Cardio-Oncology

RESEARCH Open Access

Paediatric cardio-oncology: strengths and challenges in developing a collaborative care pathway between oncologists and cardiologists. The Italian experience

Alice Pozza[1*], Elena Bennati[2], Nicoletta Bertorello[3], Anna Balducci[4], Gabriele Rinelli[5], Arcangelo Prete[6] and Rossella Mura[7]

Abstract

Background Paediatric cancer survival rates continue to improve with overall long-term survival now over 80%. A significant proportion of conventional and novel cancer therapies have cardiovascular toxicities which become increasingly relevant as long-term survival improves. At present, within the Italian healthcare setting, a systematic approach to the detection and management of cardiotoxicity in paediatric patients is lacking, and most available recommendations are extrapolated from adult evidence. This study aimed to assess current practices in cardiovascular care delivery for childhood cancer patients and survivors in Italy.

Materials and methods An online 23-item nation-wide questionnaire was created by the Italian Society of Paediatric Cardiology (SICP) and the Italian Paediatric Haematology-Oncology Association (AIEOP) to explore the care, management and surveillance tools used to manage cardiotoxicity among paediatric patients and survivors. The survey was distributed among physicians within the AIEOP network.

Results Thirty-six of the 49 centres answered to the survey (response rate 73.4%). Most respondents ($n=30$, 83.3%) indicated that children are regularly screened for cardiotoxicity. The cardiological evaluation included the following echocardiographic methods to guide decisions on whether to start cardioprotective strategies or modify oncologic treatment protocols: Simpson biplane ejection fraction (EF) ($n=23$, 63%) and left ventricle (LV) global longitudinal strain (GLS) ($n=5$, 13.9%).

Conclusions Results reveal significant heterogeneity in clinical practice among different centres. This report unveils the urgent need for unified recommendations to improve detection and long-term follow-up of cardiotoxicity to enhance cardiologic outcomes of paediatric cancer patients.

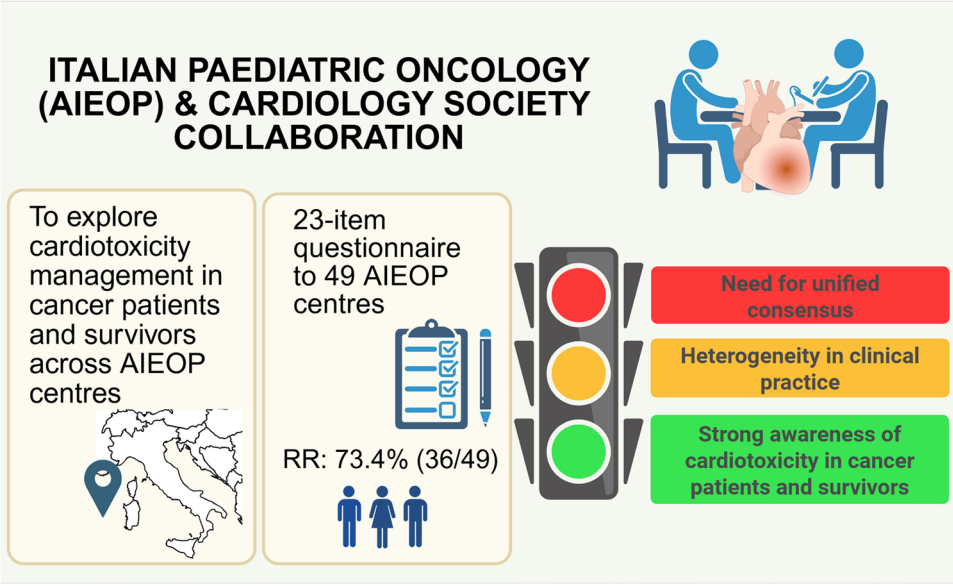
Keywords AIEOP, Paediatric cardio-oncology, Cardiotoxicity, Childhood cancer survivors

*Correspondence:
Alice Pozza
alice.pozza@aopd.veneto.it; alice.pozza@phd.unipd.it

Full list of author information is available at the end of the article

Graphical Abstract

Paediatric Cardio-Oncology framework in Italy: strengths and challenges for a collaborative care pathway



Introduction

Although cancer remains a significant cause of morbidity and mortality in children, advances in early diagnosis and novel therapies have markedly improved survival rates [1, 2]. As a result, an increasing number of childhood cancer survivors (CCS) are exposed to the long-term effects of both cancer and cancer therapies [3]. The pediatric population is often regarded as a relatively pure model for studying treatment-related cardiotoxicity. Late cardiovascular (CV) effects often persist beyond the completion of cancer therapy and frequently intensify during puberty and adulthood, once traditional CV risk factors emerge [3–5]. These effects may manifest as left ventricular (LV) dysfunction, cardiomyopathy, heart failure (HF), coronary artery disease, stroke, pericardial disease, arrhythmias, and valvular and vascular dysfunction [6]. Chemotherapy agents have different CV complications and anthracyclines (AC) are the most well-known therapy related to cardiac dysfunction, leading to both early and late-stage HF. Immune effector cell therapies used in paediatric haematological malignancies exhibit as common toxicity the cytokine release syndrome, a systemic inflammatory response which can lead to CV decompensation [7]. The risk of CV issues is further heightened by chest radiation or cranial spinal irradiation, which can result in additional damage to the myocardium, valves, and coronary arteries [8, 9]. Current guidelines recommend longitudinal monitoring of the CV health in CCS, both during and after cancer treatment, through clinical standardized cardiovascular surveillance, as well as comprehensive echocardiographic assessment [10–12]. Long-term CV effects of cancer treatments could be minimized by limiting the cardiotoxic effect of AC cumulative dose through preventive cardioprotective agents, reflecting a broader move toward proactive CV risk mitigation, rather than reactive surveillance alone [13–18]. Advances in chest radiation techniques (involved field, intensity-modulated therapy) have also reduced cardiac exposure, contributing to lower rates of HF, pericardial disease, and valvular disease. Nevertheless, CV complications during and after cancer treatment remain a significant concern, continuing to affect the long-term health of this growing patient population [19]. While adult cardio-oncology owns well-established guidelines, the management of paediatric cancer patients diagnosed with cardiotoxicity still lacks a systematic approach and uncertainties persist regarding how to integrate prevention, monitoring, and treatment strategies into the routine clinical practice [20, 21]. The expanding CCS cohort faces a lifelong risk of treatment-related late effects, underscoring the need for structured, risk-adapted long-term follow-up. In this context, the Survivor Passport (SurPass) was developed within the Pan-European Network for Care of Survivors after Childhood and Adolescent Cancer (PANCare) and the European Society for Paediatric Oncology networks [13, 22]. SurPass provides clinicians and survivors with secure access to individual medical histories, and offers surveillance and screening recommendations aligned with international guidelines [23, 24]. In the Italian setting, the healthcare system offers universal and equitable

