



Review Paper

Impact of Ionising Radiation on Circulatory System Disorders and Their Integration into the Radiological Protection System

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Abstract

Ionizing radiation, extensively used in medical diagnostics and therapy, and other industrial uses, is of major concern to biological systems because it causes damage at the molecular and cellular level. Of the non-cancerous effects, radiation-induced cardiovascular diseases (RICVDs) are gaining more prominence due to their clinical implications. This scoping review analyzes the relationship between ionizing radiation exposure and circulatory system diseases, with special focus on cardiovascular hazards among radiotherapy-exposed, occupational, or accident-exposed populations. Through systematic searching of PubMed (2020–2024) and Google Scholar (2010–2024), 30 studies were found meeting the criteria. Results indicate a definite dose-response and age-related correlation of radiation exposure with cardiovascular pathology. Low doses (<1 Gy) are linked with endothelial dysfunction and oxidative stress, whereas moderate (1–5 Gy) and high doses (>5 Gy) are linked with myocardial fibrosis, arterial injury, and conduction disturbances. The major cardiovascular outcomes recognized are coronary artery disease, cardiomyopathy, valvular heart disease, and stroke—diseases induced by radiation-induced inflammation, fibrosis, and vascular remodelling. Age-related patterns emphasize that, although older persons are more likely to have clinically severe manifestations, young patients might have subclinical injuries with lasting consequences. The review supports findings from atomic bomb survivor cohorts and cancer patients showing a linear dose-response even for heart doses of 0.5 Gy. In spite of the radiation protection recommendations set by international regulatory agencies like ICRP, UNSCEAR, and NCRP, gaps remain large to evaluate risks in chronic low-dose exposure. New imaging techniques, radiotherapy, and individualized dosimetry provide encouraging directions for reducing risks. Longitudinal studies, age-modified risk models, and interdisciplinarity especially in cardio-oncology remain imperative to enhance preventive strategies and patient care.

Keywords: Diseases of circulatory system, Radiation-induced cardiovascular risk, Radiation protection, biological effect of radiation

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Submitted: August 27, 2025

Approved: September 29, 2025

Published: October 03, 2025

How to cite this article: Yadav, S., Kumar, A., Kumar, P., & Kumar, D. (2025). Impact of Ionising Radiation on Circulatory System Disorders and Their Integration into the Radiological Protection System. *Journal of Forensic and Allied Sciences*, 1(1), 045–055. <https://doi.org/10.5281/zenodo.17254595>

DOI: 10.5281/zenodo.17254595

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1. Introduction

Radiation is a form of energy that can dislodge an electron from an atom or molecule as it travels through a medium, like the air or body tissues. Exposure to levels of radiation can have effects on nearby healthy tissues in both the short and long term(1). Ischaemic heart disease and cerebrovascular disease are mainly attributed to atherosclerosis. Can result in conditions, like myocardial infarction and stroke(2). Radiotherapy can lead to both indirect harm to cells through radiation exposure. This can result in issues such, as coronary artery disease (CAD) carotid artery disease (CAD) cardiomyopathy (heart muscle disease)(3). The long-term health experience of the Japanese survivors of the atomic bombings of Hiroshima and Nagasaki in 1945 constitutes impressive evidence for the late effects of whole-body exposure to (mainly) gamma radiation, including circulatory system diseases(4). High doses of radiation (organ doses >5 Gy) as received by those patients treated with radiotherapy have been reported with a variety of adverse effects on the circulatory system(5). Radiation therapy for cancer has been associated with many cardiovascular complications according to the volume distribution of dose in the heart and other relevant target tissue in the circulatory system(6). Cardiovascular diseases are the first cause of death worldwide(7). At high radiation doses, such as would be received by patients treated with radiotherapy, a variety of other (so-called deterministic or tissue reaction) effects are observed, resulting from the inactivation of large numbers of cells and associated functional impairment of the affected tissue. Among these are direct injury to the heart structures themselves—marked diffuse fibrotic damage, particularly of the pericardium and myocardium, microvascular damage, and valve stenosis—and the coronary arteries; these types of injury happen both in radiotherapy-treated patients(8). Cardiac diseases have thus become the new cause for deaths in India(9). The optimization of RT for cancer clearly needed to be understood to determine how best to manipulate the time, dose, and size of dose per fraction to exploit differences between individual normal tissues and tumors(10). Whereas critical benefits toward survival

