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Overview of Association Between Cardio-Oncology and Cardiovascular Medicine

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Abstract

Cardio-oncology is an emerging medical specialty that focuses on the intersection between cancer treatments and cardiovascular health. With significant improvements in cancer therapies, such as chemotherapy, targeted therapies, and immunotherapy, the survival rates for cancer patients have drastically increased. However, these treatments often come with unintended cardiovascular side effects, which can lead to conditions like heart failure, arrhythmias, and coronary artery disease. This growing field aims to better understand, prevent, and manage the cardiovascular complications that can arise during or after cancer treatment, ensuring a better quality of life for survivors. The implications of cardio-oncology are profound, as it not only addresses the long-term health of cancer patients but also requires a collaborative approach between oncologists and cardiologists to optimize treatment strategies and mitigate risks.

Keywords: Cardio-oncology, Cardiovascular diseases, Cancer care, Treatments

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Introduction

Cardio-oncology (Figure 1) is a rapidly evolving interdisciplinary field that addresses the cardiovascular complications of cancer and its treatments [2]. The growing success in cancer therapies has led to improved survival rates, making long-term cardiovascular health a crucial component of comprehensive cancer care [3]. This field bridges oncology and cardiology, focusing on the prevention, early detection, and management of cardiotoxicities associated with cancer therapies [4].

Cancer therapies, including chemotherapy (Figure 2), radiation, immunotherapy, and targeted therapies, can adversely affect cardiovascular health [6]. Common complications include heart failure, arrhythmias, ischemic heart disease, hypertension, and thromboembolic events [6]. Drugs such as anthracyclines and HER2 inhibitors are well-documented for their potential to induce cardiomyopathy, necessitating close monitoring of cardiac function during and after treatment [7]. Radiation therapy, particularly when involving the thoracic region, increases the risk of pericardial diseases and coronary artery disease [8].

The integration of cardiology into oncology care begins with risk stratification [9]. Patients are assessed based on their baseline cardiovascular risk, cancer treatment regimen, and preexisting conditions [10]. Biomarkers such as troponins and natriuretic peptides, alongside imaging modalities like echocardiography and cardiac magnetic resonance imaging (CMR), play pivotal roles in detecting early signs of cardiac dysfunction [11]. This proactive approach allows for timely interventions, reducing morbidity and improving quality of life for cancer survivors.

Prevention and management strategies in cardio-oncology involve a combination of lifestyle modifications, pharmacotherapy, and close surveillance [12]. Medications such as beta-blockers, ACE inhibitors, and angiotensin receptor blockers have demonstrated efficacy in mitigating cardiotoxic effects [13]. Furthermore, advanced imaging techniques and wearable technologies provide real-time monitoring, facilitating early intervention in high-risk patients [14]. These strategies are tailored to individual patient needs, balancing cancer treatment efficacy with cardiovascular safety [15].

Research in cardio-oncology is uncovering novel insights into the molecular mechanisms underlying cancer treatment-related cardiotoxicities [16]. Studies are exploring genetic predispositions, inflammatory pathways, and oxidative stress as contributors to cardiovascular damage [17]. This has led to the development of precision medicine approaches, such as personalized risk assessments and targeted therapies that minimize cardiac impact [18]. Collaborative efforts between cardiologists, oncologists, and researchers are essential for advancing this field.