access to care to all citizens, including long term follow-up for CCS. This uniform healthcare context provides a unique opportunity to evaluate variability in cardiotoxicity detection and management across paediatric oncology centres. Within this framework, it becomes particularly important to standardize clinical practices and harmonize care pathways in different hospital settings.

This paper reports the results of a survey investigating the current practices in the management of cardiotoxicity across Italian Paediatric Haematology-Oncology Association (AIEOP) centres. The study was not designed to assess the prognostic impact of preventive strategies, screening modalities, or therapeutic interventions for cancer treatment-related cardiotoxicity in children. On the contrary, the primary aim was descriptive, aiming to capture contemporary clinical practices across AIEOP centres and to explore areas of consistency and divergence relative to current evidence-based recommendations.

Materials and methods

The survey items were developed by a multidisciplinary team within Italian Society of Paediatric Cardiology (SICP) and AIEOP members, informed of existing international guidelines and position statements, as well as aware of areas of limited evidence and practice heterogeneity.

A cross-sectional survey was designed and submitted to all 49 haemato-oncology centres belonging to the AIEOP network. Each centre was invited to participate and provided with a link to complete the questionnaire, which was administered online through the Google Forms platform between August and December 2024. Only one response per centre was admitted and the cover letter accompanying the questionnaire emphasized that responses should reflect local hospital practices rather than personal opinions. To maximize the accuracy of centre-level data and reflect institutional policies, the survey targeted senior paediatric oncologists in leadership position, often serving as division director or clinical lead staff. The questionnaire comprised 23 questions divided into four sections, and it is available in the *Supplemental Material*. The survey questions focused on key domains where recommendations vary or remain incompletely defined, reflecting the ongoing gap in detection and management of cardiotoxicity in paediatric cancer patients [25–27].

The first section consisted of seven items addressing the general characteristics of cancer patients treated at each centre. These items covered the centre's clinical specialization (haematology, hemato-oncology, and/or oncology), the availability of a haematopoietic stem cell transplantation (HSCT) programme (autologous and/or allogeneic), and the framework for cardiologic referral.

The second section comprised eight questions focusing on the biochemical monitoring of cardiotoxicity during cancer treatment. Specifically, we investigated the use of cardiac biomarkers, troponin I (TnI), troponin T (TnT), and N-terminal pro-brain natriuretic peptide (NT-proBNP), given that their diagnostic and prognostic roles in the paediatric setting remain incompletely defined [28–32]. We also included questions on routinely assessed echocardiographic parameters, with the aim of identifying which measures guide chemotherapy changes or the initiation of cardioprotective therapy [10]. Finally, questions addressing the use of cardiac magnetic resonance (CMR) were included to evaluate how centres integrate advanced multimodality imaging as an adjunct to echocardiography in the assessment of cardiotoxicity [33–35].

The third section examined locally implemented cardioprotective strategies, focusing on primary and secondary pharmacological interventions, in light of the limited consensus on their use and timing in paediatric cardio-oncology [16].

The final section addressed the management of long-term follow-up after completion of oncologic treatment, including surveillance protocols for CCS and oncologists' evaluation of satisfaction with cardiology services.

Results

Thirty-six of the 49 AIEOP centres responded to the survey, reaching a 73.4% response rate. Notably, all high-enrolling centres (i.e. university hospitals managing the full spectrum of oncologic diseases) were among the respondents.

Characteristics and organization of centres (items 1–7)

Among the 36 centres that participated in the survey, 17 (47.2%) were in hospitals with a paediatric unit, 6 (19.4%) in paediatric hospitals with an oncology-haematology unit, and 13 (33.3%) in paediatric hospitals with both oncology-haematology and transplant units. Within these facilities, 10 centres (83.3%) perform both autologous and allogeneic HSCT, while 2 centres (16.7%) perform only autologous HSCT. Over half of the respondent centres ($n = 21$, 58.3%) oversee the full spectrum of oncological and non-oncological conditions, including malignant and non-malignant haematological disorders, brain tumours, solid tumours, and immunodeficiencies (Fig. 1).

Most respondents ($n = 30$, 83.3%) reported working in centres with dedicated cardio-oncology referral pathways, incorporating both instrumental and biochemical monitoring in case of systolic dysfunction, as well as structured long-term follow-up protocols. Figure 2 illustrates the cardiology referral frameworks available for cardiotoxicity monitoring across centres, with cardiology

