Review Article
Advancements in Life Sciences – International Quarterly Journal of Biological Sciences

ARTICLE INFO

Date Received: 12/12/2024;
Date Revised: 09/11/2025;
Available Online: 28/12/2025;

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How to Cite:
Beg MMA, Ashfaq F, Khan MI, Khan RM, Shrivastav D (2025). Contribution of Environmental Toxicants and Lifestyle in Development of Cardiovascular Diseases. Adv. Life Sci. 12(4): 710-720.

Keywords:
Lifestyle Factors; Pesticides; Environmental Toxins; Cardiovascular Diseases

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Contribution of Environmental Toxicants and Lifestyle in Development of Cardiovascular Diseases

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Abstract

Environmental pollutants and lifestyle factors are significantly contribute to the development of cardiovascular diseases (CVD), which are the major cause of mortality and morbidity worldwide. Exposure of heavy metals such as lead, chromium and Arsenic particulate matter (PM 2.5 and PM 10), and persistent organic pollutants like dichloro diphenyl trichloroethane and dichlorodiphenyl dichloroethylene are critical factors affecting cardiovascular health and cause CVD. Evidence suggests that these pollutants and various lifestyle choices such as smoking, and physical inactivity, activates multiple pathways including oxidative stress, systemic inflammation, and endothelial dysfunction thereby increasing risk of CVD. This review aims to critically analyze the complex relationship between environmental contaminants and sedentary lifestyle and their involvement in CVD risk.

Introduction

In the environment, various hazardous pollutants or environmental toxicants such as pesticides, plastic additives, contaminated soil, polluted water, and air pollution are present that negatively impact the health of human and other living organisms and can cause multiple disease. These toxicants can enter human body through various processes such as ingestion, inhalation, adsorption and absorption leading to diseases related to reproductive system, nervous system, intestinal disorder, bone disease, cancers and CVDs [1]. Nowadays the environment including soil, air, and water are contaminated by various hazards substances for example, air pollution by particulate matter (PM 2.5) which consist of fine particles smaller than 2.5 micrometers in diameter. The air is contaminated by various gases including carbon monoxide, sulfur dioxide, ozone, nitrogen oxides, heavy metals, volatile organic compounds which are emitted from vehicle exhaust, industrial activities and fuel combustion [2]. Water pollutants such as agricultural waste, industrial waste, pesticides, heavy metals, plastic additives, and others contaminate drinking water and cause waterborne diseases [3]. The soil becomes polluted with pesticides, heavy metals, plastic additives, and organic pollutants, which can potentially enter the food chain via cultivation of crops in contaminated soil [4].

CVDs are disorders of blood vessels and heart including heart failure, peripheral arterial disease, stroke, aortic disease and coronary artery disease. These diseases are major contributor to mortality and morbidity worldwide imposing a significant burden on individuals, families, and health care systems globally [5]. Nowadays the addressing growing burden of CVDs requires a multifaceted approach that targets risk factors, promotes early detection and support the management of healthy lifestyles and environments [6]. Additionally, it has been noted that besides exposure to environmental contaminants, some modifiable risk factors such as smoking, poor diet, and physical inactivity act as powerful contributors, intensifying the negative effects of these toxins and increasing the risk of CVD [7,8]. Figure 1 represents the various environmental pollutants and lifestyle factor involved in occurrence of CVD.

Socioeconomic effect of environmental toxicants

Environmental toxicants adversely affect the social and economic development of impacted populations in addition to their health, particularly in underprivileged communities where exposure to these hazardous substances is higher. According to the National Health and Nutrition Examination Survey (NHANES), environmental toxicants such as lead (Pb), cadmium (Cd), antimony (Sb), arsenic (As) mercury (Hg), thallium (Tl), cesium (Cs), , benzophenone-3, perfluorononanoic acid (PFNA), perfluorooctanoic acid (PFOA), mono(carboxyoctyl) phthalate, and three phthalates (mono-benzyl, mono-isobutyl, and mono-n-butyl) and bisphenol A have been associated and low blood pressure in children living in poverty [9]. Exposure to environmental toxins varies worldwide and depends on socioeconomic status. Countries with low socioeconomic experience higher exposure of dichlorodiphenyl dichloroethylene (DDE) and dichlorodiphenyl trichloroethane (DDT) whereas, higher socioeconomic status are more frequently exposed to polychlorinated biphenyls and mercury [10]. According to global health data, PM2.5-related illnesses and deaths resulted in economic losses about $5.7 trillion in 2016, or 4.8% of the global GDP. The highest costs were observed in South Asia and East Asia & the Pacific where expenses reach up to 7.3% and 5.4% of global GDP respectively, region largely comprises low- and middle-income population [11]. In Latin America and the Caribbean were cost 2.4% of GDP. The economic impact was particularly significant in countries like China and India (7.5–8%) and upper-middle-income countries (6.0%). Although the cost were lower in low-income countries (2.7%), but burden is still significant due to their inadequate health systems. Premature deaths accounted for about 87% of these expenses, demonstrating the fatal effects of unequal pollution exposure on susceptible groups [11]. The aim of this review is to critically the complex relationship between environmental contaminants and sedentary lifestyle and involved in CVD risk.

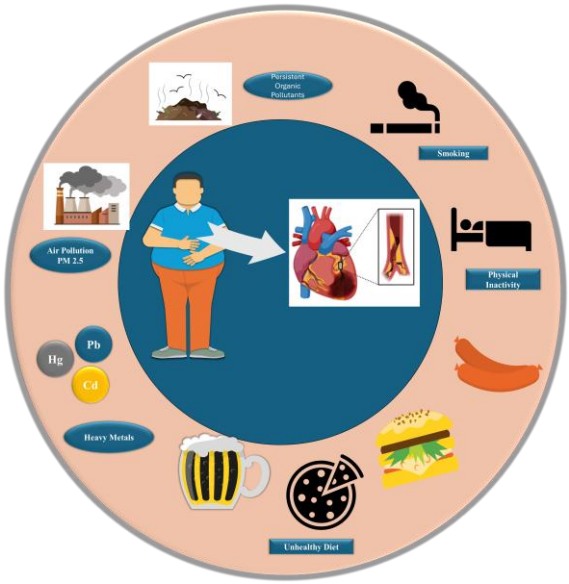

Figure 1: Various environmental pollutants contributing to the occurrence of cardiovascular disease.

Methods

Literature search strategy and selection criteria

The literature was searched in PubMed database using Boolean operators were used to combine relevant keywords like ("environmental pollutants" OR "air pollution" OR "particulate matter" OR "PM2.5" OR "heavy metals" OR "persistent organic pollutants" AND ("cardiovascular disease" OR "heart disease" OR "atherosclerosis") AND ("oxidative stress" OR "inflammation" OR "endothelial dysfunction"). To ensure the inclusion of recent and relevant research, further we applied filters to limit the results to papers that were published last five years free full text research articles and included relevant data.

