cohort	P-Value
Male sex	2633 (47.2)	4608 (46.4)	0.37
Median age, years (IQR)	70 (58–79)	69 (58–78)	0.012
White	3834 (68.7)	6764 (68.1)	0.91
Black	809 (14.5)	1462 (14.7)	
Hispanic	673 (12.1)	1218 (12.3)	
Other race	268 (4.8)	489 (4.9)	
Socioeconomic factors			
Unemployed	1153 (20.6)	1827 (18.4)	0.0007
Family PIR <300%	2916 (52.2)	5559 (56.0)	<0.0001
Food insecurity	1049 (18.8)	1858 (18.7)	0.91
High school education or below	2579 (46.2)	5338 (53.7)	<0.0001
Private insurance	3149 (57.5)	5392 (55.9)	<0.0001
Not married or living with partner	1819 (32.6)	3460 (34.8)	0.15
Lifestyle factors			
Currently smoking	843 (15.1)	1507 (15.2)	0.006
Heavy drinking	559 (10.0)	1108 (11.2)	0.002
No physical activity	839 (15.0)	1502 (15.1)	0.97
Clinical factors			
Obesity	1818 (32.6)	3215 (32.4)	0.82
Central obesity	3133 (56.1)	5484 (55.2)	0.46
Hypertension	3120 (55.9)	4976 (50.1)	<0.0001
Hypercholesterolemia	2660 (47.6)	4213 (42.4)	<0.0001
Diabetes	1247 (22.3)	1996 (20.1)	0.001

directions of association for key socioeconomic factors were broadly consistent with those observed for the composite endpoint (Table S12). Food insecurity remained significantly associated with heart failure and showed consistent positive associations across other outcomes (Table S10).

Discussion

In the current study, we used data from the NHANES database (1999–2023), a national-level representative database of diverse racial and ethnic groups in the U.S., to examine differences in the associations of socioeconomic, lifestyle, and clinical factors with prevalent CVD in cancer survivors vs a matched population without cancer. Although we found that traditional socioeconomic, lifestyle, and clinical factors with prevalent CVD are common in the general population similarly affect cancer survivors, certain factors, specifically food insecurity, low education level, and non-private health insurance or uninsured status, were independently associated with prevalent CVD among cancer survivors.

In the general population, prior prospective studies have established an association between lower SES and higher CVD prevalence [18, 21–23]. Similarly, in adult cancer survivors, low education level, non-private health insurance or uninsured status, and food insecurity are associated with poor health outcomes and elevated mortality rates [24–28]. Our study further strengthened these findings by demonstrating that these three factors are independent and elevated among cancer survivors. The inverse relationship observed between educational level and CV event prevalence might be explained by cancer survivors with higher education levels being more likely to receive early diagnoses and effective treatments, and to adhere to their therapy, thus decreasing their CVD prevalence [29, 30]. Insurance status also emerged as an independent CV-associated factor in our study. Previous research has suggested that individuals without insurance or with Medicaid coverage experience delays in diagnosis, limited access to standard interventions, and diminished survival rates [31]. A lack of insurance or having limited insurance often correlates with