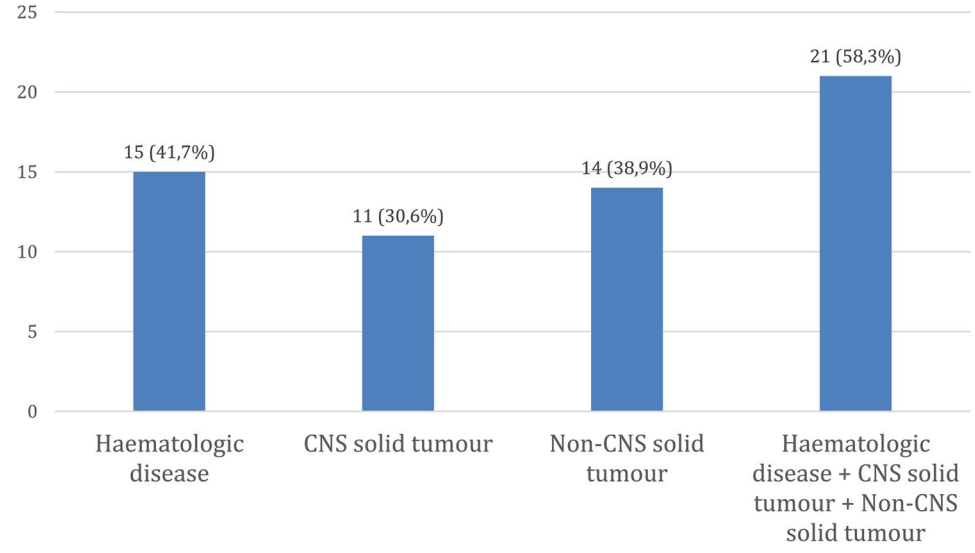


Fig. 1 Distribution of treated diseases among surveyed AIEOP centres (CNS: central nervous system)

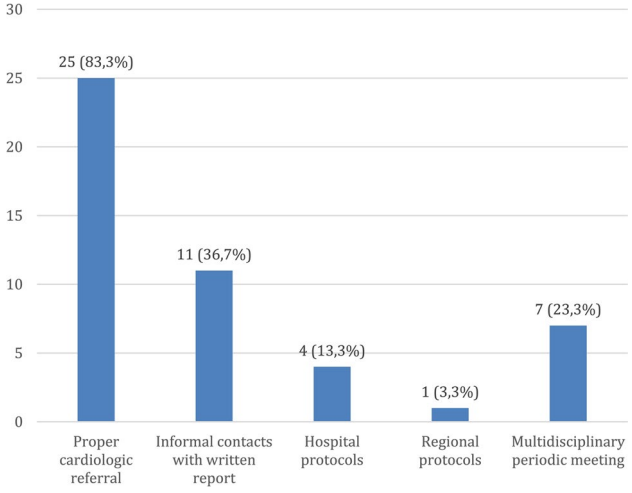


Fig. 2 Type of cardiological referral in the surveyed AIEOP centres

evaluations being requested directly through a designated referral service in 25 centres (83.3%).

Referral patterns differed according to the cardiologist's training: half of the centres ($n = 18$) referred patients to a paediatric cardiologist and 5 (13.9%) to an adult cardiologist, while cardio-oncologists were involved in 36.1% of centres (Fig. 3).

The survey also explored whether referrals are supported by sufficiently detailed clinical information. In 23 centres (80.6%), referrals are accompanied by comprehensive information, including the patient's cancer history, risk stratification, treatment phase, and cumulative AC dose. In contrast, 13 centres (19.4%) provide no accompanying documentation, with the cardiology evaluation requested solely through direct phone contact from the oncologist in 6 centres (31%).

Strategies for cardiovascular health surveillance (items 8–15)

Routinary use of biomarkers during cancer treatment is not common. However, in case of suspected cardiotoxicity, 25 centres (69.4%) perform biochemical monitoring. Amon these, 24 centres (68.6%) measure NT-proBNP, TnI, and TnT while only 9 centres (25.7%) use TnI alone.

Regarding instrumental imaging, advanced echocardiographic techniques are used infrequently: right ventricular strain in 7 centres (19.4%), 3-dimensional (3D) EF calculation in 4 (11.1%), and myocardial performance assessment using Myocardial Work (MW) only in 2 (5.6%).

The standard evaluation of left ventricle ejection fraction (LVEF) using short axis m-mode measurement with the Teichholz formula remains the most common approach (83.3%, $n = 30$), followed by the Simpson biplane EF method (77.8%, $n = 28$). Global longitudinal strain (GLS) is performed in just over half of the centres (52.8%, $n = 19$). Any changes in chemotherapy protocols or the start of cardioprotective strategies are mostly based on Simpson biplane LVEF reductions ($n = 23$, 63%) and 5 centres (13.9%) rely only on GLS measurement (Fig. 4).

CMR is not routinely performed. In 25 centres (75.8%) it is used in case of suspected acute myocarditis, whereas in 21 centres (63.6%) it is employed to assess chronic myocardial dysfunction. The use of CMR for research purposes is limited to only 4 centres (12.1%).

Pharmacologic strategies for mitigating and preventing cancer treatment-related cardiotoxicity (item 16–18)

Primary cardioprotective strategies were implemented in 17 centres (47.2%). All 17 centres used liposomal AC, and among these, 8 centres (22.2%) additionally administered

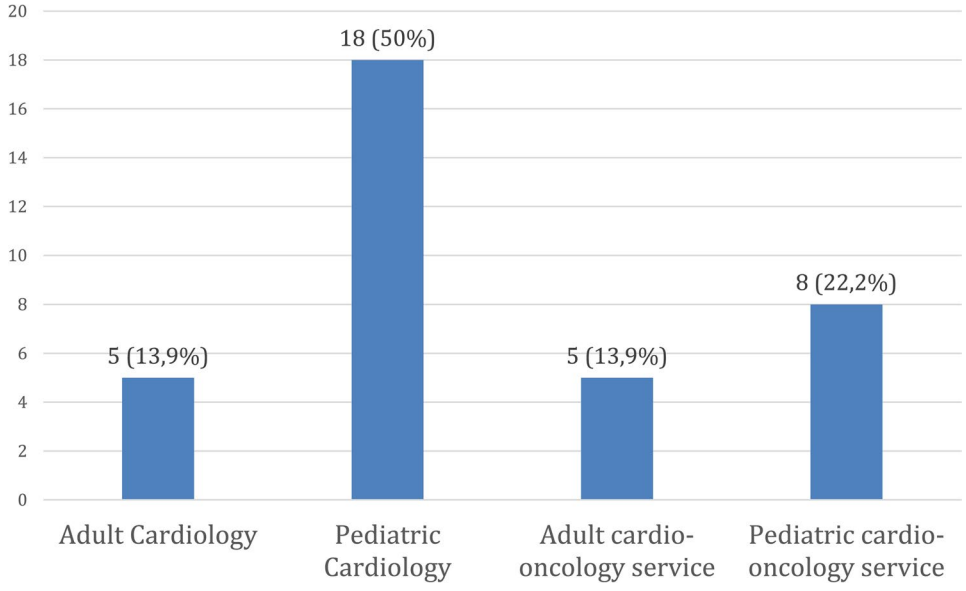


Fig. 3 Schematic representation of cardio-oncology referral pathways among different AIEOP centres