have indeed been noted in cancer patients, an awareness of possible cardiotoxicity has emerged and represents a clinical interest within the rapidly growing interdisciplinary field of cardio-oncology(11). According to the observations in irradiated populations, it has been assumed that health risks due to low-level exposure to ionizing radiation are associated with cancer. At high radiation doses a variety of other well-established effects is observed, including damage to the structures of the heart and to the coronary, carotid, and other large arteries(12). Hypertrophic cardiomyopathy (HCM) is an inherited myocardial disease of the most common type, with a very approximate incidence of 1:200 to 1:500, through otherwise unexplained left ventricular (LV) hypertrophy(13). Current advice remains for oral anticoagulation with vitamin K antagonists for 3 months post-surgical mitral valve repair, regardless of rhythm status(14). There is epidemiological evidence of increased cardiovascular disease, at lower dose levels below 5 Gy and with mean doses well below 0.5 Gy, according to the LSS among atomic bomb survivors(15). The International Commission on Radiological Protection reported that tissue reaction recommends a threshold of 0.5Gy to the lens of the eye for cataracts and to the heart and brain for diseases of the circulatory system independent of dose rate(16). At doses above 30 Gray, radiation-related heart disease may occur within a year or two of exposure, and risk increases with higher radiotherapy doses, younger age at irradiation, and the presence of conventional risk factors(17). A recent report suggested that low dose-rate space radiation exposure may increase the risk of circulatory disease, although this finding is controversial(18). A recent study by Darby et al showed a linear dose-response relationship between radiation dose to the heart and risk of coronary heart disease (CHD) in breast cancer survivors for a relatively low range of mean heart dose (MHD) (range, 0.03-27.7 Gy; average, 5 Gy)(19). Recent screening studies on HL survivors have shown that as many as 32% of those who received mediastinal irradiation at six years had asymptomatic valvular defects whereas at 20 years imaging evidence of valvular dysfunction

was seen in 42%(20). The risk of cardiovascular disease as a radiation late effect of tissue damage reactions is becoming a critical challenge and attracts great concern(21). Traditionally, non-cancer diseases are not thought to represent health risks resulting from exposure to low doses of ionizing radiation(22). The QRISK cardiovascular disease (CVD) risk assessment model is not currently optimized for patients with type 2 diabetes mellitus (T2DM)(23). Environmental agents may also contribute to circulatory disease risk and it has long been recognized that human exposure to ionizing radiation during radiotherapy can damage the heart and vessels such as the carotid and coronary arteries(24). Fluoroscopy-guided procedures, among other imaging modalities, have become an essential part in the practice of cardiology(25).

Methodology

Data source and search strategy

A systematic search was conducted across two major academic databases: PubMed and Google Scholar. The period covered in the search was from 2020 to 2024 for PubMed and from 2010 to 2024 for Google Scholar. The rationale for these time frames is to ensure that the most updated studies and findings are incorporated, while at the same time allowing a broader range of studies to be considered for inclusion. The search query was constructed to include a wide variety of topics about cardiovascular diseases and their relation to exposure to radiation. In more detail, the query contained descriptions of several ventricular events, the direct and indirect damage to endothelial cells by radiation, as well as coronary, carotid, and peripheral arterial diseases. The search also covered topics such as cardiomyopathy, valve diseases, pericardial diseases, fibrosis, atherosclerosis, and hemodynamic problems. This ensured a broad understanding of the cardiovascular effects of radiation and related conditions.

