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CHALLENGES AND TRENDS IN THE PREVENTION OF CARDIOVASCULAR SIDE EFFECTS IN CANCER THERAPIES: A BIBLIOMETRIC APPROACH

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***ABSTRACT*:**

The prolonged survival of cancer patients has highlighted a consequence that was, until recently, underestimated. Among the most frequent side effects are hypertension, arrhythmias, heart failure, and myocarditis. The present study aims to address the following questions: Can bibliometric analysis be used to evaluate trends in the scientific production related to cardiovascular prevention and side effects in cancer therapies? And can co-occurrence network analysis help identify the challenges in cardiovascular prevention and adverse effects associated with cancer treatments? To answer these questions, a bibliometric study based on co-occurrence network analysis was conducted. The evaluated corpus comprised 159 scientific articles. The results allowed for the identification of four highly relevant clusters: Cluster 1: Natural Compounds and Alternative Oncoprotective Therapies; Cluster 2: Oncological Hormonal Therapies and Associated Systemic Risks; Cluster 3: Cardioprotective Strategies and Risk Management in Cancer Patients; and Cluster 4: Advanced Diagnostics and Biomarkers in Preventive Cardio-Oncology. These findings contribute new avenues of knowledge, enabling researchers interested in this field to explore novel constructs and apply advanced factorial models.

Palabras claves: Prevención cardiovascular, efectos secundarios, terapias contra el cáncer, bibliometría, Python

***Keywords**: Prevention of cardiovascular, side effects, cancer therapies, bibliometric, Python*

INTRODUCTION

In recent decades, advances in early detection, the development of targeted therapies, and improved survival rates have radically transformed the prognosis of cancer. An increasing number of individuals are living beyond diagnosis and treatment, prompting a new focus on the long-term quality of life of cancer patients. However, this clinical success has introduced new challenges, among which cardiovascular side effects associated with antineoplastic treatments stand out. Drugs such as anthracyclines, HER2 inhibitors, and immunotherapies have shown a significant association with cardiotoxicities, including heart failure, arrhythmias, hypertension, thromboembolism, and vascular inflammation [1], [2]. These complications may present acutely or emerge many years after treatment, severely compromising the cardiovascular health of cancer survivors [3].

The rising incidence of these adverse events has led to the emergence of cardio-oncology as a clinical and scientific discipline, aiming to prevent, diagnose, and manage cardiovascular complications resulting from cancer therapies. However, significant gaps remain in clinical practice: limited integration of interdisciplinary teams, lack of consensus on surveillance protocols, underuse of predictive biomarkers, and unequal access to specialized resources hinder the delivery of comprehensive and equitable care [4], [5]. These gaps are also reflected in scientific research, where the production of consolidated evidence to guide effective and sustainable prevention policies remains limited, particularly in low- and middle-income settings [6].

In this context, bibliometrics emerges as a powerful tool for understanding the evolution of knowledge surrounding this emerging issue. Through quantitative and qualitative analysis of the scientific literature, it is

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possible to identify thematic trends, research gaps, collaboration networks, key authors and institutions, and the dynamics of academic citations in the field of cardiovascular side effect prevention in cancer therapies. This approach enables the mapping of the state of the art, the identification of the most pressing challenges, and the guidance of future research from a critical, integrative, and evidence-based perspective [7].

The present bibliometric study aims to analyze the scientific production related to cardiovascular effects associated with oncological treatments, with a particular focus on preventive strategies, the evolution of thematic lines, and the structural challenges of the field. Through this analysis, the study seeks to provide a comprehensive overview that contributes to strengthening the integration between oncology and cardiology, promoting more effective preventive approaches, and fostering global, inclusive research with high clinical impact [8], [9].

Scientific Trends in Cardio-Oncology: Evolution and Emerging Areas of Interest

The field of cardio-oncology has experienced remarkable growth over the past two decades, as evidenced by the sustained increase in scientific publications, the expansion of international collaborative networks, and the advancement of clinical specialization [10], [11]. This interdisciplinary discipline has evolved from the need to understand and mitigate the cardiovascular adverse effects caused by cancer treatments, particularly in a context where cancer survival has improved dramatically. In the United States alone, more than 18.6 million people currently live with a history of cancer a number projected to exceed 22 million by 2035 [12].

Bibliometric analysis applied to this field reveals a thematic concentration around four main axes. First, there are studies focused on anthracycline- and trastuzumab-induced cardiotoxicity, which is extensively documented in breast cancer. These agents can lead to a range of cardiac complications, from left ventricular dysfunction to congestive heart failure [13].

Second, the literature has shown a growing number of publications related to the cardiovascular effects of new therapies, such as immune checkpoint inhibitors (e.g., PD-1, CTLA-4) and targeted therapies, which can induce hypertension, thrombotic events, and myocardial inflammation [14], [15].

Third, there has been sustained growth in research evaluating the use of cardiac biomarkers such as high-sensitivity troponin and B-type natriuretic peptide (BNP) as tools for the early detection of myocardial injury [16]. Finally, an expanding line of research is emerging that aims to develop predictive models using artificial intelligence, integrating clinical, genomic, and imaging data to estimate individual risk of cardiovascular toxicity [17], [18].

Geographically, studies are concentrated in the United States, Western Europe, and Canada, with low representation from developing countries [19]. Interinstitutional collaborations occur primarily between leading oncology hospitals and high-level cardiovascular centers, while journals such as Journal of Clinical Oncology, Circulation, and JACC: CardioOncology lead in citation count and scientific output [20], [21]. This distribution also reveals an imbalance in global research and underscores the urgent need to expand access to detection and monitoring technologies in resource-limited settings [22].

Main Clinical Challenges in the Prevention of Cardiovascular Effects

The effective prevention of cardiovascular events in patients undergoing oncological therapies faces multiple clinical and structural challenges [23]. One of the fundamental challenges lies in the early identification of cardiovascular risk before initiating cancer treatment. Although risk assessment algorithms such as the HFA-ICOS score from the European Society of Cardiology are available, their implementation in real-world clinical settings remains limited due to time constraints, lack of diagnostic resources, or insufficient training of medical personnel [24], [25].

Another significant challenge is the lack of standardization in monitoring protocols. In most oncology centers, cardiovascular assessments are not routinely conducted during treatment, and active surveillance is typically limited to patients with evident prior history [26]. This gap is concerning, as effects such as myocardial dysfunction or hypertension can remain asymptomatic for months and progress to irreversible stages [27].