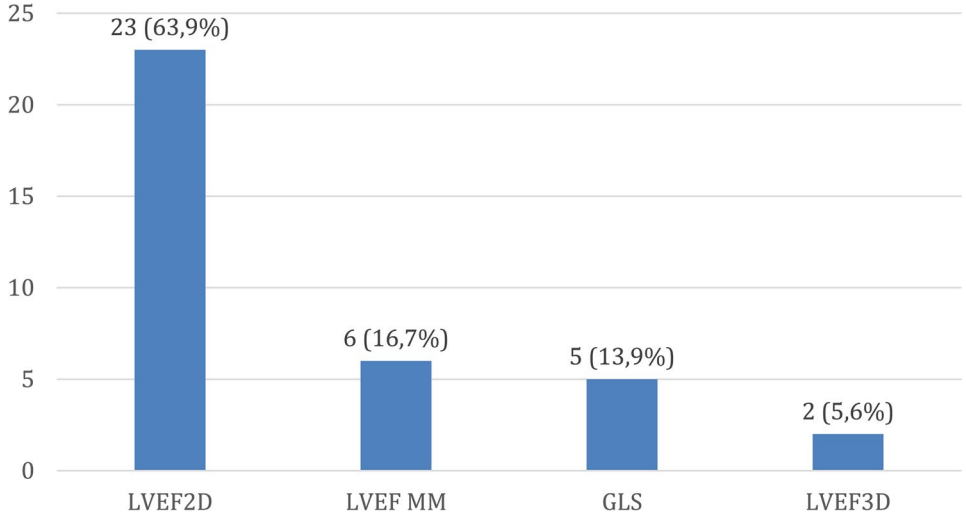


Fig. 4 Distribution of echocardiographic parameters used to start cardioprotective therapy or adjust cancer treatment (LVEF2D: Simpson biplane ejection fraction; LVEF MM: m-mode ejection fraction; GLS: global longitudinal strain; LVEF 3D: three-dimensional ejection fraction)

dexrazoxane. A detailed overview of cardioprotective strategies and secondary cardioprotective therapies is provided in Table 1.

In most centres ($n = 31$, 83.3%) the decision to start cardioprotective therapy or modify the chemotherapy protocol is shared between oncologist and cardiologist in a multidisciplinary meeting.

Follow-up strategies (item 19–23)

In all 36 surveyed AIEOP centres, patients at the end of treatment enter an internal follow-up program and 27 centres (75%) routinely use the survivor passport (SurPass) to support the long-term follow-up [22]. Regarding exercise prescription, 22 centres (61.1%) offer a structured physical rehabilitation program, which is implemented during cancer treatment in 21 centres (55.6%). Finally, 23 oncologists (75%) report good collaboration with cardiologists.

Discussion

This survey, conducted across 36 AIEOP centres in Italy, aimed to assess current practices, identify challenges, and highlight areas of improvement in the management of paediatric oncology patients at risk of cardiotoxicity. The high response rate underscores strong awareness of cardiotoxicity, particularly among centres experienced in treating the full spectrum of paediatric malignancies. The features of participating centres reflect the heterogeneous

Table 1 Distribution of cardioprotective strategies and secondary cardioprotective therapies across participating centres ($n = 36$), presented as n (%). Primary and secondary cardioprotection categories describe the overall strategy adopted, while listed combinations represent specific pharmacological regimens used for secondary cardioprotection (BB: beta-blockers; ACE-i: angiotensin-converting enzyme inhibitors; ARB: angiotensin receptor blockers; Ca^{2+}A: calcium channel antagonists; SGLT2-i: sodium–glucose cotransporter-2 inhibitors)

Variable	Centre *n* (%)
Cardioprotective strategy	
Primary Cardioprotection	17 (47.2%)
Primary+Secondary Cardioprotection	19 (52.8%)
Secondary Cardioprotection	36 (100%)
Secondary cardioprotective regimen	
BB	4 (11.1%)
ACE-i/ARB	6 (16.7%)
BB+Ca^{2+}A	2 (5.5%)
BB + ACE-i/ARB	11 (30.6%)
BB+Ca^{2+}A+ACEi/ARB	6 (16.7%)
BB + ACE-i/ARB+SGLT2-i+Ivabradine	2 (5.5%)
BB+Ca^{2+}A + ACE-i/ARB+Ivabradine	1 (2.8%)
Ca^{2+}A + ACE-i/ARB	1 (2.8%)
ACE-i/ARB+Ivabradine	1 (2.8%)
BB + ACE-i/ARB+Ivabradine	2 (5.5%)
Total	36 (100%)

nature of services provided across Italian institutions, where cardiological care is frequently delivered within multidisciplinary teams. This variability highlights the need for standardized cardiological protocols and uniform approaches to ensure equitable and optimal management of cardiotoxicity.