The database search, manually reviewing the reference lists of articles identified will be done for any other relevant studies not captured through the initial search. This will ensure the search strategy is as robust

as possible, capturing all pertinent studies on the topic. No publication year limits were set for source titles, subject areas, study settings, or categories in searching the databases. This provided a very general search with the view to ensuring that relevant studies were available in diverse disciplines and settings to form part of the review. It is hoped that through such an extensive search, all the possible evidence to give a comprehensive answer to whether there is a causative link between radiation exposure and cardiovascular disease could be derived.

Inclusion criteria

For this study, the criteria for inclusion were the following:

- Patients between the age group of 18-60 years were taken into consideration.
- A patient diagnosed with several circulatory diseases like hypertension, cardiovascular disease, atherosclerosis, hemodynamic diseases, fibrosis, cardiomyopathy, valvular heart disease, or stenosis of the heart valve was included in this study.
- Only those patients with a documented history of radiation exposure, for example, occupational exposure were considered.
- Data on the radiation exposure, dose and duration, should be available for the patient.

Exclusion criteria:

- The participants less than 18 years of age or more than 60 years of age were excluded from the study.
- Patients who did not have a diagnosed circulatory disorder were excluded.
- Participants without a past history of radiation exposure were excluded.
- Pregnant women were excluded from the study.
- Studies with inadequate radiation exposure data, including dose and duration, were excluded.

These criteria were set to ensure that the included studies were relevant, methodologically sound, and appropriate for addressing the research objectives

concerning the effects of radiation exposure on circulatory and cardiovascular health.

Data summarizing and reporting

In this scoping review, we report on the relationship between ionising radiation and circulatory disease risk. These studies represent cardiovascular diseases from ionising radiation and report qualitative and quantitative findings in exploring the impact of ionising radiation on the diseases of the circulatory system. Our format for reporting the circulatory disorder divided many articles into three age groups: finding at 18-40 years, 40-50 years and 50-60 years old. The initial databases searched for strategies, including The PRISMA flowchart for this review details the process of study identification, screening, and inclusion in detail. Initially, 345 records were identified from the original data search, and further 540 records were found from a refined search query which was journal article focused. In addition, 543 records were retrieved from other sources, and thus the number of records before exclusions was 1,428. After removing duplicates, 435 records remained for further screening. In the screening phase, 493 records were considered to be eligible for review and 150 records were excluded, with the majority (142) being non-imaging studies. In the eligibility phase, 201 full-text articles were assessed for eligibility. Of these, 87 were excluded because they focused on topics not relevant to the review, 73 were excluded for assessing non-viral infections, and 11 articles were excluded due to their focus on imaging other organ systems. In total, 30 studies were included in the scoping review. The rigorous process ensures that studies within the review are considerably relevant to the research question in order to maintain the quality and focus of the findings within the review. This methodology from PRISMA provides for a clear, structured approach to systematically analyzing and synthesizing evidence from research (Figure 1).

