E-ISSN: 3062-0392

JUCVM

jucvm.com

Journal of Updates in Cardiovascular Medicine

Volume 14 | Issue 3

September 2026

www.jucvm.com

REVIEW ARTICLE

RESEARCH ARTICLES

HEART AND HEALTH FOUNDATION OF TURKEY

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E-mail: info@galenos.com.tr/yayin@galenos.com.tr **Web:** www.galenos.com.tr | **Publisher Certificate Number:** 14521
Online Publishing Date: September 2026 **E-ISSN:** 3062-0392
International scientific journal published quarterly.

Editorial Consultants

Journal of Updates in Cardiovascular Medicine use both "Editorial review" and "blind peer review" policy.

Owner

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The journal is published online.

Owner: Heart and Health Foundation of Türkiye

Responsible Manager: Öztekin Oto

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Advances in Mobile Health Strategies for Atrial Fibrillation Detection and Patient Care

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Abstract

Atrial fibrillation (AF), a prevalent cardiac arrhythmia, poses significant risks for stroke and other severe complications. Traditional approaches frequently lack accessibility, accuracy, and patient engagement despite advancements in detection and management. The revolutionary effects of mobile health (mHealth) technologies on the treatment of AF are reviewed in this paper. These innovations, which make use of wearable technology, smartphone apps, and sophisticated algorithms, improve patient adherence, increase early detection, and lower healthcare costs. Better results are produced when real-time monitoring and patient-centered tools are incorporated into daily life because they empower people and allow for prompt interventions. However, issues like device restrictions, possible user anxiety, and fair access still exist. This study recognizes areas for additional research and development while highlighting the potential of mHealth to transform the management of AF.

Keywords: Atrial fibrillation, mHealth, medical devices

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Received: 04.07.2026 **Accepted:** 21.08.2026 **Publication Date:** 25.09.2026

Cite this article as: Vyas P, Klemens E, Shaha A, et al. Advances in mobile health strategies for atrial fibrillation detection and patient care. J Updates Cardiovasc Med. 2026;14(3):57-67

DOI: 10.32596/jucvm.galenos.2025.2026-11-144

Introduction

Atrial fibrillation (AF) is a common type of arrhythmia where the heart beats irregularly and too fast, leading to reduced blood flow to the body. The sinus node in the heart sends signals to regulate heart contractions, but in individuals with AF, these signals are chaotic and untimely due to electrical misfirings[1]. These misfirings result in trembling in the atriums–the upper chambers of the heart–which limits the efficiency of the heart. AF is characterized by the atriums beating out of rhythm with the heart's ventricles, typically from electrical misfiring. AF symptoms include tachycardia (120-160 bpm), light-headedness, shortness of breath, chest pain, fatigue, high blood pressure, dizziness, and weakness[1]. While this condition is not directly life-threatening, it can lead to higher risks of stroke, myocardial infarction, chronic kidney disease, dementia, and cancer[2]. However, almost one-third of all patients with AF are asymptomatic, resulting in a lack of treatment to prevent these more life-threatening side effects of AF from appearing[2].

There are four main types of AF: paroxysmal, persistent, long-standing persistent, and permanent AF. With paroxysmal AF, symptoms last from a few minutes to a few hours and are relatively low risk. The heart rhythm is inconsistent for longer periods with persistent AF, and patients with long-standing persistent AF exhibit symptoms that last over twelve months. In cases of persistent AF, medical procedures may be required to correct the arrhythmia in these instances. Permanent AF, the most severe type of AF, results when the patient's heart rhythm cannot be reset, and medications are required to prevent blood clot formation[1]. Risk factors for developing AF include age, body mass index, hypertension, height, diabetes mellitus, obstructive sleep apnea, past myocardial infarction, heart failure, smoking, and genetic predisposition (Information, et al. 2017). AF affects 5% of the adult population or approximately 10.5 million adults, so developing new and accessible treatment and prevention plans is essential to improving lifestyles for affected individuals throughout the world[3].

Mobile health (mHealth) technology has improved the rapidity of AF diagnosis and patient engagement due to advancements in technology such as the modern use of smartphones and watches as electrocardiography (ECG) monitors. Research shows that mHealth interventions improve outcomes compared to standard care. A PubMed study testing the facilitation of smartwatches with AF detection explains, "...13 of 14 studies support the effectiveness of mHealth interventions compared with standard care" and "smartphone-connectable ECG devices provide patients with the ability to document a rhythm disturbance more easily than with standard care, which may increase empowerment and engagement about their illness"[4]. The accessibility and ease of self-monitoring directly relate to potentially reducing the need for emergency room visits and lowering mortality rates. Adding these devices to AF management may improve outcomes through early stroke prevention and fewer hospital visits for AF patients. In a study from the University of North Carolina, wearables directly correspond with continuous monitors, resulting in timely care[3]. This increased awareness of individual health caused by monitoring devices directly helped with early detection of potentially drastic health consequences and visits to the emergency room. These studies indicate the benefits that mHealth technology is bestowing upon patients throughout the world. This analysis will convey how the field of mHealth advances as new research highlights the benefits of wearable technology and mobile applications in detecting AF earlier.

Materials and Methods

This comprehensive review synthesizes current research and technological developments in AF detection, patient engagement, and healthcare outcomes. The methodology consisted of three primary components: literature review, technology assessment, and outcomes analysis.

Literature Review

We conducted a systematic review of peer-reviewed articles, clinical studies, and medical research papers published between 2014 and 2024. Key databases searched included PubMed, NCBI, and AHA Journals. Studies were included if they focused on AF detection methods, patient engagement strategies, or outcome measurements. Articles were excluded if they were published before 2014 or focused solely on pharmaceutical interventions.

Technology Assessment

The evaluation of AF detection technologies involved analyzing multiple device categories:

1. Traditional monitoring devices (12-lead ECG, Holter monitors)
2. Wearable technologies (smartwatches, fitness trackers)
3. Mobile applications (FibriCheck, CardiacRhythm, Preventicus, PULSESMART)
4. Implantable devices
5. Novel prototypes (Bitalino ECG sensor systems)

For each technology category, we assessed:

- Detection accuracy (sensitivity and specificity rates)
- Data collection duration capabilities
- Real-world performance metrics
- User accessibility and engagement factors
- Integration with healthcare systems

Outcomes Analysis

Patient outcomes were evaluated through multiple metrics:

1. Clinical outcomes:
   - AF detection rates
   - Time to medical intervention
   - Emergency room visit frequency
   - Hospitalization rates
2. Patient engagement metrics:
   - Adherence to monitoring protocols such as how consistently patients follow prescribed monitoring regimens, such as wearing a heart monitor daily or checking blood pressure at home.
   - Treatment compliance
   - Quality of life measurements referring to the patient's overall well-being, considering both physical and mental health.
3. Economic impact:
   - Healthcare resource utilization
   - Cost-effectiveness of various detection methods
   - Impact on different socioeconomic groups

Data Synthesis

The collected data was synthesized to identify:

1. Comparative effectiveness of different detection technologies
2. Barriers to implementation and adoption
3. Impact on patient outcomes and healthcare delivery
4. Economic implications of various detection strategies
5. Areas requiring further research or development

This methodological approach enabled a comprehensive assessment of current AF detection technologies, their implementation in healthcare settings, and their impact on patient outcomes and healthcare delivery systems.

Device Accuracy and Detection Rates

Understanding the accuracy and reliability of different detection devices is a crucial factor in selecting the most appropriate device for monitoring AF. Conventionally, the Holter monitor has been used as the primary ECG device for detecting AF in patients[5]. However, the rise of more wearable, less-cumbersome technology provides more options for physicians and patients to select from[6].

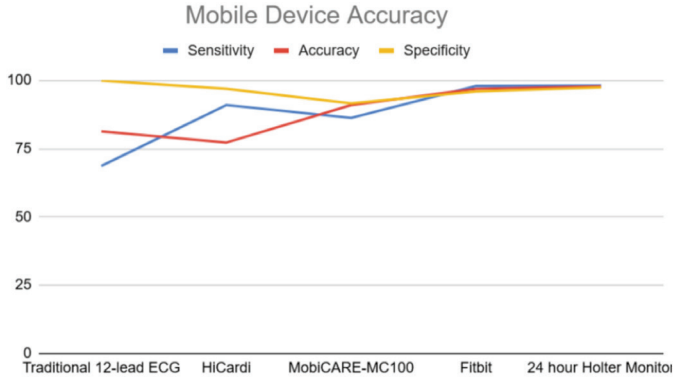
It is necessary that this new technology is compared to more established AF monitoring devices to ensure that these new devices can accurately detect AF in patients.

Numerous studies have tested the accuracy of using electrocardiogram patches or Holter monitors to detect AF. A study from the Ajou University School of Medicine utilized a new patch ECG device called MobiCARE-MC100 on AF patients undergoing cardiac surgery and compared its effectiveness in detecting AF detection to the conventional Holter device[6]. Patients wore the patch ECG as well as the Holter monitor for 24 hours to determine whether both devices detected the same number of AF events. The results of the study demonstrated that both devices detected the exact same number of AF events, indicating a similar level of accuracy with the new MobiCARE-MC100 device[6]. This study provides backing for new ECG devices that can be used to detect AF and allow for patients to monitor AF with ease and comfort, as the patch ECG requires minimal maintenance and is easy to apply. An additional study by the Seoul National University Hospital measured the accuracy of AF detection using the conventional Holter test and with an adhesive patch-type device[7]. Similar to the study by Ajou University School of Medicine, this study measured the number of AF detection events in both devices for 24 hours, measuring the same number of events in patients[7]. Both studies indicate that adhesive patches can be used to detect AF in patients with the same accuracy rates as a Holter test[6,7]. Additionally, the ECG patches such as the MobiCARE-MC100 are more discrete and thus easier to wear for extended periods of time without uncomfortability or hindrance, which may result in patients being more willing to undergo the testing period[6].

These studies also measured the effects of patch testing over longer periods of time. While the Holter monitor is typically only administered for 24 hours, the ease and minimal invasiveness of patch testing can allow for the testing to occur for longer periods of time, thus increasing the number of AF events that could be detected. A study by Scripps Translational Science Institute in California studied the effects of a 14-day patch ECG in AF detection compared to the 24-hour Holter monitor test. The results of the study demonstrated the patch monitor detected significantly more AF events than the Holter monitor, with 96 arrhythmia events detected compared to 61 ($p<0.001$)[8]. These findings are supported by the studies from the Ajou University School of Medicine and Seoul National University Hospital, as these studies also tested the effects of wearing the adhesive patch ECG for 72 hours[7]. The Ajou University School of Medicine detected an increase in AF events from 9% to 38% within 48 hours of the 72 hour testing period (https://pubmed.ncbi.nlm.nih.gov/38419583/). Seoul National University Hospital found that wearing the patch ECG for 72 hours increased the detection rate of AF by 1.5-fold, and the detection rate of paroxysmal AF increased with the patch ECG by 2.2-fold[7]. These studies indicate that the ability for patch ECGs to be worn for extended periods of time shows significant improvement in the detection of AF events among patients[8]. This discovery is revolutionary to mHealth field, as wearing patch ECGs could allow for detection of AF in early presenting individuals to allow for immediate treatment and improve their duration of life. While patch testing may require a more extended duration of application, the benefits outweigh the drawbacks as the ability to detect AF more accurately can allow for faster diagnosis of AF and treatment of the patient. Future testing should consider the effects of even longer patch testing to determine whether an even more extended time period could reveal more AF events and lead to further beneficial diagnoses for patients.

While a variety of new devices have been developed, there remain several limitations in their detection rates and practicality, including their monitoring windows, false positives, and recording dependence. In most studies conducted with monitors, researchers report a range of patient participation from 64% to 80% of patients consistently complying with device usage[9,10]. The table below indicates the rates of wear compliance across several studies testing device accuracy with AF detection. Due to the varying compliance of patients wearing recording technology, there may be a higher

number of AF events not recorded. Another limitation includes the false positive rate of AF detection. Several studies indicated patients received false alerts due to irregular pulse notifications or misinterpreted ECG data[11,12]. Advances are still being made today to rectify these errors and eliminate the frequency of false errors. Detection rates of various recording devices can be seen in Table 1 below. Devices will shorter monitoring windows such as the short-term chest monitors and handheld single-lead ECG may result in a decreased AF detection rate due to the finite window of detection time. In part, the accuracy of mobile devices is dependent on the diligence of the patient. The handheld single-lead ECG depends on the frequency of the user to record AF events, therefore attributing to its lower detection rate. Overall, these ECG devices are accurate to a fault, with several limitations remaining in their operating structure, patient compliance, and detection rates[9,11,13]. Device accuracy rates shown comparatively in Graph 1, with comparative accuracy, efficiency, and accessibility data shown in Table 1.



Graph 1. The graph above indicates the sensitivity, accuracy, and specificity of various mobile health devices in regards to atrial fibrillation detection[5-13]
ECG: Electrocardiogram

Table 1. The wear compliance and detection rates of different types of atrial fibrillation recording devices is shown above[9-12]

	Wear compliance	AF detection rates
Short-term chest monitors	67%	70%
Smartwatches (PPG)	35%	34%
Handheld single-lead ECG	74%	79%
Insertable/implantable loop recorders	100%	52%

ECG: Electrocardiogram, PPG: Photoplethysmography, AF: Atrial fibrillation

Impact on Timely Patient Interaction

The development of wearable technology such as wristwatches, chest bands, and implantable ECGs has facilitated the transition of AF treatment from in-hospital procedures to outpatient prevention[4]. With new mobile applications such as FibriCheck, CardiacRhythm, Preventicus, and PULSESMART, wearable devices can detect arrhythmias and symptoms of AF, alerting the patient via the app when signs occur. The devices conduct an electrocardiogram, or ECG, at regular intervals and can detect AF in as little as thirty seconds with a single lead ECG[14]. Detection of AF with this single-lead ECG can prompt more in-depth screening with 12-lead ECGs to further confirm an AF diagnosis[15]. Due to this new technology, patients can become aware of their symptoms and seek medical attention more rapidly, resulting in a decreased risk of AF developing into cardiac arrest or stroke[14].

Traditional ECG testing is expensive and requires patients to visit a clinical setting for monitoring, which makes it impracticable for frequent tracking and daily, personal use. This reliance on in-clinic testing can delay diagnosis, especially for individuals without immediate access to healthcare facilities. Moreover, the need for trained professionals to operate the ECGs is a burden for healthcare providers because resources like time, staff, and equipment are heavily allocated to ECG testing, leaving less capacity for other patient needs[4].

A new prototype has been developed to create a low-cost, user-friendly device for early detection of AF in home settings, allowing for timely intervention and emergency medical services (EMS). This prototype uses a Bitalino ECG sensor, which is a simple and affordable device that allows for the real-time collection of high-quality heart signals, making it ideal for portable health monitoring. The prototype is integrated with an Arduino microcontroller, a system that processes ECG data,

runs the arrhythmia detection algorithm, and identifies abnormalities such as high beats per minute (BPM) or irregular R-R intervals. Healthy ECG data was collected via self-testing, and AF data came from the Massachusetts Institute of Technology-Beth Israel Hospital AF database. The AF detection algorithm identifies high BPM (>100) and inconsistent R-R intervals (outside 0.6-1.2s), achieving 88% accuracy, which improved with a lower BPM threshold of 90. This device can help patients seek timely EMS support, reducing risks associated with delayed treatment. Future improvements for the device include more advanced microcontrollers, better sensors, and larger-scale testing to improve reliability and accessibility for a larger population[16]. Additionally, as telehealth becomes more prevalent today, physicians can access patient data from these mobile applications to receive a more extensive overview of the patient's condition and provide necessary treatment. Another benefit of mHealth applications is to promote early screening for AF, allowing patients to receive a diagnosis earlier and enabling them to take preventative measures before symptoms worsen[14].

New evidence highlights the importance of implementing a simple, scalable, and pragmatic population-based pathway for AF screening. Systematic screening is recommended for individuals aged 65 and over. Consumer-led screening can be an entry point into this systematic approach but requires careful evaluation of its diagnostic implications and healthcare resource demands. With an emphasis on quantifying the claimed benefits of mobile technologies, the authors carried out a systematic review to look at the data pertaining to the influence of mobile handheld technology on hospital physicians' work practices and patient care. Thirteen studies were found by the authors to show how personal digital assistants (PDAs) can improve data management and accessibility, error prevention, and rapid response. PDA use is most beneficial in situations where time is of the essence and prompt action is essential. This technology can facilitate immediate action by physicians to inform patients of health concerns or a necessary adjustment to ongoing treatments in response to this mobile data. In one instance, a hospital that switched to this method of data transmission experienced a 50% decrease in the number of patients admitted to the hospital via emergency transportation for coronary occlusions, which is an artery blockage that can be exacerbated by having AF[13].

Developing effective AF surveillance strategies remains challenging, with limited evidence supporting their utility for broad population use. However, the integration of mHealth technologies and wearable devices has revolutionized AF detection and management, enabling earlier diagnosis, timely interventions, and more efficient use of healthcare resources, ultimately reducing the risks of severe complications and improving patient outcomes.

Patient Outcomes

Advancements in healthcare are not only about improving clinical outcomes as they also emphasize enhancing patient's quality of life. In recent years, mHealth technologies have emerged as promising tools in managing chronic conditions like AF. mHealth technologies in treating AF have even gone beyond simple treatment; one study concluded an improvement in quality-of-life questionnaire scores after 6 months of using myAlgos, an app for symptom and treatment management[2]. The app offers frequent reminders as well as physician-approved laymen information. Its usability is targeted at laypeople, improving patient outcomes in high percentages of the population.