First, records were identified from the PubMed database, resulting in 647 entries. Prior to screening, 387 records were excluded because they were published more than five years ago, 101 were removed due to unavailability of full text, and 138 were marked as ineligible for lack of associated data. In the next phase, 21 records were screened in detail. All 21 records were sought for retrieval and assessed for eligibility. During this assessment, studies were further excluded: 6 review articles, 6 studies involving non-human subjects, 1 study on non-cardiovascular disease, and 1 review article with only a study protocol. Ultimately, 7 studies were included in the final systematic review after following this rigorous selection process. The PRISMA diagram [12] represented in figure 2.

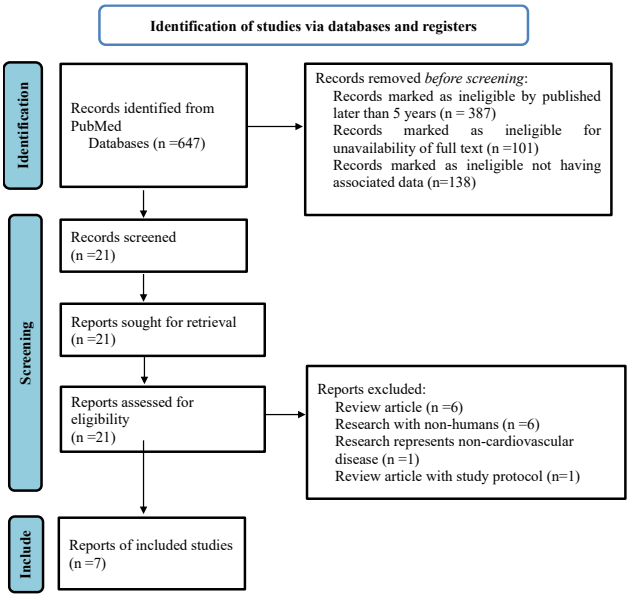

Figure 2: PRISMA diagram of selection of studies for literature review.

Discussion

S. No.	Country	Year	Environmental Toxicants	Participants	Specific Pollutants	Effect	Reference
1	UK	2021	Noise Pollution	502651	Noise in road traffic (more than 65 decibel)	TG, HbA1c, SBP, DBP	[13]
2	US	2021	Air Pollution	6,814	O3, NO2, PM 2.5 and SO2	(sLOX-1), NO cause vascular complication	[14]
3	US	2021	Air Pollution	503	PM >2.5	leukopoietic activity and arterial inflammation	[15]
4	USA	2021	Heavy Metal	392	Pb, Mn, Fe, and Zn	IL-6, IL-1β, and TNF-α	[16]
5	USA	2021	Air Pollution	299	PAH4, PAH5, PAH6, NO2, >PM2.5	HbA1c, SBP, DBP	[17]
6	China	2021	Air Pollution	7915	PM2.5, PM10, PM1, and NO2	hsCRP and inflammatory response	[18]
7	USA	2021	Organic Pollutants	615	1,3-Butadiene, Acrolein, and Crotonaldehyde	SBP, endothelial function, norepinephrine and normetanephrine	[19]

UK: United kingdom, USA: United State of America, US: United States, TG: triglycerides, SBP: systolic blood pressure, DBP: diastolic blood pressure, sLOX-1: Soluble lectin-like oxidized LDL receptor-1, IL-6: Interleukin -6, IL-1β: Interleukin 1 beta, and TNF-α: Tumour necrosis factor-alpha, PAH4, PAH5, PAH6: (polycyclic aromatic hydrocarbons with 4, 5, or 6 rings), NO_2: Nitrogen Dioxide, $PM_{2.5}$: Particulate matter $_{2.5}$, PM_{10}: Particulate matter$_{10}$

Table 1: Basic included study in systematic literature review.

This systematic literature review highlights significant effects of environmental toxicants on cardiovascular health and identify a few mechanisms by which these exposures lead to the development of disease, including oxidative stress, inflammation, and metabolic dysregulation. increased glycated haemoglobin Various environment toxicants and their pathophysiology (Figure 1) are given below.

Many environmental toxicants increase the risk of cardiovascular disease by several ways as follows. Noise pollution more than 65 decibel (db) from road traffic, increases glycated haemoglobin, serum triglycerides, and systolic and diastolic blood pressure, cause hemodynamic stress and metabolic disruption [13]. The air pollutants for example SO_2, NO_2, O_3, and PM 2.5 have been associated increased level of soluble lectin-like oxidised low density lipoprotein receptor-1 (sLOX-1), oxidative stress and vascular inflammation [14]. Additionally, exposure to PM 2.5 or higher, is significantly related with decreased leukopoiesis and contribute in inflammation within arteries [15]. Exposure to heavy metals like lead, manganese, and iron increased levels of interleukin -6 (IL-6), interleukin 1 beta (IL-1β), and tumour necrosis factor-alpha (TNF-α), cause immune-mediated vascular injury. [16]. Additionally, Traffic-related air pollution is associated with impaired glucose metabolism and hypertension by altering systolic blood pressure and HbA1c levels [17]. In environmental pollution the air pollution has a major contribution to increase risk of CVDs. The air particles, particulate matter (PM) 2.5 to

less than 10 micrometres are significantly associated with risk of CVDs [18]. Study from USA observed exposure of traffic-related air pollution is associated with increased risk of high blood pressure and CVDs [19]. These findings represent that various environmental toxicants impact the CVDs via several pathways that include oxidative stress, systemic inflammation, endothelial dysregulation, and metabolic disturbances (Table 1).

Cardiovascular disease and pollution

Globally, leading cause mortality and disability is CVDs. it is estimated that in 2019, approximately 18.6 million deaths reported in worldwide [20]. The pollution also known as unused and unwanted substances was through into environment by humans [21] which is another risk factor for occurrence of CVDs. Studies suggest that the small particle air (air pollution) can show some harmful effects in cardiovascular and circulatory systems [22,23]. The detailed pathophysiology of cardiovascular by pollution is as follows.

Pathophysiology of cardiovascular disease in pollution

The air borne particulate matter is the mixture of many chemical compounds and aerosol of small droplets; solid substance and their size vary. The size of PM 2.5 is 2.5 micrometres (μm) or less and size of PM 10 is 10 μm or less. Due to the small and tiny size of these particles may enter human body via various process like inhalation and travel to blood stream cause vascular toxicity and oxidative stress and reached to respiratory tract and impacting respiratory system [24]. Moreover, PM exposure affects the calcium regulation in cardiomyocytes and elevate cytosolic calcium levels and cause hypertrophy and contractility of cardiomyocytes. Overall combined effects of oxidative stress and increased calcium open pore of mitochondrial permeability and effect mitochondrial function and further harms the cardiovascular system [25]. In the cells of endothelium PM reduces nitric oxide and cause dysfunction of endothelial cells cause vasoconstriction [26]. Additionally, it causes oxidative stress and pulmonary inflammation, which activates the release of inflammatory cytokines. This inflammation cause endothelial dysfunction contributes to rupture of atherosclerosis plaques and cause thrombosis. Additionally, PM-induced ROS cause endothelial dysfunction, increase blood pressure, and activate the Rho/ROCK pathway [27,28].