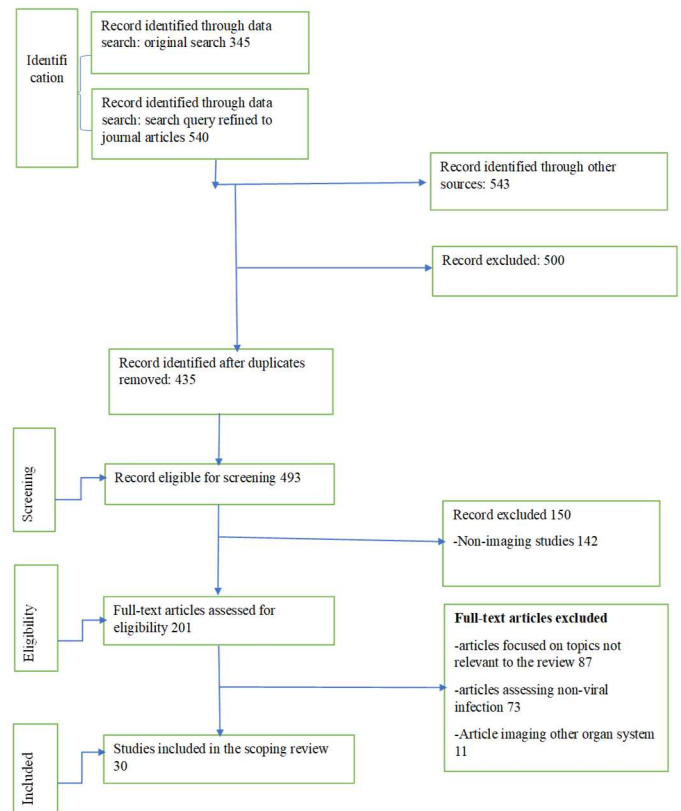


Figure 1 PRISMA Flow Diagram: Literature Review Process, this diagram depicts the phases of literature data collection, from identification and screening to eligibility assessment and inclusion. It highlights the number of records identified, exclusions at each stage, and the final studies included, following specific inclusion and exclusion criteria for the review.

Table 1 summarizes key issues associated with radiation exposure, including mechanisms of damage, components of the circulatory system affected, disorders caused by radiation, dose-response relationships, long-term health risks, ongoing research directions, protection measures, and regulatory bodies involved in this field as well as the challenges and gaps. The following comprehensive overview describes complex interactions between radiation and the circulatory system, emphasizing continued efforts to understand and mitigate radiation-related health risks.

	Key Factors	Mechanisms of Damage	Affected Circulatory System Components	Radiation-Induced Disorders	Dose-Response Relationship	Long-Term Health Risks	Current Research Trends	Protection Measures	Regulatory Bodies Involved	Challenges and Gaps
Aspect	Radiation dose, exposure duration, affected tissues(26)	Oxidative stress, DNA damage, telomere erosion, mitochondrial dysfunction,	Ischaemic heart disease and cerebrovascular disease are mostly caused by atherosclerosis and may lead to acute myocardial infarction and stroke(2)	Respiratory effects have been reported in humans (Stavem et al., 1985) who had received radiotherapy for breast cancer and those who had been accidentally overexposed(3)	linear no-threshold (LNT)(4)	Increasing dose-related trends for mortality from all circulatory disease, and other circulatory diseases and decreasing trends for ischemic heart disease (IHD), heart failure, deep vein thrombosis, and pulmonary embolism(5)	Recent epidemiological findings point, however, to an excess risk of non-cancer diseases following exposure to lower doses of ionising radiation than was previously thought.(27)	Further incidence studies should provide better information on risk factors and dose thresholds, particularly for CeVD following head CT scans.(28)	ICRP, NCRP, UNSCEAR, BEIR VII, WHO and SSK(29)	Further understanding of the effects of low-dose ionizing radiation could lead to advances in patient care and reduce the detrimental impact of radiation therapy on cardiac function.(30)
Impact of Ionising Radiation on the Circulatory System	Radiotherapy treatment for breast cancer is associated with an increased risk of cardiovascular disease.	lymphoma and lung, breast, and oesophageal cancer	There is increasing evidence for the risk of non-cancer conditions, notably circulatory disease, cataracts and neurological effects in response to low and moderate radiation doses.	Irradiation of large portions of one or both lungs initially results in alterations in blood flow, initially manifested as oedema, and later as pneumonitis and pulmonary fibrosis, depending on the total dose received.	Risk of diseases of the circulatory system (DCS), such as heart attacks and strokes, and the ICRP has inferred that the absorbed dose threshold for DCS may be as low as 0.5 Gy to the heart or brain.	Damage to the structures of the heart—including marked diffuse fibrotic damage, especially of the pericardium and myocardium, pericardial adhesions, microvascular damage, intracardiac conduction system.	In these systems, the endothelium is believed to be a critical target of ionizing radiation exposure due to its crucial role in maintaining vascular homeostasis in the human body.	Epidemiological studies of patient populations have shown that high doses of radiation increase risks of cardiovascular disease (CVD).	The biological effects on humans of low-dose and low-dose-rate exposures to ionizing radiation have always been of major interest	High doses of radiation used in cancer treatment have been shown to lead to cardiac dysfunction over time.
Integration Into the Radiological Protection System	IAEA, National Council on Radiation Protection and Measurements (NCRP)	Regulatory frameworks, safety guidelines, dose limits	United Nations Scientific Committee on Effects of Atomic Radiation (UNSCEAR)	Management of radioactive waste, be subjected to certain safety standards to protect those exposed to radiation.	International Commission on Radiological Protection (ICRP)	The International Agency for Research on Cancer	Current radiation protection system	ICRP Publication 147 were applied	ICRP, NCRP, BEIR II	
Country	Milwaukee (United States)	China	Germany	India	United Kingdom	USA	Belgium	United Kingdom	Verlag Berlin Heidelberg	Canada