Adherence to treatment plans is critical in achieving longevity of positive health outcomes.

However, it is reported that as many as one-third to two-thirds of patients struggle with adhering to their treatments that included physiotherapy[17]. This struggle could be due to factors such as lack of motivation, forgetfulness, or just having a demanding lifestyle. A study examining the impact of a mHealth app on physical health treatments found that apps and wearable technology significantly

improve a patient's ability to stick to their treatments by providing reminders, tracking progress over some time, and being able to communicate with healthcare providers more efficiently[17]. The article by Greenstein et al.[17] also showed that patients using the Kanvas app were more likely to keep their follow-up appointments.

15.25 to 13.82 of physician-discharged patients and 7.79 to 4.58 of self-discharged patients kept their appointments, again, the Kanvas app patients kept their appointments more frequently[17]. This trend speaks to enhanced patient outcomes, with those who are more likely to keep their appointments more likely to receive better health outcomes overall. Having wearable technology that sends alerts like high heart rate or abnormal ECG results can help one stay aware of issues and set reminders to take prescribed treatments, attend appointments, and maintain a healthy lifestyle. Some apps that have these features that lead to timely EMS contact are FibriCHeck, CardiacRhythm, etc. These features can help patients monitor their condition closely and ensure AF symptoms are caught beforehand. Furthermore, apps that are tailored for AF management can offer educational resources to empower patients on the importance of lifestyle changes like diet, exercise, and stress management.

mHealth technologies have been shown to have economic benefits, particularly due to their positive impact on treating AF. One research paper that used a retrospective, observational, single-center study method analyzed the cost-effectiveness of mHealth technologies and treating AF and examined the outcomes of standard treatment and treatment supplemented with mHealth. The study found that reduced incidences of various subsequent AF-related outcomes such as stroke, rehospitalization, or even death, led to overall reduced costs[18]. Another descriptive observational study relating mHealth technology to economic disparity shows that there is a significantly high percentage of interest in participation within low-income communities in having access to mHealth technologies. This positive uptake can be attributed to mHealth applications that are sensitive to user needs and a diverse population. By considering the visual and linguistic design of mHealth applications to better overcome mobile application fluency, the divide in healthcare fluency and disparities can decrease with diverse economic groups[19].

AF is a significant public health challenge because of its broad impact on the patient and healthcare systems. Patients who have AF face a higher risk of stroke, heart failure, and mortality which contributes to heightened healthcare resources used and economic burdens[15]. The higher risk of severe complications such as stroke and heart failure not only decrease the patient's quality of life but can strain healthcare infrastructure. These outcomes emphasize the need for early detection and preventative measures to steer away from major heart issues and improve patient outcomes. The Global Burden of Disease Study reported that in 2019 alone, AF was the cause of 315,000 deaths and these outcomes disproportionately affect populations with limited access to preventative care and lower socio-demographic backgrounds. Addressing changeable factors, like hypertension and obesity through public health projects like affordable screenings, patient education, and equitable access to healthcare can reduce AF's global impact[15].

Despite the plethora of potential benefits that mHealth presents in treating AF and managing symptoms, the potential pitfalls of this methodology are present. One limitation noted by a study from a trial utilizing smartwatches and smartphones found that most participants recorded a surprisingly low number of AF symptoms due to needing to recharge the devices[20]. Additionally, there have been concerns those technologies with a heightened awareness of little fluctuations in the heart's activity increase anxiety among the wearers. This may lead to unnecessary hospital visits or unneeded medical interventions. Despite the concerns, these connections do not have solidified studies to support such claims and should not discourage the use of these technologies. New technologies have even begun to be implemented in the treatment of this disease, aiming to remedy these limitations and provide even better care to those with AF.

Innovation in Detection Technologies

For years, the primary method of diagnosing AF and other causes of sudden cardiac death has been through the traditional 12-lead ECG, or more recently, through the use of wearable device technologies. The 12-lead ECG has been the standout method for detection up until recent years because it makes use of electrodes to provide a multi-dimensional view of the heart's activity. The use of the 12-lead ECG is considered "traditional" because the noninvasive imaging test allows for quick diagnosis on-site as it relates to coronary artery disease, myocardial infarction, or other episodes[19]. While this method has proven effective and essential to the growing knowledge surrounding sudden cardiac death, it can be time-consuming, requires preparation beforehand, and is not a constant detection method.

A specific interest for technologies aiming to detect AF and/or similar episodes is for said technology to be constant, easily monitorable, and most importantly quickly alert the patient of a risk in their condition. For this reason, wearable device technologies have gained popularity in recent years because they allow for a similar security that the 12-lead ECG provides to become portable and therefore provide a persistent source of monitoring, with the main goal being to recognize complications in real-time. One of the earliest and most well-known wearable detection technologies is FitBit, which makes use of optical photoplethysmography (PPG) sensors to measure pulse rate[21]. Since the creation of Fitbit, PPG has been used and refined as a technology through other brands as well as the development of mobile apps to accompany wearable devices. The development and function of wearable device technologies have also greatly been aided by artificial intelligence algorithms. The integration of AI algorithms has increased the success rates of both prevention and treatment significantly when it comes to sudden cardiac death, with automation of monitoring services and alert systems becoming an important focus. AI has helped improve patient prognosis through earlier detection and a notable improvement in accuracy through its use in both traditional technology such as ECGs and wearable devices, or even more specified and advanced modern technology that gears their focus towards cardiac electrophysiology, the physiological function of the electrical conduction system of the heart. Innovative AI-powered personal devices have achieved a near clinical-grade accuracy in detecting AF. For example, the six-lead KardiaMobile 6L smartphone ECG showed an approximate 99% sensitivity and an approximate 91% specificity of AF for studies testing validation[9]. Its single-lead precursor similarly showed high diagnostic accuracy, with sensitivity ranging from 92% to 99% and specificity ranging from 92% to 99%[22,23]. The KardiaMobile devices are also relatively affordable, with the single-lead product priced at around 83 euros, which is equivalent to about $110, and the six-lead model launches at approximately $149.23,30 Another product is the Apple Watch Series 9, which has on device AI algorithms that use both ECG and PPG sensors. These sensors detect AF with about 95% sensitivity and 95% specificity[23,24]. In the Apple Heart Study, an irregular pulse notification from an earlier model of an Apple Watch had a positive predictive value of approximately 84% for AF[25]. Apple's latest watch being the series 11, retails for $399 excluding taxes. Data for comparative pricing shown in Table 2

Detection technology as a whole has increasingly grown over the past decade, with notable feats in application to mobile devices, smartwatches, and everyday technology that make crucial information about one's cardiac health easily accessible and most importantly, capable of direct analysis. Two examples of current successful monitoring technology include the HiCardi and MobiCARE devices, which have proven that a new era of cardiological health crisis prevention is quickly approaching–one in which accuracy, efficiency, and accessibility play a role in transforming the prognosis associated with typical causes of sudden cardiac death (see Table 1 below). Sensor technology has also greatly improved through the efficient use of machine learning which has led to the ability for

Table 2. The above table indicates the cost, charge time, and recording time of various mobile health devices in detecting atrial fibrillation[22-25]

	Cost	(Max) charge time	Recording time
Traditional 12-lead ECG	$178-$600	N/A	10 seconds
HiCardi	$280-$730	1.5	72 hours
MobiCARE-MC100	$360-$1800	1.5	72 hours
Fitbit (PPG)	$130-$300	1-2	6-10 days
24-hour holter monitor	$150-$600	4	24 hours

ECG: Electrocardiogram, PPG: Photoplethysmography

even minute body-language detection mechanisms to play a role in the prevention and treatment of cardiac crises. While current technology applied to cardiological crises has improved greatly, we aim to analyze the growth and projection of these current technological feats as they build off of traditional interventions, but with greater automation and efficiency, with certain criteria in mind such as patient comfort and accessibility, provider education, trust, and real-time reliability. With major improvements to wearable devices such as more compact and lightweight designs, wearability has increased, allowing patients to monitor their heart health with ease continuously. These developments contribute to the seamless integration of technology into everyday life, ensuring that critical health insights are available and reliable, improving not only the overall monitoring of cardiac health but also patient quality of life.

Summary

This review highlights the transformative role of mHealth technologies in AF management, emphasizing advancements in device accuracy, timely patient interaction, patient outcomes, and detection innovation. Devices such as wearable technologies, smartphone-connected ECGs, and implantable cardiac monitors demonstrate high sensitivity and specificity for AF detection, with smartphone ECG devices like Kardia achieving sensitivity rates of 98.5% and specificity rates of 91.4%[24]. These technologies surpass traditional tools like Holter monitors in accessibility and ease of use, but limitations such as short monitoring durations and the risk of false positives highlight the need for optimization[26]. In parallel, mHealth tools have revolutionized timely patient interactions, enabling rapid identification of AF episodes through wearable devices and mobile apps such as FibriCheck and CardiacRhythm. For instance, prototypes like the Bitalino ECG sensor integrated with Arduino microcontrollers have achieved promising detection accuracy, offering affordable solutions for home-based monitoring[16]. Despite these advances, challenges remain, including device recharging needs and user anxiety stemming from frequent alerts[20].

Beyond detection, mHealth technologies significantly improve patient outcomes by enhancing treatment adherence and promoting engagement. Features such as reminders and real-time monitoring have demonstrated success in reducing hospitalizations and increasing appointment attendance rates[17]. Importantly, these tools address healthcare disparities by providing cost-effective options for underserved populations, with studies showing high interest and usability among low-income groups[19]. However, economic barriers and disparities in technology access highlight the need for affordable and inclusive solutions to ensure equitable adoption.

Innovations in detection technologies further solidify mHealth's role in AF management. Developments in PPG and artificial intelligence (AI) have improved the accuracy and efficiency of wearable devices, with AI enabling predictive analytics and personalized care strategies[21]. Lightweight and compact designs enhance device usability, while real-time health insights empower patients to take a proactive role in their care.

These advances pave the way for systematic population-wide screening, particularly among high-risk groups, to reduce the global burden of AF.

Conclusion

A paradigm shift in AF detection, treatment, and patient engagement has been brought about by the incorporation of mHealth technologies. This thorough analysis conveys how improvements in wearable technology, smartphone apps, and creative detection tools greatly improve patient outcomes and early AF detection. With their high sensitivity and specificity in detecting AF, technologies like implantable cardiac monitors, smartphone-connected ECGs like Kardia, and wearables based on PPG have reduced the need for invasive, in-clinic procedures while facilitating prompt intervention. Additionally, these tools give patients the ability to actively monitor their health, which improves treatment plan adherence and lowers the need for emergency medical care.

Mobile applications and wearable technologies also enhance accessibility to AF management, with features that encourage preventive care and lifestyle changes. However, challenges persist, including device limitations such as short monitoring durations, the risk of false positives, and barriers related to cost and user education. Notably, while the economic benefits of these technologies are evident, their adoption must consider the needs of low-income populations and those with limited healthcare access.

Emerging technologies, such as prototypes leveraging Bitalino ECG sensors and Arduino microcontrollers, indicate a promising future for affordable and scalable AF detection. These innovations highlight the potential for systematic population-wide screening, especially in high-risk groups. Despite concerns like anxiety induced by continuous monitoring and device recharging issues, the overarching benefits of mHealth in AF care outweigh its limitations.

The results highlight how important it is to conduct additional investigations in order to improve device performance, address inequalities in technology adoption, and smoothly incorporate these tools into healthcare systems. mHealth technologies have the potential to transform AF care by emphasizing patient comfort, real-time dependability, and equitable access, ultimately lessening the burden of the condition on both individuals and healthcare systems.

To encourage broader adoption, future research should concentrate on improving detection devices' efficiency and accuracy, lengthening their monitoring periods, and making them more user-friendly. It will also be crucial to address inequalities in access to mHealth technologies, especially by creating affordable devices and educational materials specifically for marginalized communities[20]. The long-term clinical and financial effects of these technologies, including their potential to lower AF-related complications and enhance healthcare delivery, require more investigation. Furthermore, investigating the incorporation of artificial intelligence into wearable technology may open the door to customized treatment plans and predictive analytics. In order to counteract the increasing burden of AF, the future of mHealth in AF management promises to provide creative, fair, and patient-centered solutions by filling in these gaps.

Ethics

Acknowledgement

Thank you to Sudden Cardiac-death Awareness and Research Foundation for providing peer review and instruction regarding the meta-analysis process. Thank you to the University of Illinois at Urbana-Champaign for accepting our meta-analysis to the Undergraduate Research Symposium. No financial support was provided in the writing of this manuscript.

Footnotes

Authorship Contributions

Concept: Vyas P, Design: Vyas P, Analysis and/or Interpretation: Vyas P, Klemens E, Shaha A, Khosla R,

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Conflict of Interest: The authors declare no conflicts of interest concerning the authorship or publication of this article.

Financial Disclosure: This research received no specific grants from any funding agency in the commercial or not-for-profit sectors.

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Research Article

JUCVM Journal of Updates in Cardiovascular Medicine

J Updates Cardiovasc Med 2026;14(3):68-78 **DOI:** 10.32596/jucvm.galenos.2025.2026-7-184

Metal Artifact Reduction in Chest CT of Patients with Cardiac Implantable Devices

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Abstract

Objectives: To determine whether smart metal artifact reduction (SMAR) combined with adaptive statistical iterative reconstruction (ASIR) improves thoracic computed tomography (CT) image quality in patients with cardiac implantable electronic devices (CIEDs) compared with ASIR alone.

Materials and Methods: In this retrospective single-center study (January 2022-December 2024), 30 consecutive CIED carriers (mean age 63.4±14.5 years; 18 pacemakers, 12 implantable cardioverter-defibrillators) who underwent thoracic CT on a 512-slice scanner were evaluated. Paired ASIR-only and ASIR+SMAR reconstructions were generated from identical raw data. Two blinded radiologists graded image quality on a 5-point scale across soft-tissue, osseous, and pulmonary windows at proximal (<3 cm), intermediate (3-5 cm), and distal (>5 cm) zones. A third radiologist measured quantitative artifact load as the Hounsfield unit standard deviation (HU-SD) in proximal-zone regions of interest.

Results: ASIR+SMAR significantly reduced proximal-zone HU-SD compared with ASIR alone (43.60±17.33 vs. 90.40±42.11; $p<0.001$; Cohen's $d=1.42$), representing a 52% reduction. Overall qualitative scores improved significantly (3.84±0.48 vs. 2.92±0.47; $p<0.001$). The greatest gains occurred on the soft-tissue windows in the proximal and intermediate zones ($p<0.001$). However, algorithm-related streaks appeared in distal lung parenchyma in 13 of 30 patients (43.3%), with 5 (16.7%) being severe enough to preclude evaluation. Inter-reader agreement was substantial (weighted κ: 0.68-0.72).

Conclusion: SMAR combined with ASIR significantly improves image quality metrics in the proximal and intermediate zones around CIED generators. However, algorithm-induced artifacts in distal lung parenchyma occur in approximately 43% of patients. A dual-reconstruction review strategy is recommended for clinical practice.

Keywords: Thoracic computed tomography, metal artifact reduction, cardiac pacemaker, implantable cardioverter-defibrillator, iterative reconstruction

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Received: 05.04.2026 **Accepted:** 25.06.2026 **Publication Date:** 25.09.2026

Cite this article as: Genç Ö, Baş S, Tabakçı ÖN. Metal artifact reduction in chest CT of patients with cardiac implantable devices. J Updates Cardiovasc Med. 2026;14(3):68-78

DOI: 10.32596/jucvm.galenos.2025.2026-7-184

Introduction

The clinical deployment of cardiac implantable electronic devices (CIEDs)—encompassing pacemakers, implantable cardioverter-defibrillators (ICDs), and cardiac resynchronization therapy systems—has expanded steadily as therapeutic indications broaden and populations age. These devices generally comprise a subcutaneous pulse generator positioned in the infraclavicular region together with one or more endovascular leads coursing through the central venous system to the myocardium[1]. Although magnetic resonance imaging capabilities have advanced, thoracic computed tomography (CT) retains a central role in chest assessment, offering high-resolution depiction of pulmonary, mediastinal, cardiac, and musculoskeletal anatomy. Nevertheless, the metallic housing of the pulse generator frequently gives rise to image degradation that hampers evaluation of neighboring structures and diminishes overall diagnostic utility[2].

The physical mechanisms underlying metallic artifacts primarily involve beam hardening, photon starvation, and X-ray scatter[3]. Multiple remediation strategies have been proposed. Fundamental acquisition-level approaches include increasing tube potential and current, narrowing collimation, using iterative reconstruction kernels, applying softer convolution filters, and increasing the reconstructed section width[2,4]. A distinct paradigm leverages dual-energy CT to generate virtual monoenergetic datasets at selected photon energies, thereby attenuating beam-hardening effects;[5-7] however, this benefit wanes with high-atomic-number alloys, bulky hardware, and angular geometries. A third category employs projection-domain metal artifact reduction (MAR) software that detects corrupted sinogram projections passing through metallic components and substitutes them with estimated values derived from adjacent, unaffected data[8,9].