Cardiovascular disease and heavy metals

Naturally, heavy metals are found in Earth's crust. Unfortunately, various industrial activities are introducing rapid and dramatic changes in the soil chemical cycle. These activities release heavy metals and affect plant and animal life. In the previous 50 years the exposure of heavy metals to human dramatically increases [29]. Nowadays the human body having exposure of approximate 23 heavy metals including iron, copper, chromium, cerium, arsenic, antimony, bismuth, cadmium, cobalt and zinc by residuals and occupational exposure **[30]**. Some heavy metals, although of minimal importance for good health and can be found in food chain but these heavy metals can be toxic and harmful when in high concentrations. In the excessive amounts can lead to decreased energy levels, damage, and deterioration of organs such as brain, lungs, liver, kidneys, blood vascular system. Heavy metals also affect various metabolic pathways and accumulate in organs like kidney, liver and brain and fluctuate normal physiology of these organs. The prolong exposure of heavy metals can cause life-threatening disease like neurodegenerative disease (Alzheimer's disease, Parkinsons disease), musculoskeletal (muscular dystrophy) and can also cause cancer. Toxic levels for some heavy metals can even be exceeded at concentrations slightly higher than their natural environment. It has been suggested that the heavy metal such as cadmium, lead and arsenic clinically associated with cardiovascular disease. [31, 32].

Lead (Pb), once commonly used in gasoline, paint, and plumbing related materials. In the US, gasoline released around 200,000 tons of lead into the air each year, exposing nearly all population. It is suggested that exposure of lead affects 14 million (approximately) years of healthy life lost and 0.54 million deaths globally in 2016. In India 4.5 million (approximately) years lost and nearly 165,000 deaths. In the 20th century the major source of lead was tetraethyllead (TEL) and gasoline which was used as anti-knock agent in automobiles and engines. It was observed that approximately 80-90 % of cities population were under exposure of lead air pollution. In 1970s the products having led (gas and paints) were banned for lowering the lead pollution. India phased out leaded gas from 1996-2000, and studies showed blood lead levels dropped by around 33-60% in major cities [33]. The contamination of Arsenic is a worldwide problem and poses a serious threat to various countries such as USA, India, China, Argentina, Bangladesh, Mexico, Taiwan and Chile. Humans are expose to Arsenic via by contaminated food and water especially pesticides used for agricultural and mining activities [34]. Cadmium used in batteries and cells, as well as in alloys, pigments, plastic stabilizers, paints, dyes, glassmaking, and galvanic industrial materials. The U.S. produces approximately 600 tons of cadmium compounds annually, with an additional 150 tons imported. Iranian

rice samples exceeded the FAO/WHO permitted cadmium level of 0.2 mg/kg, raising concerns about food safety and cadmium exposure through other farm products and seafood **[35]**. Study suggested that even low-level environmental cadmium exposure may contribute to heart failure risk, particularly in men [36].

Pathophysiology of cardiovascular disease by heavy metals

A common toxic heavy metal, cadmium, accumulates in the vascular endothelium and results in inflammation and endothelial cell death. Cadmium diffuses into the blood vessel's media layer and enters smooth muscle cells because of the endothelial integrity being compromised. Cadmium contributes to lipid accumulation and atherogenic lipid profiles there by upsetting ion homeostasis, producing cytotoxicity, and encouraging smooth muscle cell proliferation even at low concentrations [37]. Additionally, it raises levels of inflammatory cytokines, which accelerate the process of atherosclerosis and vascular inflammation. Prolonged exposure to cadmium causes endothelial dysfunction, decreases nitric oxide bioavailability, and increases total cholesterol. Cadmium may also affect myocardial metabolism and function by compromising mitochondrial respiration in heart muscle cells. Monocytes and macrophages loaded with cadmium can penetrate vessel walls and form foam cells, which start and encourage atherosclerotic plaques [38].

lead exposure also a major causative factor for cardiovascular disease via several pathways, such as increased blood pressure, oxidative stress, inflammation, endothelial dysfunction, and renal impairment. In animal models, atherosclerosis has been demonstrated to be caused by lead at even low concentrations (as low as 0.8 ppm in drinking water). Lead can cause vascular smooth muscle cells and fibroblasts to proliferate at concentrations ranging from 0.5 to 10 µM [39]. Additionally, it damages kidney function, which is a major cause of high blood pressure and heart disease. lead-induced oxidative stress and reactive oxygen species damages cellular constituents and encourages atherosclerosis. Additionally, there is increased inflammation, which leads to plaque development and vascular damage. The imbalance in nitric oxide (NO) levels caused on by inflammation and oxidative stress causes endothelial dysfunction, which is characterised by decreased vasodilation and increased permeability. Lead can also alter the cardiovascular system's autonomic regulation, which can result in arrhythmias and other cardiac problems [40].

Arsenic activates Rac1-GTPase in vascular cells through Gαi-coupled receptor subtypes, which in turn stimulates NADPH oxidase (NOX) activity, leading to superoxide anion (O_2^-) production, ROS generation, oxidative stress, endothelial dysfunction, and inflammation. [41]. The chronic exposure of arsenic disrupts nitric oxide signalling, which exacerbates endothelial dysfunction and affect adhesion molecules on cell surface, which increase leukocyte infiltration into blood vessel walls and accelerate the formation of atherosclerotic lesions. When combined, these effects increase the risk of arsenic exposure-related hypertension, atherosclerosis, and ischaemic heart disease and CVD [42].

Cardiovascular disease and Persistent organic pollutants

Persistent organic pollutants (POPs) act as non-degradable toxicants and environmental pollutants. These POPs are entering into food chain and build up in the living tissues, which have a bad impact on human health. These POPs are ranges of chemicals, including industrial chemicals like polychlorinated biphenyls (PCB), dichlorodiphenyltrichloroethane (DDT), and byproducts of industrial process (like dioxins and furans) [43]. These POPs affect immune system, reproductive system and endocrine system may cause cancer [44]. These POPs increase oxidative stress and affect lipid metabolism cause dyslipidaemia and increase accumulation of plaque in the arteries cause atherosclerosis that result in heart attacks and strokes. Additionally, it has been demonstrated they also dysregulation of blood pressure and increase hypertension risk [45]. In a Spanish cohort study authors observed that long term exposure (15 years) of POPs to human adipose tissue having organopesticide specifically PCB-153 and β-HCH increases the risk of CVD [46].

Pathophysiology of cardiovascular disease by Persistent organic pollutants (POPs)

These POPs are mainly affecting endocrine system and act as agonists or antagonists for receptor of various sex hormones and interfering with hormonal system. The POPs affect the ratio of ROS and antioxidants and ultimately generates oxidative stress. In Southern Spain, long-term POP exposure significantly raises public healthcare costs, with cohort expenses totaling €9.64 million over 14 years (54.6% hospital care, 45.4% primary care). Chronic diseases like cardiovascular conditions (62%), cancer (20%), and diabetes (15%) affected 76% of participants and drove these costs, with stronger links in semi-rural areas. [47]. This oxidative and free radical reacts with affects nitric oxide (NO) pathways and reduce its bioavailability and exacerbate endothelial dysfunction by damage endothelium layer by which lipid molecule can enter blood vessels and arteries and accumulate and cause atherosclerosis and

increase risk of CVD. Moreover, these POPs also activate various inflammatory pathways and increase release inflammatory [48].