Wagle et al. (2025) report that the use of anthracyclines, HER2 inhibitors, and hormonal therapies is directly associated with cardiovascular damage in breast cancer patients, with higher frequency and severity observed among Afro-descendant populations and individuals from lower socioeconomic backgrounds [28].

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Moreover, there is a persistent underutilization of cardioprotective agents such as dexrazoxane, despite its demonstrated efficacy in mitigating anthracycline-induced cardiotoxicity [29]. Its use is restricted due to regulatory limitations, high cost, or lack of clinical awareness. This is further compounded by the absence of specialized training: few centers offer integrated cardio-oncology services, and care is often fragmented between oncologists and cardiologists, with limited communication and no shared protocols [30].

From a population-based perspective, another key challenge is ensuring equity in access to cardiovascular follow-up, as significant racial and geographic disparities persist. Recent studies have documented that Black women are less likely to receive appropriate hormonal treatment, experience higher rates of adverse effects, and have poorer survival outcomes compared to White women [31].

These challenges highlight the need to promote integrated care models, equity-centered health policies, and continuous education programs in cardio-oncology, enabling progress toward effective and systematic prevention across all clinical settings [32].

Emerging Technologies and Innovative Approaches in Diagnosis and Monitoring

Technological innovation has opened new possibilities for the early diagnosis and prevention of cardiovascular effects in oncology patients [17], [18]. One of the most significant advancements is the use of advanced cardiovascular imaging techniques, such as speckle-tracking echocardiography (global longitudinal strain) and cardiac magnetic resonance imaging (CMR), which enable the detection of subclinical alterations in ventricular function before clinical symptoms appear [33].

Serum biomarkers such as high-sensitivity troponin, BNP, and inflammatory myokines have also proven useful as early warning tools for identifying incipient myocardial damage [34]. In patients treated with trastuzumab, elevated troponin levels are correlated with a higher likelihood of developing persistent ventricular dysfunction [13].

Recently, the use of artificial intelligence (AI) has begun to transform clinical practice. Machine learning models trained on electronic health records, imaging, and genomic data can predict the risk of cardiotoxicity with greater accuracy than traditional methods [35]. These algorithms also enable the personalization of follow-up frequency and treatment intensity, thereby reducing costs and improving clinical outcomes [36].

In addition, digital platforms and mobile applications have emerged for the remote monitoring of blood pressure, heart rhythm, and related symptoms. This enables continuous home-based surveillance, which is particularly beneficial for patients with limited mobility or those living in remote areas far from specialized centers [37]. However, their adoption remains uneven due to technological, educational, and regulatory barriers [22], [38].

On the other hand, personalized medicine based on genetics and pharmacogenomics is beginning to emerge as a key tool. Understanding polymorphisms in genes involved in drug metabolism (e.g., CBR3, HER2, UGT1A6) can guide the selection of therapeutic regimens that are less cardiotoxic [39].

These advances offer a promising outlook, although their full implementation will require strategic investments, extensive clinical validation, and inclusive technology policies to bridge the digital divide in healthcare [6].

Bibliometric Findings on Inequities and Research Gaps

Bibliometric analysis makes it possible to highlight existing disparities in scientific production and thematic gaps in the prevention of cancer-associated cardiovascular events [40]. First, there is a noticeable geographic concentration of research in high-income countries, particularly the United States, the United Kingdom, Germany, and Canada, which account for over 70% of the most cited publications in this field [41]. Latin America, Africa, and South Asia show low participation in the literature, which limits the generalizability of findings at the global level [3].

Second, there are gender biases in authorship and in the design of clinical studies. Most of the reviewed trials include unbalanced samples with respect to sex, and women particularly those from minority ethnic groups are underrepresented in cardiovascular prevention studies [42]. As demonstrated by Wagle et al. (2025), in breast cancer, Black women exhibit lower treatment adherence and response rates; however, this population is rarely addressed in controlled clinical studies [43].

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Thematic analysis through keyword co-occurrence reveals a lack of studies focused on pediatric and adolescent populations, as well as on geriatric patients with comorbidities [44]. There is also a noticeable lack of longitudinal studies evaluating late-onset cardiovascular effects beyond five years post-treatment, which is critical given the sustained increase in life expectancy among cancer survivors [45].

Moreover, institutional collaboration networks are highly fragmented. Despite the existence of certain collaborative hubs such as universities affiliated with the American Cancer Society or the MD Anderson Cancer Center most studies remain isolated, lacking sustained interdisciplinary synergies and active involvement from primary care centers [46].

These bibliometric disparities underscore the urgent need to promote inclusive, multicenter, and equity-oriented research. Funding agencies and scientific publishers must take a proactive role in addressing these biases to ensure that the knowledge generated benefits all affected populations [47], [40].

Aplicaciones de metodología PRISMA en investigaciones de la prevención cardiovascular en terapias de cáncer

The growing concern over cardiovascular adverse effects resulting from cancer treatments has driven the need to develop rigorous methodological frameworks for synthesizing the available scientific evidence. In this context, the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodology and its extension for scoping reviews (PRISMA-ScR) have become key tools for ensuring transparency, comprehensiveness, and reproducibility in scientific literature reviews [48]. Its application in the field of cardio-oncology has enabled a structured mapping of the emerging landscape of strategies for preventing cardiotoxicity induced by anticancer therapies [49].

A paradigmatic example of this application is found in the scoping review conducted by Biondi and Madonna (2025), who employed the PRISMA-ScR guidelines to analyze the cardioprotective potential of glucagon-like peptide-1 receptor agonists (GLP1-RAs) against cardiovascular toxicity induced by antineoplastic treatments. The study included thirteen investigations selected through a specific search string applied to databases such as PubMed and EMBASE, filtering exclusively for experimental studies reporting cardiotoxicity-related outcomes. Thanks to the PRISMA framework, the authors structured the selection process using a flow diagram that transparently details each phase of screening, exclusion, and inclusion of studies, thereby reinforcing the methodological validity of the review [50].

The use of PRISMA enabled the researchers to identify not only the types of models employed (in vitro, animal, and retrospective clinical studies), but also to document variations in experimental protocols, the molecular pathways involved, and the relevant biomarkers [51]. It also facilitated a systematization of the findings regarding the positive effects reported for GLP1-RAs on mitochondrial dysfunction, oxidative stress, inflammation, and apoptosis all of which are central mechanisms in cardiotoxicity associated with drugs such as anthracyclines, cisplatin, and methotrexate [52], [53].

