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This is the final peer-reviewed author's accepted manuscript (postprint) of the following publication:

Published Version:

Farinetti, A., Cocchi, C., Coppi, F., Mattioli, A.V. (2026). The Exposome, Social Determinants, and Environmental Pollution: Comprehensive Cardiovascular Risk in Women. AMERICAN JOURNAL OF LIFESTYLE MEDICINE, 20(5), 752-759 [10.1177/15598276241313329].

Availability:

This version is available at: <https://hdl.handle.net/11585/1002113> since: 2026-08-03

Published:

DOI: <http://doi.org/10.1177/15598276241313329>

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The Exposome, Social Determinants, and Environmental Pollution: Comprehensive Cardiovascular Risk in Women

Alberto Farinetti^{1*}, Camilla Cocchi ^{2*}, Francesca Coppi ¹, Anna Vittoria Mattioli ³

**The first two authors equally contributed to the preparation of the manuscript*

- 1 Department of Medical and Surgical Sciences for Children and Adults, University of Modena and Reggio Emilia, Modena, Italy
- 2 University “Cattolica del Sacro Cuore”, Rome, Italy
- 3 Department of Quality of Life Sciences, University of Bologna-Alma Mater Studiorum, Bologna, Italy.

Word count: 3,077

Type of article: **Perspectives**

ORCID:

Mattioli Anna Vittoria: 0000-0003-1487-9530

Authors disclosure: no conflict of interest

Funding: none

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Abstract

Cardiovascular disease (CVD) remains a significant global health concern for women, influenced by a complex interplay of social, economic, and environmental factors. This article examines cardiovascular risk through the lens of the exposome, which encompasses all environmental exposures from conception onward, including pollution, diet, and chronic stress. Social determinants such as socioeconomic status (SES), education, and stress management play crucial roles in shaping women's cardiovascular health. Lower SES and education are associated with greater exposure to adverse living conditions, poor nutrition, and limited access to healthcare, increasing the risk of CVD. Environmental pollution, particularly air pollution and climate-related changes, further exacerbates cardiovascular risk by promoting oxidative stress and inflammation. Additionally, gender-specific factors, such as pregnancy and menopause, interact with the exposome, heightening the vulnerability of women to cardiovascular risks over their lifetime. Addressing these risk factors requires a comprehensive approach, incorporating public health strategies that focus on reducing pollution, improving food security, and mitigating social inequalities. By addressing the cumulative and interacting exposures that contribute to cardiovascular disease, especially in women, more effective prevention strategies can be developed to improve long-term health outcomes.

Key word: exposome; cardiovascular prevention; climate change; pollution; socioeconomic status; women; gender.

Introduction

Cardiovascular disease (CVD) is a significant concern for women globally, but preventing it requires addressing a complex web of social and environmental factors. ^{1,2,3}

These determinants profoundly influence women's cardiovascular health, often beginning early in life and across women's lifespan. ¹⁻⁶ Furthermore, the widespread misconception that women are only at risk of cardiovascular disease after menopause can cause young and adult women to underestimate their risk, leading to a lack of proactive preventive measures during these critical years. ^{2,3,6} To improve outcomes, we must understand these influences and implement early prevention strategies.

The Exposome and Cardiovascular Risk in Women

Exposome refers to the sum of all environmental exposures an individual encounters throughout life. ^{7,8} This includes external factors (pollution, diet, lifestyle choices) and internal processes (metabolism, inflammation). ⁹ The exposome differs by gender, due to differences in occupational exposure, societal roles, and biological responses to environmental stressors. ⁷⁻¹⁰ Discuss how women's specific exposome, shaped by social roles and responsibilities, interacts with cardiovascular risk factors.

Understanding cardiovascular risk in women through the lens of the exposome provides a comprehensive approach that integrates how diverse environmental and social factors cumulatively affect health outcomes over a lifetime.

The exposome framework shifts the focus from individual risk factors to a broader understanding of how environmental exposures interact over time to influence disease risk. ⁷⁻¹⁰ CVD is influenced by multiple, long-term exposures, including pollution, socioeconomic factors, stress, and diet. For women, these exposures interact with biological factors such as hormonal changes throughout life, further shaping cardiovascular risk. ^{10,11}

Key Components of the Exposome in Women's Cardiovascular Health.