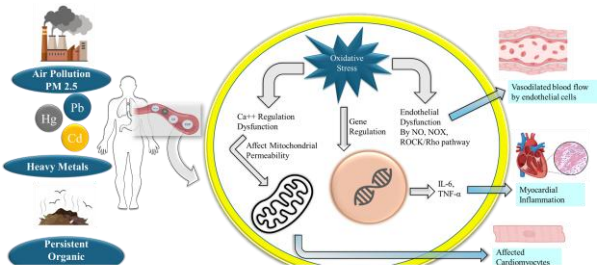

Figure 3: Pathophysiology of environmental pollutants cause cardiovascular disease; Diagram illustrated that the exposure of environmental pollutants by inhalation and digestion lungs and stomach move to blood and create oxidative stress inside cells which activates multiple pathway like ca2+ dysregulation which affect mitochondrial permeability, affect gene regulation and increases secretion of inflammatory cytokine and also cause endothelial dysfunction by affect level of Nitric oxide and Rho/Rock pathway which ultimately affect cardiomyocytes, myocardial inflammation and vasodilation of endothelial cells and overall increase risk of cardiovascular disease.

Lifestyle Factors and Cardiovascular Diseases

Smoking, poor eating habits, and lack of physical activity are major risk factor for the emergence of crippling CVDs, lifestyle factors those seemingly harmless decisions and behaviours that permeate our everyday lives can have a long and sneaky negative impact on cardiovascular health. Smoking is a dangerous habit resulting from a complex interaction of physiological, psychological, and social factors. Its components cause a significant molecular damage to the cardiovascular system (figure 3).

Smoking

In the lifestyle factors the smoking have a major contributing factor in occurrence of cardiovascular disease. Various hazardous chemical found in tobacco and smoke like carbon monoxide (CO) affect lungs and blood vessels and increase risk of CVD. The smoking major increases the level of triglycerides, reduce HDL (good cholesterol), increase the thickness of blood which can block brain and heart, affect endothelium cells and can increase atherosclerosis [49]. The carbon monoxide generated by smoking attach to haemoglobin, reduce the red blood cell's ability to carry oxygen and affecting tissue oxygenation [50].

Dietary factors

In the lifestyle factors the unhealthy diet is the major contribution in occurrence of CVD. The poor diet quality like foods with elevated refined grains, added sugar and salts, foods with preservatives and food with unhealthy fats, processed and ultra processed food, fried foods can significantly promote the risk of CVD. One of major components found in fried foods is advanced glycation end products (AGEs) which react with collagen of heart muscle reduce pumping capacity of heart muscle and ultimately cause heart disease. Moreover, the overconsumption of this unhealthy food can cause dyslipidaemia and the buildup of cholesterol rich plaques in the arterial walls cause atherosclerosis and [51]. The overeating unhealthy foods also cause Insulin resistance and affect glucose metabolism in body increase risk metabolic syndrome and which is another significant risk factors for CVD. Furthermore, poor dietary habits can affect the gut microbiota [52].

Physical inactivity

Physical inactivity or lack of regular exercise creates an imbalance between energy intake and expenditure and contribute to excess body fat and development of obesity which common risk factor for CVD [53]. According to physical activity guideline for Americans advisory committee intensive exercise for 2 hours 30 minutes or vigorous exercise for 1 hour and 15 minutes reduce the risk of CVD. Recent studies show that exercise reduce the body weight, decrease blood glucose, and decrease TG level. Several studies also suggested exercise increase the glucose uptake of glucose and insulin resistance by stimulating the transfer of glucose transporter-4 (GLUT 4) from inside the cell (cytoplasm) to outside the cell (plasma membrane) which reduce plasma glucose level and ultimately reduces risk of diabetes and CVD.

Microbiome

The lifestyle choices and dietary habits play a major role in affecting gut microbiota which also a significant risk factor for CVD. The consumption foodstuffs like liver, meats, egg yolks, nuts and bean, and high-fat dairy products having choline, free choline and choline esters, such as phosphatidylcholine (PC) or lecithin. Gut microbiota (*Clostridium sporogenes, Escherichia fergusonii, Clostridium hathewayi, Edwardsiella tarda, , Clostridium asparagiforme, Proteus penneri, Anaerococcus hydrogenalis, Providencia rettgeri)* metabolizes some dietary nutrients like phosphatidylcholine, choline, L carnitine and generate gut bioactive metabolite trimethylamine N-oxide (TMAO) [55-57]. Several studies suggested that TMAO actively contributes in development of atherosclerosis by formation of foam cells by macrophage and macrophage migration. It also increases accumulation of oxidized LDL into macrophages by upregulation of CD 36 expression by this process more macrophages converted into foam cells. This TMAO also increase the

synthesis of inflammatory markers, in response to inflammation macrophages start penetrating blood vessel through endothelial barrier and accumulate in intima media and start the plaque formation progress in atherosclerosis [58,59].

Preventive strategies and interventions for cardiovascular disease

Modifications in lifestyle

To mitigate the risk of CVD, it is important to follow a holistic approach it includes physical, mental, social health treatment. For the physical health treatment, the individual should have balance diet with rich in vegetables, lean proteins, good fat, fresh and seasonal fruits. The individuals must involve in physical activity minimum 150 minutes/weeks. The physical activity in the form of swimming, brisk walking, cycling, running etc. This physical activity maintains body weight, blood pressure and improves heart health. For the mental health, manage stress by truthful coping mechanism and practicing mindfulness, relaxation techniques, involve with enjoyable activities. The persons should avoid processed food, food with added sugars, saturated and trans-fat in their diet also quit smoking and avoid second hand smoke exposure. Reduce air pollution, toxic chemicals, and other environmental hazards exposure and advocating for stricter regulations, using eco-friendly products, and promoting sustainable practices. Individuals also visit for regular health check-ups, monitor cholesterol levels, blood pressure level and other relevant biomarkers, for early management and detection CVD risk. Individuals with existing conditions like hypertension or diabetes, closely follow prescribed medication regimens and consult healthcare professionals regularly [61].

Dietary Changes and their Molecular Benefits:

A healthy diet may have significant molecular benefits in the prevention of CVD. Changes in diet can affect a variety of biological pathways and processes that contributes to CVD risk. Eating a diet rich in green vegetables and fruits and whole grains rich in antioxidants, vitamins and phytochemicals [62]. These compounds can neutralize harmful free radicals, decrease oxidative stress and reduce inflammation, which increase the risk of CVD. Use healthy fats like olive oil, avocados, and fruits are included by lowering harmful and increasing beneficial LDL cholesterol HDL cholesterol can be improved [63]. Additionally, these fats contribute to the improvement of endothelial function and the regulation of inflammation, both of which are critical for the maintenance of healthy blood vessels. Dietary ingredients like flaxseeds and fatty fish are rich in omega-3 fatty acids, have anti-inflammatory and anti-thrombotic qualities that reduces the risk of blood clots and decrease risk of CVD. Reduce processed foods with saturated fats and added sugars in diet which can prevent the accumulation of AGEs and reduce insulin resistance which are also linked to elevated inflammation and oxidative stress and increase risk factor for CVD and metabolic disorder [52,64].