In summary, the PRISMA methodology not only adds methodological rigor to systematic reviews in the field of cardio-oncology, but also serves as a powerful tool for identifying knowledge gaps, generating hypotheses, and guiding the design of future clinical studies [54]. Its application, as demonstrated by this review, is particularly useful in multidisciplinary contexts where cardiovascular pharmacology, oncology, and translational medicine converge [55], [56].

Ranking of Publications in Indexed Journals

Bibliometric analysis of the scientific output related to cardiovascular side effects in cancer therapies reveals a significant concentration of articles in high-impact scientific journals, reflecting the consolidation of cardio-oncology as an emerging interdisciplinary field [4], [57]. This specialty is positioned at the intersection of clinical oncology and preventive cardiology, addressing the challenges posed by antineoplastic treatments on patients' cardiovascular health [58]. The academic visibility of this line of research has increased considerably over the past decade, largely due to its dissemination in top-tier indexed journals, particularly those ranked in Quartile 1 (Q1) according to the Journal Citation Reports (JCR) and the Scimago Journal Rank (SJR) [59].

Recent studies reveal that journals such as Journal of Clinical Oncology, JACC: CardioOncology, Circulation, European Heart Journal, and Cardio-Oncology have concentrated a significant portion of the scientific output on

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this topic [60]. For example, JACC: CardioOncology, a subdivision of the renowned Journal of the American College of Cardiology (JACC), has rapidly established itself as a leading platform for disseminating clinical research on cardiac toxicity induced by cancer treatments [61], [40]. This positioning is supported by a growing impact factor and a high citation rate per article, highlighting the relevance and influence of the studies published in this journal within the international scientific community [62].

Likewise, Circulation, one of the most influential journals in the cardiovascular field, has included in its recent issues a significant proportion of research focused on cardiovascular adverse effects resulting from treatments with anthracyclines, HER2 inhibitors, immune checkpoint inhibitors, and other therapeutic agents [63]. The impact factor of Circulation has exceeded 38 in recent years, placing it among the top five journals in the medical field [64]. Its involvement in this thematic area helps validate the clinical importance of preventive approaches to cardiotoxicity in oncology patients and facilitates the dissemination of findings to a broader medical audience [30], [27].

Another noteworthy case is that of the European Journal of Cancer and Breast Cancer Research and Treatment, both of which are frequently cited in recent bibliometric studies on cardio-oncology [7], [65]. Although primarily focused on oncological research, these journals have published numerous articles addressing cardiovascular complications resulting from treatments such as trastuzumab or thoracic radiotherapy, as well as therapeutic proposals for their mitigation [66]. The inclusion of cardiovascular-focused articles in oncology-oriented journals is a clear indicator of the cross-disciplinary growth of this field and underscores the need for integrated approaches in biomedical research [67].

Bibliometric analyses based on Web of Science, Scopus, and PubMed have also shown a sustained increase in the number of publications between 2010 and 2025, with a turning point beginning in 2017, when systematic research on the prevention of cardiotoxicity related to targeted therapies and immunotherapy started to gain visibility [68]. This surge has enabled journals such as Cardio-Oncology (published by BioMed Central) to gain greater prominence by providing a dedicated space for the convergence of disciplines that were previously published in a fragmented manner across single-specialty journals [69], [70].

On the other hand, the ranking of the most cited authors in this field highlights figures such as Bonnie Ky, Daniel Lenihan, and Alexander Lyon, who appear consistently in high-impact indexed journals. This reflects both the concentration of expertise and the consolidation of international collaboration networks in cardio-oncology research. These publications often achieve a high H-index an indicator of academic productivity and impact and their frequent citation in systematic reviews and meta-analyses further reinforces their role as primary sources of clinical evidence [71], [72].

At the regional level, most publications originate from academic centers in the United States and Western Europe, with a progressive increase in contributions from Asia, particularly China and Japan. Although a representation gap persists in regions such as Latin America and Africa, international collaboration initiatives and the open-access policies adopted by many of these journals have facilitated greater inclusion in recent years [73].

In this study, two research questions are proposed. The first question asks: Can bibliometric analysis be used to evaluate trends in the scientific production on cardiovascular prevention and side effects in cancer therapies? This question aims to examine bibliometric indicators to identify thematic and temporal trends within the studied field. The second question is: Can co-occurrence network analysis help identify the challenges in cardiovascular prevention and side effects in cancer therapies? This inquiry seeks to assess network analysis and establish thematic clusters based on conceptual terms defined by the researchers.

Therefore, the prolonged survival of cancer patients has brought to light a previously underestimated consequence. Among the most common side effects are hypertension, arrhythmias, heart failure, and myocarditis some of which may develop many years after the completion of treatment [74].

International experts agree that the increasing complexity of oncological treatments has outpaced the existing evidence regarding their cardiac effects. The occurrence of fatal myocarditis in patients treated with immune checkpoint inhibitors is a critical example of how modern therapies can lead to severe, albeit rare, cardiac complications. Such findings underscore the need for prospective studies and more precise diagnostic tools to enhance the understanding of the central theme of this study [75].

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METHODOLOGY

To address the challenges and trends in cardiovascular prevention within cancer therapies and their associated side effects, we conducted a bibliometric analysis. In accordance with the best practices of the PRISMA methodology (see Figure 1), we applied a structured document selection process relevant to the study context. Additionally, tailored search equations were developed for each selected database (see Table 1).