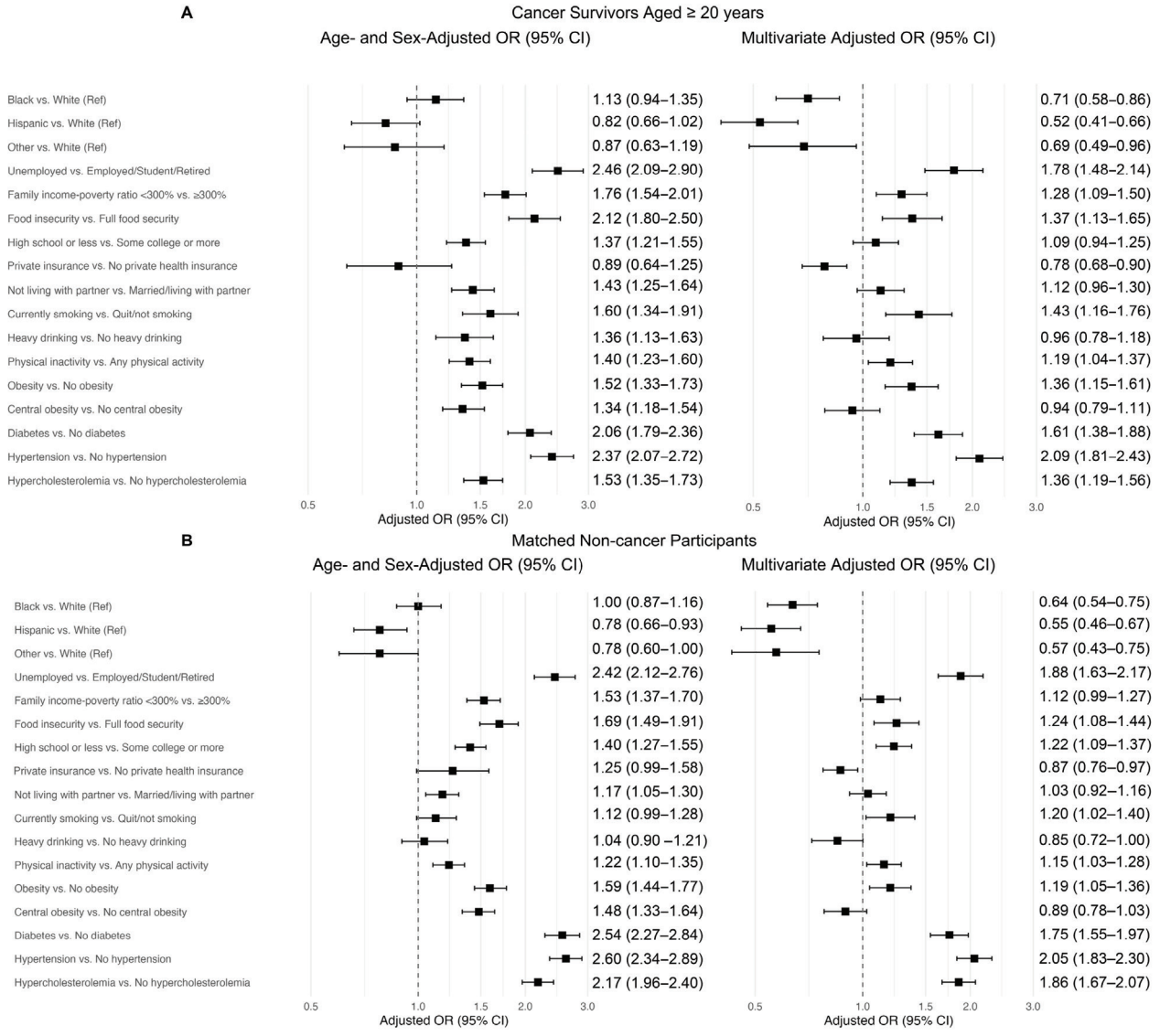

Figure 1 Multivariable-adjusted ORs (95% CIs) of social, lifestyle, and clinical factors associated with (A) U.S. cancer survivors ≥20 years of age and (B) matched participants without cancer.

lower SES, financial challenges, inconsistent medication adherence, and limited access to optimized survivorship care [32, 33]. Furthermore, our findings confirmed previously described associations of food insecurity and poor nutrition with elevated CV prevalence [34]. In the future, healthcare policies for cancer survivors aimed at enhancing food assistance programs and promoting access to healthful food should be strongly considered, to improve CV health [35].