Published evidence indicates that MAR processing can meaningfully diminish artifactual degradation in post-operative thoracic CT images and bolster image interpretability[10,11]. At the same time, MAR algorithms may occasionally engender secondary artifacts, particularly at locations remote from the implant, and vendor-specific implementations can produce divergent outcomes[9,12]. The most pertinent prior investigation involving CIEDs was reported by Pennig et al.[6] who examined virtual monoenergetic images and MAR post-processing derived from spectral-detector CT in a 34-patient cohort. That work confirmed artifact mitigation around both the generator and the leads, yet did not evaluate pulmonary parenchymal windows or delineate how MAR-induced artifacts vary with distance from the hardware.

Notwithstanding these contributions, rigorous assessment of proprietary MAR solutions across diverse tissue displays and at graduated distance intervals among CIED carriers remains sparse. In particular, the GE smart metal artifact reduction (SMAR) algorithm has not been evaluated in this patient population across soft-tissue, osseous, and pulmonary windows and across defined spatial strata, nor has any report systematically mapped the distance-dependent emergence of algorithm-related artifacts in the lung fields of CIED recipients.

Accordingly, the present investigation was designed to retrospectively appraise the influence of SMAR, applied in conjunction with adaptive statistical iterative reconstruction (ASIR), on thoracic CT image quality in CIED carriers, compared with ASIR alone, using both quantitative artifact metrics and qualitative reader-based evaluations across predetermined tissue displays and distance intervals.

Materials and Methods

This single-institution retrospective analysis adhered to the principles of the Declaration of Helsinki and was structured following the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) framework. Institutional Ethics Committee approval was obtained İstanbul Yeni Yüzyıl University Clinical Research Ethics Committee (decision no: 2021/04-653, date: 06/04/2021), and the requirement for informed consent was waived because of the retrospective nature of the study and the exclusive use of anonymized datasets.

Study Design and Participant Selection

We identified all consecutive CIED carriers who underwent thoracic CT at our facility between January 2022 and December 2024. Eligibility was determined according to the following criteria:

Inclusion criteria: (a) a functioning CIED (pacemaker, ICD, or cardiac resynchronization device) present during the CT acquisition, and (b) complete availability of both ASIR-only and ASIR+SMAR image datasets generated from the same scan.

Exclusion criteria: (a) incomplete or technically failed image reconstructions attributable to archival malfunction or algorithmic error, and (b) clinically meaningful pulmonary parenchymal abnormality—operationally defined as radiologically apparent consolidation, ground-glass attenuation spanning more than a single lobe, diffuse interstitial lung disease, substantial pleural effusion (occupying >1/3 of the hemithorax), or history of pulmonary resection. This restriction was imposed to maintain uniform baseline lung tissue characteristics, thereby ensuring reliable artifact quantification and consistent region-of-interest placement.

Of 35 consecutively identified patients, 5 were excluded owing to technically incomplete reconstructions: archiving errors disrupted ASIR datasets in 3 cases, while SMAR processing failed in the remaining 2 cases. The resultant analytic cohort numbered 30 individuals.

Sample Size Rationale

The sample size was determined by the number of consecutive eligible patients identified during the predefined study period. Given the retrospective design of the study, no formal a priori sample size calculation was performed. The final cohort consisted of 30 paired observations. Therefore, analyses of secondary endpoints should be interpreted with caution and considered exploratory.

Demographic and Device Data

Clinical demographics and device specifications were extracted from institutional electronic health records. Recorded variables included age, sex, body mass index (BMI), reason for CT referral, intravenous contrast use, device category (pacemaker, ICD, or cardiac resynchronization system), hardware manufacturer, lead count and configuration (single-chamber, dual-chamber, or biventricular), and generator laterality.

Image Acquisition Protocol and Reconstruction

Every examination was acquired on a single-source, 512-slice platform (Revolution CT, GE Healthcare, USA) using the following parameters: tube potential 120 kVp, tube current modulation via SmartmA (range 100–500 mA), detector aperture 40 mm, helical pitch factor 0.992, gantry rotation period 0.80 s, reconstructed section thickness 1.25 mm, section increment 1.25 mm, and display field of view 50 cm. Radiation exposure was tracked through DICOM-structured dose reports to facilitate ongoing optimization[13].

Two reconstruction pipelines were applied to identical raw projection datasets. ASIR, a hybrid iterative technique operating in both the projection and image domains, models photon and electronic noise statistics and iteratively refines the image by comparing forward-projected estimates with acquired data; the 50% blending ratio—our institutional default—was selected as the optimal trade-off between noise suppression and texture preservation. SMAR is a projection-completion algorithm that segments high-attenuation metal voxels by thresholding, identifies the corrupted “metal trace” within the sinogram, replaces those samples, guided by a prior image, with values interpolated from adjacent uncorrupted projections, and reconstructs the corrected sinogram with ASIR before reinserting the metal voxels. The manufacturer-defined “thorax” preset, employed throughout, incorporates chest-optimized segmentation thresholds and interpolation kernels. Both reconstructions used identical raw data, required no modification of the acquisition protocol, and added approximately 60–90 seconds of offline workstation processing time per dataset when using the SMAR pipeline[14,15].

Paired image sets were interpreted on an Advantage Windows Workstation 4.7 (GE Healthcare, Milwaukee, WI). Three display configurations were employed: soft-tissue [window width 400 Hounsfield unit (HU), center 35 HU], osseous (width 2500 HU, center 480 HU), and pulmonary (width 1500 HU, center −600 HU). Assessment was confined to the axial orientation.

Outcome Definitions

Two co-primary endpoints were designated: (1) quantitative artifact load, operationalized as the standard deviation of (HU-SD) within proximal zone regions of interest (ROI) adjacent to the pulse generator, and (2) aggregate qualitative image-quality score. Secondary endpoints comprised qualitative ratings for each of the nine display–zone pairings (soft-tissue, osseous, and pulmonary displays across proximal, intermediate, and distal zones), together with the frequency and severity classifications of algorithm-related artifacts arising in the distal lung parenchyma.

Qualitative Image Appraisal

Two independent readers with thoracic CT interpretation experience (Reader A: 16 years; Reader B: 10 years) conducted qualitative assessments under blinded conditions. ASIR and ASIR+SMAR datasets were displayed in randomized sequence during workstation sessions separated by a minimum 14-day interval. Neither reader was informed of the reconstruction method applied to a given image set.

Global image quality was graded on a 5-point ordinal scale: 1= severe degradation rendering adjacent anatomy invisible; 2= pronounced artifacts causing substantial distortion; 3= moderate artifacts permitting structural identification; 4= minor artifacts with slight blurring; 5= artifact-free appearance.

In addition, each of the three display settings (soft-tissue, osseous, and pulmonary) was evaluated at three graduated distance bands from the device: proximal (<3 cm), intermediate (3–5 cm), and distal (>5 cm), producing nine display–zone combinations.

Algorithm-induced artifacts were characterized separately on a 3-tier scale: 1= absent; 2= present but permitting diagnostic interpretation; 3= present and precluding diagnostic interpretation. Such artifacts were operationally defined as degradations present in the ASIR+SMAR dataset but absent from the corresponding ASIR-only images.

When readers' scores diverged, disagreements were adjudicated through structured discussion. In 4 of 270 aggregate display–zone evaluations (1.5%), consensus was unattainable; therefore, the arithmetic mean of the two ratings was adopted; these averaged values were rounded to the nearest whole number prior to statistical testing to preserve ordinal data integrity.

Quantitative Artifact Assessment

A third radiologist (Reader C, 12 years of thoracic CT experience, uninvolved in qualitative assessment) performed objective measurements by positioning three elliptical (ROIs, each with a fixed 1.5-cm diameter) within the proximal zone adjacent to the pulse generator on the axial section exhibiting peak artifact intensity. ROIs were systematically placed at three anatomically defined sites: (1) anteriorly, (2) medially, and (3) posteriorly relative to the device, deliberately avoiding overlap with major vasculature or aerated lung, in accordance with the measurement protocol of Subhas et al.[11]. The HU-SD within each ROI was recorded, and the arithmetic mean across all three ROIs constituted the quantitative artifact index. Elevated HU-SD values denote greater artifact contamination.

Measurement reproducibility was assessed in two ways. For inter-observer reliability, a fourth radiologist (Reader D, 8 years of experience) independently repeated the measurements on a randomly selected subset of 10 patients (33%), following the same protocol. To assess intra-observer consistency, Reader C remeasured the same 10-patient subset after a 3-week interval. Two-way mixed-model intraclass correlation coefficients (ICCs) with absolute agreement were computed for both reliability dimensions.

Mitigation of Potential Bias

Multiple safeguards were instituted to limit systematic error. Qualitative raters were blinded to the reconstruction strategy, and the display order was randomized. Quantitative measurements were conducted by an independent reader to prevent contamination by qualitative impressions. ROI placement adhered to a fixed-size, anatomically predetermined protocol. Consecutive enrollment minimized selection bias. Inter- and intra-observer reproducibility was formally quantified. Notwithstanding these precautions, unmeasured confounders and institutional workflow characteristics inherent in a retrospective single-site design cannot be fully excluded.

Statistical Analysis

Analyses were performed using SPSS version 28.0 (IBM Corp., Armonk, NY). Continuous variables are reported as mean ± standard deviation; medians and interquartile ranges are additionally provided when distributions depart from normality. The Shapiro-Wilk test was used to assess the distributional form of the data, and Levene's test was used to assess the homogeneity of variances.

Co-primary endpoints were compared using for data that were normally distributed, with results expressed as mean differences, 95% confidence interval (CI), and p-value. A two-sided significance threshold of $p<0.05$ was applied to the two co-primary comparisons. For the nine secondary display–zone contrasts, a Bonferroni-adjusted threshold of $p<0.0056$ ($0.05 \div 9$) was enforced. Paired data that were not normally distributed were analyzed using Wilcoxon signed-rank tests. Categorical frequencies were compared using Fisher's exact test. The particular test employed for each comparison is specified in the Results.

Paired effect sizes were quantified using Cohen's d. Inter-reader concordance for ordinal qualitative scores was evaluated using weighted kappa (linear weighting) with 95% CIs; interpretive benchmarks followed Landis and Koch: 0–0.20 slight, 0.21–0.40 fair, 0.41–0.60 moderate, 0.61–0.80 substantial, 0.81–1.00 nearly perfect. Linear-weighted kappa was preferred to its unweighted counterpart because ordinal scales penalize larger discrepancies more heavily.

To gauge robustness against the interval-scale assumption underlying parametric analysis of ordinal ratings, all primary and secondary paired comparisons initially analyzed by t-test were replicated using Wilcoxon signed-rank tests as a pre-specified sensitivity check.

Five individuals were excluded because of incomplete reconstructions; the remaining 30 had complete data for every measurement. No additional missing values existed among objective or qualitative endpoints, obviating the need for imputation procedures.

Results

Cohort Characteristics

Of the 35 screened individuals, 30 met all eligibility requirements and were included in the final analysis. Mean age was 63.4 ± 14.5 years (range 25-89), with a female-to-male ratio of 16:14 (53.3% vs. 46.7%). Mean BMI was 27.8±5.2 kg/m^2. The primary reasons for CT referral were surveillance (n=14, 46.7%), investigation of breathlessness (n=8, 26.7%), suspected infectious complications (n=5, 16.7%), and procedural planning (n=3, 10.0%). Intravenous contrast was administered in 22 studies (73.3%).

The cohort comprised two CIED categories: conventional pacemakers (18 patients, 60.0%) and transvenous ICDs (12 patients, 40.0%); no isolated CRTs, subcutaneous ICDs, or leadless devices were represented. Lead configurations were single-chamber (one right ventricular lead) in 8 patients (26.7%), dual-chamber (right atrial plus right ventricular leads) in 16 (53.3%), and biventricular (right atrial, right ventricular, and coronary sinus leads) in 6 (20.0%), yielding 60 endovascular leads in total (mean 2.0 per patient). Hardware devices were manufactured by Medtronic (n=14, 46.7%); Boston

Scientific (n=9, 30.0%); Abbott/St. Jude (n=5, 16.7%); and Biotronik (n=2, 6.7%). Generators were positioned in the left infraclavicular pocket in 27 patients (90.0%) and in the right infraclavicular pocket in 3 patients (10.0%). Full demographic and device data appear in Table 1.

Distribution Testing

The Shapiro-Wilk test confirmed that HU-SD values were normally distributed for both the ASIR series (W=0.961, p=0.327) and the ASIR+SMAR series (W=0.953, p=0.208), supporting the use of the paired t-test. Global qualitative scores likewise conformed to normality across both reconstruction methods (all p>0.05).

Descriptive Visual Observations

On soft-tissue displays, ASIR+SMAR reproducibly attenuated proximal-zone streaking and beam-hardening artifacts, enhancing the depiction of peri-device musculature and vascular anatomy relative to ASIR alone (Figure 1). In the intermediate zone (Figure 2), osseous structures showed diminished metallic degradation and sharper cortical delineation of thoracic skeletal elements. Pulmonary images demonstrated reduced proximal-zone artifacts with ASIR+SMAR; however, distal-zone (>5 cm) band-like streaks were intermittently noted in aerated parenchyma (Figure 3).

Table 1. Demographic and device profile of the study cohort (n=30)

Variable	Result
Age, years (mean ± SD)	63.4±14.5
Age range, years	25–89
Female sex, n (%)	16 (53.3)
BMI, kg/m² (mean ± SD)	27.8±5.2
Contrast-enhanced study, n (%)	22 (73.3)
Referral indication, n (%)	
Surveillance	14 (46.7)
Breathlessness workup	8 (26.7)
Suspected infection	5 (16.7)
Procedural planning	3 (10.0)
Device category, n (%)	
Pacemaker	18 (60.0)
ICD	12 (40.0)
Hardware manufacturer, n (%)	
Medtronic	14 (46.7)
Boston scientific	9 (30.0)
Abbott/St. Jude	5 (16.7)
Biotronik	2 (6.7)
Lead arrangement, n (%)	
Single-chamber	8 (26.7)
Dual-chamber	16 (53.3)
Biventricular	6 (20.0)
Left-sided generator, n (%)	27 (90.0)

SD: Standard deviation, BMI: Body mass index, ICD: Implantable cardioverter-defibrillator

Quantitative Artifact Load (Co-primary Endpoint 1)

Mean HU-SD in proximal-zone ROIs (<3 cm from the generator) was substantially lower with ASIR+SMAR than ASIR alone (43.60±17.33 vs. 90.40±42.11), corresponding to a 52% decrement. The mean paired

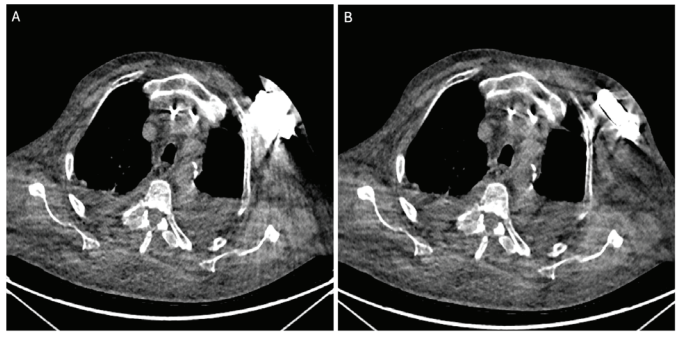

Figure 1. Soft-tissue window in a CIED patient: ASIR+SMAR reduces peri-device streak and beam-hardening and improves depiction of adjacent soft tissues and vascular structures compared with ASIR
CIED: Cardiac implantable electronic device, ASIR: Adaptive statistical iterative reconstruction, SMAR: Smart metal artifact reduction

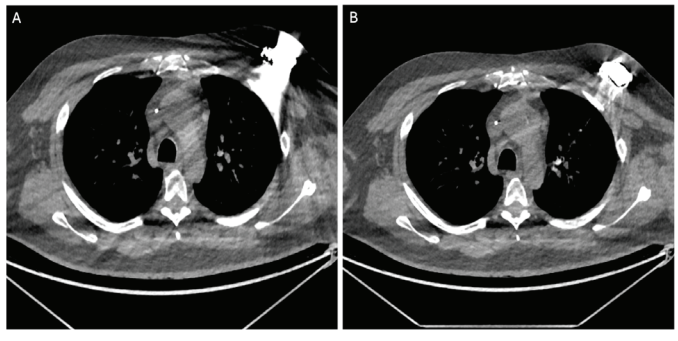

Figure 2. On bone-window images, ASIR+SMAR reduces metallic artifacts and improves visualization of the cortical bone and thoracic skeleton adjacent to the generator compared with ASIR
ASIR: Adaptive statistical iterative reconstruction, SMAR: Smart metal artifact reduction

difference was 46.80 HU (95% CI: 38.2–55.4; paired t-test, p<0.001; Cohen's d=1.42). This comparison is graphically summarized in Figure 4.