Figure 1. ***Flow diagram PRISMA***

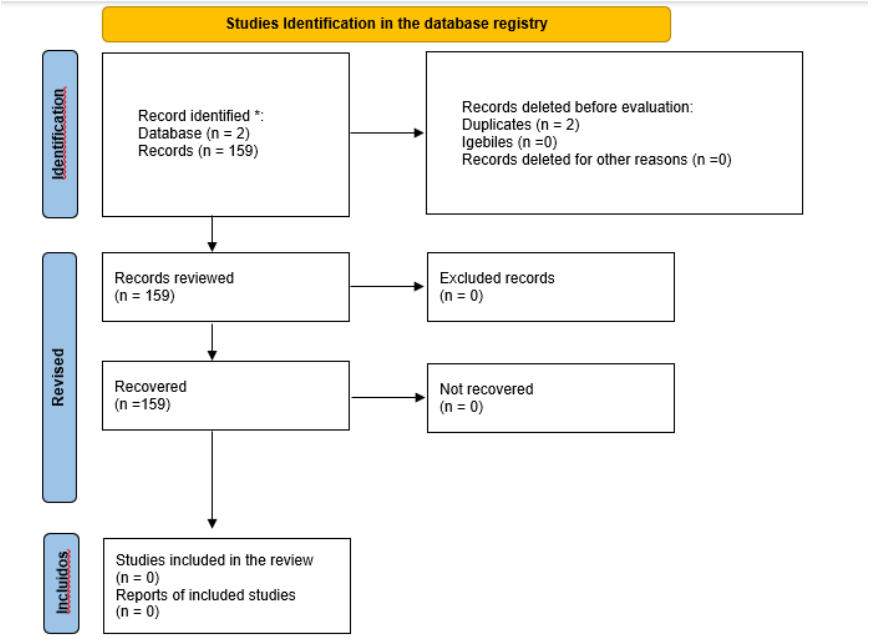

Table 1. Search equation for each data base

Data Base	Search equation	Article found
Scopus	TITLE-ABS-KEY("cardiovascular" and "cancer therapies" and "prevention" and "side effects")	181
Web Of Science	"Cardiovascular" (All fields) And "Cancer Therapies" (All Fields) And "Prevention" (All Fields) And "side effects" (All Fields) Document Types: Article	24
	Summary	205

To answer the proposed research questions, we designed the following workflow (see Figure 2):

1. The bibliographic records relevant to our study were downloaded in .bib format from the selected databases.
2. A Python script was developed to merge the datasets and remove duplicates, generating a final .bib file containing a total of 159 articles.
3. Using the Bibliometrix 5.0 package, we obtained the main bibliometric indicators, which allowed us to address the first research question.
4. With the software VOSviewer 1.6.20, a keyword co-occurrence network was constructed.
5. Based on the JSON file generated by VOSviewer 1.6.20, the study's thematic clusters were identified, and a Python script was used to extract the terms and their corresponding clusters into a .csv file.
6. A Python script was also developed to extract the articles related to each cluster's terms, enabling the construction of the literature review organized by cluster.

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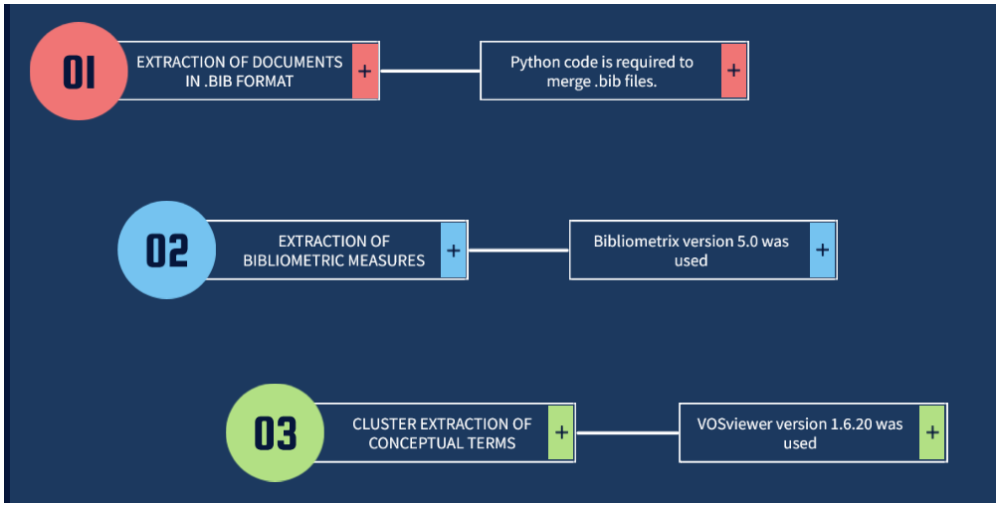
Figure 2. ***Workflow design***



RESULTS

Trends in Cardiovascular Side Effects of Cancer Treatments: An Analysis of Key Bibliometric Indicators
The bibliometric analysis of the scientific production related to cardiovascular side effects in cancer therapies covers the period from 1993 to 2025 (see Figure 3), highlighting a growing attention to this issue within the biomedical and oncological fields. A total of 186 scientific documents were identified, distributed across 159 sources, including scientific journals, books, book chapters, and conference proceedings. This body of literature exhibits an annual growth rate of 8.6%, reflecting a sustained increase in academic interest in understanding, preventing, and mitigating cardiovascular complications associated with cancer treatments.

In terms of academic impact, the analyzed documents report an average of 45.7 citations per publication (see Figure 4), indicating high relevance and visibility within the scientific community. The average document age is 7.74 years, reflecting a balance between recent studies and well-established research that has contributed to the development of a robust theoretical framework. The analyzed literature is supported by a total of 1,727 references, suggesting a strong theoretical and empirical foundation for addressing the topic.

Regarding content, 2,902 terms were identified in Keywords Plus (ID) and 3,296 author-defined keywords (DE) (see Figure 5), demonstrating significant conceptual diversity and the emergence of new thematic lines within the field. This finding is consistent with the interdisciplinary nature of the area, where cardiology, oncology, pharmacology, and epidemiology converge.

In terms of document types, systematic reviews clearly predominate (114), followed by original research articles (56), indicating a strong orientation toward knowledge systematization and the consolidation of theoretical frameworks. Other minor contributions include book chapters (6), short surveys (4), editorials (1), notes (1), and one retracted document, which may reflect editorial quality control.

At the authorship level, a total of 947 researchers participated in the analyzed publications, among whom 16 authors produced single-author publications (see Figure 6). However, collaborative work overwhelmingly predominates, with an average of 5.42 co-authors per document, consistent with the collaborative nature of biomedical research. Notably, no publications with international co-authorship were identified, which may indicate a limitation in the internationalization of knowledge production in this specific field.

Finally, the most influential documents tend to address both the pathophysiological mechanisms of cardiovascular damage induced by chemotherapy and radiotherapy, as well as preventive clinical strategies and cardiovascular monitoring protocols. This positions the topic at the intersection between clinical practice and translational research.