Increasing physical activity and its molecular impact

In the preventive strategies the physical activity has a major contribution. In the physical exercise including aerobic, physical training or both combat the negative impact of sedentary lifestyle and environmental toxicants [65]. The physical exercise promotes the synthesis of endothelial progenitor cells, which are essential for vascular regeneration and repair [66]. It is also suggested that routine exercise regulate lipid and glucose metabolism and lowering the insulin resistance, metabolic syndrome and dyslipidaemia risk and encourage healthy lipid profile. Studies also suggested that physical activity promote absorption of glucose by skeletal muscle [67].

Reducing exposure to environmental toxicants

As we already seen that the exposure of environmental toxicants can cause cardiovascular disease, therefor It is essential to limiting the exposure of toxicants via implementing major policies and strategies to mitigate the risk of CVD. It is important to make regulations and laws to reduce pollution emissions from transportation, industries, other resources of air pollution. it is also suggested that installation of common air filter system to eliminate PM < 2.5 and PM <10 from environment. To reduce exposure of hazardous chemical and POP, increase the use of eco-friendly, organic product [31]. Regulatory and governmental organizations and plays a critical role in in making policy decisions for reducing exposure of environmental toxicants and lowering the risk of CVD in general populations. Government should make some strict regulation to control [68]. Make regulations controlling manufacture of polychlorinated biphenyls (PCBs), and certain pesticides [69]. The preparation of new and strict guidelines for which maintains the quality standards of consumers goods and reduces the toxic substance from their products [70].

Personalized Risk Assessment and Molecular Biomarkers:

Assessment of CVD risk and prevention at individual level using genetic and molecular marker is very crucial. The health care individuals may accurately identify the risk factors of CVD by several molecular markers with using high-end technology and diagnostic

tools [71,72]. The regular monitoring of several biomarkers improves the understanding the stage of disease and assess the risk level. Recent advanced technologies for example genomics, proteomics and metabolomics in diagnosis of CVD and offers specific pathway for its development. So, health care provider can improve the diagnostic, prevention and create treatment plans and increase overall health outcomes in CVD patients [73].

Development of targeted interventions and biomarkers and therapeutics:

For the efficient treatment and prevention of CVD and the formation of targeted interventions and therapeutics by molecular and genetic markers play a major role. There are multiple pathways are suggested in which various genes and proteins which are involved CVD development in exposure of environmental toxicants and sedentary lifestyle. The several researchers suggested some biological drugs like monoclonal antibodies and gene therapy which target these gene and protein and improve the disease outcome [74]. These targeted agents are effective and have less side effects compared with traditional broad-spectrum therapies. Another interesting approach is to explore RNA therapies, including small interfering RNA (siRNA) and antisense oligonucleotides, which can selectively inhibit or repress the expression of pathogenic genes by specific molecular mechanisms contributing to heart disease In addition, researchers use stem cell therapies to repair or regenerate damaged cardiovascular tissue and explore the potential of various neuromechanical techniques, offer new treatment options for CVD [75].

Policy Interventions and Societal-Scale Actions

Pollution Control at Source and Clean Energy Transition Government supported initiatives that reduce pollution at its source and promote a swift switch to clean energy are the only ways to prevent pollution-related cardiovascular disease for the long term. This has two benefits: it slows down climate change. Air Quality Standards: To guarantee improved air quality, support and enforce strict National Ambient Air Quality Standards (NAAQS). Lessen Reliance on Fossil Fuels: Reduce dependence on energy-intensive farming, industrial pollution, and transportation based on fossil fuels. Encourage Green Energy and Spaces: Encourage the creation of green spaces and the use of green energy sources [76].

Implement thorough indoor and outdoor air pollution mitigation strategies to address household air pollution (HAP), particularly in areas where solid fuels (wood, coal, and agricultural waste) are used for heating, cooking, and lighting. Switching to clean fuels, such as electricity and gas, dramatically reduces indoor particulate matter levels [9]. Steer clear of mining and manufacturing that uses a lot of resources: Minimise actions that cause manufactured chemicals and hazardous metals to spread through the air [10]. Control Manufactured Chemicals: Create and advocate for substitutes for bisphenol A (BPA), phthalates, polychlorinated biphenyls (PCBs), plastics, and perfluoroalkyl and polyfluoroalkyl substances (PFAS) [77].

Machine learning and Artificial intelligence (AI) for predicting and preventing cardiovascular disease

Artificial intelligence and machine learning approaches are game-changing technologies in CVD diagnosis and prediction, prevention, diagnosis, and treatment. Artificial intelligence (AI) algorithms are used to predict the onset of disease, customise treatment, and enhance clinical decision-making by utilising enormous volumes of clinical, imaging, and biosignal data. Machine learning (ML) models, especially deep learning frameworks such as long short-term memory (LSTM) and convolutional neural networks (CNNs), have shown exceptional performance in identifying heart failure, myocardial infarction, and arrhythmias from imaging and electrocardiogram (ECG) data [78]. Through the integration of data from wearable technology, imaging modalities, and electronic health records, the American Heart Association emphasises AI's contribution to precision medicine by identifying at-risk groups and optimising treatment. American Heart Association (AHA) suggested the role of AI in medicine precision by using of health records including patients' data and imaging to identify the risk of CVD and treatment. Moreover, tools in AI improves the automated interpretation of cardiac imaging and ECG and increase the efficiency and accessibility specifically in socially disadvantaged areas. In hospital areas, AI algorithms can use frequently for predetermine several cardiac events like cardiac arrest, arrhythmias and heart failure decompensation and immediate rapid response for treatment of CVD [79]. A study suggested that AI can predict the risk of CVD in diabetes by using association rule mining (ARM). Authors observed that by AMR the elevated random blood sugar (more than 175 mg/dl) and blood HbA1c (more than 6.6 %) increases risk of CVD in diabetes conditions [80].

Limitation

While numerous studies suggested possible links between environmental pollutants and cardiovascular disease, they also have many limitations. It is difficult to demonstrate cause and effect because much of the evidence to date is observational. Comparing studies is complicated due to differences in study design, the way

exposure was measured, and the populations/groups examined. Studies from middle and low-income countries and are often missing, and we rarely have evidence from longitudinal studies. Additionally, while people are generally exposed to mixtures of pollutants, many studies examine only individual pollutants, and we do not have standardized tools to quantify the exposure or the health effects. Future studies should also include better designs, broader populations, and more real-life exposure scenarios.