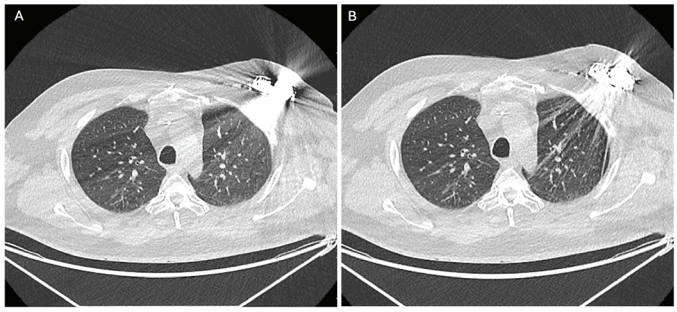

Figure 3. In the lung parenchymal window, ASIR+SMAR reduces near-field artifacts but reveals distance-dependent far-field streaks
ASIR: Adaptive statistical iterative reconstruction, SMAR: Smart metal artifact reduction

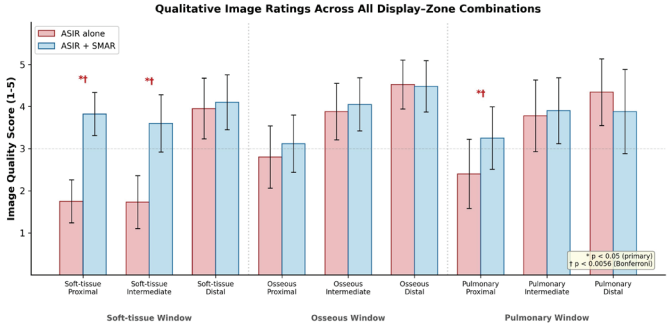

Figure 4. Aggregate qualitative scores: Reader-averaged ratings across 30 subjects demonstrating improvement with ASIR+SMAR on soft-tissue, osseous, and pulmonary displays at three distance intervals
ASIR: Adaptive statistical iterative reconstruction, SMAR: Smart metal artifact reduction

Measurement Reproducibility

Inter-observer agreement for HU-SD quantification (Reader C vs. Reader D, 10-patient subset) was excellent (ICC=0.94; 95% CI: 0.82-0.98). Intra-observer consistency (Reader C, 3-week washout, same subset) was equally high (ICC=0.96; 95% CI: 0.88–0.99).

Qualitative Image Ratings (Co-primary Endpoint 2)

Aggregate qualitative scores were significantly superior under ASIR+SMAR compared with ASIR alone (3.84±0.48 vs. 2.92±0.47; paired t-test, p<0.001; Cohen's d=1.93). Comprehensive display–zone results are presented in Table 2.

The most marked score elevations occurred on the soft-tissue display at the proximal interval (1.75±0.51 vs. 3.82±0.51; paired t-test, p<0.001; Cohen's d=1.12) and intermediate interval (1.73±0.63 vs. 3.60±0.68; paired t-test, p<0.001; Cohen's d=0.98). Both withstood Bonferroni adjustment (threshold p<0.0056).

Osseous display ratings trended upward with ASIR+SMAR at the proximal (p=0.064, Cohen's d=0.38) and intermediate (p=0.18, Cohen's d=0.34) intervals without attaining statistical significance. Conversely, pulmonary display scores were somewhat lower under ASIR+SMAR in the distal zone (4.34±0.79 vs. 3.88±1.00; Wilcoxon signed-rank, p=0.016, Cohen's d=0.52), though this difference did not survive Bonferroni correction (threshold p<0.0056).

Table 2. Qualitative image ratings by display and zone: ASIR versus ASIR+SMAR (n=30, reader-averaged)

Display-zone	ASIR (mean ± SD)	ASIR+SMAR (mean ± SD)	p-value	Cohen's d	Weighted κ (95% CI)
Global quality	2.92±0.47	3.84±0.48	<0.001*	1.93	0.72 (0.55–0.89)
Soft-tissue–Prox (<3 cm)	1.75±0.51	3.82±0.51	<0.001*†	1.12	0.70 (0.52–0.88)
Soft-tissue–Inter (3–5 cm)	1.73±0.63	3.60±0.68	<0.001*†	0.98	0.68 (0.49–0.87)
Soft-tissue–Dist (>5 cm)	3.95±0.72	4.10±0.65	0.28	0.22	0.74 (0.57–0.91)
Osseous–Prox (<3 cm)	2.80±0.74	3.12±0.68	0.064	0.38	0.66 (0.46–0.86)
Osseous–Inter (3–5 cm)	3.88±0.67	4.05±0.63	0.18	0.34	0.71 (0.53–0.89)
Osseous–Dist (>5 cm)	4.52±0.58	4.48±0.61	0.72	0.07	0.75 (0.58–0.92)
Pulmonary–Prox (<3 cm)	2.40±0.82	3.25±0.74	<0.001*†	0.86	0.69 (0.50–0.88)
Pulmonary–Inter (3–5 cm)	3.78±0.85	3.90±0.78	0.42	0.15	0.72 (0.54–0.90)
Pulmonary–Dist (>5 cm)	4.34±0.79	3.88±1.00	0.016	0.52	0.68 (0.48–0.88)

ASIR: Adaptive statistical iterative reconstruction, SMAR: Smart metal artifact reduction, SD: Standard deviation, CI: Confidence interval

Sensitivity analyses using Wilcoxon signed-rank tests across all comparisons produced outcomes concordant with the parametric results, thereby affirming the robustness of the findings irrespective of the distributional assumptions.

Algorithm-generated Artifacts

Newly emerging algorithm-related artifacts were detected in 13 of 30 individuals (43.3%; 95% CI: 25.5–62.6%). Every instance was localized to the distal pulmonary zone (>5 cm from the generator). Among these 13 cases, 8 (26.7%) exhibited low-grade streaks that still permitted diagnostic assessment (tier 2), while 5 (16.7%) exhibited high-grade degradation that precluded reliable interpretation (tier 3). The remaining 17 subjects (56.7%) were free of algorithm-related artifacts.

Reader Concordance

Weighted kappa values for qualitative scoring ranged from 0.66 to 0.75 across all display-zone pairings (Table 2), indicating substantial agreement. For aggregate image quality, weighted κ was 0.72 (95% CI: 0.55–0.89) under ASIR and 0.68 (95% CI: 0.50–0.86) under ASIR+SMAR. Structured discussion was necessary for 24 of 270 display–zone evaluations (8.9%); 20 disagreements were resolved through deliberation, while the remaining 4 (1.5%) required averaging with integer rounding.

Discussion

Key Observations

In this retrospective paired reconstruction analysis of 30 CIED carriers, the addition of SMAR to ASIR produced a marked decline in quantitative artifact intensity within the proximal zone surrounding the pulse generator, corresponding to approximately half of the baseline artifact load and indicating a large effect size. Concurrently, reader-assigned qualitative scores rose substantially, with the greatest benefit manifested in soft-tissue displays in the proximal and intermediate zones. Counterbalancing these gains, algorithm-induced streaks were observed in the distal lung parenchyma of nearly half the cohort, reaching a severity that precluded interpretation in roughly one-sixth of cases.

Practical Clinical Relevance

The enhanced proximal-zone image quality indices suggest that SMAR may improve conspicuity of peri-device tissues and adjacent vasculature, a consideration germane to the detection of complications such as device-pocket infection, hematoma formation, or thrombotic events. We stress, however, that our study quantified image quality surrogates—noise-based metrics and ordinal reader scores—rather than diagnostic accuracy parameters such as sensitivity, specificity, or downstream clinical action. Establishing whether these image quality gains yield tangible diagnostic or therapeutic benefit necessitates purpose-designed accuracy trials.

The frequency of algorithm-generated distal-zone streaks in the lung fields carries direct workflow implications, including a tangible risk of false-positive interpretations: focal artifactual densities may be mistaken for pulmonary nodules (raising spurious concern for malignancy, septic emboli, or metastatic disease); band-like streaks may simulate ground-glass opacity or consolidation; and reticular patterns may mimic early interstitial disease—each capable of triggering unnecessary follow-up imaging or invasive workup, particularly in a CIED population already burdened with cardiopulmonary comorbidities. Our data, therefore, support a dual-reconstruction review strategy whereby ASIR+SMAR datasets serve for proximal- and intermediate-zone evaluation, while unmodified ASIR images are concurrently consulted for peripheral pulmonary assessment. Any candidate parenchymal lesion seen only on the SMAR-processed series and absent on the corresponding ASIR-only reconstruction should be regarded as algorithm-induced until proven otherwise.

Technical Context

The magnitude of metallic artifacts is governed by alloy composition, physical dimensions, and hardware

geometry. Within the CIED spectrum, ICDs generally elicit more pronounced degradation than pacemakers, owing to their bulkier pulse generators and high-voltage defibrillation coils. ICDs constituted two-fifths of our cohort, potentially amplifying the observed improvements. Although formal subgroup comparison by device type was precluded by sample-size constraints, a descriptive review indicated higher baseline artifact burdens in ICD recipients than in pacemaker carriers—an observation consistent with the expected relationship between device bulk and artifact severity.

SMAR belongs to the family of projection-completion algorithms that identify and replace artifact-corrupted sinogram entries through interpolation from intact projections[16,17]. Comparable solutions from competing vendors—Siemens iMAR, Philips O-MAR, Canon SEMAR—employ distinct algorithmic approaches. Cross-platform benchmarking under standardized conditions remains an unmet need, as both the efficacy and the secondary-artifact profile of each solution may differ materially[8,18].

Contextualization with Prior Evidence

The existing literature addressing metallic artifacts arising specifically from CIEDs in thoracic CT is limited. Pennig et al.[6] investigated artifact mitigation in 34 CIED recipients using spectral-detector CT with virtual monoenergetic images and MAR post-processing, reporting effective artifact suppression around both the generator housing and endovascular leads. Their evaluation, however, centered on pectoral soft-tissue and peri-lead cardiac structures and did not extend to pulmonary parenchymal displays or to characterization of algorithm-related artifacts as a function of distance.

The present work advances this evidence base by providing display-stratified and distance-stratified assessments across soft-tissue, osseous, and pulmonary windows, delivering a more granular portrait of the spatial distribution of both artifact reduction and algorithm-induced artifact formation. The observation that SMAR confers its greatest benefit in the proximal field, while distal pulmonary artifacts remain a recurring concern, complements the findings of Pennig et al.[6] and furnishes actionable guidance for clinical radiologists.

Algorithm-Induced Artifacts: Mechanism and Precedent

Although MAR processing enhances image fidelity near metallic hardware, it may simultaneously engender secondary degradation in remote tissue, a phenomenon amply documented in the literature. Huang et al.[9] tested three MAR implementations and reported that both O-MAR and gemstone-spectral-imaging-based MAR generated new artifacts on thoracic CT. In the orthopedic domain, Shim et al.[19] demonstrated that O-MAR in shoulder arthroplasty patients can impair trabecular and cortical bone visualization, producing appearances resembling cementation or notching. These previous reports are consistent with our observation of distal lung streaks in a substantial proportion of cases.

Such artifacts are generally ascribed to overcorrection within the sinogram interpolation step, yielding dark-star patterns on axial images that correspond to zones of residual photon starvation[15,19]. Notably, not every published series has encountered newly generated artifacts; this discrepancy is likely attributable to inter-vendor algorithmic variation, differing patient populations, and the particular tissue types under scrutiny.

Study Limitations

First, the retrospective single-institution design and modest cohort size limit the strength and generalizability of the findings. In particular, the sample size may have reduced sensitivity to detect modest differences in secondary endpoints; therefore, non-significant findings in osseous-display comparisons should be interpreted with caution.

Second, deliberate exclusion of individuals with substantial pulmonary parenchymal disease—while methodologically motivated—constrains the applicability to the very population that stands to gain most from

optimized thoracic CT. Whether algorithm-generated distal-zone artifacts would obscure genuine pathology (nodules, infiltrates, interstitial abnormalities) remains unresolved and merits dedicated investigation.

Third, only one vendor's algorithm was tested under a single acquisition protocol, limiting generalizability to other MAR implementations. Fourth, systematic analysis was confined to generator-related artifacts; lead-associated degradation was not independently quantified. Fifth, the study evaluated image quality surrogates rather than diagnostic accuracy endpoints, leaving the translational impact on clinical decision-making undetermined. Any bias stemming from the exclusion of parenchymal disease could inflate the apparent benefit of MAR, because artifact assessment is inherently more straightforward against a homogeneous pulmonary background.

Subsequent investigations should prioritize: (1) multi-site comparisons of competing vendors' MAR solutions under harmonized protocols; (2) assessment of MAR utility in patients harboring defined pulmonary pathologies to gauge effects on lesion conspicuity; (3) standardized evaluation of lead-related artifacts using strategies tailored to the elongated geometry of endovascular leads—including high-keV virtual monoenergetic reconstruction from dual-energy acquisitions, photon-counting detector CT, deep learning–based MAR algorithms trained on lead morphology, lead-aware segmentation thresholds within projection-completion frameworks, and acquisition-level optimization such as tin filtration with adaptive tube current modulation; and (4) exploration of synergistic protocols coupling MAR with dual-energy CT and photon-counting detectors, which have shown promise in attenuating beam-hardening effects from metallic hardware[20,21].

Conclusion

Pairing SMAR with ASIR delivers statistically robust and clinically meaningful gains in both quantitative and qualitative image quality indices within the proximal and intermediate zones adjacent to CIED generators on thoracic CT. Soft tissues within 5 cm of the device showed the greatest benefit. Conversely, algorithm-generated artifacts in the distal lung parenchyma arise in roughly 43% of cases, with approximately 17% severe enough to impede diagnostic assessment. A combined review paradigm—leveraging ASIR+SMAR for proximal and intermediate evaluation alongside native ASIR for peripheral pulmonary appraisal—represents a pragmatic clinical workflow. These conclusions apply to individuals without significant parenchymal lung disease; corroboration in heterogeneous clinical populations and linkage to diagnostic accuracy endpoints remain essential next steps.

Ethics

Ethics Committee Approval: This retrospective analysis received institutional ethics committee approval İstanbul Yeni Yüzyıl University Clinical Research Ethics Committee (decision no: 2021/04-653, date: 06/04/2021) and conformed to the Declaration of Helsinki. The consent requirement was waived in view of the retrospective design and reliance on de-identified data.

Informed Consent: This single-institution retrospective study followed the Declaration of Helsinki and STROBE guidelines.

Data Availability

The underlying datasets may be obtained from the corresponding author upon reasonable request.

Footnotes

Authorship Contributions

Surgical and Medical Practices: Genç Ö, Concept: Genç Ö, Baş S, Tabakçı N, Design: Genç Ö, Baş S, Data Collection and/or Processing: Genç Ö, Tabakçı N, Analysis and/or Interpretation: Genç Ö, Baş S, Tabakçı N, Literature Search: Genç Ö, Writing: Genç Ö, Baş S, Tabakçı N.

Conflict of Interest: The authors declare no conflicts of interest concerning the authorship or publication of this article.

Financial Disclosure: This research received no specific grants from any funding agency in the commercial or not-for-profit sectors.

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J Updates Cardiovasc Med 2026;14(3):79-86 **DOI:** 10.32596/jucvm.galenos.2025.2026-10-191

Hypertension and Heart: Are We Aware? Hypertension Awareness and Cardiovascular Risk Profile in Health Care Professionals

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Abstract

Objectives: Coronary artery disease (CAD) is a leading cause of mortality and morbidity worldwide, and hypertension (HT) is a chronic condition characterized by high blood pressure. Early diagnosis and treatment are the most important goals in CAD and HT. The SCORE2 estimates 10-year risk of fatal and non-fatal cardiovascular events. Although the number of patients receiving treatment for HT and CAD has increased in recent years, awareness of these diseases has not yet reached satisfactory levels. We aimed to assess awareness of HT and CAD among healthcare professionals.

Materials and Methods: The study covered topics related to HT awareness, cardiovascular disease (CVD) prevention, diet, nutritional habits, and lifestyle. Blood pressure was measured with a standard, calibrated sphygmomanometer after participants rested for at least 5 minutes and was repeated 10 minutes after the survey. Cardiovascular risk scores were calculated using SCORE2.

Results: Among the 169 healthcare professionals included in the study, 40.2% (68) were male, and 59.8% (101) were female. The median age was 40 years. 13.6% of healthcare professionals had a diagnosis of HT. The rate of newly diagnosed HT was found to be 4.1%. The median SCORE2 was 2.4 in the night-shift group and 1.7 in the non-night-shift group (p=0.024).

Conclusion: Regular blood pressure measurement among healthcare professionals was insufficient. While shift work does not increase CVD risk, this finding is thought to be due to the younger age of healthcare professionals who perform it.

Keywords: Hypertension, healthcare professionals, cardiovascular risk, awareness, lifestyle

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Received: 01.07.2026 **Accepted:** 17.08.2026 **Publication Date:** 25.09.2026

Cite this article as: Kış M, Oktay Ç, Şentürk B, Yılmaz MB. Hypertension and heart: are we aware? Hypertension awareness and cardiovascular risk profile in health care professionals. J Updates Cardiovasc Med. 2026;14(3):79-86

DOI: 10.32596/jucvm.galenos.2025.2026-10-191

Introduction

Hypertension (HT) is considered one of the most common and preventable risk factors for cardiovascular diseases (CVD) and related mortality[1,2]. According to World Health Organization 2024 data, approximately 36.9% of individuals living in Europe are diagnosed with HT[3]. Epidemiological studies conducted in Türkiye have determined the prevalence of HT to be 31.8%, with only 40.7% of individuals reported to be aware of the disease and 31.1% receiving treatment[4,5]. In a study conducted on healthcare workers in Türkiye, the prevalence of HT was reported as 14.8%[6].

CAD is a leading cause of mortality and morbidity in Türkiye and worldwide. Early diagnosis, treatment, and cardiac rehabilitation are the most important goals in CAD[7]. To estimate the 10-year fatal and non-fatal CV risk, SCORE2 is recommended for patients aged 40–69 years, and SCORE2-OP for those aged ≥70 years[8-10]. The SCORE2 risk calculation is based on age, gender, systolic blood pressure (BP), total cholesterol, high-density lipoprotein (HDL) cholesterol, smoking status, and regional cardiovascular mortality data[9,10]. The guidelines recommend calculating SCORE2/SCORE2-OP for the management of HT in patients with high BP, and antihypertensive treatment is recommended for patients with a SCORE2 ≥10%[2,8]. According to Global Burden data, risk areas are divided into four categories: low, moderate, high, and very high risk. Türkiye is included in the high-risk area in this classification[11].