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Figure 3. ***Bibliometric measures***

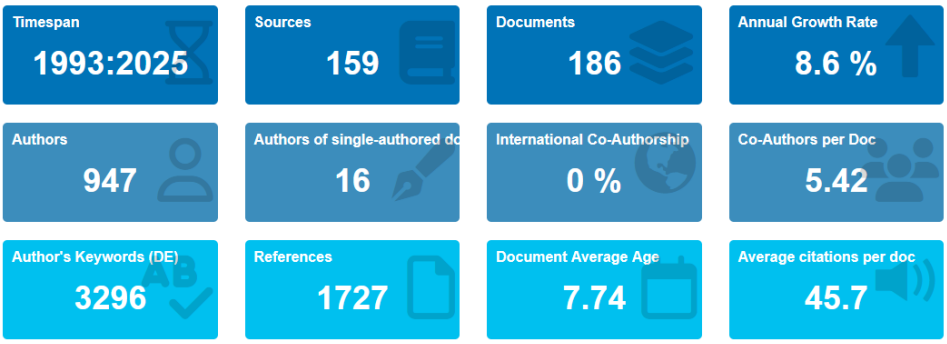


Figure 4. Average citations per year

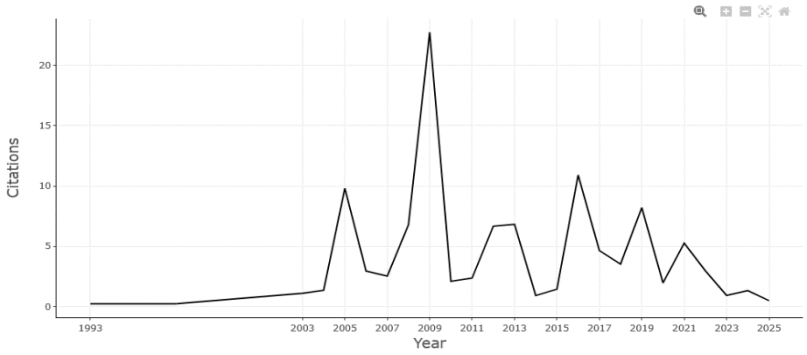
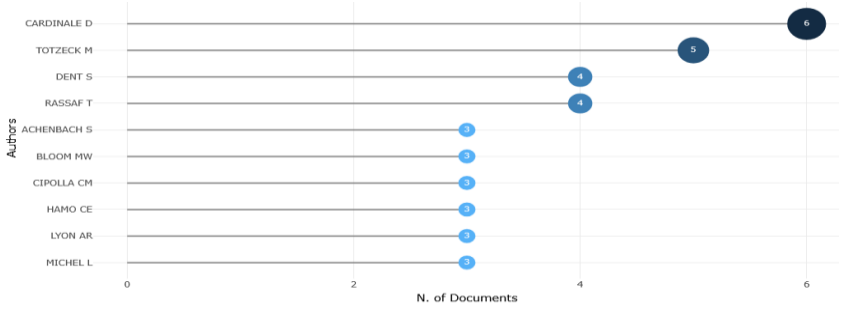


Figure 5. ***Wordcloud defined by the author***

Figure 6. ***Most relevant authors***



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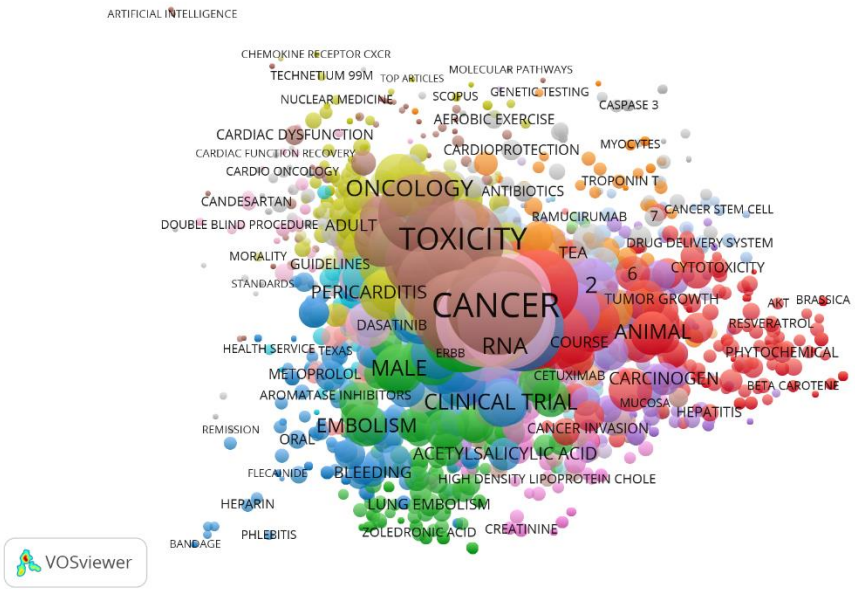
Analysis of the Challenges of Cardiovascular Side Effects in Cancer Treatments: A Co-Occurrence Network Approach.

To address the co-occurrence analysis of terms, a total of 3,296 conceptual terms defined by 947 authors were examined (see Figure 7). Based on the construction of the term co-occurrence network, four thematic clusters were identified. The first cluster was labeled Natural Compounds and Alternative Oncoprotective Therapies. The second cluster was named Oncological Hormonal Therapies and Associated Systemic Risks. The third cluster was designated Cardioprotective Strategies and Risk Management in Cancer Patients. Finally, the fourth cluster was titled Advanced Diagnostics and Biomarkers in Preventive Cardio-Oncology. In the following section, each cluster is analyzed in detail based on the most relevant publications associated with its conceptual terms.

Figure 7. Co-occurrence network



Clúster 1: Natural Compounds and Alternative Oncoprotective Therapies

Cluster 1 synthesizes the predominant elements from the set of terms associated with “Natural Compounds,” encompassing the broad presence of secondary metabolites, phytochemicals, and plant extracts (Fig. 8). Additionally, the term “Alternative Oncoprotective Therapies” refers both to the preventive and palliative role of these compounds in mitigating damage induced by conventional cancer treatments, and to their potential antitumor therapeutic properties.

This approach arises from the growing need to mitigate cardiotoxicity induced by therapies such as anthracyclines and HER2 inhibitors, which, despite significantly improving survival rates across various cancer types, have also imposed an additional clinical burden on patients' cardiovascular health [4], [76].