Socioeconomic Status (SES) and education:

SES is a significant component of the exposome, influencing access to healthcare, quality nutrition, safe living environments, and the ability to manage stress. Women in lower socioeconomic brackets are more likely to live in polluted areas, have limited access to healthcare, and face chronic stress—all factors that amplify cardiovascular risk. SES shapes lifestyle behaviors, such as physical inactivity and smoking, which further contribute to heart disease. SES encompasses various factors such as income, occupation, and social status, all of which can profoundly influence access to healthcare, healthy lifestyles, and overall well-being. ¹ Women from lower SES backgrounds often face numerous barriers, including limited access to healthcare, healthy foods, and safe environments for physical activity. ^{1,2,12,13}

These barriers contribute to higher rates of obesity, hypertension, and diabetes, all of which are major risk factors for CVD. ^{3,14}

In a previous study, we found that women with lower SES had a significantly higher risk of asymptomatic peripheral arterial disease. ¹⁵ We analyzed the influence of SES on cardiovascular disease in a population of apparently healthy women screened for peripheral arterial disease (PAD). ¹⁵ This connection was linked to the many barriers low SES individuals encounter in maintaining a healthy lifestyle. Women from lower SES backgrounds, for instance, are more likely to struggle with obesity and smoking—both major contributors to CVD risk. ¹⁵ These challenges are compounded by limited access to heart-healthy resources, such as nutritious foods, safe spaces for physical activity, and preventive healthcare services. In contrast, individuals with higher SES are more likely to adhere to health-promoting diets, like the Mediterranean diet, and engage in regular physical activity, which protect against CVD. ¹⁵

We further underscored the role of education as a critical factor. Higher levels of education enhance health literacy, empowering individuals to make informed decisions about their health, including dietary choices, exercise habits, and smoking cessation. This disparity in health knowledge and access creates a cycle in which lower SES groups had greater difficulty in adopting preventive behaviors, further exacerbating health inequalities.¹⁵ Globally, these patterns are consistent, with SES emerging as a central determinant of cardiovascular health. Addressing these disparities requires robust public health strategies that focus on reducing barriers to healthcare access, improving education on healthy lifestyles, and tackling the structural inequities that perpetuate poor health outcomes. By doing so, it is possible to mitigate the disproportionate cardiovascular burden faced by lower SES populations and improve overall public health outcomes.

Lower SES is associated with reduced access to resources that promote a healthy lifestyle, such as safe environments for physical activity, affordable healthy foods, and health education programs. Consequently, women in lower SES brackets are more likely to adopt unhealthy behaviors such as smoking, poor diet, and physical inactivity, all of which contribute to elevated cardiovascular risk.

Wang Q. and coworkers investigated the association between SES with CVD and cardiovascular risk factors (CVRFs) and performed a meta-analysis of 31 eligible studies.¹⁶ They concluded that SES is inversely correlated with CVD outcomes. Women are more sensitive to income and education in terms of CVD incidence, while men are more sensitive to income and education in terms of CVD mortality.

Financial instability, job insecurity, and living in deprived neighborhoods contribute to chronic stress and mental health issues. The Continuous National Health and Nutrition Examination Survey (NHANES) study found a significant relationship between poverty and increased risk of arteriosclerotic cardiovascular disease.¹⁷ The study also found that

lower socioeconomic status was associated with higher cause-specific and all-cause mortality.¹⁷

Education plays a crucial role in cardiovascular health outcomes, with higher educational levels often linked to better health literacy, healthier lifestyles, and improved access to healthcare resources.^{18,19} Studies show that individuals with lower educational status have a higher prevalence of unhealthy lifestyle behaviors and poorer cardiovascular health, leading to increased mortality risk.^{11,18,19} Specifically focusing on women, research highlights significant gaps in awareness and knowledge of CVD risk factors among those of reproductive age, with limited understanding of symptoms and risk factors contributing to delayed diagnosis and poorer outcomes.²⁰ Lower educational attainment is independently associated with an increased risk of all-cause and CVD mortality, emphasizing the importance of education in empowering individuals to make informed decisions about their health and adhere to preventive measures and treatments.²¹ Furthermore, educated women are more likely to engage in health-promoting behaviors such as regular exercise, balanced diets, and avoiding smoking and excessive alcohol consumption.²² These behaviors significantly reduce the risk of developing cardiovascular diseases. Higher education often leads to better job opportunities and financial stability, which can reduce stress and its negative health impacts.²³ Educational attainment has distinct associations with ideal CV health that differs by race and ethnicity, and the need to elucidate barriers preventing individuals from racial and ethnic minority groups from achieving equitable CV health is demonstrated.²³ Additionally educated women are more likely to have strong social networks that provide emotional and practical support, further promoting cardiovascular health.²⁴⁻²⁶