Despite their medical background, healthcare professionals frequently face high occupational stress, irregular working hours, and lifestyle constraints, which can paradoxically increase their vulnerability to chronic conditions and lead to lower adherence to personal preventive health behaviors. Healthcare workers serve a pivotal role not only in managing public health but also in acting as role models for their patients; therefore, assessing their personal awareness and control regarding major cardiovascular risk factors and HT n is of paramount clinical importance[12,13].

Although the proportion of patients receiving treatment for HT and CAD has increased in recent years, awareness of these diseases has not yet reached the desired level. Our study aimed to assess healthcare professionals' awareness of HT and CAD and to determine the prevalence of HT and of CV risk profiles.

Materials and Methods

This study is a descriptive and analytical cross-sectional study involving healthcare professionals working at Dokuz Eylül University Hospital. Prior to the study, the necessary ethical approval was obtained from the Dokuz Eylül University Ethics Committee (decision no: 2025/08-13). The study was conducted among healthcare professionals between 06/03/2025 and 30/06/2025. Written informed consent was obtained from all participants in accordance with ethical standards. The 17-question survey was designed to assess HT awareness, CV protection, dietary and nutritional habits, lifestyle behaviors, and knowledge of coronary artery disease.

Blood Pressure Evaluation Protocol

Systemic BP evaluations were carried out in strict accordance with the contemporary recommendations of the European Society of Cardiology and the European Society of Hypertension. Data collection took place within a quiet, climate-regulated setting. Following completion of the questionnaire and after a minimum five-minute stabilization period, participants were maintained in a relaxed seated posture with adequate lumbar support and uncrossed lower extremities. Prior to evaluation, individuals refrained from physical exertion, caffeine ingestion, and tobacco use for at least half an hour, with urinary bladder evacuation ensured when clinically indicated[8].

The examined upper extremity was carefully supported at heart level to prevent pressure increases induced by isometric contraction, and clothing over the cuff application site was removed to avoid a tourniquet effect from rolled-up sleeves. Measurements were performed using a standard, calibrated automated oscillometric device

(Omron M2 Basic HEM-7121J-E) with appropriately sized cuffs. The inferior border of the cuff was secured a few centimeters proximal to the antecubital crease to avoid placing the stethoscope beneath the cuff.

During the measurements, at least two measurements were taken with at least two minutes between each reading, and the average of the obtained values was recorded for analysis[8].

In the study, HT was diagnosed based on the 2024 ESC Guidelines for the Management of High Blood Pressure and Hypertension, using the criterion of systolic BP ≥140 mmHg and/or diastolic BP ≥90 mmHg, confirmed by the average of consecutive measurements taken at least two minutes apart. Furthermore, the SCORE2 score was calculated for CV risk classification in individuals over 40 years of age using data on gender, age, smoking status, systolic BP, total cholesterol, HDL cholesterol, and regional CV mortality[8-10].

Statistical Analysis

The obtained data were analyzed using SPSS 29.0. Descriptive data were reported as numbers and percentages (%) for categorical variables and as mean ± standard deviation or median (interquartile range: 25th–75th percentile) for continuous variables. The distribution of continuous variables was assessed using the Kolmogorov-Smirnov and/or Shapiro-Wilk tests; comparisons were made of normally distributed data using Student's t-test. Correlations between categorical variables were analyzed using the Pearson chi-square test. Fisher's exact test was used when the necessary assumptions were not met. In all statistical analyses, a two-sided $p<0.05$ was considered the significance threshold.

Results

A total of 169 healthcare professionals were included in our study, and analysis of the demographic characteristics revealed that 40.2% (n=68) were male and 59.8% (n=101) were female. The median age was 40 years, and the median body mass index was 26.5 kg/m^2. Detailed data on the participants' demographic characteristics are provided in Table 1.

13.6% (n=23) of the healthcare professionals were previously diagnosed with HT. Based on standard BP measurements taken before and 10 minutes after the survey, 4.1% (n=7) of participants were newly diagnosed with HT. The rate of participants diagnosed with diabetes mellitus was 1.8% (n=3). The majority of the participants were nurses (27.8%, n=47. Among other occupational groups, 26% (n=44) worked as cleaning personnel, 17.2% (n=29) as physicians, and 18.9% (n=32) as medical secretaries; additionally, 66.3% (n=112) of healthcare workers actively worked shifts (Table 1).

The majority of participants (48.5%) preferred a Mediterranean diet, which emphasizes vegetables. One of the striking findings of the study was that 92.3% (n=156) of participants reported believing their home BP was within the normal range; however, only 24.3% (n=41) reported regularly monitoring their BP. The proportion of participants with daily salt consumption above 5–6 grams was 39.6% (n=67). The responses to the 17 survey questions directed at healthcare professionals are presented in Tables 2 and 3.

A history of CAD was present in the first-degree relatives of 33.7% of participants (n=57). The prevalence of smoking and alcohol consumption among healthcare workers were 37.3% and 40.8%, respectively. When the participants' lipid profiles were examined, the median low-density lipoprotein (LDL) cholesterol level was 124 mg/dL. Additionally, the SCORE2 risk assessment was used to determine the 10-year CVD risk in individuals aged 40 and older. In the analysis of data from 79 participants in this age group, the median SCORE2 was 1.9. The findings are detailed in Table 3. This group comprised shift workers (n=49) and non-shift workers (n=30) (Table 4). The median age of the shift group was 37, while that of the non-shift group was 44; this difference was statistically significant (p=0.0159). No statistically significant differences were found between the two groups for the other parameters.

Table 1. Demographic characteristics

Age	40 [30-46]*	
Height cm	169 [162-174]*	
Weight kg	78 [65-85]*	
BMI kg/m^2	26.5 [23.6-30.05]*	
Clinical characteristics		N (%)
Gender	Male Female	68 (40.2) 101 (59.8)
Marital status of participants	Single Married	65 (38.5) 104 (61.5)
Occupational distribution of participants	Environmental services staff Nurse Doctor Medical secretaries Medical technicians Academicians Student	44 (26) 47 (27.8) 29 (17.2) 32 (18.9) 12 (7.1) 2 (1.2) 3 (1.8)
Presence of a previous diagnosis of hypertension	Previously diagnosed with hypertension No prior hypertension diagnosis	23 (13.6) 146 (86.4)
Frequency of newly identified hypertension cases		7 (4.1)
Presence of diabetes mellitus DM	Previously diagnosed with diabetes mellitus DM No prior diagnosis of diabetes mellitus DM	3 (1.8) 166 (98.2)
Presence of hyperlipidemia	Previously diagnosed with hyperlipidemia No prior diagnosis of hyperlipidemia	3 (1.8) 166 (98.2)
Institution of employment	Inpatient clinic Angiography Intensive care and emergency department Outpatient clinic Operating room Other	 71 (42) 30 (7.8) 50 (29.6) 17 (10.1) 1 (0.6)
Educational status	Primary school Middle school High school University degree	5 (3) 4 (2.4) 3 (21.9) 123 (72.8)
Night shift status	I don't work night shifts I work night shifts	57 (33.7) 112 (66.3)

**medians [interquartile range, IQR (Q1-Q3) (25-75)], BMI: Body mass index, DM: Diabetes mellitus*

The median SCORE2 value was 2.4 in the non-shift group and 1.7 in the shift group; the difference was statistically significant (p=0.024) (Table 4).

Discussion

The study covered topics related to CV risk, HT awareness, CVD prevention, nutritional habits, and lifestyle. The rate of regular BP measurements among healthcare professionals is low. New cases of HT were identified in 4% of healthcare workers, even though they worked in a hospital environment. One of the striking findings of the study was that 92.3% (n=156) of participants stated that they believed their home BP was within the normal range; however, only 24.3% (n=41) reported regularly monitoring their BP.

According to the ESC 2021 CVD Prevention Guidelines, following a Mediterranean-type or equivalent diet, replacing saturated fats with unsaturated fats, and reducing salt intake are strongly recommended for the prevention of CVD, with a Class I recommendation[14]. The majority of healthcare workers (48.5%) adhere to a diet primarily focused on vegetables, similar to a

Table 2. Answers given to the questionnaire items

	Answer	N (%)
Have you been diagnosed with hypertension?	Previously diagnosed with hypertension No prior hypertension diagnosis	23 (13.6) 146 (86.4)
Do you think your blood pressure measurements at home are within the normal range?	Yes No	156 (92.3) 13 (7.7)
Is your daily salt intake more than 5–6 grams?	Yes No	67 (39.6) 102 (60.4)
Do you measure your blood pressure at regular intervals?	Yes No	41 (24.3) 128 (75.7)
Do you know the values that define normal blood pressure?	Yes No	130 (76.9) 39 (23)
Do you think hypertension can lead to heart attack and heart failure?	Yes No	158 (92.7) 11 (6.3)
In your opinion, what is the frequency of hypertension in the population?	Between 10–20% Between 20–40% Between 40–60% 60% and above	28 (16.6) 72 (42.6) 51 (30.2) 18 (10.7)
Is there a history of hypertension among your first-degree relatives?	Yes No	110 (65.1) 59 (34.9)
In your opinion, is taking medication alone enough to control blood pressure in individuals with hypertension?	Yes No	23 (13.6) 146 (86.4)
How would you describe your current diet?	Vegetable-based mediterranean diet carbohydrate-dominant diet rich in pastries meat-based, protein-rich diet	82 (48.5) 31 (18.3) 56 (33.1)
How significant do you think the Mediterranean diet is in managing blood pressure?	Important Not important I don't know	126 (74.6) 4 (2.4) 39 (23.1)
How significant do you think regular physical activity is in managing blood pressure?	Important Not important I don't know	154 (91.1) 2 (1.2) 13 (7.7)
What is the appropriate time for hypertensive patients to take their medications?	Regularly every day Only when blood pressure exceeds 140/90 mmHg	162 (95.9) 7 (4.1)
In your opinion, under what circumstances should blood pressure be measured?	I don't know Dizziness Routine check without symptoms Palpitations Feeling unwell Blackout/vision dimming All of the above	11 (6.5) 4 (2.4) 9 (5.3) 1 (0.6) 5 (3) 1 (0.6) 138 (81.7)
Do you have a blood pressure monitor at home?	Yes No	90 (53.3) 79 (46.7)

Mediterranean-type diet. While the alcohol consumption rate in Türkiye as of 2023 was reported to be 10.2%[15], our study determined that the alcohol consumption rate among healthcare workers was quite high, reaching 40.82%. Especially among individuals under 50 years, the risk of CVD is approximately five times higher in smokers compared to non-smokers[16,17]. While the smoking rate in Türkiye was reported to be 34.8% in 2023[15], our study found that this rate was slightly higher among healthcare workers, reaching 37.3%.

Results from randomized controlled trials show that lowering LDL levels safely reduces the risk of CVD even at low levels[18,19]. Current literature clearly demonstrates that low HDL levels (<30–35 mg/dL) increase the risk of

atherosclerotic CVD; it has also been shown that very high HDL levels (>90 mg/dL) may be paradoxically associated with an increased risk[20,21]. In a study conducted among nurses working in a hospital, the median LDL level was reported as 114.02 mg/dL, the HDL level as 55.86 mg/dL, and the total cholesterol level as 189.63 mg/dL[22]. Similarly, in our study, when evaluating the lipid profiles of healthcare workers, the median LDL was 124 mg/dL, HDL was 54.7 mg/dL, and total cholesterol was 207 mg/dL.

Table 3. **Cardiovascular risk assessment**

	Answer	**N (%)**
Do you use tobacco products?	Yes No	63 (37.3) 100 (59.2)
Do you consume alcohol?	Yes No	69 (40.8) 100 (59.2)
Do any of your family members (mother, father, siblings) have coronary artery disease?	Yes No	57 (33.7) 112 (66.3)
Basic lipid profile		
LDL (mg/dL)	124 [104.3-146.6]*	
HDL (mg/dL)	54.7 [48.0-64.1]*	
Total cholesterol (mg/dL)	207 [175.5-238.5]*	
**medians [interquartile range, IQR (Q1-Q3) (25-75)], HDL: High-density lipoprotein, LDL: Low-density lipoprotein*		

Table 4. **Comparison based on night shift work status**

	Participants not working night shifts (n=57)	**Participants working night shifts (n=112)**	**p-value**
Age	44 [35-47]*	37 [29-45]*	**0.015**
Initial pulse measurement	80 [71.5-83.5]*	76 [71-84.75]*	0.351
Second pulse measurement	79 [72-85]*	77.5 [70.25-77.5]*	0.331
Initial systolic blood pressure measurement	119 [105-127.5]*	115.5 [106-115.5]*	0.443
Initial diastolic blood pressure measurement	77 [72-82]*	76 [69-83]*	0.448
Second systolic blood pressure measurement	116 [106-130]*	111 [105-125.5]*	0.269
Second diastolic blood pressure measurement	77 [70-85]*	75.5 [69-81]*	0.649
Height (cm)	170 [160.5-174.5)]*	168.5 [163-174]*	0.592
Weight (kg)	25.7 [64.5- 83.5]	78 [65.5-87.75]*	0.419
BMI (kg/m^2)	30.89 [46.6-66.32]	26.75 [23.32-30.47]*	0.621
LDL (mg/dL)	128.15 [108.2-148.4]	121.6 [100.4-144.4]*	0.315
HDL (mg/dL)	56.650[46.6-66.3]	54 [48.6-63.1]*	0.927
Total cholesterol (mg/dL)	207.5 [177.2- 241]	205.0 [173.5-205]*	0.524
SCORE2	2.4 [1.40-4.67]* (n=30)	1.7 [1.0-3.15]* (n=49)	**0.024**
	n (%)	n (%)	
Existence of hypertension	10 (17.5)	13 (11.6)	0.287
Frequency of newly diagnosed hypertension	3 (5.3)	4 (3.69)	0.689
**medians [interquartile range, IQR (Q1-Q3) (25-75)], BMI: Body mass index, HDL: High-density lipoprotein, LDL: Low-density lipoprotein*			

According to the SCORE2 risk score, if the 10-year fatal and non-fatal CV disease risk is below 2.5%, it is defined as low to moderate CV risk, if it is between 2.5% and <7.5%, it is defined as high CV risk, and if it is ≥7.5%, it is defined as very high CV risk[8-10]. In our study, SCORE2 was calculated for CV risk assessment in 79 participants over the age of 40. The median SCORE2 value was 1.9, indicating that the participants were generally in the low-to-moderate risk group. In strict accordance with the current European Society of Cardiology (ESC) guidelines, SCORE2 and SCORE2-OP calculations were restricted to participants aged 40 years and older, as these risk-estimation models are specifically calibrated and validated for individuals aged 40–69 years and ≥70 years, respectively. Applying this algorithm to younger cohorts is not clinically recommended since 10-year short-term risk calculations are not designed for individuals under 40, in whom lifetime cardiovascular risk remains the primary consideration[8-10]. The observed low SCORE2 values in our cohort primarily reflect the age distribution and demographic profile of the participating healthcare professionals. Although short-term calculated risks appear low, contemporary guidelines emphasize that early identification and management of modifiable risk factors, such as BP control and lifestyle modifications, remain essential to mitigate cumulative lifetime cardiovascular burden in professional populations. In this study, the median age of the shift group is younger than that of the non-shift group. The median SCORE2 value was 2.4 in the non-shift group and 1.7 in the shift group, and the difference was statistically significant (p=0.024). These findings indicate that shift work in hospitals does not have a significant effect on the CV risk profile; however, this may be related to the younger age of individuals working shifts.

Study Limitations

Limitations of this study include its single-center design, relatively small total sample size (n=169), and the limited number of participants over the age of 40 included in the SCORE2 risk calculations (n=79). Due to these methodological constraints and the single-center setting, the findings cannot be fully generalized to all healthcare professionals across different institutions or broader healthcare systems; therefore, the results should be interpreted within this specific context. Additionally, several parameters, including daily salt consumption, dietary habits, and perceptions of home BP measurements, were obtained via questionnaires, which inherently limits the ability to rely solely on self-reported information. Despite these limitations, this study provides preliminary and clinically relevant data on HT awareness and cardiovascular risk profiles among healthcare professionals.

Conclusion

The rate of regular BP measurement among healthcare workers is low. The rate of newly diagnosed HT was 4.1%. In this cohort, shift work was not associated with a higher SCORE2-estimated cardiovascular risk; however, this finding should be interpreted cautiously because shift workers were significantly younger than non-shift workers. Healthcare workers have higher rates of smoking and alcohol use than the general population.

Ethics

Ethics Committee Approval: Prior to the study, the necessary ethical approval was obtained from the Dokuz Eylül University Ethics Committee (decision no: 2025/08-13).

Informed Consent: This study is a descriptive and analytical cross-sectional study involving healthcare professionals working at Dokuz Eylül University Hospital

Acknowledgement

We would like to thank Dokuz Eylül University Faculty of Medicine for supporting this study within the scope of the Special Study Modules (SSM). We also extend our gratitude to the medical students who contributed to this study: Dilara Yasıt, Elif Koç, Gülsenur Kutlu, Hayrunnisa Sakallı, İpek Kara, Meral Kuşçu, and Yaren Elif Bayram.