Several studies within this cluster address the use of natural products with antioxidant, anti-inflammatory, and cytoprotective properties, particularly in the context of breast cancer, the most common cancer among women worldwide [28]. These studies highlight the ability of certain phytochemicals to modulate molecular pathways associated with inflammation, oxidative stress, and cellular apoptosis key factors in the development of cardiovascular damage during chemotherapy. In this regard, both plant extracts and purified bioactive compounds are examined, revealing a growing trend toward the integration of pharmacognosy into cardio-oncology [77].

"Moreover, increasing attention is being given to the perspective of personalized medicine, which acknowledges the heterogeneity in treatment responses and seeks to tailor therapeutic strategies to the patient's clinical profile. This is particularly relevant for cancer survivors a population that has grown significantly in recent decades giving rise to a new category of chronic patients with specific needs for long-term monitoring and secondary prevention [78].

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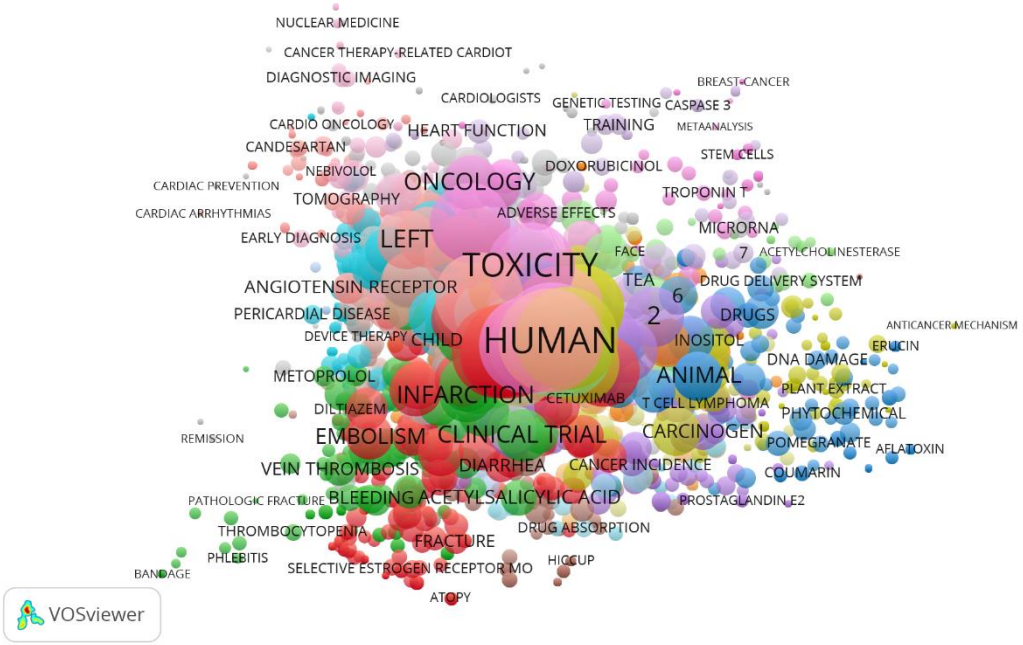
This cluster also reflects a shift toward combined therapies that aim not only to eradicate the tumor but also to preserve the patient's quality of life. In this context, multidisciplinary approaches and clinical protocols for early cardiological monitoring have been reviewed, complemented by nutritional and pharmacological interventions based on natural compounds. Such integrative strategies point toward a more preventive, resilient, and patient-centered approach to oncology.

Taken together, the findings of this cluster position natural compounds and alternative oncoprotective therapies as a promising frontier in the fight against oncology-related cardiotoxicity. Their development not only expands the available therapeutic arsenal but also reinforces the need for a more holistic and sustainable approach to medicine.

Figure 8. Clúster 1: Natural Compounds and Alternative Oncoprotective Therapies



Cluster 2: Oncological Hormonal Therapies and Associated Systemic Risks

The term “Oncological Hormonal Therapies” reflects the core of this cluster the use of hormonal agents in cancer treatment, particularly in breast and prostate cancer. In addition, “Associated Systemic Risks” captures the range of side effects and complications cardiovascular and beyond that accompany these therapies, including fractures, thromboembolism, and metabolic and hormonal imbalances (Fig. 9). This cluster name accurately integrates a dual focus: therapeutic and preventive, in alignment with the overarching theme of the bibliometric study on the challenges of preventing cardiovascular effects during cancer treatments.

Hormonal therapies represent a key strategy in the treatment of hormone-dependent tumors, particularly breast cancer. This type of neoplasm, recognized as the most common among women worldwide, often expresses hormone receptors such as the estrogen receptor, enabling the use of treatments like tamoxifen or aromatase inhibitors [28]. As survival rates continue to rise, the number of individuals living with a history of cancer is also increasing, prompting a reconsideration of the long-term effects of these treatments [58].

However, the positive impact of hormonal therapies is counterbalanced by a range of systemic risks that can compromise patients' quality of life. One of the most significant adverse effects is cardiotoxicity, which has been extensively documented in the context of prolonged oncologic treatments. This phenomenon stands out as a critical cause of morbidity, particularly among patients who have received therapies with cumulative effects on cardiovascular function [79].

Moreover, therapeutically induced hormonal alterations can impact other physiological systems, particularly the endocrine and metabolic systems. The role of the HER receptor family in cellular signaling exemplifies how

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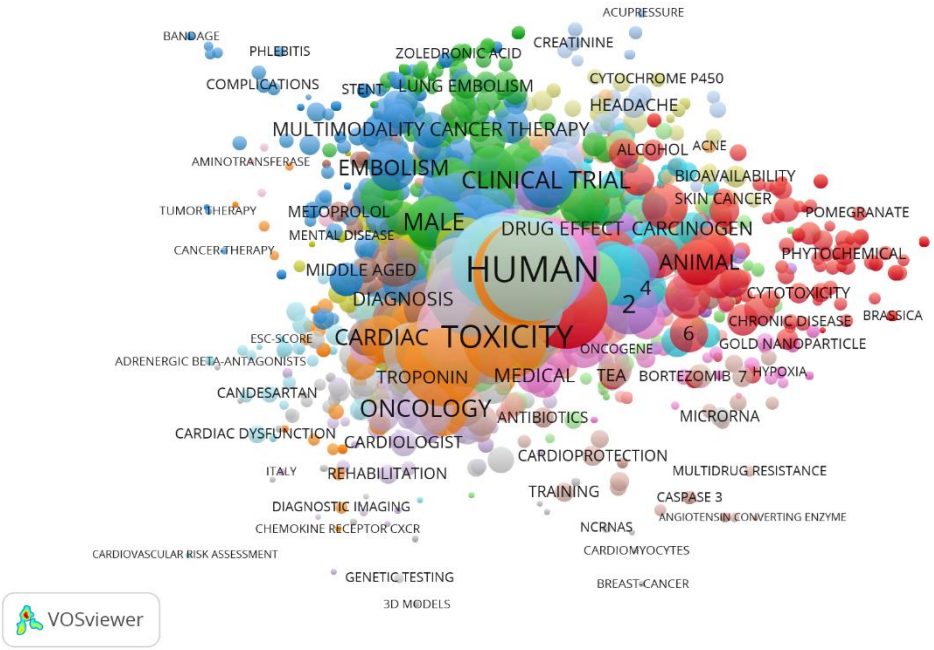
targeted therapies can also exert effects beyond the tumor tissue, leading to systemic side effects such as hypertension, dyslipidemia, and hormonal imbalances [80].