Although most centres have established cardio-oncology pathways, differences in cardiological referrals remain, and paediatric specialists are available in only half of centres. This gap in expertise underscores the need for care tailored to children, as adult cardiologists may lack the specialized training required to assess and manage paediatric cardiotoxicity effectively. The marked variability in the cardiology referral process raises concerns about its consistency and thoroughness, suggesting a lack of standardized procedures, which could result in incomplete or delayed assessments and potentially compromise the quality and effectiveness of care. Furthermore, relying on phone contact from oncologists for cardiologic evaluation may create communication gaps. On the other hand, the fact that 80.6% of cardiologic referrals include a comprehensive oncological history and risk stratification indicates that most centres recognize the importance of contextualizing the evaluation according to the patient's treatment stage.

The survey highlights that most centres implement biochemical monitoring as supplementary evaluation to detect cardiotoxicity, with NT-proBNP and troponins being the most used biomarkers. Interestingly, a significant proportion of centres adopt a combination of these biomarkers, while a smaller number rely only on TnI. This inconsistency in monitoring practices may reflect differences in practitioners' preferences as well as access to resources and reflects the lack of standardized biochemical tools, which hinders multicentre studies on this aspect and highlights the scarce literature in the paediatric field [31, 32, 36, 37].

The finding that most centres continue to rely exclusively on conventional echocardiographic parameters, with only half incorporating GLS for assessment of LV function, suggests that many institutions may lack access to the most up-to-date guideline-recommended imaging modalities for cardiotoxicity surveillance, which advocate the use of GLS, particularly when LVEF is borderline [10, 38]. Notably, in five centres, clinical decisions to start cardioprotective therapy are based exclusively on GLS, highlighting further heterogeneity in practice and underscoring the need for standardized imaging protocols across institutions [10, 19, 39, 40]. Strain-guided management in adult patients tested in the Strain-Guided Management Trial in Cardio-Oncology demonstrated that early initiation of cardioprotective therapy based only on GLS changes improved CV outcome compared with standard EF monitoring [41]. Nevertheless, Kouwenberg et al. conducted a systematic reviewed showing that GLS should not be used as a standalone parameter, as it lacks sufficient robustness to serve as the sole diagnostic marker of cardiotoxicity in the paediatric population [26, 42]. Furthermore, initiation of cardioprotective therapy in children based solely on GLS changes cannot be universally recommended, and paediatric-strain evidence is still too limited to confirm assumptions derived from adult data [19, 40]. Ongoing trials are further refining the prognostic and clinical role of deformation imaging in paediatric cardio-oncology [43]. These efforts highlight the potential of GLS to evolve into a more robust clinical standard tool, possibly guiding therapeutic decision-making in survivorship care.

The infrequent use of CMR among the surveyed centres likely reflects both limited access and the current lack of strong guideline recommendations emphasizing its routine use, despite its potential to provide detailed assessments of myocardial function and tissue characterization [35].

The widespread use of angiotensin converting enzyme inhibitors and angiotensin receptor blockers across participating centres underscores the adherence to evidence-based strategies for mitigating cancer therapy-related cardiotoxicity [44, 45]. This pharmacologic pattern reflects current guideline-driven recommendations, which emphasize the role of neurohormonal modulation

in preserving cardiac function [20, 46]. However, the different use of cardioprotective strategies indicate variability in physicians' comfort, perceived risk profiles, or institutional protocols, warranting further exploration of barriers to full implementation. The limited adoption of newer therapies such as SGLT2 inhibitors highlights the need for further education and integration of newer treatments into clinical practice, which are currently off-label for the paediatric age [47].

The survey results advocate the importance of establishing and implementing standardised surveillance protocols, rather than providing long-term follow-up. All 36 centres have currently internal follow-up programs at the end of cancer treatment, with 75% routinely using SurPass to track patients' long-term health, a commendable practice that can help ensure continuity of care and facilitate timely interventions [12, 48]. Additionally, over half of the centres offer physical rehabilitation and prescribe exercise during cancer treatment, reflecting growing recognition of the role of these interventions in survivorship care. These practices are crucial not only for mitigating treatment-related physical impairments but also for promoting long-term quality of life, consistent with current evidence-based guidelines [46, 49].

Although most centres report good collaboration between oncologists and referral cardiologists, there remains a notable proportion where communication and coordination could be improved. Strengthening interdisciplinary communication and collaboration could enhance patient's outcome and reduce the burden of CV diseases in paediatric cancer survivors.

One limitation of the survey is that it was distributed to AIEOP centres and completed by oncologists, without directly interviewing cardiologists. This may provide a partial perspective, particularly on cardiologic-specific aspects.

Conclusions

The survey findings highlight priority areas for harmonization and targeted implementation efforts within a national consensus framework. There is substantial alignment with international recommendations in terms of multidisciplinary collaboration, risk-informed cardiology consultations, and comprehensive long-term follow-up programs. In contrast, notable gaps and heterogeneity remain in biochemical monitoring of cardiotoxicity and in the adoption of advanced imaging techniques for diagnosis and follow-up [40]. This inter-society collaborative report represents the first step towards mutual understanding between SICP and AIEOP, with a view to future collaboration in developing shared protocols to detect, treat, and study cardiotoxicity during and after paediatric cancer treatment. Given the complex interplay between oncology and cardiology in cancer treatment, fostering closer collaboration between these areas and integrating multidisciplinary care models could improve patient's outcome and streamline care delivery.

Abbreviations

AC	anthracycline
AIEOP	Italian Paediatric Haematology-Oncology Association
CCS	childhood cancer survivor
CMR	cardiac magnetic resonance
CV	cardiovascular
EF	ejection fraction
GLS	global longitudinal strain
HF	heart failure
HSCT	haematopoietic stem cell transplant
LV	left ventricle
MW	myocardial work
NT-pro BNP	N-terminal-pro brain natriuretic peptide
SGLT2	sodium glucose transporter 2
SICP	Italian Society of Paediatric Cardiology
SurPass	Survivor Passport
TnI	Troponin I
TnT	Troponin T

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s40959-026-00470-6.

Supplementary Material 1.

Acknowledgements

The authors thank Luca Zanella, MD (Division of Cardiac Surgery, Peter Munk Cardiac Centre, Toronto General Hospital, University of Toronto) for his support with statistical review and figures editing.