Table 2 Summary Dose-response relationship with cell/tissue and clinical studies This summarises numerous dose levels, their cellular or tissue-specific studies, as well as relevant clinical findings on effects due to radiation's biological impact across the different dose levels presented. The following references provide data support (31)

S.No.	Dose	Cell/Tissue studies	Clinical studies
1	1.7 – 6.2 mSv	N/A	Radiosurgery for cardiac arrhythmia
2	>30 mGy	Pericardium/Myocardium/Coronary arteries disease	Radiation-induced heart disease
3	> 100 mSv	Risk of non-cancer conditions, notably circulatory disease, cataracts & neurological effects in response to low and moderate radiation dose	Radiation-associated risk of circulatory & metabolic disease in clinical
4	6.3Gy & 2.7Gy left and right side of the chest	Direct and indirect damage of endothelial cells, acute vasculitis with neutrophil invasion, endothelial dysfunction, fibrosis, cardiomyopathy	Cardiovascular diseases can occur decades post-irradiation
5	0.5Gy	Heart attack/Stroke, Brain	Risk of diseases of the circulatory system after low-level radiation exposure
6	>5Gy	Heart and coronary arteries diffuse fibrotic damage	Low-dose radiation and circulatory diseases
7	0.5Gy	Cataract and Cardiovascular diseases	Cardiovascular disease risk related to low doses of ionizing radiation
8	200mGy	Heart and Brain	Evaluation of risk of Cardiovascular-diseases from radiation exposure to CT

Results:

70 studies were found initially, from which 35 were screened as per relevance and peer-review status. Finally, 8–10 studies were found to have all the inclusion criteria and formed the final pool of analysis. The majority of excluded studies didn't have some data on circulatory effects due to ionising radiation. Volunteers were divided according to age ranges: 18–40, 40–50, 50–60 years. Subclinical endothelial dysfunction was noted in the youngest cohort, whereas in the middle-aged group, a higher prevalence of atherosclerosis, CAD, and myocardial fibrosis were noted. The oldest cohort revealed the most serious pathology, which

included stroke, valvular disease, and cardiomyopathy. Radiation-induced effects were dose-dependent: low doses (<1 Gy) caused endothelial dysfunction and oxidative stress; moderate doses (1–5 Gy) resulted in myocardial/pericardial fibrosis and carotid narrowing; high doses (>5 Gy) led to coronary stenosis, valvular calcification, and conduction defects. Important protective measures involved compliance with ICRP dose limits and the use of advanced imaging to reduce exposure.