Angiogenesis a process partially regulated by hormones and growth factors is also disrupted during oncologic treatments. This disruption may contribute not only to tumor control but also to the emergence of vascular and systemic adverse events, underscoring the need for multidisciplinary monitoring throughout therapy [81].

In this context, it is essential to adopt an integrative approach that combines the antineoplastic efficacy of hormonal therapies with the active prevention of their collateral effects. Cardio-oncology thus emerges as a key interdisciplinary field to address this therapeutic complexity, proposing treatment strategies that consider not only tumor regression but also the long-term preservation of cardiovascular, metabolic, and endocrine health.

Figure 9. Cluster 2: Oncological Hormonal Therapies and Associated Systemic Risks



Cluster 3: Cardioprotective Strategies and Risk Management in Cancer Patients

For Cluster 3, the term “Cardioprotective Strategies” encompasses preventive, pharmacological, and surgical therapies aimed at mitigating cardiovascular side effects. In parallel, the term “Risk Management in Cancer Patients” refers to the approach applied to populations undergoing cancer therapies, with an emphasis on preventing adverse cardiovascular events. This cluster name accurately reflects its content and highlights its relevance within the bibliometric focus of the present studyo (Fig. 10).

The management of cardiovascular adverse effects induced by oncologic therapies represents one of the most pressing challenges in contemporary clinical practice, given the growing population of cancer survivors. Various cardioprotective strategies have been proposed with the aim of mitigating cardiotoxicity without compromising the efficacy of antineoplastic treatment. Early identification of at-risk patients through biomarkers, functional assessments, and imaging techniques has become a fundamental tool in designing personalized treatment protocols [76].

The literature review shows that cardiovascular complications can arise even decades after treatment, highlighting the need for longitudinal follow-up and coordinated care between oncology and cardiology [82]. The development of multidisciplinary approaches such as cardio-oncology has enabled the optimization of risk assessment, the implementation of preventive measures, and the establishment of pharmacological and non-pharmacological interventions aimed at preserving cardiac function [77].

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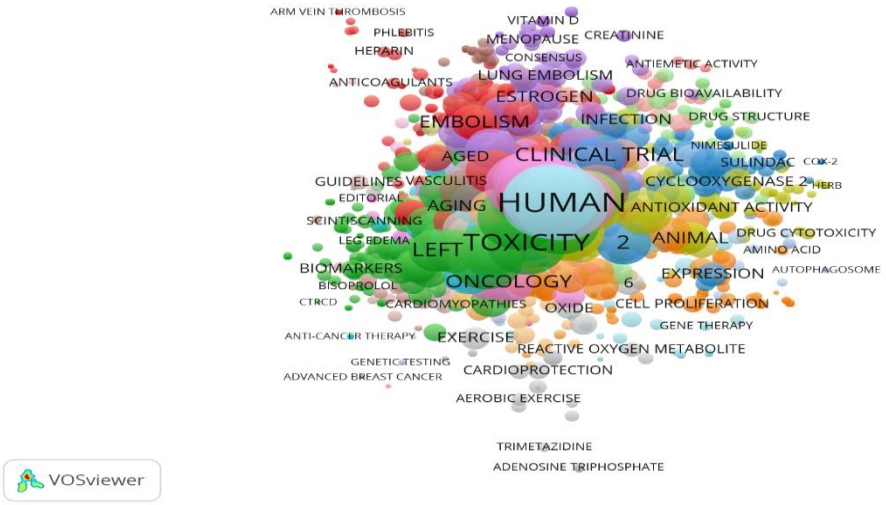
Among emerging strategies, cardioprotective agents such as ACE inhibitors, beta-blockers, and, in experimental settings, phytocompounds with antioxidant and anti-inflammatory potential stand out. For instance, the therapeutic utility of compounds derived from Saraca asoca has been documented, suggesting a protective profile against chemotherapy-induced myocardial damage. However, robust clinical studies are still needed to validate their efficacy [83].

The integration of predictive models has also gained relevance. Through artificial intelligence and machine learning technologies, algorithms are being developed to stratify patients and anticipate cardiovascular events during and after cancer treatment [81]. This approach complements the use of traditional clinical tools and may be key to reducing morbidity associated with antineoplastic treatments.

Finally, the implementation of clinical guidelines and patient education are foundational pillars in the comprehensive management of cardiovascular risk. Educating patients about early symptoms, promoting heart-healthy habits, and ensuring close monitoring before, during, and after treatment are measures recommended by various scientific societies as part of safe and sustainable oncologic care.

Figure 10. ***Cluster 3: Cardioprotective Strategies and Risk Management in Cancer Patients***



Cluster 4: Advanced Diagnostics and Biomarkers in Preventive Cardio-Oncology
In Cluster 4, the term "Advanced Diagnostics" highlights the focus on highly specialized imaging techniques and functional assessments. Additionally, "Biomarkers" emphasizes the importance of molecular indicators for the early prediction of cardiovascular damage. In this context, the term "Preventive Cardio-Oncology" reflects the interdisciplinary integration and current clinical approach aimed at the early identification and monitoring of cardiovascular adverse effects resulting from oncological therapies (Fig. 11).

The growing prevalence of oncologic diseases has driven the development of specialized diagnostic tools aimed at preventing and detecting the cardiovascular adverse effects of antineoplastic therapies. This preventive approach is grounded in the recognition of cardiotoxicity as a critical complication that can compromise both survival and quality of life in cancer patients [4].