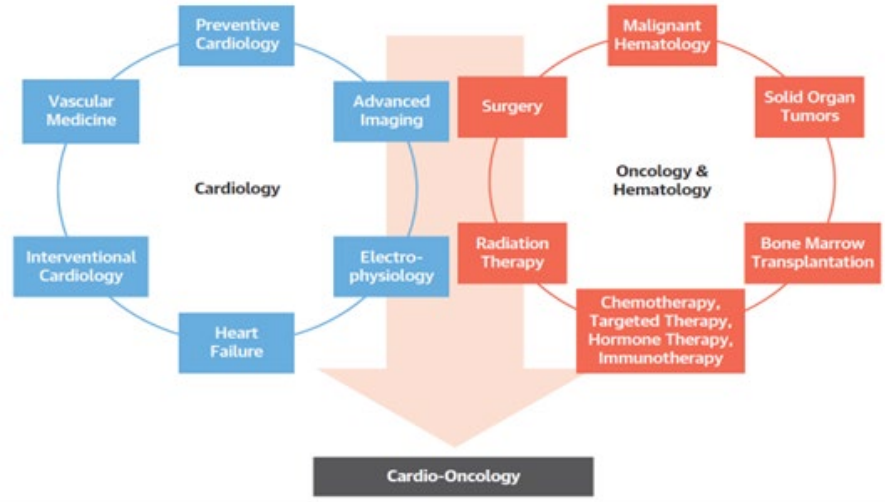

Figure 1: Integration of cardiology and oncology. Reproduced from [1].

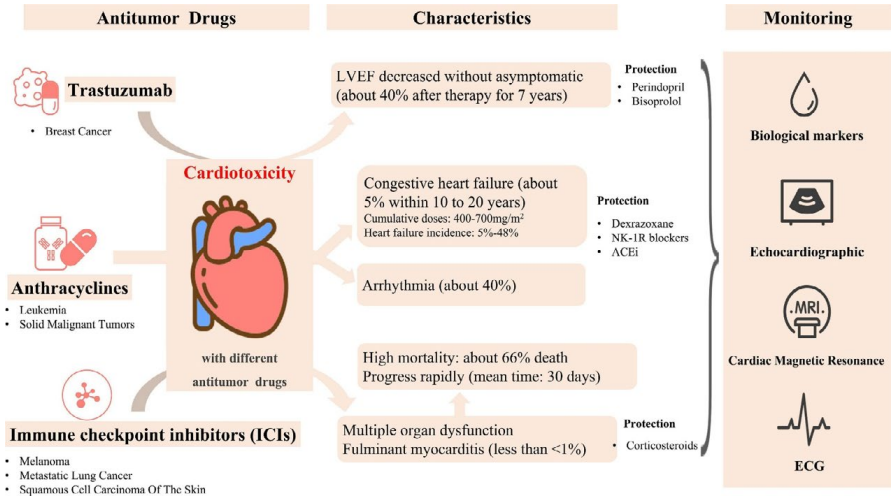

Figure 2: Cardiotoxicity associated with cancer drugs. Reproduced from [5].

Cardio-oncology underscores the importance of a multidisciplinary approach in modern medicine. By integrating expertise from cardiology and oncology, this field not only aims to improve clinical outcomes but also enhances survivorship care. As cancer survivorship continues to grow, cardio-oncology is poised to play an increasingly vital role in ensuring the holistic health of patients. This dynamic field exemplifies the synergy of innovation and patient-centered care in addressing complex health challenges [19].

Understanding Cardio-oncology as a Medical Subspecialty

Cardio-oncology is an interdisciplinary subspecialty that focuses on the prevention, diagnosis, and management of cardiovascular diseases (CVDs) and related complications arising in cancer patients [20]. This field addresses the unique interplay between cancer and cardiovascular health, recognizing that cancer therapies, while lifesaving, can exert significant cardiovascular strain [21]. These complications stem from macro-circulatory and micro-circulatory defects induced by the cancer itself or its treatments, which affect the heart and vascular system in diverse and often complex ways [22].

Macro-circulatory defects in cancer patients are typically associated with large vessel dysfunction. Chemotherapy agents such as anthracyclines can lead to myocardial damage, causing cardiomyopathy and heart failure [23]. Similarly, radiation therapy targeting the thoracic region can induce fibrosis and scarring large arteries, increasing the risk of coronary artery disease. These structural and functional changes compromise blood flow, elevating the risk of ischemic events. Cardio-oncology seeks to mitigate these risks through advanced imaging, biomarkers, and pharmacological interventions, which enable early detection and tailored treatment plans [2].

Micro-circulatory defects, on the other hand, involve the smaller blood vessels and capillaries, which are critical for tissue perfusion. Cancer therapies like anti-angiogenic agents disrupt the formation of new blood vessels, impairing the microcirculation [24]. This can lead to endothelial dysfunction, hypertension, and reduced oxygen delivery to tissues. Additionally, certain cancers release pro-inflammatory cytokines, creating a hypercoagulable state that exacerbates microvascular damage and increases the risk of thromboembolic events [25]. Understanding these mechanisms allows cardio-oncology

specialists to design therapies that balance oncologic efficacy with cardiovascular safety.