Authors' contributions

All authors contributed to the study conception and design. Material preparation and analysis were performed by A.P.; E.B.; N.B. and R.M. The first draft of the manuscript was written by A.P. and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Funding

No funding was received to complete this study.

Data availability

The dataset during the current study is available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Author details

[1]Paediatric Cardiology Unit, Department of Women's and Children's Health, University of Padua, Padua, Italy
[2]Cardiology, Meyer Children's Hospital IRCCS, Florence, Italy
[3]Paediatric Onco-Haematology Department, Regina Margherita Children's Hospital, Turin, Italy
[4]Paediatric Cardiology Unit, IRCCS Azienda Ospedaliera-Universitaria Di Bologna, Bologna, Italy

[5]Paediatric Cardiology Unit, Bambino Gesù Children's Hospital, IRCCS, Rome, Italy
[6]Paediatric Oncology and Hematology Unit, IRCCS Azienda Ospedaliero Universitaria di Bologna, Bologna, Italy
[7]Paediatric Haematology-Oncology, ARNAS G. Brotzu, Cagliari, Italy

Received: 31 December 2025 / Accepted: 10 March 2026
Published online: 19 March 2026

References

1. Armenian SH, Jurczak W, Carver JR, Gennari A, Minotti G. MS Ewer Helping the cardio-oncologist: from real life to guidelines. Semin Oncol. 2019;46:433–6. https://doi.org/10.1053/j.seminoncol.2019.01.005.
2. Armenian SH, Armstrong GT, Aune G, Chow EJ, Ehrhardt MJ, Ky B, et al. Cardiovascular Disease in Survivors of Childhood Cancer: Insights Into Epidemiology, Pathophysiology, and Prevention. J Clin Oncology: Official J Am Soc Clin Oncol. 2018;36:2135–44. https://doi.org/10.1200/JCO.2017.76.3920.
3. Lipshultz SE, Adams MJ, Colan SD, Constine LS, Herman EH, Hsu DT, et al. Long-term Cardiovascular Toxicity in Children, Adolescents, and Young Adults Who Receive Cancer Therapy: Pathophysiology, Course, Monitoring, Management, Prevention, and Research Directions: A Scientific Statement From the American Heart Association. Circulation. 2013;128:1927–95. https://doi.org/10.1161/CIR.0b013e3182a88099.
4. Bhatia S, Tonorezos ES, Landier Clinical Care for People Who Survive Childhood Cancer. Rev JAMA. 2023;330:1175. https://doi.org/10.1001/jama.2023.16875.
5. Chen Y, Chow EJ, Oeffinger KC, Border WL, Leisenring WM, Meacham LR, et al. Traditional Cardiovascular Risk Factors and Individual Prediction of Cardiovascular Events in Childhood Cancer Survivors. JNCI: J Natl Cancer Inst. 2020;112:256–65. https://doi.org/10.1093/jnci/djz108.
6. Chow EJ, Leger KJ, Bhatt NS, Mulrooney DA, Ross CJ, Aggarwal S, et al. Paediatric cardio-oncology: epidemiology, screening, prevention, and treatment. Cardiovascular Res. 2019;115:922–34. https://doi.org/10.1093/cvr/cvz031.
7. Ross AB, Puri K, Johnson TL, Correa LD, John TD, Friend B, et al. Cardiovascular Complications of Immune Effector Cell Therapies in Pediatric Hematological and Solid Tumors. Pediatr Blood Cancer. 2025;72:e31557. https://doi.org/10.1002/pbc.31557.
8. Bertorello N, Luksch R, Bisogno G, Haupt R, Spallarossa P, Cenna R, et al. Cardiotoxicity in children with cancer treated with anthracyclines: A position statement on dexrazoxane. Pediatr Blood Cancer. 2023;e30515. https://doi.org/10.1002/pbc.30515.
9. Verginadis II, Citrin DE, Ky B, Feigenberg SJ, Georgakilas AG, Hill-Kayser CE, et al. Radiotherapy toxicities: mechanisms, management, and future directions. Lancet. 2025;405:338–52. https://doi.org/10.1016/S0140-6736(24)02319-5.
10. Mertens L, Singh G, Armenian S, Chen M-H, Dorfman AL, Garg R, et al. Multimodality Imaging for Cardiac Surveillance of Cancer Treatment in Children: Recommendations From the American Society of Echocardiography. J Am Soc Echocardiogr. 2023;36:1227–53. https://doi.org/10.1016/j.echo.2023.09.009.
11. Bennati E, Castaldi B, Derchi ME, Spoto S, Chinali M, Bertorello N et al. [Italian Society of Pediatric Cardiology (SICP) position paper on the prevention, diagnosis, treatment and follow-up of cardiotoxicity in pediatric patients with cancer]. *Giornale Italiano Di Cardiologia* (2006). 2024; 25:453–463. https://doi.org/10.1714/4269.42470.
12. DeVine A, Landier W, Hudson MM, Constine LS, Bhatia S, Armenian SH, et al. The Children's Oncology Group Long-Term Follow-Up Guidelines for Survivors of Childhood, Adolescent, and Young Adult Cancers: A Review. JAMA Oncol. 2025. https://doi.org/10.1001/jamaoncol.2024.6812.
13. de Beijer IAE, Skinner R, Haupt R, Grabow D, Bardi E, Beccaria A, et al. European recommendations for short-term surveillance of health problems in childhood, adolescent and young adult cancer survivors from the end of treatment to 5 years after diagnosis: a PanCare guideline. J Cancer Survivorship: Res Pract. 2025;19:603–13. https://doi.org/10.1007/s11764-023-01493-z.