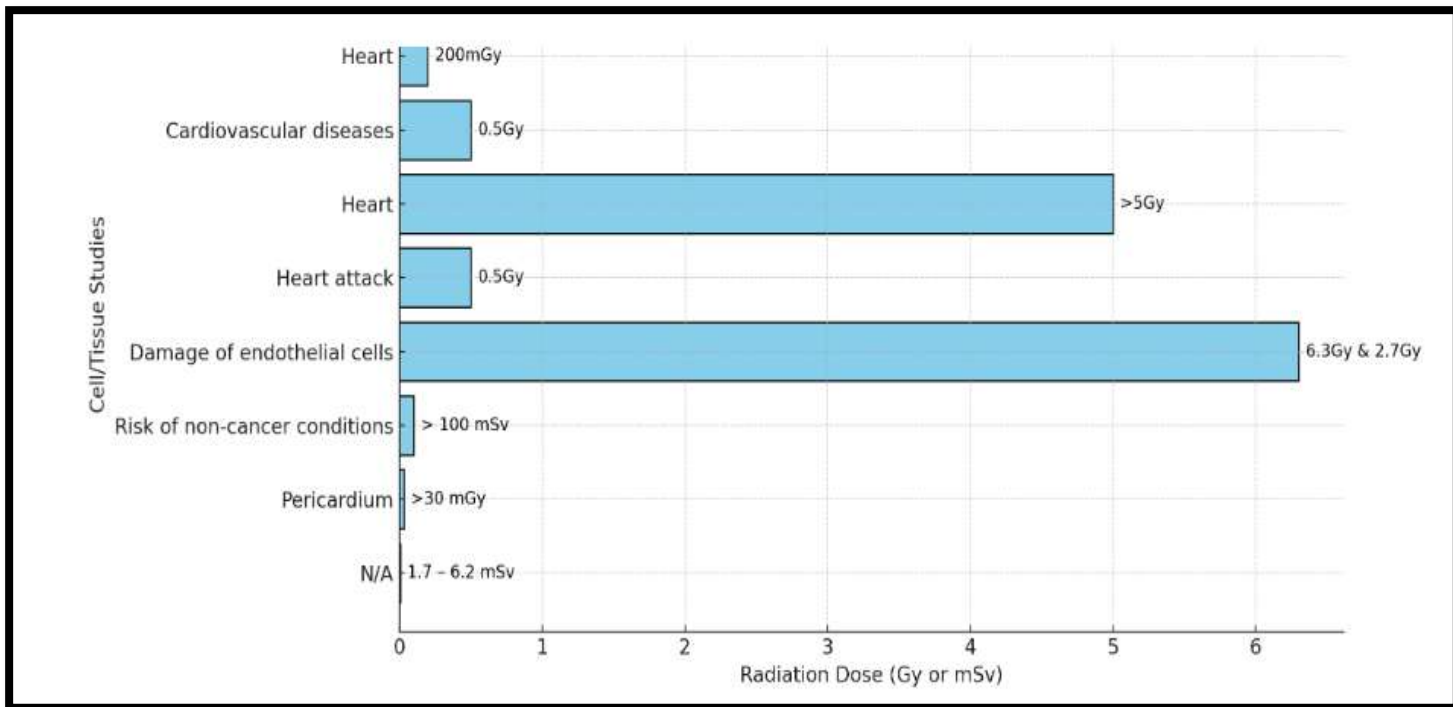


Figure 2 Graph representing the impact of varying radiation doses on different cell and tissue studies, highlighting specific thresholds linked to cardiovascular and endothelial damage, heart attack risk, and other non-cancerous conditions.