Organ failure mediated by circulatory defects is another key focus of cardio-oncology [26]. Impaired circulation can lead to multi-organ dysfunction, as seen in cases where reduced cardiac output compromises kidney and liver function. For example, cardiorenal syndrome-a condition where heart and kidney dysfunctions are interrelated-is a common challenge in cancer patients receiving nephrotoxic chemotherapy [27, 28]. These scenarios require an integrated approach to care, combining expertise in cardiology, oncology, and nephrology to optimize patient outcomes.

Moreover, cardio-oncology emphasizes the importance of long-term surveillance, as cardiovascular complications may emerge years after cancer treatment [29]. Survivorship care plans incorporate routine cardiovascular monitoring, lifestyle interventions, and patient education to prevent late-onset organ failure [30]. By addressing both macro- and micro-circulatory health, the subspecialty ensures that cancer survivors not only live longer but also maintain a better quality of life.

In essence, cardio-oncology represents a convergence of cardiology and oncology, dedicated to understanding and mitigating the cardiovascular impacts of cancer and its treatments (Table 1) [29]. By focusing on the intricate relationship between circulatory defects and organ dysfunction, this subspecialty exemplifies a holistic approach to managing the dual burdens of cancer and CVDs [31, 32].

Pathophysiology of CVDs in Cardio-oncology

The pathophysiology of CVDs in cardio-oncology involves complex interactions between cancer, its therapies, and the cardiovascular system [33]. These interactions result in macrovascular and microvascular dysfunctions, myocardial injury, and systemic inflammatory responses that collectively contribute to the development of various cardiac conditions [1]. Understanding these mechanisms is crucial for preventing, diagnosing, and managing cardiotoxicities in cancer patients (Figure 3).

One of the primary mechanisms of CVD in cardio-oncology is direct myocardial injury caused by cancer therapies [35]. Chemotherapeutic agents such as anthracyclines disrupt the function of topoisomerase II beta in cardiomyocytes, leading to double-strand DNA breaks, oxidative stress, and the activation of apoptotic pathways [36]. This cumulative damage results in cardiomyopathy and left ventricular dysfunction, which may progress to heart failure [37]. Similarly, HER2 inhibitors, used in breast cancer treatment, interfere with cellular signaling pathways essential for cardiomyocyte survival, exacerbating myocardial stress [37].

Vascular toxicity is another significant contributor, mediated by macrovascular and microvascular effects. Radiation therapy targeting the thoracic region induces endothelial cell damage, inflammation, and fibrosis in the coronary arteries, increasing the risk of atherosclerosis and coronary artery disease [38]. Anti-angiogenic therapies, which inhibit vascular endothelial growth factor (VEGF), compromise the integrity of the microvasculature [39]. This leads to impaired capillary perfusion, systemic hypertension, and exacerbation of myocardial ischemia, particularly in patients with preexisting cardiovascular conditions [40].

Systemic inflammation plays a pivotal role in the pathogenesis of CVD in cardio-oncology [33]. Cancer itself and certain therapies stimulate the release of pro-inflammatory cytokines, such as interleukins and tumor necrosis factor-alpha [41]. These cytokines

Table 1: Cardiotoxicity of common cancer drugs [29].

Drug	Cardiotoxicity mechanism
ICIs	Oxidative stress and immune inflammation with T-cell infiltration of the myocardium
TKIs	Apoptosis, mitochondrial damage, and oxidative stress of cardiomyocytes
5-fluorouracil	ROS production, direct toxic effect on vascular endothelial dysfunction
Cisplatin	Mitochondrial dysfunction and oxidative stress
Cyclophosphamide	Increased pro-apoptotic/pro-inflammatory activities and endothelial damage
Trastuzumab	Interruption of ErbB4/ErbB2 heterodimerization and activation of autophagy-inhibitory Erk/mTOR/Ulk1 signaling cascade
Anthracyclines	Dysregulation of cardiomyocyte autophay

Figure 3: Cardiotoxicity prevention and detection. Reproduced from [34].

disrupt endothelial function, enhance platelet aggregation, and promote a pro-thrombotic state. Consequently, cancer patients are at an increased risk of thromboembolic events, including deep vein thrombosis and pulmonary embolism [42]. Inflammatory pathways also contribute to vascular stiffness and the development of heart failure with preserved ejection fraction (EF) [43].