Conclusion

To tackle the global burden of cardiovascular diseases, a holistic approach is necessary that incorporates lifestyle changes, environmental damage reduction, and targeted actions. By adopting healthier lifestyles, reducing exposure to toxins, and using personalized risk assessments and molecular biomarkers, we can add layers of defence against cardiovascular disease. The usage of targeted therapeutics based on individuals' genetic and molecular profiles is also enormously promising. By utilizing a multidisciplinary approach, and committing to early prevention and intervention, and precision medicine, we reduce the risk of cardiovascular disease so people will be healthy.

we can longitudinally shift the course of cardiovascular disease into the normal context of resilience and finally not as disablement.

Conflict of interest

None

Author Contributions

Mirza Masroor Ali Beg and Dharmsheel Shrivastav contributed to the concept and design of the study, collection of data and materials, manuscript writing, and performed final corrections and approval. Fauzia Ashfaq, Mohammad Idreesh Khan, and Rashid Mumtaz Khan contributed to manuscript writing, final corrections and approval, as well as visualization of tables and figures.

References

1. Aryal N, Wood J, Rijal I, Deng D, Jha MK, Ofori-Boadu A. Fate of environmental pollutants: A review. Water Environmental Research, (2020); 92(10): 1587-1594.
2. Manisalidis I, Stavropoulou E, Stavropoulos A, Bezirtzoglou E. Environmental and Health Impacts of Air Pollution:A review. Frontiers in Public Health, (2020); 8: 14.
3. Gomes M, Ralph TJ, Humphries MS, Graves BP, Kobayashi T, Gore DB. Waterborne contaminants in high intensity agriculture and plant production: A review of on-site and downstream impacts. The Science of the Total Environment, (2025); 958: 178084.
4. Alengebawy A, Abdelkhalek ST, Qureshi SR, Wang MQ. Heavy Metals and Pesticides Toxicity in Agricultural Soil and Plants: Ecological Risks and Human Health Implications. Toxics, (2021); 9(3): 42.
5. Di Cesare M, Perel P, Taylor S, Kabudula C, Bixby H, Gaziano TA, et al. The Heart of the World. Global Heart, (2024); 19(1): 11.
6. Ghodeshwar GK, Dube A, Khobragade D. Impact of Lifestyle Modifications on Cardiovascular Health: A Narrative Review. Cureus, 2023;15(7): e42616.
7. Shrivastav A, Swetanshu, Singh P. The Impact of Environmental Toxins on Cardiovascular Diseases. Current Problems in Cardiology, 2024 Jan;49(1 Pt C):102120.
8. Global Cardiovascular Risk Consortium; Magnussen C, Ojeda FM, Leong DP, Alegre-Diaz J, Amouyel P, Aviles-Santa L, et al. . Global Effect of Modifiable Risk Factors on Cardiovascular Disease and Mortality. The New England Journal of Medicine, (2023); 389(14): 1273–1285.
9. Tyrrell J, Melzer D, Henley W, Galloway TS, Osborne NJ. Associations between socioeconomic status and environmental toxicant concentrations in adults in the USA: NHANES 2001-2010. Environment International, (2013); 59: 328-335.
10. Vrijheid M, Martinez D, Aguilera I, Ballester F, Basterrechea M, Esplugues A, et al. Socioeconomic status and exposure to multiple environmental pollutants during pregnancy: evidence for environmental inequity?. Journal of Epidemiology and Community Health, (2012); 66(2): 106–113.
11. Awe Y, Larsen B, Hoossein S, Sánchez-Triana E. The Global Health Cost of Ambient PM2.5 Air Pollution. World Bank, 2020.
12. Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D. et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. British Medical Journal (Clinical Research Edition), (2021) 372, n71. https://doi.org/10.1136/bmj.n71
13. Kupcikova Z, Fecht D, Ramakrishnan R, Clark C, Cai YS. Road traffic noise and cardiovascular disease risk factors in UK Biobank. European Heart Journal, (2021); 42(21): 2072–2084.
14. Ni Y, Tracy RP, Cornell E, Kaufman JD, Szpiro AA, Campen MJ, et al. Short-term exposure to air pollution and biomarkers of cardiovascular effect: A repeated measures study. Environmental Pollution (Barking, Essex: 1987), (2021); 279: 116893.
15. Abohashem S, Osborne MT, Dar T, Naddaf N, Abbasi T, Ghoneem A, et al. A leucopoietic-arterial axis underlying the link between ambient air pollution and cardiovascular disease in humans. European Heart Journal, (2021); 42(7): 761–772.
16. Tripathy S, Marsland AL, Kinnee EJ, Tunno BJ, Manuck SB, Gianaros PJ, et al. Long-Term Ambient Air Pollution Exposures and Circulating and Stimulated Inflammatory Mediators in a Cohort of Midlife Adults. Environmental Health Perspectives, (2021); 129(5): 57007.
17. Mann, J. K., Lutzker, L., Holm, S. M., Margolis, H. G., Neophytou, A. M., Eisen, E. A., et al.. Traffic-related air pollution is associated with glucose dysregulation, blood pressure, and oxidative stress in children. Environmental research, (2021); 195, 110870.
18. Elbarbary, M., Oganesyan, A., Honda, T., Morgan, G., Guo, Y., Guo, Y., et al. Systemic Inflammation (C-Reactive Protein) in Older Chinese Adults Is Associated with Long-Term Exposure to Ambient Air Pollution. International journal of environmental research and public health, (2021); 18(6), 3258.
19. McGraw KE, Riggs DW, Rai S, Navas-Acien A, Xie Z, Lorkiewicz P, et al. Exposure to volatile organic compounds - acrolein, 1,3-butadiene, and crotonaldehyde - is associated with vascular dysfunction. Environmental Research, (2021); 196: 110903.