Footnotes

Authorship Contributions

Surgical and Medical Practices: Yılmaz MB, Concept: Kış M, Yılmaz MB, Design: Kış M, Yılmaz MB, Data Collection and/or Processing: Oktay Ç, Analysis and/ or Interpretation: Şentürk B, Literature Search: Kış M, Oktay Ç, Writing: Kış M.

Conflict of Interest: The authors declare no conflicts of interest concerning the authorship or publication of this article.

Financial Disclosure: This research received no specific grants from any funding agency in the commercial or not-for-profit sectors.

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JUCVM Journal of Updates in Cardiovascular Medicine

Research Article

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J Updates Cardiovasc Med 2026;14(3):87-95 **DOI:** 10.32596/jucvm.galenos.2025.2026-11-192

Acute Rheumatic Fever: A Five-year Tertiary Center Experience and Post-pandemic Trends

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Abstract

Objectives: Acute rheumatic fever (ARF) remains a significant cause of acquired heart disease among children in developing countries. This study aimed to evaluate the clinical, laboratory, and echocardiographic characteristics; treatment approaches; and outcomes of ARF patients followed in a tertiary pediatric cardiology center and to explore differences between pandemic and post-pandemic periods.

Materials and Methods: In this retrospective study, 122 patients diagnosed with ARF between May 2020 and August 2025 were analyzed. Using June 2022—when pandemic restrictions were eased—as a reference point, patients were divided into two groups: pandemic (n=41) and post-pandemic (n=81). Demographic characteristics, clinical findings, laboratory results, echocardiographic findings, treatments, and follow-up data were compared.

Results: The mean age was 12.8±2.4 years, and 62.3% of patients were male. The monthly number of cases increased from 1.58 to 2.13 in the post-pandemic period (p=0.048). Carditis was detected in 95% of patients, consistent with the tertiary referral profile of our study population. Although the rate of carditis was numerically higher in the post-pandemic period, the difference was not statistically significant (92% vs. 96%, p=0.403). Delayed presentation and elevated C-reactive protein levels were associated with carditis.

Conclusion: An apparent increase in ARF cases was observed in the post-pandemic period; however, this likely reflects referral dynamics rather than a true epidemiological shift. Delayed presentation and increased inflammatory burden were associated with more severe cardiac involvement.

Keywords: Acute rheumatic fever, rheumatic heart disease, coronavirus disease-2019

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Received: 10.07.2026 **Accepted:** 17.08.2026 **Publication Date:** 25.09.2026

Cite this article as: Genç HZ, Güzelbağ AN, Çevlik B, Çoban Ş, Öztürk E. Acute rheumatic fever: a five-year tertiary center experience and post-pandemic trends. J Updates Cardiovasc Med. 2026;14(3):87-95

DOI: 10.32596/jucvm.galenos.2025.2026-11-192

Introduction

Acute rheumatic fever (ARF) is a multisystem inflammatory disease that develops after group A beta-hemolytic streptococcal (GABHS) pharyngitis and particularly affects children and adolescents[1]. Although its incidence has markedly decreased in developed countries, it remains the leading cause of acquired heart disease in developing countries and populations with low socioeconomic status[2]. The disease may progress to rheumatic heart disease (RHD) by causing permanent valvular damage, leading to significant morbidity and mortality. The diagnosis of ARF is based on the Jones criteria, which combine clinical and laboratory findings; these criteria were updated in 2015 to include echocardiographic findings[3].

The coronavirus disease-2019 (COVID-19) pandemic imposed unprecedented pressure on health systems worldwide, leading to disruptions in access to healthcare and difficulties in the follow-up of chronic diseases. Restrictions during the pandemic, quarantines, and public hesitancy to seek hospital care led to delays in the diagnosis of many childhood diseases[4,5]. In diseases such as ARF, where timely diagnosis and treatment directly affect prognosis, the consequences of delays are critical. The literature reports conflicting data regarding the course of GABHS infections and the trends in ARF case numbers during the pandemic[6,7].

This study aimed to describe the clinical, echocardiographic, and outcome characteristics of ARF patients followed at a tertiary pediatric cardiology center over five years and investigate differences in case volume, clinical presentation, and disease severity between the pandemic and post-pandemic periods.

Materials and Methods

This retrospective observational study reviewed data from newly diagnosed and subsequently followed patients in the pediatric cardiology clinic of a tertiary hospital between May 2020 and August 2025. Approval for the study was obtained from the University of Health Sciences Türkiye, Başakşehir Çam and Sakura City Hospital, Clinical Research Ethics Committee on October 22, 2025 (decision number 332).

The study periods were classified as the pandemic period (May 2020–June 2022, 26 months) and the post-pandemic period (July 2022–August 2025, 38 months), with June 2022 serving as the transition point, corresponding to the nationwide easing of major COVID-19 public health restrictions in Türkiye, including the lifting of mask mandates and travel restrictions, and the resumption of routine social, educational, and pediatric outpatient activities. Each calendar month was treated as an independent observational unit. This classification was also consistent with the approach used in similar studies[4].

Patients aged ≤18 years who were consecutively diagnosed with a first episode of ARF according to the 2015 Revised Jones Criteria during the study period were eligible for inclusion. No patients younger than 6 years of age were identified during the study period. Eligible patients were identified through the hospital electronic medical record system and the pediatric cardiology database. Only newly diagnosed cases were included to ensure a homogeneous study population and to avoid potential confounding related to previous disease episodes or long-term treatment. Patients with recurrent ARF attacks, established RHD, or incomplete clinical, laboratory, or echocardiographic data were excluded from the study.

Standard transthoracic echocardiography was performed using commercially available ultrasound systems according to current pediatric echocardiography recommendations. Two-dimensional imaging with color Doppler, pulsed-wave Doppler, and continuous-wave Doppler was routinely performed. Standard parasternal long-axis, parasternal short-axis, apical four-, five-, and two-chamber views, as well as subcostal views, were systematically acquired, and color Doppler interrogation was performed in all standard views to optimize the detection of valvular regurgitation. Carditis was defined as the presence of pancarditis, pericarditis, pathologic

valvular regurgitation, or unexplained myocardial dysfunction according to the 2015 Revised Jones Criteria. Pathologic mitral regurgitation was diagnosed only when all four Doppler criteria were fulfilled: (1) visualization in at least two echocardiographic views, (2) a jet length ≥2 cm in at least one view, (3) a peak regurgitant velocity >3 m/s, and (4) a pansystolic jet on spectral Doppler. Pathologic aortic regurgitation required: (1) visualization in at least two views, (2) a jet length ≥1 cm in at least one view, (3) a peak regurgitant velocity >3 m/s, and (4) a pandiastolic jet on spectral Doppler. Regurgitation not fulfilling all four criteria was considered physiologic and was excluded from the analysis. Valvular regurgitation severity was graded according to current guideline recommendations. Multivalvular involvement was defined as the simultaneous presence of pathological mitral and aortic regurgitations that fulfill the 2015 Revised Jones Criteria. All echocardiographic examinations were performed and interpreted by experienced pediatric cardiologists with expertise in congenital heart disease, using standardized institutional imaging protocols[3,8,9].

Demographic characteristics (age, sex), clinical findings [(joint pain/swelling, fever, fatigue, palpitations, presence of carditis), laboratory results (complete blood count, erythrocyte sedimentation rate (ESR), C-reactive protein (CRP), anti-streptolysin O (ASO) titer, leukocyte count], echocardiographic findings, treatment approaches, surgical requirements, and outcomes were retrospectively collected from the hospital information system and patient files. Patients were divided into three age groups: 6–10 years, 11–15 years, and 16–18 years. This categorization was based on the commonly reported epidemiological distribution for ARF, in which school-aged children and early adolescents constitute the group at highest incidence.

Blood samples were obtained at the time of initial hospital admission before initiation of anti-inflammatory therapy. Laboratory analyses were performed in the hospital's central clinical laboratory using standardized automated analyzers and following institutional quality-control procedures; results were interpreted using age-appropriate reference ranges. According to the 2015 Revised Jones Criteria, elevated acute-phase reactants were defined as an ESR ≥60 mm/h and/or a CRP level ≥ 3.0 mg/dL (30 mg/L). ASO titers were evaluated as supportive evidence of preceding group A streptococcal infection. Delayed presentation was defined as a hospital admission occurring more than 7 days after the first ARF-related symptom (most commonly joint symptoms or fever), based on the symptom onset documented in the medical records. Anti-inflammatory therapy followed current guideline recommendations: aspirin as first-line therapy; naproxen substituted in cases of aspirin intolerance; and prednisolone added for moderate-to-severe carditis, tapered based on clinical and echocardiographic response. Secondary prophylaxis with intramuscular benzathine penicillin G was initiated in all patients.

All patients were hospitalized during the acute phase. After discharge, follow-up visits were scheduled at 1, 3, and 6 months; patients with mild or no regurgitation were subsequently followed annually, while those with moderate-to-severe involvement were seen every 6 months. Clinical response was defined as resolution of fever and joint symptoms within 72 hours of treatment initiation. In patients with a documented prior episode, recurrent ARF was diagnosed according to the 2015 Revised Jones Criteria.

Statistical Analysis

Categorical variables are presented as n (%) and are compared using the chi-square test or Fisher's exact test, as appropriate. Continuous variables are presented as mean ± standard deviation; normality was assessed graphically, and comparisons were performed using the independent-samples t-test or Welch's t-test as appropriate. To identify factors associated with carditis, a multivariable binary logistic regression model was constructed using the Enter method. Candidate variables were selected based on clinical plausibility and univariate association with carditis at $p<0.10$; these included age, sex, delayed presentation (>7 days from symptom onset), CRP, ESR, ASO titer, and pandemic period. Results are reported as

odds ratios (ORs) with 95% confidence intervals (CIs). Model fit was assessed using the Hosmer–Lemeshow test, and multicollinearity was checked with variance inflation factors.

Statistical analyses were performed using IBM SPSS Statistics for Windows, version 26.0. T wo-sided p-values were considered statistically significant ($p<0.05$).

Results

A total of 122 newly diagnosed ARF cases were included in the study. Among the patients, 62.3% were male and 37.7% were female. The 11–15-year age group was the most common, accounting for 66.4%, and the mean age was 12.8±2.4 years. The demographic characteristics of the patients are summarized in Table 1.

During the pandemic, 41 patients were evaluated, corresponding to a mean of 1.58 cases per month. In the post-pandemic period, 81 patients were evaluated, corresponding to a monthly mean of 2.13 cases. This 34.8% increase in the monthly mean number of cases was statistically significant (independent-samples t-test, p=0.048). Case numbers were lowest in 2020 and 2021, began increasing, peaked at 32 cases in 2023, and remained high in 2024.

At presentation, the most common symptoms and findings were joint involvement (arthritis/arthralgia) (87.7%), fever (71.3%), and fatigue (59%). Carditis was detected in 95% (n=116) of patients. Although the rate of carditis appeared higher in the post-pandemic period than in the pandemic period, the difference was not statistically significant (92% vs. 96%, p=0.403). The distribution of clinical findings by period is given in Table 2.

Echocardiographic evaluation of patients with carditis showed that the most common finding was mitral regurgitation (90.2%), followed by aortic regurgitation (75.4%). Multivalvular involvement was present in 70.4% of patients. The degree of regurgitation was mainly mild to moderate. Although there was a slight increase in valve involvement rates in the post-pandemic period, this increase did not reach statistical significance. Echocardiographic findings and valve involvement are given in Table 3.

Table 1. Demographic characteristics of the patients

Characteristic	Total (n=122)	Pandemic (n=41)	Post-pandemic (n=81)	p-value
Sex				0.856
Male	76 (62.3%)	26 (63.4%)	50 (61.7%)	
Female	46 (37.7%)	15 (36.6%)	31 (38.3%)	
Age groups				0.880
6–10 years	25 (20.5%)	9 (22.0%)	16 (19.8%)	
11–15 years	81 (66.4%)	26 (63.4%)	55 (67.9%)	
16–18 years	16 (13.1%)	6 (14.6%)	10 (12.3%)	
Mean age (years)	12.8±2.4	12.7±2.3	12.9±2.5	0.674

Data are presented as n (%)
**Mean ± standard deviation, Student's t-test*

Table 2. Comparison of clinical findings by period

Symptom/finding	Total (n=122)	Pandemic (n=41)	Post-pandemic (n=81)	p-value
Joint pain/swelling	107 (87.7%)	35 (85.4%)	72 (88.9%)	0.591
Fever	87 (71.3%)	28 (68.3%)	59 (72.8%)	0.600
Fatigue	72 (59%)	23 (56.1%)	49 (60.5%)	0.644
Palpitations	50 (41%)	15 (36.6%)	35 (43.2%)	0.492
Presence of carditis	116 (95%)	38 (92%)	78 (96%)	0.403

A marked elevation of acute-phase reactants was detected in the great majority of patients. Elevated ASO, CRP, and ESR were found in 89.3%, 73.8%, and 85.2% of subjects, respectively. The mean ESR value in the post-pandemic period was significantly higher than in the pandemic period (92±33 mm/h vs. 83±30 mm/h, p=0.034). No significant differences were found in other laboratory parameters. Laboratory findings and their distribution by period are given in Table 4.

All patients were started on benzathine penicillin G for secondary prophylaxis. As anti-inflammatory therapies, aspirin (81.1%) and steroids (31.1%) were used most frequently. The mean hospital stay was 11.5±4.8 days. During a mean follow-up of 28±18 months, no deaths occurred. Surgical intervention was required in 4.9% (n=6) of patients.

In multivariable logistic regression analysis, delayed presentation (>7 days from symptom onset) (adjusted OR: 13.76, 95% CI: 1.20–157.67, p=0.035) and elevated CRP levels (per 10 mg/L increase; adjusted OR: 1.13, 95% CI: 1.00–1.28, p=0.044) remained independently associated with the presence of carditis after adjustment for age, sex, ESR, ASO titer, and pandemic period (Table 5). Model fit was adequate according to the Hosmer–Lemeshow test (p=0.839), and no significant multicollinearity was detected.

Six patients required surgical intervention for refractory heart failure despite optimal medical therapy. Echocardiographic evaluation demonstrated severe rheumatic valvular regurgitation in all patients. Three patients had isolated severe mitral regurgitation and underwent mitral valve replacement; one patient had

Table 3. Echocardiographic findings in the overall study cohort according to pandemic and post-pandemic periods

Valvular regurgitation	Total (n=122)	Pandemic (n=41)	Post-pandemic (n=81)	p-value
Mitral regurgitation	110 (90.2%)	36 (87.8%)	74 (91.3%)	0.535
– Minimal/trace	37 (30.3%)	12 (29.2%)	25 (30.8%)	
– Mild	52 (42.6%)	17 (41.4%)	35 (43.2%)	
– Moderate	19 (15.5%)	6 (14.6%)	13 (16%)	
– Severe	2 (1.6%)	1 (2.4%)	1 (1.2%)	
Aortic regurgitation	92 (75.4%)	29 (70.7%)	63 (77.7%)	0.393
– Minimal/trace	30 (24.5%)	10 (24.3%)	20 (24.6%)	
– Mild	43 (35.2%)	13 (31.7%)	30 (37%)	
– Moderate	18 (14.7%)	6 (14.6%)	12 (14.8%)	
– Severe	1 (0.8%)	0 (0)	1 (1.2%)	
Multivalvular involvement	86 (70.4%)	27 (65.8%)	59 (72.8%)	0.424

*Data are presented as n (%). Minimal/trace findings shown in the table reflect patients who additionally satisfied all four Jones Doppler criteria despite low-grade severity; trivial regurgitations not meeting these criteria were excluded. Multivalvular involvement was defined as the simultaneous presence of pathological mitral and aortic regurgitation fulfilling the 2015 Revised Jones Criteria. Percentages are calculated using the entire study cohort (n=122) as the denominator. *Comparisons were performed using chi-square or Fisher's exact tests*

Table 4. Comparison of laboratory findings

Parameter	Total mean ± SD	Pandemic	Post-pandemic	p-value
ASO (IU/mL)	1285±445	1208±425	1325±455	0.161
CRP (mg/L)	118±78	106±74	125±80	0.184
ESR (mm/h)	89±32	83±30	92±33	0.034
Leukocytes (/μL)	12,100±3,800	11,400±3,500	12,400±3,900	0.156

ASO: Anti-streptolysin O, CRP: C-reactive protein, ESR: Erythrocyte sedimentation rate, SD: Standard deviation
Data are presented as mean ± standard deviation
Continuous variables were compared using Student's t-test or Welch's t-test as appropriate

isolated severe aortic regurgitation requiring aortic valve replacement; and two patients had combined severe mitral and aortic regurgitation requiring combined mitral and aortic valve surgery. All surgically treated patients met echocardiographic criteria for severe rheumatic valvular disease and underwent multidisciplinary evaluation by pediatric cardiologists and cardiovascular surgeons before surgical intervention. Of the six patients requiring surgery, five were diagnosed during the post-pandemic period and one during the pandemic period.

No statistically significant differences were found between periods in terms of treatment and outcomes. A comparison of treatments is presented in Table 6.

Discussion

This study provides a comprehensive evaluation of a newly established tertiary pediatric cardiology center's five-year experience with ARF and of the effects of the COVID-19 pandemic on disease dynamics. The most striking finding of our study is the statistically significant increase in ARF cases following the easing of pandemic restrictions. The decline in ARF cases observed during the pandemic may be more plausibly explained by reduced transmission of group A streptococcal infections due to school closures, physical distancing, and decreased social contact than by changes in diagnostic or prescribing practices. However, the reopening of schools, the lifting of public health restrictions, increased social interaction, and renewed exposure among susceptible individuals may have contributed to a rise in GAS transmission and, consequently, in ARF presentations. Similarly, a Canadian study reported an increase in the number of ARF cases in the post-pandemic period[7]. The increase in ARF observed in our study is in line with observations reported in selected settings.