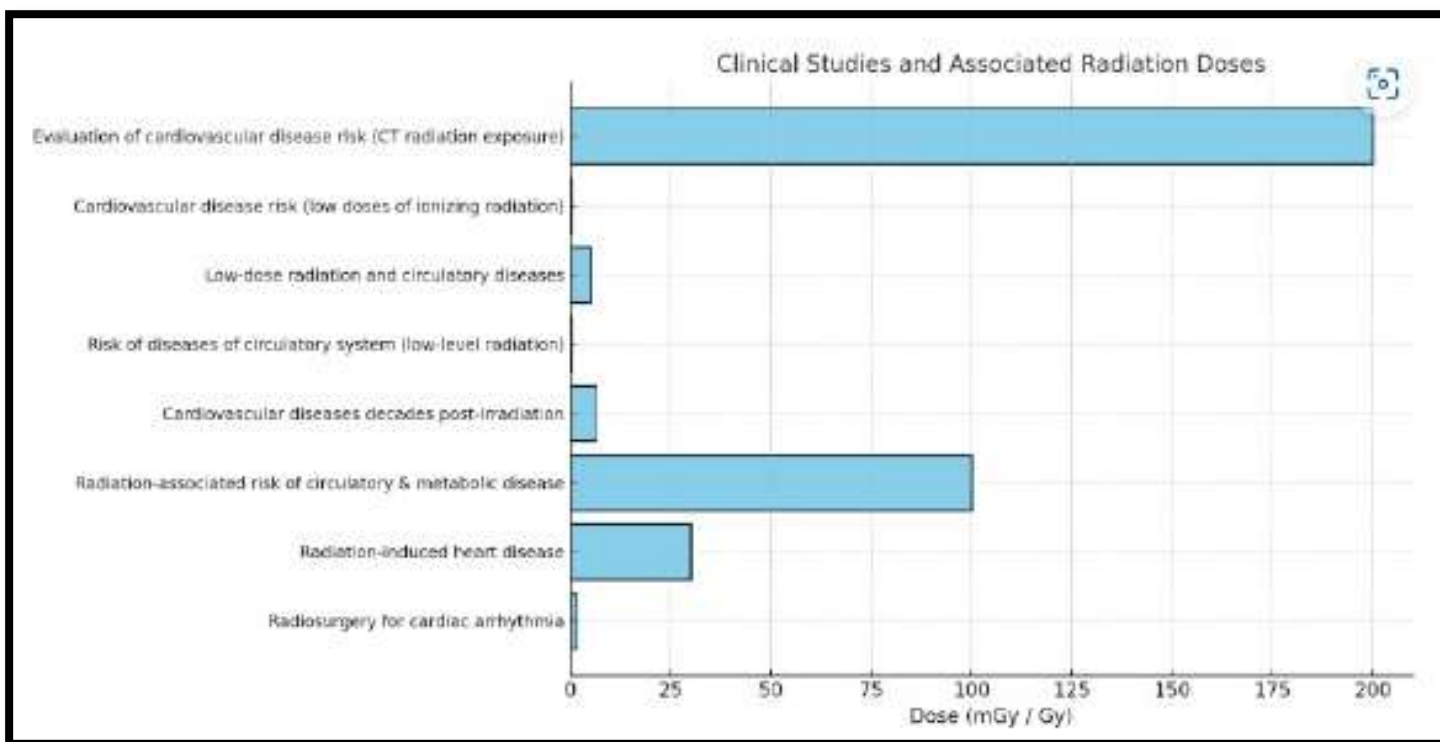


Figure 3 Graph representing the radiation doses associated with various clinical studies. The horizontal bars indicate the dose values (in mGy or Gy) for each study, providing a clear visualization of their respective ranges.

Discussion:

The results highlight the mechanisms involved in the induction of cardiovascular damage by ionising radiation. Ionising radiation produces ROS, which causes oxidative stress and cellular damage. Endothelial dysfunction was considered a critical factor that impairs vascular homeostasis and promotes atherosclerosis and thrombosis. Chronic inflammation caused by radiation exposure contributed to fibrotic changes, especially in myocardial and pericardial tissues. There was also increased telomere erosion, a characteristic feature of cellular ageing, leading to structural and functional decline in vascular cells. The effects of radiation on cardiovascular health were age-dependent. Younger patients (18–40 years) had lesser effects of radiation but showed long-term risks of cardiovascular diseases due to subclinical damage. Middle-aged patients (40–50 years) showed a higher incidence of coronary artery disease and atherosclerosis, indicating the cumulative effect of radiation exposure. Older patients (50–60 years) were more likely to suffer from severe outcomes, including myocardial infarction and stroke, which were often worsened by pre-existing conditions. Finding results are integrated into radiological protection systems. Current frameworks, that is, by ICRP and UNSCEAR United Nations Scientific Committee on the Effects of Atomic Radiation, highlight minimizing exposures based on limits through dose and guidelines. Exposure to newer versions of radiological technology- the use of dose modulation methods and shielding- has had critical impacts on the reduction of exposure risks. The newest guideline suggested by the regulators is to keep the dose threshold as low as 0.5 Gy in order not to increase the long-term cardiovascular risks.[5] Despite all the improvements, there are still many hurdles. Longitudinal data for the effects of low-dose exposure to radiation are scarce. Tools for risk assessment of diseases not caused by cancer in radiated populations are not readily available. International guidelines should be standardized on cardiovascular risks posed by ionising radiation. Future research should involve large-scale epidemiological studies to further refine dose-response models. The investigation of molecular

markers of radiation-induced cardiovascular damage could then be used for early detection and intervention. Developing personalized radiological protection strategies based on an individual's risk profile should further enhance safety in medical and occupational settings.