Non-White participants exhibited a lower prevalence of age-and-sex-adjusted CVD than White individuals. This observation was more pronounced after adjustment for SES, lifestyle, and clinical factors. These findings support the results of prior studies in the general population [18, 36–39]. In the Multi-Ethnic Study of Atherosclerosis, race-based disparities (Black vs White) in CVD mortality disappeared after adjustment for SES, as well as clinical, lifestyle, and psychological candidate factors [35]. In a recent analysis of NHANES general population data, Hispanic participants showed significantly lower CVD mortality after adjustment for SES, lifestyle, and clinical factors [18]. In the Multiethnic Cohort Study, the Hispanic group, compared with the White cohort, had lower prevalence of SES, lifestyle, and clinical factors, as well as modestly lower rates of CVD mortality, in the

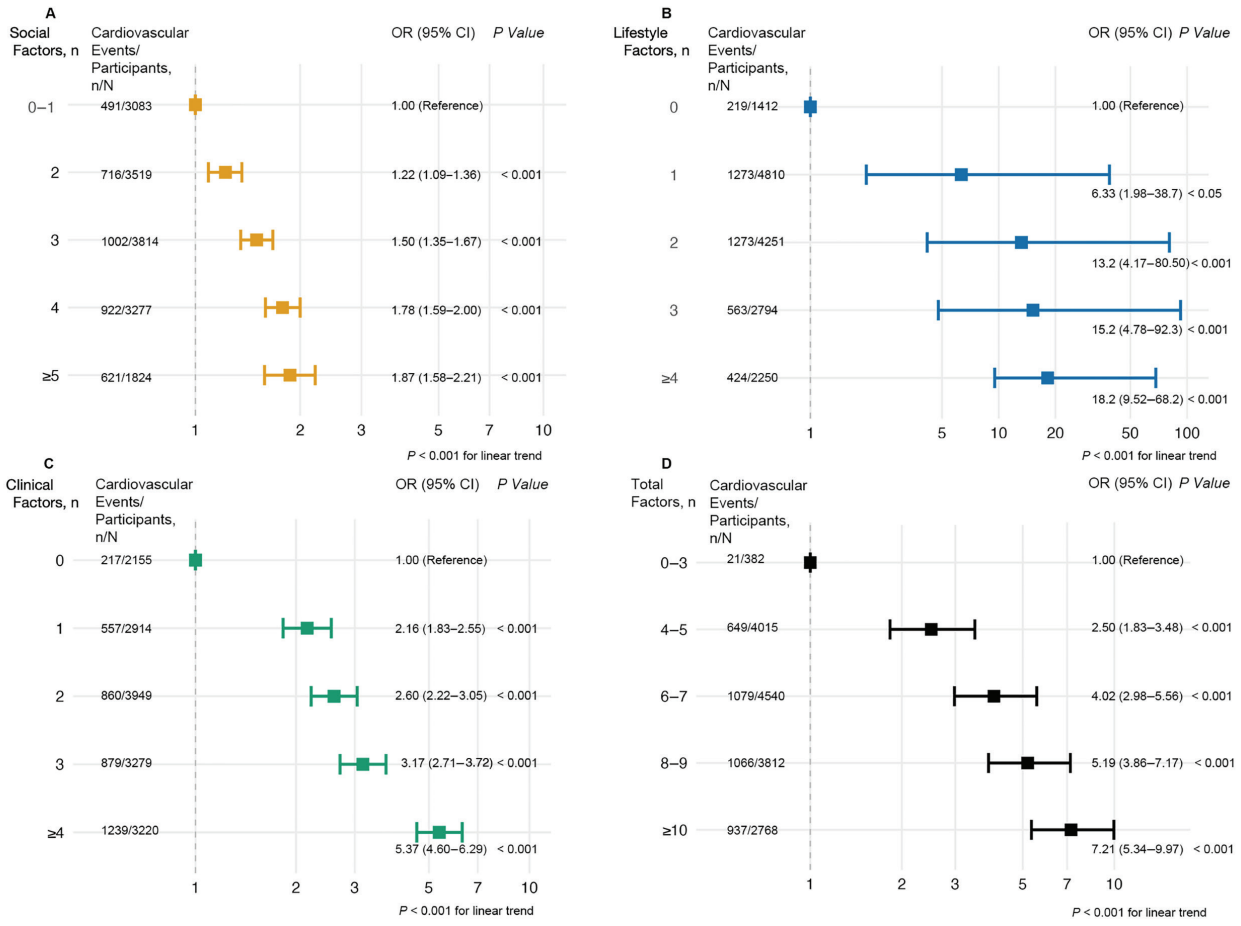

Figure 2 OR of CVD events associated with the number of social, lifestyle, and clinical factors in the U.S. adult population with cancer. OR of CVD events stratified by (A) the number of socioeconomic factors; (B) the number of lifestyle factors; (C) the number of clinic metabolic factors; and (D) the number of examined factors. CVD, cardiovascular disease. For (B), the age factor was more than 40 or less than 40 years.