Oxidative stress and mitochondrial dysfunction are central to the cardiotoxic effects of cancer therapies. Reactive oxygen species (ROS) generated during chemotherapy damage cellular proteins, lipids, and DNA, leading to mitochondrial dysfunction [44]. This reduces ATP production in cardiomyocytes, impairing contractility and contributing to heart failure. Additionally, the accumulation of ROS triggers fibrotic remodeling and chronic inflammation, further aggravating cardiac dysfunction [45, 46].

The interplay between cancer and CVD extends to metabolic dysregulation and immune responses [47]. Metabolic alterations induced by cancer treatments, such as insulin resistance and dyslipidemia, create a pro-atherogenic environment. Immune checkpoint inhibitors (ICIs), while effective against tumors, can provoke immune-mediated myocarditis. This condition involves T-cell infiltration of myocardial tissue, resulting in severe inflammation and potentially life-threatening cardiac dysfunction [48, 49].

In conclusion, the pathophysiology of CVD in cardio-oncology encompasses a multifaceted interplay of myocardial injury, vascular toxicity, systemic inflammation, oxidative stress, and immune dysregulation. These mechanisms underline the importance of early detection and integrated care to mitigate cardiovascular complications while maintaining the efficacy of cancer therapies. A thorough understanding of these processes informs the development of targeted interventions and personalized strategies for optimizing patient outcomes.

Implications

The emergence of cardio-oncology as a distinct field highlights the significant cardiovascular implications of cancer therapies and their impact on long-term patient outcomes [26]. The increasing prevalence of cancer survivorship has brought attention to the unintended consequences of life-saving treatments, such as chemotherapy, immunotherapy, and radiation, on cardiovascular health [50]. These implications are critical, given that CVDs have become one of the leading non-cancer-related causes of morbidity and mortality among cancer survivors.

One major implication is the heightened risk of heart failure due to cancer therapies. Drugs such as anthracyclines and HER2 inhibitors are known for their cardiotoxic effects, potentially leading to left ventricular dysfunction [51]. In many cases, these effects may manifest years after treatment, emphasizing the need for long-term surveillance. Cardio-oncology addresses these challenges by advocating for early detection through biomarkers, imaging, and risk assessment tools, which enable clinicians to mitigate the risk of heart failure in vulnerable populations [52].

Another significant implication involves arrhythmias, which can arise as a consequence of cancer therapies. For instance, tyrosine kinase inhibitors (TKIs) and certain immunotherapies have been associated with an increased risk of atrial fibrillation and QT interval prolongation [53]. These arrhythmias not only complicate treatment regimens but also increase the risk of stroke and sudden cardiac death. By incorporating electrophysiology expertise, cardio-oncology aims to manage these risks proactively through tailored monitoring and interventions [54].

Cancer treatments also exacerbate traditional cardiovascular risk factors such as hypertension, thrombosis, and metabolic disturbances [33]. For example, anti-angiogenic agents used in cancer therapies often lead to treatment-induced hypertension, increasing the risk of myocardial infarction and stroke. Moreover, cancer itself may induce a hypercoagulable state, predisposing patients to thromboembolic events. Cardio-oncology provides a framework for managing these conditions in a comprehensive manner, ensuring that cancer treatments do not inadvertently compromise cardiovascular health [55].

The psychosocial and economic implications of cardio-oncology are equally significant [56]. Cardiovascular complications can lead to prolonged hospitalizations, increased healthcare costs, and reduced quality of life for cancer patients and survivors [57]. Additionally, the emotional burden of managing both cancer and cardiovascular risks can exacerbate stress and anxiety in patients. The interdisciplinary nature of cardio-oncology helps address these challenges by fostering patient-centered care that emphasizes education, support, and shared decision-making [58].