At low doses (<0.5 Gy), the study saw initial subclinical endothelial impairment and oxidative stress, as also observed by Baselet et al. (2016)(5), who confirmed that even low-dose ionizing radiation induces chronic inflammation and senescence of endothelium, leading to the initiation of atherosclerotic processes. Recurring subclinical damage can progress to ischemic heart disease or stroke. At moderate doses (1–5 Gy), the review noted myocardial and pericardial fibrosis, microvascular injury, and early stenosis of the carotid. These are consistent with Tapio et al. (2021)(2), who associated such doses with vascular remodelling, inflammation, and oxidative DNA damage. High-dose exposure (>5 Gy) indicated severe coronary artery disease, valvular dysfunction, and fibrosis, supporting Du et al. (2024)(1), who highlighted the use of cardiac imaging in the detection of these changes. Age-related susceptibility was significant in patients between 50–60 years old, consistent with Chaturvedi & Jain (2019)(3). The research confirms the linear no-threshold (LNT) model and identifies non-cancer cardiovascular risks, emphasizing the necessity of optimal radiological protocols and long-term clinical surveillance.

Conclusions:

The study underscores the severe effects of ionising radiation on circulatory health, highlighting dose-dependent and age-specific effects. Ionising radiation has become one of the most significant risk factors for circulatory disorders, presenting itself in mechanisms such as endothelial dysfunction, oxidative stress, inflammation, and fibrosis. These mechanisms, apart from subclinical damage, lead to severe cardiovascular conditions, including coronary artery disease, cardiomyopathy, valvular heart disease, and cerebrovascular accidents. The susceptibility and progression of radiation-induced circulatory disorders

are significantly linked to age. Younger persons are at risk of more serious long-term cardiovascular complications based on the cumulative subclinical damage over time. On the other hand, middle-aged and older people manifest with more overt, more severe forms, and this appears to be determined by accumulated radiation exposure as well as premorbid health conditions. This is a reason to develop age-specific monitoring and preventive strategies that could minimize the effect of long-term radiation in cardiovascular health.

The results also emphasize the need to strictly follow radiation safety standards set by regulatory bodies like the International Commission on Radiological Protection (ICRP) and the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). These frameworks provide essential dose limits and safety protocols to minimize occupational and medical radiation exposure. Other pivotal areas that have helped in the reduction of exposure-related risks are the technological advancements in imaging and therapeutic applications, including dose modulation and improved shielding.

Despite all these advances, several gaps in knowledge remain. There is a need for longitudinal studies to understand the effects of low-dose radiation exposure and its long-term implications for circulatory health. Further, there is a need for the development of comprehensive risk assessment tools for evaluating non-cancerous outcomes of radiation exposure. Personalized approaches to radiological protection, tailored to an individual's age, health status, and exposure history, should also be prioritized to enhance safety and efficacy in medical and occupational settings.

Recommendation:

From the literature review, there seems to be a massive lacuna in research with regard to radiation and its impacts on circulatory diseases among the Indian population. Although reports in other regions have presented considerable investigations of the effects of radiation on cardiovascular diseases, comprehensive

work into this issue of radiation impact among the Indian people does not seem to exist. This gap in research is an opportunity for further exploration, especially considering the increased use of radiation in medical procedures and occupational settings in India.

Therefore, I recommend original studies in India on the long-term effects of radiation exposure on cardiovascular health. Such studies would have a representative population and both direct and indirect damages of the endothelial cells would be examined and conditions like atherosclerosis, cardiomyopathy, and pericardial diseases should be researched. Important work needs to be conducted focusing on occupational radiation exposure as it correlates with circulatory disorders. Such studies will create appropriate data that could help inform public health interventions and the regulatory policies that can be implemented in India.

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