multivariate-adjusted model [37]. Moreover, the Office of Minority Health from the U.S. Department of Health and Human Services has documented lower rates of CVD incidence and mortality in Hispanic American adults than non-Hispanic White adults [36]. Specifically among cancer survivors, differences in CVD mortality between Black and White individuals were decreased, and the Hispanic group also showed lower CVD mortality, in the multivariate-adjusted model [39]. Collectively, the above findings highlight the importance of the social construct of race, because of its associations with non-race-based social determinants of health, including education, food security, and insurance status. Additional studies are needed to further explore and describe the complex interplay among SES factors (given their mutual associations), as well as between those factors and both lifestyle and clinical characteristics. Such studies would enable a more holistic characterization of our patients and communities, and facilitate personalized treatment strategies to enhance long-term CV health in cancer survivors.

Together, these findings underscore the need for future longitudinal studies to develop and validate CV assessment strategies integrating socioeconomic, lifestyle, and clinical factors in cancer survivors.

Study Limitations

This study has several notable limitations. First, because our study was cross-sectional, we

cannot establish the temporal sequence between the examined factors and prevalent CVD, and the findings should be interpreted as associations rather than evidence of causality. Reverse causation is possible, and potential residual confounding from unmeasured factors cannot be excluded. Second, data regarding CV comorbidities and the examined factors were self-reported. Although this aspect is a standard limitation of survey-based research, recall bias and misclassification might have been introduced. This broad, self-reported definition is likely to have contributed to the high prevalence of the composite outcome. Consequently, the absolute probability estimates from the model should be interpreted with caution, whereas the relative associations between studied factors and CVD are likely to be more robust. However, prior research has shown that self-reported CV conditions in NHANES are generally reliable and align well with medical records [6, 18]. Third, the MissForest imputation is based on an assumption that data are missing at random; violations of this assumption might have biased the results. To address this concern, we performed the same analyses on complete case analysis, which yielded similar outcomes. Fourth, the cancer survivor group showed heterogeneity in cancer type, stage, medication status, and time since diagnosis. However, this heterogeneity was not accounted for and might have limited the model's applicability to specific subgroups. Although adjustments were made for known confounders, residual confounding from unmeasured factors, such as genetic predisposition, stress, or treatments, remains possible. Fifth, our findings represent associations with CVD prevalence, and prospective longitudinal cohorts are required to validate these factors. Our validation was temporal and restricted to later NHANES cycles, which shared the same sampling strategy, measurement protocols, and U.S. healthcare context as the derivation cohort. We did not evaluate our findings in an independent, clinically assembled cohort of cancer survivors or in geographically or ethnically distinct populations. Consequently, the study's generalizability and clinical utility outside NHANES, particularly to other healthcare systems and non-U.S. populations, remain unknown and require dedicated external validation studies before implementation. Finally, our findings represent associations with prevalent CVD in a cross-sectional setting. Therefore, the results should not be interpreted as evidence of predictive performance or causal relationships. Future longitudinal studies are required to validate these associations and to determine their utility in CVD events.