Lastly, the implications of cardio-oncology extend to healthcare systems and policy development [59]. As the field grows, it underscores the need for updated clinical guidelines, specialized training for clinicians, and the integration of cardio-oncology services into standard cancer care. The establishment of dedicated cardio-oncology units and collaborative care models exemplifies a commitment to addressing the dual burden of cancer and CVDs [60]. By prioritizing this holistic approach, the field not only improves individual patient outcomes but also contributes to the sustainability of healthcare systems.

In summary, cardio-oncology has profound implications for patients, clinicians, and healthcare systems. It underscores the importance of balancing oncologic efficacy with cardiovascular safety, ensuring that the progress in cancer treatment does not come at the expense of long-term cardiovascular health [61]. This evolving field serves as a model for interdisciplinary collaboration, advancing both clinical practice and research to meet the complex needs of patients facing dual health challenges.

Advances in Diagnostic Tools

The field of cardio-oncology has witnessed transformative advancements in diagnostic tools, enabling the early detection and effective management of cardiotoxicities caused by cancer treatments [62]. These tools integrate cutting-edge imaging modalities, biomarker analysis, wearable technologies, and artificial intelligence (AI) to provide comprehensive assessments of cardiovascular health in cancer patients, ensuring that potential complications are addressed proactively [63].

Cardiac imaging has become a cornerstone of cardio-oncology diagnostics. Advanced echocardiographic techniques, such as speckle-tracking echocardiography (STE), allow for the early detection of myocardial dysfunction by measuring global longitudinal strain (GLS), often identifying damage before a decline in EF is evident [64, 65]. Meanwhile, three-dimensional (3D) echocardiography enhances the precision of volume measurements. CMR offers unparalleled accuracy in assessing myocardial structure and function, with T1 and T2 mapping detecting early fibrosis and inflammation. Late gadolinium enhancement (LGE) further identifies scarring, often caused by chemotherapy or radiation [66].

Biomarkers have also revolutionized cardiotoxicity monitoring. Troponins, released during myocardial injury, serve as sensitive

indicators of acute cardiac damage and are instrumental in predicting long-term cardiovascular outcomes [67]. Natriuretic peptides, including B-type natriuretic peptide (BNP) and aminoterminal pro B-type natriuretic peptide (NT-proBNP), are key in identifying heart failure risks, especially in patients undergoing treatments with anthracyclines or HER2 inhibitors. Emerging biomarkers, such as galectin-3 and microRNAs, offer insights into inflammation, fibrosis, and oxidative stress, expanding the scope of personalized diagnostic strategies in cardio-oncology [68].

Nuclear imaging techniques are gaining traction for their ability to assess myocardial metabolism and perfusion. Positron emission tomography (PET) and single-photon emission computed tomography (SPECT) are valuable in detecting ischemia, inflammation, and viability, particularly in cases of radiation-induced cardiomyopathy [69, 70]. These modalities complement traditional imaging techniques, providing a detailed understanding of the cardiac impacts of oncologic therapies.

Wearable and remote monitoring technologies are transforming how cardio-oncology patients are managed. Devices like smartwatches and implantable loop recorders (ILRs) facilitate continuous monitoring of heart rate, blood pressure, and arrhythmias such as atrial fibrillation [71]. Remote systems allow clinicians to detect abnormalities in real time, enabling early interventions that mitigate risks. These tools enhance the accessibility and responsiveness of cardiovascular care, especially in outpatient and rural settings [72].

AI and machine learning are reshaping diagnostic capabilities by analyzing large datasets to identify patterns and predict risks [73]. AI-powered algorithms enhance imaging interpretation, such as improving the sensitivity and specificity of GLS measurements. Additionally, risk prediction models integrate biomarker levels, imaging results, and patient demographics to forecast the likelihood of cardiotoxic events, supporting personalized treatment plans [74, 75].

Finally, multi-modality approaches that combine diagnostic tools enhance precision in cardio-oncology. For example, pairing GLS measurements from echocardiography with troponin levels provides a robust framework for detecting early cardiotoxicity [76]. Similarly, integrating CMR and PET imaging offers comprehensive insights into myocardial structure, function, and metabolism, supporting complex clinical decision-making [77].