14. De Baat EC, Van Dalen EC, Mulder RL, Hudson MM, Ehrhardt MJ, Engels FK, et al. Primary cardioprotection with dexrazoxane in patients with childhood cancer who are expected to receive anthracyclines: recommendations from the International Late Effects of Childhood Cancer Guideline Harmonization Group. Lancet Child Adolesc Health. 2022;6:885–94. https://doi.org/10.1016/S2352-4642(22)00239-5.
15. Shaikh F, Dupuis LL, Alexander S, Gupta A, Mertens L. Cardioprotection and Second Malignant Neoplasms Associated With Dexrazoxane in Children Receiving Anthracycline Chemotherapy: A Systematic Review and Meta-Analysis. J Natl Cancer Inst. 2016;108:djv357. https://doi.org/10.1093/jnci/djv357.
16. Pozza A, Candia AD, Zanella L, Stefors EJ, Bennati E, Somigli C, et al. Emerging Strategies for the Prevention of Chemotherapy-Induced Cardiotoxicity in Paediatric Cancer Patients: Advances and Future Perspectives. Pharmaceuticals (Basel Switzerland). 2025;18:1604. https://doi.org/10.3390/ph18111604.
17. Conyers R. DA Elliott Straight to the heart: Protecting the patient's heart during chemotherapy. Cell Stem Cell. 2024;31:1715–6. https://doi.org/10.1016/j.stem.2024.10.010.
18. Jang KH, Wallins JS, Lin I-H, Movva S, Tap WD, Liu JE, et al. Association of early dexrazoxane with reduced cardiotoxicity risk in sarcoma patients treated with anthracycline chemotherapy. Oncologist. 2025;30:oyaf370. https://doi.org/10.1093/oncolo/oyaf370.
19. Ryan TD, Bates JE, Kinahan KE, Leger KJ, Mulrooney DA, Narayan HK, et al. Cardiovascular Toxicity in Patients Treated for Childhood Cancer: A Scientific Statement From the American Heart Association. Circulation. 2025;151. https://doi.org/10.1161/CIR.0000000000001308.
20. Lyon AR, López-Fernández T, Couch LS, Asteggiano R, Aznar MC, Bergler-Klein J, et al. 2022 ESC Guidelines on cardio-oncology developed in collaboration with the European Hematology Association (EHA), the European Society for Therapeutic Radiology and Oncology (ESTRO) and the International Cardio-Oncology Society (IC-OS). Eur Heart J. 2022;43:4229–361. https://doi.org/10.1093/eurheartj/ehac244.
21. Bennati E, Girolami F, Spaziani G, Calabri GB, Favre C, Parrini I, et al. Cardio-Oncology in Childhood: State of the Art. Curr Oncol Rep. 2022;24:1765–77. https://doi.org/10.1007/s11912-022-01329-6.
22. Haupt R, Essiaf S, Dellacasa C, Ronckers CM, Caruso S, Sugden E, et al. The 'Survivorship Passport' for childhood cancer survivors. Eur J Cancer (Oxford England: 1990). 2018;102:69–81. https://doi.org/10.1016/j.ejca.2018.07.006.
23. Filbert A-L, Kremer L, Ladenstein R, Chronaki C, Degelsegger-Márquez A, van der Pal H, et al. Scaling up and implementing the digital Survivorship Passport tool in routine clinical care - The European multidisciplinary PanCareSurPass project. Eur J Cancer (Oxford England: 1990). 2024;202(114029). https://doi.org/10.1016/j.ejca.2024.114029.
24. Gazzarata R, Strübin M, Chronaki C, Cangioli G, Saraceno D, Schreier G, et al. Childhood Cancer Survivorship Passport Challenges in the European Health Data Space. Stud Health Technol Inform. 2024;316:1302–6. https://doi.org/10.3233/SHTI240651.
25. Huang J, Lam R, Pozza A, Hassan H, Schneiderman JE, Nathan PC, et al. Evaluating the safety and cardiac impact of resistance training in anthracycline-treated patients: a systematic review. Cardio-Oncology. 2026. https://doi.org/10.1186/s40959-025-00425-3.
26. Beke N, Jockers X, Hernádfői M, Kói T, Lakatos K, Párniczky A, et al. Cardiotoxicity in pediatric oncology: a systematic review and meta-analysis. Pediatr Res. 2025. https://doi.org/10.1038/s41390-025-04601-0.
27. Johnson P, Whitney E, Evans C, Beam D. A systematic review of long-term cardiotoxic effects of treatment in survivors of childhood acute lymphoblastic leukemia. Mol Cell Pediatr. 2025;12:9. https://doi.org/10.1186/s40348-025-00196-y.
28. Meo L, Savarese M, Munno C, Mirabelli P, Ragno P, Leone O, et al. Circulating Biomarkers for Monitoring Chemotherapy-Induced Cardiotoxicity in Children. Pharmaceutics. 2023;15:2712. https://doi.org/10.3390/pharmaceutics15122712.
29. Michel L, Mincu RI, Mrotzek SM, Korste S, Neudorf U, Rassaf T, et al. Cardiac biomarkers for the detection of cardiotoxicity in childhood cancer—a meta-analysis. ESC Heart Fail. 2020;7:423–33. https://doi.org/10.1002/ehf2.12589.
30. Mladosievicova B, Urbanova D, Radvanska E, Slavkovsky P. Simkova Role of NT-proBNP in detection of myocardial damage in childhood leukemia survivors treated with and without anthracyclines. J Experimental Clin Cancer Res. 2012;31:86. https://doi.org/10.1186/1756-9966-31-86.
31. Mavinkurve-Groothuis AMC, Groot-Loonen J, Bellersen L, Pourier MS, Feuth T, Bökkerink JPM, et al. Abnormal NT-pro-BNP levels in asymptomatic long-term survivors of childhood cancer treated with anthracyclines. Pediatr Blood Cancer. 2009;52:631–6. https://doi.org/10.1002/pbc.21913.
32. Leerink JM, Verkleij SJ, Feijen EAM, Mavinkurve-Groothuis AMC, Pourier MS, Ylänen K, et al. Biomarkers to diagnose ventricular dysfunction in childhood cancer survivors: a systematic review. Heart. 2019;105:210–6. https://doi.org/10.1136/heartjnl-2018-313634.