Conclusion

Our study identified distinct association patterns of socioeconomic, lifestyle, and clinical factors with prevalent CVD among cancer survivors vs a population without cancer. Although traditional CVD-associated factors, which are prevalent in the general population, also affect cancer survivors, certain socioeconomic factors, specifically food insecurity, low education level, and a lack of private or any health insurance, were associated with the prevalence of CVD events in this group. This differential association underscores the particular challenges faced by cancer survivors, and highlights the need for specialized CVD assessment and management strategies tailored to their specific circumstances. However, these findings should be interpreted cautiously, because the outcome was self-reported and might have been subject to recall bias and misclassification. Future cardio-oncology research should follow an interdisciplinary approach integrating insights from clinical practice, patient experiences, sociology, and health equity metrics [40]. Such a multifaceted strategy would facilitate a deeper understanding of health equity in CVD outcomes in the population with cancer and potentially lead to novel treatments and interventions addressing both cancer and CVDs, which together are the leading causes of mortality worldwide.

Data Availability Statement

The datasets analyzed in this study were derived from publicly accessible NHANES resources. All relevant data are presented within the manuscript, and additional supporting materials can be obtained from the corresponding author on reasonable request.

Ethics Statement

No direct interactions with human or animal subjects were involved. Therefore, ethical approval and informed consent were not required.

Author Contributions

AS, YL, and JS contributed equally as co–first authors. PL, MJ, and JP are co–corresponding authors. AS, YL, and JS were responsible for conceptualization, methodology, formal analysis, data curation, drafting, and visualization. PF, KH, YS, WB, and PJ contributed to investigation. WB, EA, PL, MJ, and JP provided critical review and editing. PL, MJ, and JP supervised the study, managed the project, and secured funding.

Funding

This study received funding support from the National Natural Science Foundation of China (82421001, U21A20341, 82470394, and 82300365); Shanghai Municipal Science and Technology Commission (24DZ2202700, 25Y12800500); China Postdoctoral Science Foundation (2023M742339 and 2025T180615); Shanghai Key Laboratory for Nucleic Acid Chemistry and Nanomedicine (2025ZYC017); and Shanghai Pujiang Programme (25PJD073).

Acknowledgements

The graphical abstract was created in BioRender (https://www.biorender.com/).

Conflicts of Interest

Jun Pu is Co-Editor-in-Chief of *Cardiovascular Innovations and Applications* but was not involved in the peer-review or handling of the manuscript. The other authors have no other competing interests to disclose.

Supplementary Material

Supplementary Material for this article can be found at the following link https://cvia-journal.org/wp-content/uploads/2026/05/CVIA_520_SUPPLEMENTARY_MATERIALS.docx. The file names are listed below.

Table S1: Candidate Social, Lifestyle, and Clinical Factors Among Study Participants.

Table S2: Summary of Cancer Types and CVD Events.

Table S3: Age and Sex Adjusted Odds Ratios of Social, Lifestyle, and Clinical Factors Associated with Cardiovascular Disease in U.S. Cancer Survivors 20 Years or Older.

Table S4: Age and Sex Adjusted Odds Ratios of Social, Lifestyle, and Clinical Factors Associated with Cardiovascular Disease in the Matched Non-Cancer Group.

Table S5: Multivariable Odds Ratios of Social, Lifestyle, and Clinical Factors Associated with Cardiovascular Disease in U.S. Cancer Survivors 20 Years or Older.

Table S6: Multivariable Adjusted Odds Ratios of Social, Lifestyle, and Clinical Factors Associated with Cardiovascular Disease in the Matched Non-Cancer Group.

Table S7: Multivariable Adjusted Odds Ratios of Factors Associated with Cardiovascular Disease and Their Interactions with Cancer Status in U.S. Adults 20 Years or Older.

Table S8: Multivariable Adjusted Odds Ratios of Social, Lifestyle, and Clinical Factors Associated with Cardiovascular Disease in U.S. Cancer Survivors 20 Years or Older (Different Cut Points).

Table S9: Age and Sex Adjusted and Multivariable Odds Ratios of Social, Lifestyle, and Clinical Factors Associated with Cardiovascular Disease in U.S. Cancer Survivors 20 Years or Older (Complete Case Analysis).

Table S10: Sensitivity Analyses of Associations Between Associated Factors and Major Individual CVD Outcomes Among Cancer Survivors.

Figure S1: Pairwise Correlations Among Social, Lifestyle, and Clinical Factors in U.S. Cancer Survivors 20 Years or Older.

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