In conclusion, advances in diagnostic tools have greatly enriched cardio-oncology by enabling the early detection of cardiovascular complications, optimizing patient outcomes, and minimizing disruptions to cancer treatment [78]. These innovations underscore the importance of precision medicine and interdisciplinary collaboration in managing the dual challenges of cancer and CVDs.

Role of Advanced Imaging

Advanced imaging plays a critical role in cardio-oncology, enabling precise assessment of cardiovascular health in patients undergoing cancer treatments [79]. Imaging modalities provide non-invasive tools to detect, monitor, and manage cardiotoxic effects of cancer therapies, facilitating timely interventions to mitigate risks of long-term cardiovascular complications [80]. These techniques integrate state-of-the-art technologies with scientific principles to offer comprehensive evaluations of myocardial function, structure, and perfusion.

One of the cornerstones of advanced imaging in cardio-oncology is echocardiography, particularly with the adoption of STE. STE measures GLS, a sensitive parameter that detects subtle myocardial deformation before conventional metrics like EF decline [81]. This is particularly important for monitoring patients on anthracyclines or HER2 inhibitors, as early identification of myocardial dysfunction allows for the timely introduction of cardioprotective agents, minimizing the risk of heart failure. The ability to assess myocardial strain derives from tracking natural acoustic markers in tissue, providing real-time data on cardiac mechanics [82].

CMR is another powerful tool, offering unparalleled accuracy in visualizing myocardial structure and detecting subtle changes. CMR employs advanced techniques such as T1 and T2 mapping to quantify tissue characteristics, including edema, fibrosis, and fat infiltration [83, 84]. These features are particularly relevant for detecting radiation-induced cardiotoxicity and inflammatory responses to immunotherapy. LGE, a hallmark of CMR, highlights myocardial scarring by exploiting differences in gadolinium uptake between healthy and damaged tissues. This technique is invaluable in assessing myocardial viability and guiding therapeutic decisions [85].

Nuclear imaging, including PET and SPECT, extends the scope of cardio-oncology imaging by evaluating myocardial metabolism and perfusion [86]. PET imaging uses radiotracers like fluorodeoxyglucose to detect inflammatory activity or ischemic areas within the myocardium [86]. SPECT, on the other hand, identifies perfusion defects that may arise from microvascular damage or coronary artery disease induced by cancer treatments [86]. These modalities provide insights into the pathophysiology of cardiotoxicity at the molecular and cellular levels, offering opportunities for early detection and tailored interventions.

3D echocardiography and contrast-enhanced imaging further enhance diagnostic accuracy. 3D echocardiography provides volumetric assessments of cardiac chambers, improving reproducibility and precision in measuring EF [87]. Contrast-enhanced techniques amplify the visualization of endocardial borders, aiding in the detection of subtle structural abnormalities that may not be apparent with standard imaging [88]. These advancements are particularly beneficial in patients with challenging anatomies or poor acoustic windows.

Emerging imaging modalities, such as strain-encoded magnetic resonance (SENC) and cardiac computed tomography (CT), are also contributing to the field. SENC provides high-resolution strain imaging without the need for intravenous contrast, making it a valuable option for patients with contraindications to gadolinium [89]. Cardiac CT, equipped with dual-energy and high-resolution capabilities, is used to evaluate coronary artery disease and calcifications, which are risks exacerbated by cancer therapies like radiation [90].

In summary, advanced imaging modalities are indispensable in cardio-oncology, offering robust and scientifically grounded methods to evaluate and mitigate cardiotoxic risks. They not only enhance early detection of subclinical dysfunction but also inform therapeutic strategies, ultimately improving outcomes for cancer patients. As technology continues to evolve, these tools will play an increasingly pivotal role in integrating cardiology and oncology for holistic patient care.

Cancer Therapy-Related Cardiovascular Toxicity

Cancer therapies, while essential for treating malignancies, often have significant off-target effects on the cardiovascular system, leading to a spectrum of cardiovascular toxicities. These toxicities can manifest acutely during treatment or as delayed effects years after therapy, significantly impacting the quality of life and survival of cancer patients

[91]. Understanding the mechanisms and types of cardiotoxicities is critical to managing and mitigating these complications.