Combined Effects of SES and Education

The interaction between SES and education significantly influences cardiovascular risk, especially for women facing lower education levels and economic challenges. SES, including factors like household income and occupation, is associated with a higher risk of cardiovascular disease and mortality, emphasizing the impact of social disadvantage on health outcomes.²⁷ Additionally, a polysocial risk score incorporating living environment, socioeconomic, and psychosocial factors is linked to an increased incidence of atherosclerotic cardiovascular disease, highlighting the multifaceted nature of risk factors in cardiovascular health.²⁸

Addressing these compounded barriers through targeted prevention strategies and improved access to healthcare is crucial in mitigating the heightened cardiovascular risk faced by women with lower education levels and economic hardships. Addressing these disparities requires community-level interventions and policy changes aimed at improving access to healthcare, providing education on healthy lifestyles, and creating supportive environments.^{1,3} Public health initiatives should focus on reducing economic barriers and promoting education to empower women to take control of their cardiovascular health.

Chronic Stress

Stress can profoundly impact the cardiovascular system through several physiological mechanisms, including the activation of the sympathetic nervous system, the hypothalamic-pituitary-adrenal (HPA) axis, and inflammatory pathways.^{6,12,29,30}

When stress activates the sympathetic nervous system, it leads to the release of catecholamines such as epinephrine and norepinephrine from the adrenal glands. These hormones increase heart rate, cardiac output, and blood pressure. Prolonged activation of the sympathetic nervous system can result in hypertension and elevate the risk of cardiovascular diseases. Chronic stress disrupts the balance between the sympathetic and

parasympathetic branches of the autonomic nervous system. This imbalance, characterized by heightened sympathetic activity and reduced parasympathetic tone, can lead to alterations in heart rate variability, blood pressure dysregulation, and increased susceptibility to arrhythmias.³¹ Stress also triggers the HPA axis.³² This process begins with the release of corticotropin-releasing hormone from the hypothalamus, which then stimulates the pituitary gland to produce adrenocorticotrophic hormone (ACTH). ACTH prompts the adrenal glands to release cortisol. Cortisol affects the cardiovascular system by increasing heart rate, promoting vasoconstriction, and enhancing the mobilization of glucose and fatty acids for energy. Chronically elevated cortisol levels can lead to insulin resistance, dyslipidemia, and inflammation, all of which are risk factors for cardiovascular diseases.³³ Chronic stress fosters a persistent inflammatory response in the body through the release of pro-inflammatory cytokines and the activation of immune cells. This low-grade inflammation is linked to endothelial dysfunction, oxidative stress, and plaque formation in the arteries, contributing to the development and progression of atherosclerosis. The inflammatory processes in the cardiovascular system heighten the risk of coronary and vascular artery disease.^{6,30,33} Stress-induced activation of the sympathetic nervous system and HPA axis can cause endothelial dysfunction, which is marked by reduced production of nitric oxide, a potent vasodilator. Impaired endothelial function results in vasoconstriction, inflammation, and thrombosis, further exacerbating cardiovascular risk.^{33,34}

Strong social networks can significantly influence cardiovascular health by providing emotional support and resources that help women manage stress.^{6,12} Women with robust social support systems are more likely to engage in health-promoting behaviors and experience less severe stress, which is a known risk factor for cardiovascular diseases.

Environmental Factors

Air Pollution

Environmental determinants, including pollution and climate change, further exacerbate cardiovascular risks. Air pollution, especially particulate matter and ozone, has been linked to increased cardiovascular disease risk. These pollutants can cause inflammation and oxidative stress in the cardiovascular system, accelerating the progression of atherosclerosis. ³⁵⁻³⁸

Climate change affects food by causing changes in nutritional composition that lead to nutrient depletion and an inadequate diet. ³⁹ This affects the development of chronic diseases which are strongly influenced by the diet. The favorable effects of good adherence to a healthy diet are partially attenuated by the poor quality of food. ⁴⁰⁻⁴²

The Lancet Commission on pollution and health has cited pollution as the foremost environmental cause of morbidity and premature mortality. ⁴² According to the Global Burden of Diseases study, pollution accounted for 5.5 million CVD-related deaths in 2019, and epidemiologic studies estimate that pollution could cause 6–9 million deaths annually through 2060, given the current and projected levels of global pollution. ⁴³ Despite acknowledging this significant public health threat, there is a lack of data supporting effective strategies to mitigate the impact of pollution on CV health.