The demographic profile of our cohort is consistent with the classical epidemiological patterns of ARF, in which school-age children and early adolescents (predominantly aged 5–15 years) are most affected, and a modest male predominance is commonly observed[10]. These features are also consistent with previously published Turkish ARF series[11].

Table 5. Univariate and multivariable logistic regression analyses (Enter method) for factors associated with carditis

Variable	Carditis negative (n=6)	Carditis positive (n=116)	Crude OR (95% CI)	Adjusted OR (95% CI)	p-value
Delayed presentation (>7 days)	1 (16.7%)	82 (70.7%)	14.91 (0.80–277.16)	13.76 (1.20–157.67)	0.035
CRP (mg/L) (per 10 mg/L increase)	24±20	58±43	1.14 (1.01–1.30)	1.13 (1.00–1.28)	0.044
Age (years)	11.6±2.6	12.9±2.4	1.24 (0.91–1.69)	1.13 (0.81–1.58)	0.458
Sex (male)	4 (66.7%)	72 (62.1%)	1.01 (0.20–5.04)	0.86 (0.14–5.18)	0.865
ESR (mm/h) (per 10 mm/h)	99±29	89±31	0.79 (0.61–1.01)	0.82 (0.63–1.06)	0.131
ASO titer (IU/mL) (per 100 IU/mL)	890±430	820±480	0.96 (0.80–1.14)	0.95 (0.79–1.14)	0.555
Post-pandemic period	3 (50.0%)	78 (67.2%)	2.04 (0.43–9.56)	2.53 (0.48–13.19)	0.271

Model fit was adequate (Hosmer–Lemeshow p=0.839), with no significant multicollinearity.
OR: Odds ratio, CI: Confidence interval, CRP: C-reactive protein, ESR: Erythrocyte sedimentation rate (mm/h); ASO: Anti-streptolysin O (IU/mL)

Table 6. Comparison of treatment characteristics of patients with acute rheumatic fever

Treatment/outcome	Total (n=122)	Pandemic (n=41)	Post-pandemic (n=81)	p-value
Aspirin	99 (81.1%)	32 (78%)	67 (82.7%)	0.562
Naproxen	31 (25.4%)	12 (29.3%)	19 (23.5%)	0.503
Steroid	38 (31.1%)	11 (26.8%)	27 (33.3%)	0.477
Surgical requirement	6 (4.9%)	1 (2.4%)	5 (6.2%)	0.410

The rate of carditis in our study was 95%, which is higher than the 50–80% range reported in developed countries[12,13] but similar to that in developing countries[14,15]. The rates of mitral (90.2%) and aortic (75.4%) regurgitation observed in our cohort are markedly higher than those reported in the literature. This discrepancy is most likely explained by the tertiary-referral nature of our center, which is enriched for more severe cases, and by the systematic use of echocardiography, which leads to the detection of subclinical valvular involvement in accordance with the 2015 Revised Jones Criteria. Therefore, the high prevalence of valvular involvement in our study should not be interpreted as representative of the general ARF population. The relatively high rate of carditis observed in both periods may be related to the tertiary referral nature of our center, which likely receives more severe or complicated cases. Subclinical valvular involvement detected on echocardiography using the 2015 Revised Jones Criteria may have contributed to the overall prevalence of carditis.

Although carditis and valve involvement rates were numerically higher in the post-pandemic period, these differences did not reach statistical significance. The relatively small sample size and uneven group distribution may have reduced statistical power to detect modest differences in clinical sub parameters.

Delayed presentation and elevated CRP levels were identified as factors associated with carditis in the multivariable analysis, supporting a role for inflammatory burden and diagnostic delay in disease severity. This finding is consistent with classic epidemiological data showing that early antibiotic treatment reduces disease severity[16]. Furthermore, high CRP and ESR values, reflecting the severity of the inflammatory response, have been associated with progression of valvular damage[17].

Although CRP did not differ significantly between periods, ESR was significantly higher in the post-pandemic group, possibly reflecting a more prolonged inflammatory burden given ESR's slower normalization kinetics relative to CRP. Variability in both markers on presentation may also be influenced by the timing of hospital admission, the prior use of anti-inflammatory medications, or the onset of subacute disease; the retrospective design precluded detailed time-based correlation analyses.

Secondary prophylaxis was initiated for all patients, and no deaths occurred. Notably, five of the six patients requiring surgery were diagnosed during the post-pandemic period. Although the number of surgical cases was small and the difference was not statistically significant, this observation may suggest a tendency toward more advanced valvular involvement during this period; however, this finding should be interpreted with caution. Previous studies have also identified inflammatory burden and delayed presentation as important determinants of persistent valvular disease and adverse outcomes in rheumatic carditis[18,19].

Study Limitations

This study has several important limitations. First, and most fundamentally, the cohort is subject to substantial selection and referral bias. Our hospital is a tertiary pediatric cardiology center that primarily receives patients with suspected or confirmed cardiac involvement; milder, non-carditic ARF cases managed in primary or secondary care settings are therefore not represented. Consequently, our rates of carditis (95%) and mitral and aortic regurgitation should be viewed as institution-specific patterns and must not be extrapolated to the general ARF population or to community-level epidemiology. Second, the center was newly established during the study period and its referral network expanded gradually; the post-pandemic increase in case volume therefore plausibly reflects institutional growth, increased outpatient clinic capacity, wider access to pediatric echocardiography, improved case capture, and evolving referral patterns, and any true temporal change in GAS transmission. We could not adjust for these confounders because a defined catchment denominator was not available. Third, comparisons between the pandemic and post-pandemic periods are descriptive; with only 41 pandemic-period patients, the power to detect modest between-period differences in clinical subparameters is

limited. Fourth, although all regurgitations were classified according to the four 2015 Jones Doppler criteria to minimize misclassification between physiologic and pathologic regurgitation, residual misclassification nonetheless remains possible in a retrospective review of stored images and reports. Fifth, symptom duration was categorized rather than analyzed as a continuous variable, and long-term outcomes were reported descriptively without formal time-to-event analyses. Sixth, because only six patients were free of carditis, the multivariable logistic regression model should be interpreted with caution despite an acceptable goodness-of-fit (Hosmer–Lemeshow p=0.839). The limited number of outcome-negative patients may have reduced the stability of the estimated ORs and widened the CIs. Finally, single-center retrospective data preclude causal inference regarding pandemic effects on ARF biology.

Our findings underscore the importance of sustained awareness of GABHS pharyngitis management and secondary prophylaxis, particularly during health crises. Beyond temporal trends in case counts, this study contributes detailed clinical severity data, factors associated with carditis, and structured follow-up outcomes in a tertiary referral context.

Conclusion

In this single-center study, the number of ARF cases was higher in the post-pandemic period than in the pandemic period. A high prevalence of carditis was observed, reflecting the tertiary-referral nature of our center; therefore, this finding should not be generalized to the broader ARF population. Delayed presentation and elevated inflammatory markers were associated with cardiac involvement and the requirement for surgery. These findings should be interpreted within the limitations of a retrospective tertiary-center design.

Ethics

Ethics Committee Approval: Approval for the study was obtained from the University of Health Sciences Türkiye, Başakşehir Çam and Sakura City Hospital, Clinical Research Ethics Committee on October 22, 2025 (decision number 332).

Informed Consent: This retrospective study included pediatric cardiology patients followed between May 2020 and August 2025.

Footnotes

Authorship Contributions

Concept: Genç HZ, Güzelbağ AN, Öztürk E, Design: Genç HZ, Öztürk E, Data Collection and/or Processing: Güzelbağ AN, Çevlik B, Çoban Ş, Analysis and/or Interpretation: Genç HZ, Çevlik B, Öztürk E, Literature Search: Genç HZ, Güzelbağ AN, Writing: Genç HZ, Güzelbağ AN, Çoban Ş.

Conflict of Interest: The authors declare no conflicts of interest concerning the authorship or publication of this article.

Financial Disclosure: This research received no specific grants from any funding agency in the commercial or not-for-profit sectors.

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Research Article

J Updates Cardiovasc Med 2026;14(3):96-106 **DOI:** 10.32596/jucvm.galenos.2025.2026-12-193

Baseline and Follow-up Cardiac Magnetic Resonance Findings in Pediatric Acute Myocarditis: A Single-center Experience

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Abstract

Objectives: Acute myocarditis in children has a broad clinical spectrum, and cardiac magnetic resonance (CMR) is an important non-invasive tool for diagnosis and follow-up. This study aimed to evaluate baseline and follow-up CMR findings in pediatric acute myocarditis and their relationship with clinical and laboratory markers of myocardial injury and inflammation.

Materials and Methods: This single-center retrospective study included pediatric patients who underwent CMR for clinically suspected acute myocarditis. Demographic characteristics, presenting symptoms, laboratory data, electrocardiographic and echocardiographic findings, and CMR parameters were collected. Follow-up CMR was available in a subset of patients to assess interval changes in myocardial tissue characteristics, including native T1 and T2 mapping values, extracellular volume (ECV), late gadolinium enhancement (LGE), and left ventricular ejection fraction (LVEF).

Results: Baseline CMR was performed in 139 pediatric patients with suspected acute myocarditis. Median LVEF was 50% interquartile range (IQR, 33–58): reduced systolic function (LVEF <55%) was observed in 64.7% of the cohort. LGE was identified in 91.4% of patients, with a median extent of 4% (IQR, 3–5). Follow-up CMR performed in 40 patients

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Received: 10.07.2026 **Accepted:** 17.08.2026 **Publication Date:** 25.09.2026

Cite this article as: Kangel D, Oğuz AS, Genç HZ, et al. Baseline and follow-up cardiac magnetic resonance findings in pediatric acute myocarditis: a single-center experience. J Updates Cardiovasc Med. 2026;14(3):96-106

DOI: 10.32596/jucvm.galenos.2025.2026-12-193

showed significant improvements in LVEF, native T1 and T2 relaxation times, ECV, and LGE extent (all $p<0.05$). All 40 patients had LGE at baseline, and LGE remained detectable in 32 patients (80%) at follow-up.

Conclusion: Multiparametric CMR provides comprehensive insight in pediatric acute myocarditis. Significant improvement in ventricular function and tissue characterization parameters was observed at follow-up, although LGE remained detectable in 80% of patients. These findings support the role of CMR in both the initial evaluation and follow-up of pediatric myocarditis.

Keywords: Myocarditis, pediatric, cardiac magnetic resonance, late gadolinium enhancement, T1 Mapping, extracellular volume

Introduction

Acute myocarditis is an inflammatory disease of the myocardium with a highly variable clinical presentation, ranging from mild, non-specific viral symptoms to chest pain, ventricular dysfunction, cardiogenic shock, life-threatening arrhythmias, or sudden cardiac death in previously healthy children[1-4]. Although the true incidence of pediatric myocarditis is difficult to determine because many cases remain subclinical or misdiagnosed, epidemiological studies estimate an annual incidence of 1–2 per 100,000 children and myocarditis remains an important, though frequently under-recognized, cause of sudden unexpected death in young people[5-7].

In pediatric myocarditis, infections are the most common underlying cause, with enteroviruses, adenovirus, parvovirus B19, human herpesvirus-6, and influenza viruses among the frequently identified pathogens, although the distribution of individual agents varies across regions, age groups, and diagnostic eras[1-3,8-10]. Emerging respiratory viruses, most notably SARS-CoV-2, have further contributed to the evolving epidemiology of the disease[3].

Historically, the diagnosis of myocarditis relied on endomyocardial biopsy and the Dallas criteria. However, endomyocardial biopsy is limited by its invasive nature, sampling error, and low sensitivity, especially in children[1,11]. Accordingly, current recommendations from the American Heart Association and the American College of Cardiology support a multimodal diagnostic strategy that integrates clinical assessment, cardiac biomarkers, electrocardiography, echocardiography, and importantly, cardiac magnetic resonance (CMR) imaging[2,4]. CMR has become a pivotal tool in diagnosing myocarditis because it enables noninvasive, whole-heart assessment of myocardial edema, hyperemia, necrosis, and fibrosis. With the introduction of the 2018 updated Lake Louise Criteria, multiparametric CMR, including T1 and T2 mapping and extracellular volume (ECV) analysis, has significantly improved the sensitivity and specificity for detecting active myocardial inflammation[4,12,13].

The utility of CMR in children has expanded considerably over the past decade. Multicenter data indicate that the use of CMR in pediatric myocarditis has increased substantially in recent years, reflecting its growing role in clinical decision-making[14]. In this context, T1 and T2 mapping techniques are particularly valuable in children, as they enable the detection of diffuse myocardial inflammation that may not be apparent on late gadolinium enhancement (LGE) imaging[15,16]. Moreover, mapping values correlate with biochemical markers of myocardial injury and may help differentiate acute from subacute or resolving disease[15,17]. In addition to baseline assessment, follow-up CMR provides important information on myocardial recovery, with normalization of mapping values often preceding improvement in LGE or ventricular function[12,18,19].

Despite the increasing adoption of CMR in pediatric myocarditis, real-world data on the spectrum of multiparametric CMR findings and their relationship with clinical and laboratory markers remain limited. Studies focusing on both baseline and follow-up CMR in children are particularly scarce. Given the heterogeneous presentation and variable clinical course of pediatric myocarditis, ranging from complete recovery to progression toward chronic myocardial dysfunction, comprehensive CMR evaluation can provide valuable insights into myocardial tissue changes throughout its course. This study aimed to characterize baseline multiparametric CMR findings, evaluate follow-up imaging changes, and assess the association of these findings and changes with markers of myocardial injury and inflammation in a single-center cohort of pediatric patients with acute myocarditis. Our findings may help further define the role of CMR in the diagnostic and longitudinal assessment of children with myocarditis.

Materials and Methods

Study Design and Patient Population

A retrospective, single-center study was conducted involving pediatric patients hospitalized with a diagnosis of acute myocarditis who underwent CMR between August 1, 2022, and November 1, 2025. The study included patients aged 1 month to <18 years.

The diagnosis of acute myocarditis was established based on clinical presentation, elevated cardiac biomarkers (troponin and/or CK-MB), electrocardiographic or echocardiographic abnormalities, and supportive CMR findings interpreted according to the 2018 updated Lake Louise Criteria (requiring at least one T2-based marker of myocardial edema and one T1-based marker of non-ischemic injury)[12], in accordance with current consensus recommendations[1,4]. Endomyocardial biopsy was not performed in any patient. Left ventricular systolic function was assessed by echocardiography using M-mode (Teichholz-derived) left ventricular ejection fraction. Reduced systolic function was defined as an ejection fraction of <50% on echocardiography and of <55% on CMR.

Patients with pre-existing congenital heart disease requiring surgical or catheter-based intervention (except for hemodynamically insignificant lesions), known cardiomyopathy, prior myocarditis, or systemic inflammatory, autoimmune, or metabolic disorders that could mimic myocarditis, as well as those with non-diagnostic or incomplete CMR examinations or contraindications to CMR or gadolinium-based contrast agents, were excluded. Patients with multisystem inflammatory syndrome in children (MIS-C)–associated cardiac involvement were also excluded, and no cases of MIS-C or vaccine-associated myocarditis were identified during the study period.

During the study period, 155 patients with acute myocarditis undergoing CMR were assessed for eligibility; 11 were excluded because CMR was not performed, and 5 were excluded because of incomplete data, yielding a final baseline cohort of 139 patients, of whom 40 (28.8%) underwent follow-up CMR. The patient selection process is summarized in Figure 1.

The study protocol was approved by the Ethics Committee of University of Health Sciences Türkiye, Başakşehir Çam and Sakura City Hospital (approval no: 2025/355; November 26, 2025). The study was conducted in accordance with the Declaration of Helsinki. The ethics committee waived the requirement for informed consent due to the retrospective nature of the study.

Cardiac Magnetic Resonance Acquisition and Analysis

All CMR examinations were performed using a 1.5-T Ingenia scanner (Philips Healthcare, Best, the Netherlands). In children younger than 6 years of age, imaging was performed during free breathing with motion correction applied, and sedation was used when necessary, according to institutional pediatric anesthesia protocols. Older children underwent breath-hold, electrocardiogram-gated acquisitions.