33. Cau R, Bassareo P, Cherchi V, Palmisano V, Suri JS, Porcu M, et al. Early diagnosis of chemotherapy-induced cardiotoxicity by cardiac MRI. Eur J Radiol. 2020;130:109158. https://doi.org/10.1016/j.ejrad.2020.109158.
34. Toro-Salazar OH, Gillan E, O'Loughlin MT, Burke GS, Ferranti J, Stainsby J, et al. Occult cardiotoxicity in childhood cancer survivors exposed to anthracycline therapy. Circ Cardiovasc Imaging. 2013;6:873–80. https://doi.org/10.1161/CIRCIMAGING.113.000798.
35. Toro C, Elliott DA, La Gerche A, Lange PW, Bsc FB, O'Sullivan M, et al. Optimal Detection of Cardiac Sequelae: The Need for Rigorous, Harmonized Magnetic Resonance Studies in Pediatric Survivors. JACC Cardio Oncol. 2021;3(1):154-156. https://doi.org/10.1016/j.jaccao.2021.01.010.
36. Leerink JM, Feijen EAM, Moerland PD, de Baat EC, Merkx R, van der Pal HJH, et al. Candidate Plasma Biomarkers to Detect Anthracycline-Related Cardiomyopathy in Childhood Cancer Survivors: A Case Control Study in the Dutch Childhood Cancer Survivor Study. J Am Heart Association. 2022;11:e025935. https://doi.org/10.1161/JAHA.121.025935.
37. Poudel S, Shrestha H, Pan Y, Li Q, Li K, Im C, et al. Serum Proteins Predict Treatment-Related Cardiomyopathy Among Survivors of Childhood Cancer. JACC CardioOncology. 2025;7:56–67. https://doi.org/10.1016/j.jaccao.2024.10.004.
38. Thomas JD, Edvardsen T, Abraham T, Appadurai V, Badano L, Banchs J, et al. Clinical Applications of Strain Echocardiography: A Clinical Consensus Statement From the American Society of Echocardiography Developed in Collaboration With the European Association of Cardiovascular Imaging of the European Society of Cardiology. J Am Soc Echocardiography: Official Publication Am Soc Echocardiography. 2025;38:985–1020. https://doi.org/10.1016/j.echo.2025.07.007.
39. Merkx R, Leerink JM, de Baat EC, Feijen EAM, Kok WEM, Mavinkurve-Groothuis AMC, et al. Asymptomatic systolic dysfunction on contemporary echocardiography in anthracycline-treated long-term childhood cancer survivors: a systematic review. J Cancer Survivorship: Res Pract. 2022;16:338–52. https://doi.org/10.1007/s11764-021-01028-4.
40. Slieker MG, Fackoury C, Slorach C, Hui W, Friedberg MK, Fan C-PS, et al. Echocardiographic Assessment of Cardiac Function in Pediatric Survivors of Anthracycline-Treated Childhood Cancer. Circ Cardiovasc Imaging. 2019;12:e008869. https://doi.org/10.1161/CIRCIMAGING.119.008869.
41. Marwick TH, Dewar E, Nolan M, Shirazi M, Dias P, Wright L, et al. Strain surveillance during chemotherapy to improve cardiovascular outcomes: the SUCCOUR-MRI trial. Eur Heart J. 2024;45:4414–24. https://doi.org/10.1093/eurheartj/ehae574.
42. Kouwenberg TW, van Dalen EC, Feijen EAM, Netea SA, Bolier M, Slieker MG, et al. Acute and early-onset cardiotoxicity in children and adolescents with cancer: a systematic review. BMC Cancer. 2023;23:866. https://doi.org/10.1186/s12885-023-11353-9.
43. University, Hospital. Montpellier Longitudinal Analysis of Myocardial Function by Speckle Tracking Echocardiography and Prediction of Delayed Toxic Cardiomyopathy Associated With Anthracycline Therapy in Children. 2025.
44. Costa IBSdaS, Furtado RHM, Drager LF, de Barros PGM, Silva E, de Melo MDT, Araruna P, et al. Effects of carvedilol on the prevention of cardiotoxicity induced by anthracyclines: Design and rationale of the CARDIOTOX trial. Am Heart J. 2025;285:1–11. https://doi.org/10.1016/j.ahj.2025.02.014.
45. Farooq Z, Sahar R, Ibekwe WC, Kashyap A, Mehmood K. Mitigating Cardiotoxicity Associated with Anticancer Drugs: An Updated Systematic Review. J Cancer Allied Specialties. 2024;10:613. https://doi.org/10.37029/jcas.v10i2.613.
46. Guo Z. A Javaheri Empagliflozin to Prevent Doxorubicin Cardiotoxicity. JACC CardioOncology. 2025;7:185–7. https://doi.org/10.1016/j.jaccao.2025.01.005.
47. Babecoff S, Mermillod F, Marino D, Gayet-Ageron A, Ansari M, Fernandez E, et al. Long-term follow-up for childhood cancer survivors: the Geneva experience. Swiss Med Wkly. 2022;152:w30153. https://doi.org/10.4414/SMW.2022.w30153.
48. Cifra B, Chen CK, Fan C-PS, Slorach C, Manlhiot C, McCrindle BW, et al. Dynamic Myocardial Response to Exercise in Childhood Cancer Survivors Treated with Anthracyclines. J Am Soc Echocardiography: Official Publication Am Soc Echocardiography. 2018;31:933–42. https://doi.org/10.1016/j.echo.2018.02.003.
49. Gilchrist SC, Barac A, Ades PA, Alfano CM, Franklin BA, Jones LW, et al. Cardio-Oncology Rehabilitation to Manage Cardiovascular Outcomes in Cancer Patients and Survivors: A Scientific Statement From the American Heart Association. Circulation. 2019;139. https://doi.org/10.1161/CIR.0000000000000679.

Publisher's Note