Chemotherapy-induced cardiotoxicity

Anthracyclines, a cornerstone of chemotherapy, are among the most well-documented cardiotoxic agents. They cause cumulative dose-dependent damage to cardiomyocytes by generating ROS and interfering with topoisomerase II beta, leading to DNA damage and apoptosis [92]. This results in left ventricular dysfunction and cardiomyopathy, often progressing to heart failure. HER2 inhibitors, such as trastuzumab, act synergistically with anthracyclines and disrupt cardiomyocyte signaling pathways essential for cell survival, causing reversible cardiac dysfunction in many cases [93].

Platinum-based agents, including cisplatin, contribute to cardiovascular toxicity through endothelial damage, oxidative stress, and enhanced thrombotic risk [94]. These effects can result in hypertension, myocardial ischemia, and accelerated atherosclerosis. Fluoropyrimidines like 5-fluorouracil can induce coronary vasospasm, leading to angina or acute coronary syndromes, particularly in patients with preexisting coronary artery disease [95].

Radiation therapy-induced cardiovascular effects

Radiation therapy targeting the chest area, particularly in treating breast cancer and lymphoma, poses significant risks to the cardiovascular system [96]. Radiation-induced endothelial damage promotes inflammation, fibrosis, and atherosclerosis in the coronary arteries. Long-term effects include ischemic heart disease, valvular heart disease, and pericardial disease. Pericardial fibrosis and effusions are common, and radiation can also damage the myocardium, leading to restrictive cardiomyopathy [97].

Targeted therapy-related cardiotoxicity

Targeted therapies, including TKIs and VEGF inhibitors, have expanded the therapeutic arsenal against cancer but introduced unique cardiovascular risks. TKIs, such as imatinib and nilotinib, are associated with hypertension, arrhythmias, and QT interval prolongation, which can lead to sudden cardiac death in severe cases [98]. VEGF inhibitors, by inhibiting angiogenesis, impair endothelial function, causing hypertension, proteinuria, and an increased risk of arterial thromboembolic events [99].

Immunotherapy and immune-related cardiovascular toxicity

ICIs, a revolutionary cancer treatment, can trigger immune-mediated myocarditis, pericarditis, and vasculitis. Myocarditis caused by ICIs is a rare but potentially fatal complication, characterized by T-cell infiltration of myocardial tissue [100]. This condition requires prompt diagnosis and high-dose corticosteroid treatment to mitigate the inflammatory damage. ICIs may also exacerbate atherosclerosis and promote plaque instability, increasing the risk of myocardial infarction [101].

Thrombosis and coagulation disorders

Many cancer therapies heighten the risk of thrombosis, partly due to endothelial injury and a hypercoagulable state induced by cancer itself. This is exacerbated by treatments such as anti-angiogenic agents, which impair vascular integrity. Venous thromboembolism, pulmonary embolism, and arterial thrombotic events are common cardiovascular complications in cancer patients undergoing therapy [102].

Heart failure and arrhythmia

Cancer therapies can contribute to both systolic and diastolic heart failure. Agents like anthracyclines and trastuzumab primarily cause systolic dysfunction, while radiation and certain targeted therapies can lead to diastolic dysfunction by promoting myocardial stiffness and fibrosis [103]. Arrhythmias, including atrial fibrillation and QT prolongation, are frequently observed with TKIs and fluoropyrimidines, necessitating regular ECG monitoring during treatment [104].

In summary, cancer therapy-related cardiovascular toxicity encompasses a wide range of complications, including heart failure, ischemia, arrhythmias, and thromboembolic events. These toxicities stem from direct myocardial damage, endothelial dysfunction, inflammatory responses, and metabolic disturbances induced by cancer treatments. Recognizing these risks and integrating preventive, diagnostic, and therapeutic strategies within cardio-oncology can significantly enhance patient outcomes and quality of life [2].