In addition to the direct effects of pollution on the vascular system, on the endothelium and on inflammation, we must consider the indirect effects which are determined by changes in foods. Poor nutrition can exacerbate the effects of risk factors for CVD on chronic inflammation and oxidative status. ³⁹

Climate Change and Diet

Poor nutrition is another significant factor in the exposome, with diet contributing to both direct cardiovascular risk (via cholesterol, blood pressure, and obesity) and indirectly

through its impact on inflammation and metabolic health. ^{39,40} Access to a healthy diet is often determined by SES and geographic location, with many women in lower-income brackets exposed to unhealthy food environments that promote processed, high-fat, high-sugar diets. ⁴⁴ The relationship between climate and food is bidirectional: agriculture and the entire food supply chain are among the main drivers of climate change, which in turn has a serious impact on food systems, contributing significantly to poor food quality. In fact, about 30% of global greenhouse gas emissions (GHG) are caused by food systems, equivalent to the combined emissions of all cars, trucks, planes and ships. Poor food quality can exacerbate chronic inflammation and oxidative status, promoting the development of chronic non-communicable diseases.

Climate change is an emerging threat to cardiovascular health. Climate-induced crop failures and extreme weather events can exacerbate food shortages and cause price spikes, making nutritious foods less accessible and driving consumption of cheaper, less healthy foods. ^{39,44,45} Water scarcity impacts the availability of fresh fruits and vegetables, which are vital to maintaining a heart-healthy diet. Furthermore, climate change affects food security by disrupting food supply chains and reducing access to fresh and healthy foods. ^{39,44,45} This can lead to increased consumption of processed foods high in salt, sugar and unhealthy fats, which further increase cardiovascular risk. ³⁹

Extreme weather events, such as heatwaves, can strain the cardiovascular system, leading to heat-related illnesses and increased mortality.

The Mediterranean Diet (MedD) is not only renowned for its health benefits but also plays a crucial role in addressing climate change challenges. ⁴⁴ Research highlights that the MedD, rich in bioactive compounds like polyphenols, is rooted in biodiversity and offers a sustainable food culture. ^{44, 46} However, deviations from the ideal MedD in Mediterranean countries, particularly due to meat overconsumption, contribute significantly to GHG and climate impact, with dietary patterns in these countries showing double the expected GHG

levels from a sustainable diet. ^{44,47} Furthermore, the Eastern Mediterranean Region faces vulnerability to climate change impacts, affecting water and food security, which in turn worsens the nutritional status of vulnerable populations, including women, infants, and those in poor households. ⁴⁸ Therefore, promoting adherence to the MD can not only improve health but also contribute to mitigating the effects of climate change.

Life Stages, Hormonal Changes, and the Female Exposome

The cardiovascular risk exposome for women is further complicated by “life stage-specific factors” such as pregnancy, menopause, and the use of hormone replacement therapy (HRT). These stages influence how environmental exposures, such as pollution or poor diet, interact with hormonal changes to impact cardiovascular health. ³

Pregnancy serves as a crucial period for early prevention of cardiovascular disease due to its role as a window into future cardiovascular health (CVH). ⁴⁹⁻⁵³ Adverse pregnancy outcomes, such as hypertensive disorders, gestational diabetes, and preterm birth, are linked to an increased risk of subsequent cardiovascular disease development, emphasizing the importance of monitoring CVH during the peripartum period. Women with a history of pregnancy complications should receive postpartum check-ups to assess cardiovascular risk and initiate timely interventions, including lifestyle modifications and pharmacological treatments, to mitigate future cardiovascular disease risks. ^{54,55}