20. Nawsherwan, Mubarik, S., Bin, W., Le, Z., Sang, M., Lin, Y., et al. Epidemiological Trends in Cardiovascular Disease Mortality Attributable to Modifiable Risk Factors and Its Association with Sociodemographic Transitions across BRICS-Plus Countries. Nutrients, (2023); 15(17), 3757. https://doi.org/10.3390/nu15173757
21. Shetty, S. S., D, D., S, H., Sonkusare, S., Naik, P. B., Kumari N, S., et al. Environmental pollutants and their effects on human health. Heliyon, (2023); 9(9), e19496.
22. Miller M. R. The cardiovascular effects of air pollution: Prevention and reversal by pharmacological agents. Pharmacology & therapeutics, (2022); 232, 107996. https://doi.org/10.1016/j.pharmthera.2021.107996
23. Ji J. S. Air pollution and cardiovascular disease onset: hours, days, or years?. The Lancet. Public health, (2022); 7(11), e890–e891. https://doi.org/10.1016/S2468-2667(22)00257-2
24. Dockery DW, Pope CA 3rd, Xu X, Spengler JD, Ware JH, Fay ME, et al. An association between air pollution and mortality in six U.S. cities. The New England Journal of Medicine, (1993); 329(24): 1753–1759.
25. Han B, Zhao R, Zhang N, Xu J, Zhang L, Yang W, et al. Acute cardiovascular effects of traffic-related air pollution (TRAP) exposure in healthy adults: A randomized, blinded, crossover intervention study. Environmental Pollution (Barking, Essex: 1987), (2021); 288: 117583.
26. Raheel H, Sinharoy SS, Díaz-Artiga A, Garg SS, Pillarisetti A, Balakrishnan K, et al. Effects of a liquefied petroleum gas stove and fuel intervention on head circumference and length at birth: a multi-country Household Air Pollution Intervention Network (HAPIN) trial. Environment International, (2025); 195: 109211.
27. Dávila-Román VG, Toenjes AK, Meyers RM, Lenzen PM, Simkovich SM, Herrera P, et al. Ultrasound Core Laboratory for the Household Air Pollution Intervention Network Trial: Standardized Training and Image Management for Field Studies Using Portable Ultrasound in Fetal, Lung, and Vascular Evaluations. Ultrasound in Medicine & Biology, (2021); 47(6): 1506–1513.
28. Xing YF, Xu YH, Shi MH, Lian YX. The impact of PM2.5 on the human respiratory system. Journal of Thoracic Disease, (2016); 8(1): E69–E74.
29. Pizzino G, Irrera N, Cucinotta M, Pallio G, Mannino F, Arcoraci V, et al. Oxidative Stress: Harms and Benefits for Human Health. Oxidative Medicine and Cellular Longevity, (2017); 2017: 8416763.
30. De NB, CataldiS E, Diquigiovanni C, Bonora E. Calcium and Reactive Oxygen Species Signaling Interplays in Cardiac Physiology and Pathologies. Antioxidants (Basel, Switzerland), (2023); 12(2): 353.
31. Hantrakool S, Kumfu S, Chattipakorn SC, Chattipakorn N. Effects of Particulate Matter on Inflammation and Thrombosis: Past Evidence for Future Prevention. International Journal of Environmental Research and Public Health, (2022); 19(14): 8771.
32. Hamanaka RB, Mutlu GM. Particulate Matter Air Pollution: Effects on the Cardiovascular System. Frontiers in Endocrinology, (2018); 9: 680.
33. Fu Z, Xi S. The effects of heavy metals on human metabolism. Toxicology Mechanisms and Methods, (2020); 30(3): 167–176.
34. Khan K, Room SA, Bacha AU, Nabi I,et al. Assessment of heavy metals among auto workers in metropolitan city: a case study. Frontiers in Public Health, (2023); 11: 1277182.
35. Tchounwou PB, Yedjou CG, Patlolla AK, Sutton DJ. Heavy metal toxicity and the environment. Experientia Supplementum (2012), (2012); 101: 133–164.
36. Jaishankar M, Tseten T, Anbalagan N, Mathew BB, Beeregowda KN. Toxicity, mechanism and health effects of some heavy metals. Interdisciplinary Toxicology, (2014); 7(2): 60–72.
37. Ericson B, Dowling R, Dey S, Caravanos J, Mishra N,et al. A meta-analysis of blood lead levels in India and the attributable burden of disease. Environment International, (2018); 121(Pt 1): 461–470.
38. Singh AP, Goel RK, Kaur T. Mechanisms pertaining to arsenic toxicity. Toxicology International, (2011); 18(2): 87–93.
39. Charkiewicz AE, Omeljaniuk WJ, Nowak K, Garley M, Nikliński J. Cadmium Toxicity and Health Effects-A Brief Summary. Molecules (Basel, Switzerland), (2023); 28(18): 6620.
40. Sears CG, Eliot M, Raaschou-Nielsen O, Poulsen AH, Harrington JM, et al. Urinary Cadmium and Incident Heart Failure: A Case-Cohort Analysis Among Never-Smokers in Denmark. Epidemiology (Cambridge, Mass.), (2022); 33(2): 185–192.
41. Angeli JK, Cruz PCA, de OFT, Stefanon I, Padilha AS, Vassallo DV. Cadmium exposure induces vascular injury due to endothelial oxidative stress: the role of local angiotensin II and COX-2. Free Radical Biology & Medicine, (2013); 65: 838–848.
42. Olszowski T, Baranowska BI, Gutowska I, Chlubek D. Pro-inflammatory properties of cadmium. Acta Biochimica Polonica, (2012); 59(4): 475–482.
43. Vaziri ND. Mechanisms of lead-induced hypertension and cardiovascular disease. American Journal of Physiology. Heart and Circulatory Physiology, (2008); 295(2): H454–H465.
44. Navas-Acien A, Guallar E, Silbergeld EK, Rothenberg SJ. Lead exposure and cardiovascular disease--a systematic review. Environmental Health Perspectives, (2007); 115(3): 472-482.
45. States JC, Srivastava S, Chen Y, Barchowsky A. Arsenic and cardiovascular disease. Toxicological Sciences: An Official Journal of the Society of Toxicology, (2009); 107(2): 312–323.
46. Moon K, Guallar E, Navas-Acien A. Arsenic exposure and cardiovascular disease: an updated systematic review. Current Atherosclerosis Reports, (2012); 14(6): 542–555.
47. Pérez-CFM, Barrios RR, GómezPC, Salcedo BI, Velasco GME, Jiménez MJJ, et al. Public healthcare costs associated with long-term exposure to mixtures of persistent organic pollutants in two areas of Southern Spain: A longitudinal analysis. Environment International, (2021); 156: 106734.
48. Diamanti KE, Bourguignon JP, Giudice LC, Hauser R, Prins GS, et al. Endocrine-disrupting chemicals: an Endocrine Society scientific statement. Endocrine Reviews, (2009); 30(4): 293–342.
49. Schillemans T, Yan Y, Ribbenstedt A, DonatVC, Lindh CH, Kiviranta H,et al. OMICs Signatures Linking Persistent Organic Pollutants to Cardiovascular Disease in the Swedish Mammography Cohort. Environmental Science & Technology, (2024); 58(2): 1036–1047.
50. Schwartz, L., Guais, A., Chaumet-Riffaud, P., Grévillot, G., Sasco, A. J., Molina, T. J., & Mohammad, A. (2010). Carbon dioxide is largely responsible for the acute inflammatory effects of tobacco smoke. Inhalation toxicology, 22(7), 543–551. https://doi.org/10.3109/08958370903555909
51. Bonefeld-Jørgensen EC, Ghisari M, Wielsøe M, Bjerregaard-Olesen C, Kjeldsen LS, Long M. Biomonitoring and hormone-disrupting effect biomarkers of persistent organic pollutants in vitro and ex vivo. Basic & Clinical Pharmacology & Toxicology, (2014); 115(1): 118–128.
52. Lind PM, Lind L. Are Persistent Organic Pollutants Linked to Lipid Abnormalities, Atherosclerosis and Cardiovascular Disease? A Review. Journal of Lipid and Atherosclerosis, (2020); 9(3): 334–348.
53. Farhud DD. Impact of lifestyle on health. Iranian Journal of Public Health, (2015); 44(11): 1442–1444.
54. Parmar MP, Kaur M, Bhavanam S, Mulaka GSR, Ishfaq L, Vempati R, et al. A Systematic Review of the Effects of