Role of Biomarkers in Cardio-Oncology

Cardio-oncology is a growing field that focuses on the intersection of CVDs and cancer treatments. As cancer therapies, such as chemotherapy, targeted therapy, and radiation, improve survival rates, they often come with a risk of cardiovascular complications. In this context, biomarkers have emerged as crucial tools for early detection, monitoring, and management of cardiotoxicity in cancer patients [33]. Biomarkers are measurable substances in the blood, tissues, or other body fluids that can indicate the presence or risk of disease. In cardio-oncology, they help in understanding the mechanisms of cardiovascular damage induced by cancer treatments and aid in predicting patient outcomes [33].

One of the main roles of biomarkers in cardio-oncology is identifying early signs of cardiotoxicity, which can manifest as heart failure, arrhythmias, or other cardiovascular conditions [105]. For example, biomarkers such as troponin, BNP and NT-proBNP are commonly used to detect myocardial injury or strain [106]. Elevated levels of these biomarkers can signal that heart muscle damage is occurring, allowing for early intervention to prevent further damage. Additionally, high-sensitivity C-reactive protein (hs-CRP) and interleukins help assess inflammation levels, which is often heightened in patients undergoing cancer treatments and can contribute to cardiovascular problems [107].

Biomarkers also serve as important prognostic tools in cardio-oncology. They can be used to predict the likelihood of developing CVDs following cancer treatment, allowing healthcare providers to tailor interventions [108]. For instance, the presence of certain genetic markers may indicate an increased risk of heart failure, while other molecular biomarkers could suggest a higher susceptibility to arrhythmias. Moreover, monitoring biomarkers over time can help gauge the efficacy of cardioprotective interventions, such as the use of angiotensin-converting enzyme inhibitors (ACE inhibitors) or beta-blockers, in reducing the incidence of cardiotoxicity [109].

Emerging research is exploring the role of more specialized biomarkers, such as those related to oxidative stress, mitochondrial function, and endothelial dysfunction, to better understand the underlying mechanisms of cardiotoxicity [110]. These biomarkers may also help predict long-term cardiovascular outcomes and offer new targets for therapeutic strategies. As the field of cardio-oncology continues to evolve, the integration of biomarkers into clinical practice holds the potential to improve the management of cancer patients,

mitigate cardiovascular risks, and enhance the overall quality of care [111].

In summary, biomarkers are indispensable in the field of cardio-oncology. They enable clinicians to detect early signs of cardiotoxicity, predict long-term cardiovascular risks, and guide therapeutic decisions. As research advances, the discovery of new biomarkers and their application in personalized medicine may offer even greater opportunities for improving the outcomes of cancer survivors and reducing the burden of CVDs in this vulnerable population [112].

Conclusions

Cardio-oncology has emerged as a vital interdisciplinary field that addresses the cardiovascular risks associated with cancer treatments. As cancer therapies continue to improve survival rates, there is an increasing recognition of the long-term cardiovascular consequences that can arise from these life-saving treatments. Cardiovascular complications, such as heart failure, arrhythmias, and hypertension, can significantly impact the quality of life and survival of cancer survivors. Thus, cardio-oncology plays a crucial role in bridging the gap between oncology and cardiology, ensuring that patients receive comprehensive care that addresses both their cancer and cardiovascular health.

The integration of biomarkers into cardio-oncology represents a transformative advancement in the early detection, monitoring, and management of cardiotoxicity (Figure 3). Biomarkers help identify patients at high risk for cardiovascular complications, enabling timely interventions to prevent irreversible damage. Furthermore, they provide valuable insights into the mechanisms underlying heart injury caused by cancer therapies and guide personalized treatment strategies. As research in this area progresses, the discovery of novel biomarkers and their application in clinical practice holds the promise of improving patient outcomes and reducing the burden of cardiotoxicity.

Ultimately, the future of cardio-oncology lies in the continued collaboration between oncologists, cardiologists, and researchers to develop more effective diagnostic tools, therapies, and preventive strategies. By combining advances in molecular biology, precision medicine, and cardiovascular care, the field has the potential to significantly improve the quality of life for cancer patients and survivors. As our understanding of the complex relationship between cancer and cardiovascular health deepens, cardio-oncology will play an increasingly central role in shaping the future of cancer care and survivorship.

Acknowledgements

None.

Conflict of Interest

None.

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