In this context, the integration of advanced imaging techniques has gained significant relevance. Global longitudinal strain (GLS) echocardiography, cardiac magnetic resonance imaging, and other non-invasive modalities enable the detection of subclinical ventricular dysfunction even before clinical symptoms emerge an essential factor for early intervention and the reduction of irreversible damage [83], [76]. These tools have demonstrated high sensitivity in the early detection of myocardial alterations related to chemotherapy, particularly with anthracyclines and targeted therapies.

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Simultaneously, the use of plasma biomarkers such as cardiac troponin, B-type natriuretic peptide (BNP), and galectin-3 has become well established, providing quantitative information on cardiac injury and hemodynamic overload [80], [77]. Recent studies indicate that serial measurement of these biomarkers enables monitoring of risk progression and allows for the adjustment of oncologic therapies to minimize cardiological impact [81].

"The combination of biomarkers and imaging techniques has been identified as a robust and predictive diagnostic strategy. This multimodal approach is recommended by current clinical guidelines in cardio-oncology, as it enhances the ability to identify at-risk patients and facilitates the design of personalized surveillance protocols. The implementation of risk prediction algorithms that incorporate clinical, molecular, and imaging variables has shown great potential for truly preventive medicine [70].

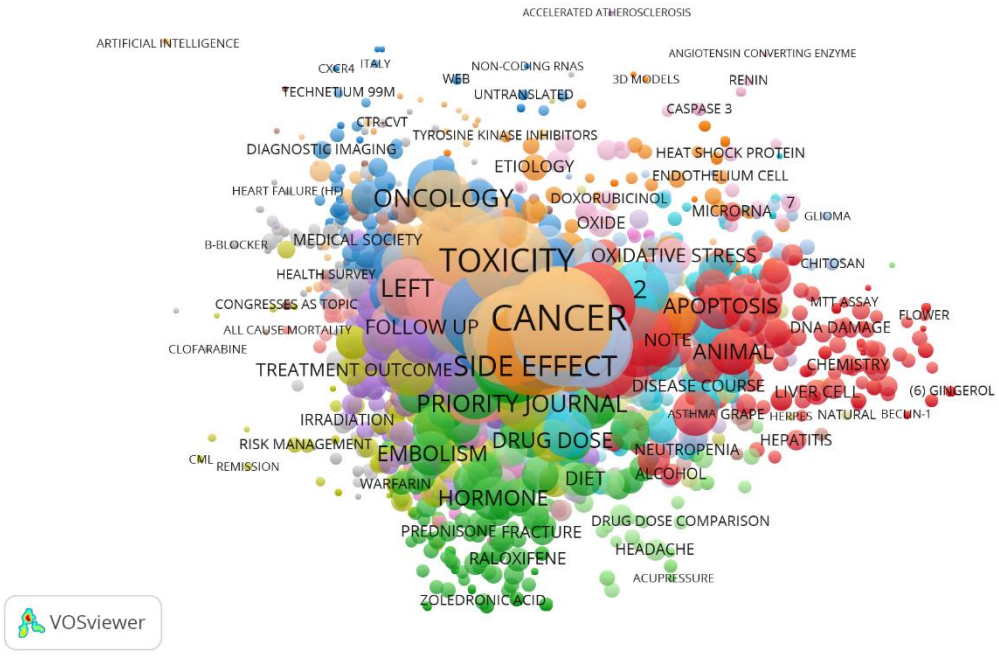
"On the other hand, the literature highlights a growing interest in emerging genetic and epigenetic biomarkers capable of predicting individual susceptibility to cardiovascular damage induced by antineoplastic therapies. This line of research points toward the personalization of diagnostics and molecular-level risk stratification, with future applications in therapeutic selection.

Additionally, the development of artificial intelligence platforms and big data analytics is being incorporated into the processing of clinical and molecular data to enhance the detection of early cardiotoxicity patterns. These innovations hold the potential to automate clinical alerts and reduce errors in the interpretation of early warning signs.

Finally, the diagnostic approach cannot be separated from the current epidemiological context. The high rate of cancer survival with projections estimating over 22 million survivors in the U.S. by 2035 demands systematic and long-term cardiovascular monitoring [10]. In this regard, the preventive approach is solidifying as both an organizational and ethical imperative for healthcare systems.

Taken together, this cluster underscores that the transition toward evidence-based preventive cardio-oncology requires not only cutting-edge technology but also integrative protocols and multidisciplinary teams trained to interpret these new diagnostic paradigms.

Figure 11. Cluster 4: Advanced Diagnostics and Biomarkers in Preventive Cardio-Oncology



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CONCLUSION

This bibliometric study provides a comprehensive overview of the evolution, challenges, and prospects of cardio-oncology, particularly regarding the prevention of cardiovascular side effects induced by cancer therapies. The reviewed evidence confirms a sustained growth in scientific production within this field, accompanied by thematic diversification and increased interdisciplinary collaboration. However, significant structural and geographic gaps persist, limiting equity in the generation and application of knowledge especially in low- and middle-income regions.

The main bibliometric findings identified four thematic clusters that represent the most developed areas: the use of natural compounds as oncoprotective therapies; the management of systemic risks associated with hormonal treatments; the implementation of cardioprotective strategies; and the advancement of diagnostic techniques through biomarkers and artificial intelligence. These clusters highlight a convergence of biomedical innovation, treatment personalization, and preventive approaches key pillars for oncology focused on long-term quality of life.

Additionally, the analysis reveals structural limitations such as the lack of standardized surveillance protocols, underrepresentation of vulnerable populations in clinical trials, and weak integration between cardiology and oncology in many healthcare systems. Methodologically, the application of tools such as PRISMA, Bibliometrix, and VOSviewer enabled a rigorous mapping of the state of the art, uncovering thematic gaps and inequalities in authorship, collaboration, and scientific dissemination.

In conclusion, cardiovascular prevention in oncology patients constitutes a strategic field that must be strengthened from a global, inclusive, and evidence-based perspective. The consolidation of cardio-oncology as a discipline will depend on the effective integration of research, clinical practice, and public policy. It is imperative to promote multicenter research, support the adoption of emerging technologies, and ensure equitable access to diagnostics and treatment across all contexts. Only through these measures will it be possible to advance toward truly safe, sustainable, and patient-centered cancer care

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