Smoking on the Cardiovascular System and General Health. Cureus, (2023); 15(4): e38073.
55. Liu AG, Ford NA, Hu FB, Zelman KM, Mozaffarian D, Kris-Etherton PM. A healthy approach to dietary fats: understanding the science and taking action to reduce consumer confusion. Nutrition Journal, (2017); 16(1): 53.
56. Clemente SVJ, Beltrán VAI, Redondo FL, Martín RA, Tornero AJF. Global Impacts of Western Diet and Its Effects on Metabolism and Health: A Narrative Review. Nutrients, (2023); 15(12): 2749.
57. Lavie CJ, Ozemek C, Carbone S, Katzmarzyk PT, Blair SN. Sedentary Behavior, Exercise, and Cardiovascular Health. Circulation Research, (2019); 124(5): 799–815.
58. Rippe JM. Lifestyle Strategies for Risk Factor Reduction, Prevention, and Treatment of Cardiovascular Disease. American journal of lifestyle medicine, (2018); 13(2): 204–212.
59. Zhu Y, Li Q, Jiang H. Gut microbiota in atherosclerosis: focus on trimethylamine N-oxide. Journal of Pathology, Microbiology and Immunology - the APMIS journal (2020); 128(5), 353–366.
60. Oktaviono YH, Dyah Lamara A, Saputra PBT, Arnindita JN, Pasahari D, Saputra ME, et al. The roles of trimethylamine-N-oxide in atherosclerosis and its potential therapeutic aspect: A literature review. Biomolecule Biomedicine. 2023; 3;23(6):936-948.
61. Masenga SK, Hamooya B, Hangoma J, Hayumbu V, Ertuglu LA, Ishimwe J, et al. Recent advances in modulation of cardiovascular diseases by the gut microbiota. Journal of Human Hypertension, (2022); 36(9): 952–959.
62. Nesci A, Carnuccio C, Ruggieri V, D'Alessandro A, Di Giorgio A, Santoro L,et al. Gut Microbiota and Cardiovascular Disease: Evidence on the Metabolic and Inflammatory Background of a Complex Relationship. International Journal of Molecular Sciences, (2023); 24(10): 9087.
63. Singh P, Meenatchi R, Ahmed ZHT, Thacharodi A, Rohinth M, Kumar RRS, et al. Implications of the gut microbiome in cardiovascular diseases: Association of gut microbiome with cardiovascular diseases, therapeutic interventions and multi-omics approach for precision medicine. Medicine in Microecology, (2024); 19: 100096.
64. Bhatnagar A. Environmental determinants of cardiovascular disease. Circulation Research, (2017); 121(2): 162–180.
65. Sharifi RJ, Rodrigues CF, Sharopov F, Docea AO, Can KA, Sharifi R M,et al. Diet, Lifestyle and Cardiovascular Diseases: Linking Pathophysiology to Cardioprotective Effects of Natural Bioactive Compounds. International Journal of Environmental Research and Public Health, (2020); 17(7): 2326.
66. Yu E, Malik VS, Hu FB. Cardiovascular Disease Prevention by Diet Modification: JACC Health Promotion Series. Journal of the American College of Cardiology, (2018); 72(8): 914–926.
67. Lobo V, Patil A, Phatak A, Chandra N. Free radicals, antioxidants and functional foods: Impact on human health. Pharmacognosy Reviews, (2010); 4(8): 118–126.
68. Losso JN. The potential of dietary bioactive compounds against SARS-CoV-2 and COVID-19-induced endothelial dysfunction. Molecules (Basel, Switzerland), (2022); 27(5): 1623.
69. Nystoriak MA, Bhatnagar A. Cardiovascular Effects and Benefits of Exercise. Frontiers in Cardiovascular Medicine, (2018); 5: 135.
70. Pagan LU, Gomes MJ, Okoshi MP. Endothelial Function and Physical Exercise. Arquivos Brasileiros de Cardiologia, (2018); 111(4): 540–541.
71. Kirwan JP, Sacks J, Nieuwoudt S. The essential role of exercise in the management of type 2 diabetes. Cleveland Clinic Journal of Medicine, (2017); 84(7 Suppl 1): S15–S21.
72. Hadley MB, Baumgartner J, Vedanthan R. Developing a clinical approach to air pollution and cardiovascular health. Circulation, (2018); 137(7): 725–742.
73. Montano L, Pironti C, Pinto G, Ricciardi M, Buono A, Brogna, C, et al. Polychlorinated biphenyls (PCBs) in the environment: Occupational and exposure events, effects on human health and fertility. Toxics, (2022); 10(7): 365.
74. Kumar R, Verma A, Shome A, Sinha R, Sinha S, Jha PK, et al. Impacts of plastic pollution on ecosystem services, sustainable development goals, and need to focus on circular economy and policy interventions. Sustainability, (2021); 13(17): 9963.
75. Dhingra R, Vasan RS. Biomarkers in cardiovascular disease: Statistical assessment and section on key novel heart failure biomarkers. Trends in Cardiovascular Medicine, (2017); 27(2): 123–133.
76. Javaid A, Zghyer F, Kim C, Spaulding EM, Isakadze N, Ding J, et al. Medicine 2032: The future of cardiovascular disease prevention with machine learning and digital health technology. American Journal of Preventive Cardiology, (2022); 12: 100379.
77. Zhan C, Tang T, Wu E, Zhang Y, He M, Wu R, et al. From multi-omics approaches to personalized medicine in myocardial infarction. Frontiers in Cardiovascular Medicine, (2023); 10: 1250340.
78. de B RA, Heymans S, Backs J, Carrier L, Coats AJS, Dimmeler S, et al. Targeted therapies in genetic dilated and hypertrophic cardiomyopathies: from molecular mechanisms to therapeutic targets. A position paper from the Heart Failure Association (HFA) and the Working Group on Myocardial Function of the European Society of Cardiology (ESC). European Journal of Heart Failure, (2022); 24(3): 406–420.
79. Barresi V, Musmeci C, Rinaldi A, Condorelli DF. Transcript-targeted therapy based on RNA interference and antisense oligonucleotides: Current applications and novel molecular targets. International Journal of Molecular Sciences, (2022); 23(16): 8875.
80. Afifa, Arshad K, Hussain N, Ashraf MH, Saleem MZ. Air pollution and climate change as grand challenges to sustainability. Science of the Total Environment, (2024); 928: 172370.
81. Kumar P, Upadhyay E, Kannan K, Yadav A. Evaluation of cooking practices in India to achieve SDGs 7.1.2. Physics and Chemistry of the Earth, (2024); 136: 103774.
82. Kumar R, Garg S, Kaur R, Johar MGM, Singh S, Menon SV, et al. comprehensive review of machine learning for heart disease prediction: challenges, trends, ethical considerations, and future directions. Frontiers in Artificial Intelligence, (2025); 8: 1583459.
83. Mathur P, Srivastava S, Xu X, Mehta JL. Artificial intelligence, machine learning, and cardiovascular disease. Clinical Medicine Insights: Cardiology, (2020); 14: 1–9.
84. Dabla PK, Upreti K, Shrivastav D, Mehta V, Singh D. Discovering hidden patterns: Association rules for cardiovascular diseases in type 2 diabetes mellitus. World Journal of Methodology, (2024); 14(2): 92608.