Additionally, gestational hypertension and preeclampsia are viewed as stress tests that reveal latent endothelial dysfunction, highlighting the need for continued follow-up post-pregnancy for early prevention of cardiovascular diseases. ⁵⁶ Optimizing cardiovascular health before pregnancy is crucial, as interventions solely during pregnancy may have limited impact, making pre pregnancy care a critical focus for cardiovascular health optimization and prevention of adverse outcomes for both the mother and offspring. ⁴⁹⁻⁵³

The American Heart Association (AHA) developed a consensus document on cardiovascular health in young women before pregnancy.⁵⁰ The consensus suggested the pre pregnancy evaluation of using Life's Essential 8. The Life's Essential 8 framework includes eight key health factors: diet, physical activity, no smoking, body mass index, blood pressure, lipids, and blood sugar and sleep health. Furthermore, the consensus underlines the fundamental role of 3 pillars: stress/resilience, social determinants, structural policies.⁵⁰ These determinants include socio-economic factors, social determinants of health, access to healthcare and resources, as well as mental well-being. Stress and depression experienced by mothers during pregnancy negatively influences the development of the fetus and is associated with increase the risk of cognitive, behavioral and emotional difficulties in offspring.^{50,52,53,55}

During pregnancy, women are typically more health-conscious and frequently interact with healthcare providers, making it an ideal period to promote long-term health habits. Menopause is a corner stone in cardiovascular risk in women. During menopause, the decline in estrogen makes women more vulnerable to the negative effects of their accumulated exposome. For example, postmenopausal women exposed to high levels of air pollution or stress may experience a sharper rise in blood pressure and cholesterol, increasing their heart disease risk.^{3,52,55}

The cumulative nature of the exposome is critical in understanding women's cardiovascular risk. Unlike isolated exposures, the exposome considers how repeated and sustained exposures—whether to pollutants, stress, or poor diet—accumulate over time to impact health. This chronic exposure to adverse environmental conditions leads to persistent inflammation, oxidative stress, and metabolic dysregulation, all of which contribute to cardiovascular disease development. Women's unique social roles and biological factors, such as pregnancy and menopause, modulate how they interact with these exposures, making their cardiovascular risk profile distinct from men's.⁵⁷

Addressing the Exposome to Improve Cardiovascular Outcomes in Women

Given the progressive nature of atherosclerosis, cardiovascular prevention must start early.¹⁻⁴ Understanding cardiovascular risk in women through the lens of the “exposome” highlights the need for a comprehensive approach to prevention. By addressing the cumulative environmental exposures that women face—ranging from pollution and stress to poor diet and social inequality—public health efforts can more effectively reduce cardiovascular disease in this vulnerable population. Women's cardiovascular health is shaped by the interactions of these lifelong exposures, and mitigating these risks requires action at both the individual and societal levels.

To reduce cardiovascular risk in women, public health strategies must address the exposome holistically. Strategies for early prevention include health education and promotion as well as policy and structural changes. Educating women about the importance of cardiovascular health and the impact of social and environmental determinants can empower them to make healthier choices.⁵⁸ Public health initiatives should focus on reducing socioeconomic disparities, improving access to healthcare, and creating supportive environments that promote physical activity and healthy eating.⁵⁹⁻⁶¹ Incorporating stress reduction techniques such as mindfulness, yoga, and cognitive-behavioral therapy can help improve cardiovascular health.⁶ Policies aimed at reducing pollution and mitigating climate change can have a positive impact on cardiovascular health. Urban planning that promotes green spaces and reduces traffic pollution can help lower cardiovascular risks. Ensuring food security through sustainable agriculture and resilient supply chains can improve access to nutritious foods, supporting cardiovascular health.

Conclusion

Preventing cardiovascular disease CVD in women requires a comprehensive approach that addresses the intricate web of social, economic, and environmental determinants influencing their health. Socioeconomic status and education significantly impact cardiovascular risk, with lower SES and educational levels associated with higher incidences of CVD due to limited access to healthcare, healthy foods, and safe physical environments. Chronic stress and mental health issues, often exacerbated by financial instability and deprived living conditions, further contribute to this risk. Environmental factors such as pollution and climate change also play a crucial role in cardiovascular health. Early prevention strategies, including health education and policy interventions aimed at reducing socioeconomic disparities and promoting supportive environments, are essential. Public health initiatives must focus on improving access to healthcare, promoting healthy lifestyles, and implementing policies to reduce pollution and mitigate climate change to empower women to take control of their cardiovascular health and reduce the global burden of CVD.

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