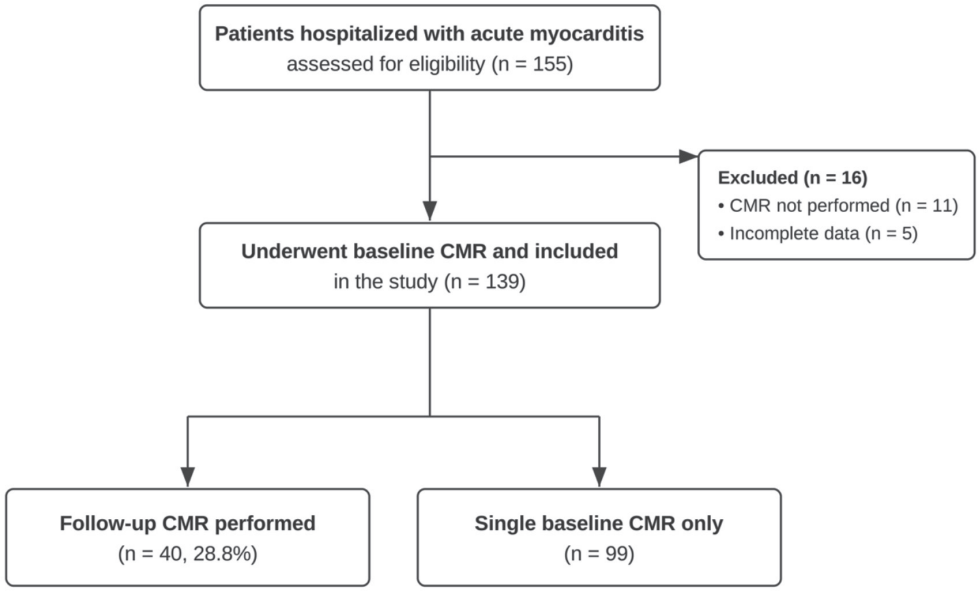

Figure 1. STROBE flow diagram of patient selection. Of 155 patients hospitalized with acute myocarditis who were assessed for eligibility, 16 were excluded (11 without CMR and 5 with incomplete data), yielding 139 patients who underwent baseline CMR. Follow-up CMR was performed in 40 patients (28.8%), while 99 patients had a single baseline study

CMR: Cardiac magnetic resonance

The protocol comprised cine steady-state free precession imaging for ventricular function; native T1 mapping (MOLLI 5(3)3) before and after contrast; T2 mapping (multi-echo GraSE) in basal, mid, and apical short-axis slices; and LGE imaging with a phase-sensitive inversion-recovery sequence 10 minutes after intravenous administration of gadolinium-based contrast (0.15 mmol/kg). Detailed acquisition parameters are provided in Supplementary Table S1.

All measurements were performed on a dedicated workstation (IntelliSpace Portal 11.2, Philips Healthcare) by an experienced radiologist (S.O.) trained in congenital cardiac imaging, who had performed more than 1500 cardiac magnetic resonance imaging examinations and was blinded to clinical details. LVEF was derived from short-axis cine images by tracing endocardial contours across all cardiac phases, with papillary muscles and trabeculations included in the ventricular blood pool. For native T1 and T2 mapping, endocardial and epicardial contours were manually drawn, excluding the blood pool and epicardial fat, and global myocardial values were generated within the defined myocardial mask. LGE was quantified on phase-sensitive inversion-recovery images using a semi-automated full-width at half-maximum thresholding method, with hyperenhanced myocardium defined as signal intensity ≥50% of the maximal intensity within the region of enhancement, and expressed as a percentage of left ventricular myocardial mass. ECV was calculated from pre- and post-contrast myocardial and blood-pool T1 values and same-day hematocrit using the formula ECV = (1 − hematocrit) × (ΔR1myocardium/ΔR1blood).

Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics for Windows, version 23.0 (IBM Corp., Armonk, NY, USA). Continuous variables were presented as median with interquartile range (IQR), and categorical variables were presented as number and percentage.

Comparisons between patients with and without follow-up CMR were performed using the Mann-Whitney U test for continuous variables and the chi-square test or Fisher's exact test for categorical variables, as appropriate. Paired comparisons between baseline and follow-up CMR findings were performed using the Wilcoxon signed-rank test for continuous variables and the McNemar test for categorical variables. The influence of the follow-up interval on the degree of was assessed using Spearman's correlation between the follow-up interval and the paired change in each CMR parameter. For paired comparisons, effect sizes were reported as the matched-pairs rank-biserial correlation; 95% confidence intervals for the median change were also provided. Associations between laboratory markers (peak troponin, peak C-reactive protein (CRP), and NT-proBNP) and baseline CMR tissue parameters (native T1, T2, ECV, and LGE extent) were assessed using Spearman rank correlations. Because myocardial native T1 varies with age in children, partial Spearman correlations adjusted for age were used as the primary analysis. 95% confidence intervals were derived using the Fisher z-transformation. LGE extent was analyzed across the full cohort, and LGE-negative studies were assigned an extent of 0%. To account for multiple comparisons within the correlation analysis, p-values were adjusted using the Benjamini-Hochberg false-discovery-rate procedure, and these associations were considered exploratory. A two-sided p-value <0.05 was considered statistically significant.

Results

During the study period, 139 pediatric patients hospitalized with acute myocarditis underwent baseline CMR. Follow-up CMR was available in 40 patients. Baseline demographic and clinical characteristics did not differ significantly between patients with and without follow-up imaging (Table 1). At baseline CMR, however, patients who underwent follow-up had a higher prevalence of LGE (100% vs. 87.9%, p=0.019) and higher T2 values (p=0.024), and showed non-significant trends toward greater LGE extent and pericardial effusion, whereas laboratory markers and other functional parameters were comparable (Supplementary Table S2). Thus, patients with more pronounced baseline myocardial involvement were preferentially selected for follow-up imaging.

The median age of the overall cohort was 12.4 years (IQR, 3.4–16.2), and 98 patients (70.5%) were male. The most common presenting symptoms were chest pain (61.2%), dyspnea (29.5%), abdominal pain (20.9%), fever (18.0%), and palpitations (13.7%). Baseline demographic and clinical characteristics of the study population are summarized in Table 1.

At baseline CMR, left ventricular systolic function was mildly reduced overall, with a median LVEF of 50% (IQR, 33–58). Reduced LVEF (<55%) was observed in 90 patients (64.7%). LGE was present in 127 patients (91.4%), with a median extent of 4% (IQR, 3–5); pericardial effusion was identified in 22 patients (15.8%). Detailed baseline CMR findings are provided in Table 2.

After adjustment for age and correction for multiple comparisons, higher peak troponin and higher peak CRP were each associated with greater baseline LGE extent ($\rho=0.39$, $q<0.001$; $\rho=0.22$, $q=0.020$, respectively). Higher NT-proBNP levels were associated with higher native T1 ($\rho=0.36$, $q<0.001$), higher T2 ($\rho=0.28$, $q=0.007$), and greater LGE extent ($\rho=0.32$, $q=0.001$). Correlations with ECV did not reach statistical significance (n = 128). Unadjusted troponin– and CRP–native T1/T2 correlations were negative, but attributable to age confounding and disappeared after age adjustment (Table 3).

Among the 40 patients who underwent follow-up CMR, both ventricular function and myocardial tissue characteristics showed significant improvement over time. The median interval between baseline and follow-up imaging was 144 days (IQR, 63–200). Median LVEF increased from 54% (IQR, 38–60) at baseline to 58% (IQR, 44–63) at follow-up ($p<0.001$). Native T1 values, T2 relaxation times, ECV, and LGE extent decreased significantly on repeat imaging ($p<0.05$ for all). Although the prevalence of LGE declined from 100% to 80%, residual LGE remained detectable in 32 patients at follow-up. In addition, the number of involved myocardial

Table 1. Baseline demographic, clinical, and laboratory characteristics of the study population

Variable	Follow-up (n=40)	No follow-up (n=99)	p-value
Demographic characteristics			
Age, years, median (IQR)	13.3 (4.5–15.6)	11.8 (2.5–16.5)	0.48
Male, n (%)	26 (65%)	72 (72.7%)	0.48
Clinical presentation			
Chest pain, n (%)	26 (65%)	59 (59.6%)	0.69
Palpitations, n (%)	5 (12.5%)	14 (14.1%)	1.00
Dyspnea, n (%)	12 (30%)	29 (29.3%)	1.00
Fever, n (%)	8 (20%)	17 (17.2%)	0.88
Abdominal pain, n (%)	8 (20%)	21 (21.2%)	1.00
Electrocardiographic findings at admission (overall cohort, n=139)			
Normal ECG, n (%)	72 (51.8%)		
ST-segment elevation, n (%)	33 (23.7%)		
Other ST-T abnormalities, n (%)	21 (15.1%)		
Arrhythmia, n (%)	13 (9.4%)		
Echocardiographic findings at admission (overall cohort, n=139)			
Normal echocardiography, n (%)	85 (61.2%)		
Reduced systolic function, n (%)	54 (38.8%)		
Pericardial effusion, n (%)	22 (15.8%)		
Time intervals (days) (overall cohort, n=139)			
Symptom onset to hospital admission, median (IQR)	2 (2–5)		
Hospital admission to baseline CMR, median (IQR)	10 (5–19)		
Troponin normalization time, median (IQR)	5 (4–10)		
Laboratory findings (overall cohort, n=139)			
Peak troponin, ng/L, median (IQR)	243 (114–449)		
C-reactive protein, mg/L, median (IQR)	16.4 (3.9–48.35)		
Procalcitonin, ng/mL, median (IQR)	0.09 (0.06–0.18)		
NT-proBNP, pg/mL, median (IQR)	729 (155–14648)		
Viral testing (n=137)	**n (%)**		
Positive viral test	73 (52.5% of cohort; 53.3% of tested)		
- Rhinovirus	24 (17.5%)		
- Adenovirus	8 (5.9%)		
- SARS-CoV-2	7 (5.1%)		
- Other viruses	34 (24.8%)		

Data are presented as median (IQR) or n (%), CMR: Cardiac magnetic resonance, ECG: Electrocardiography, IQR: Interquartile range, NT-proBNP: N-terminal pro-B-type natriuretic peptide; SARS-CoV-2: Severe acute respiratory syndrome coronavirus 2

segments decreased modestly but significantly, and the frequency of pericardial effusion was significantly reduced. Detailed paired comparisons are summarized in Table 4. The magnitude of change was independent of the follow-up interval for LVEF, T2, ECV, and LGE extent (all p>0.3); for native T1, a longer interval was associated with a greater reduction (ρ=−0.38, p=0.026), consistent with progressive reduction over time. Temporal changes in the LGE pattern are illustrated in Figure 2. The corresponding pattern transition matrix is provided in Supplementary Table S3. In the paired follow-up subgroup, higher baseline peak troponin was associated with greater residual LGE extent at follow-up (ρ=0.39, p=0.012) and showed a non-significant trend toward persistent LGE

(median 282 vs. 145 ng/L; p=0.088), whereas peak CRP and NT-proBNP were not associated.

Discussion

In this single-center cohort of pediatric patients with acute myocarditis, baseline CMR frequently demonstrated ventricular dysfunction, LGE, and pericardial effusion. The prevalence of LGE in our cohort appears relatively high compared with previously reported pediatric series, which may be related to differences in patient selection and timing of imaging[15,20,21]. Among patients who underwent repeat imaging, both ventricular function and myocardial tissue characterization parameters improved significantly over time, consistent with previous studies reporting gradual

Table 2. Baseline cardiac magnetic resonance findings in the study cohort (n=139)

Variable	Value
Ventricular function	
Left ventricular ejection fraction (%), median (IQR)	50 (33–58)
Reduced LVEF (<55%), n (%)	90 (64.7%)
Tissue characterization	
Native T1, ms, median (IQR) (n=128)	1130 (1044–1201)
T2 relaxation time, ms, median (IQR) (n=130)	62 (53–69)
Extracellular volume (%), median (IQR) (n=128)	36 (30–46)
Late gadolinium enhancement	
LGE present, n (%)	127 (91.4%)
LGE extent (%), median (IQR) [range] (n=139)	4 (3–5) [1-32]
LGE extent >10%, n (%)	9 (6.5%)
Additional findings	
Pericardial effusion, n (%)	22 (15.8%)

CMR: Cardiac magnetic resonance, IQR: Interquartile range, LGE: Late gadolinium enhancement, LVEF: Left ventricular ejection fraction

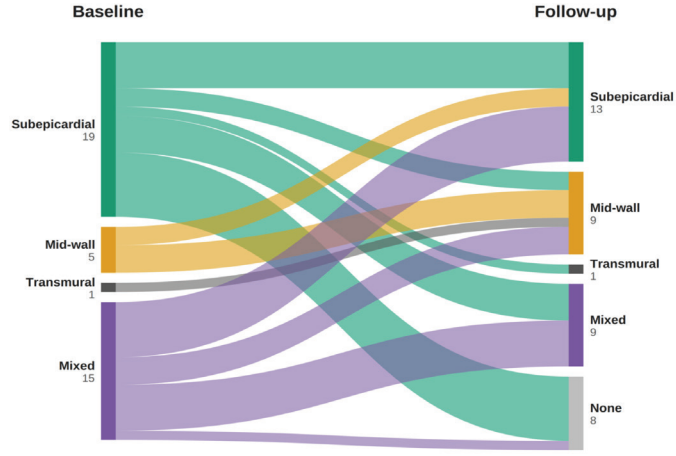

Figure 2. Temporal changes in late gadolinium enhancement (LGE) distribution patterns between baseline and follow-up cardiac magnetic resonance imaging. The Sankey-style diagram illustrates transitions in myocardial LGE patterns among pediatric patients with acute myocarditis. Most patients demonstrated reductions in both the extent and number of myocardial segments involved at follow-up, whereas a substantial proportion showed persistent LGE despite overall improvement in ventricular function and tissue characterization parameters

Table 3. Age-adjusted correlations between laboratory markers and baseline CMR parameters (n=139)

Biomarker	CMR parameter	n	Unadj. ρ	Age-adjusted ρ (95% CI)	q
Peak troponin	Native T1	128	−0.28	+0.09 (−0.09, +0.27)	0.556
	T2	130	−0.20	−0.00 (−0.19, +0.18)	0.985
	ECV	128	−0.06	+0.06 (−0.12, +0.24)	0.798
	LGE extent	139	+0.36	**+0.39 (+0.24, +0.52)**	**<0.001***
Peak CRP	Native T1	128	−0.20	+0.03 (−0.15, +0.21)	0.905
	T2	130	−0.15	−0.02 (−0.20, +0.17)	0.921
	ECV	128	−0.09	−0.04 (−0.22, +0.14)	0.905
	LGE extent	139	+0.23	**+0.22 (+0.06, +0.38)**	**0.020***
NT-proBNP	Native T1	128	+0.62	**+0.36 (+0.19, +0.51)**	**<0.001***
	T2	130	+0.42	**+0.28 (+0.10, +0.44)**	**0.007***
	ECV	128	+0.21	+0.09 (−0.09, +0.27)	0.556
	LGE extent	139	+0.16	**+0.32 (+0.16, +0.46)**	**<0.001***

*ρ: partial Spearman correlation coefficient adjusted for age, q: Benjamini–Hochberg false-discovery-rate–adjusted p-value; *q<0.05. Unadjusted ρ shown for transparency; the negative unadjusted troponin/CRP–T1/T2 correlations reflected age confounding and were abolished after adjustment, CMR: Cardiac magnetic resonance, CRP: C-reactive protein, ECV: Extracellular volume, LGE: Late gadolinium enhancement, CI: Confidence interval, FDR: False discovery rate*

Table 4. Comparison of baseline and follow-up cardiac magnetic resonance findings (n=40)

Variable	Baseline	Follow-up	Effect size	p-value
LVEF (%)	54 (38–60)	58 (44–63)	r = 1.00	<0.001
Native T1 (ms) (n=34)	1118 (1046–1209)	1037 (1005–1137)	r = −0.61	0.002
T2 (ms) (n=34)	62 (48–86)	52 (46–64)	r = −0.51	0.013
ECV (%) (n=33)	42 (30.8–51)	30.6 (27-36)	r = −0.76	<0.001
LGE extent (%), among LGE-positive	4 (4–6)	3 (2–5)	r = −0.99	<0.001
LGE present, n (%)	40 (100%)	32 (80%)	—	0.008
Number of involved segments	2 (2–4)	2 (1–3)	r = −0.53	0.031
Multi-segment involvement, n (%)	31 (77.5%)	21 (52.5%)	—	0.006
Pericardial effusion, n (%)	10 (25%)	0 (0%)	—	0.002
Myocardial localization (septal/lateral/inferior/anterior/apical/multiple/none)	7/17/6/0/2/8/0	4/16/8/0/1/3/8	—	N/A
Myocardial pattern (subepicardial/mid-wall/transmural/mixed/none)	19/5/1/15/0	13/9/1/9/8	—	N/A

Data are presented as median (IQR) or n (%).
Effect sizes are the matched-pairs rank-biserial correlation (r) for continuous variables (Wilcoxon signed-rank test); categorical variables were compared with the McNemar test. LGE extent is reported among LGE-positive patients at each time point; for the paired comparison, LGE-negative studies were assigned an extent of 0%. The matched-pairs rank-biserial correlation reflects the consistency of the direction of change rather than its magnitude. An r of 1.00 for LVEF indicates that all 40 patients showed an increase in LVEF at follow-up (median change +4 percentage points; range +3 to +9), with no patient showing a decrease or no change.
CMR: Cardiac magnetic resonance, ECV: Extracellular volume, IQR: Interquartile range, LGE: Late gadolinium enhancement, LVEF: Left ventricular ejection fraction

resolution of inflammatory CMR findings[18,20]. Follow-up CMR was performed at a median of 144 days after baseline CMR, and although LGE prevalence, extent, and segmental involvement decreased, residual enhancement remained detectable in a substantial proportion of patients, consistent with prior studies showing that LGE may regress over time but frequently does not completely resolve in the early follow-up period[17-19]. These findings suggest that myocardial recovery on imaging may lag behind functional improvement, particularly during early follow-up[17,20]. Importantly, the follow-up subgroup was not representative of the entire cohort: patients who underwent repeat imaging had more pronounced baseline abnormalities, including a higher prevalence of LGE (100% vs. 87.9%, p=0.019) and higher T2 values (p=0.024), indicating that repeat CMR was preferentially performed in more severely affected children. This has two implications. First, the significant regression in tissue parameters observed here occurred despite this enrichment, indicating that imaging improvement occurs even among the more severely affected patients. Second, because children with milder baseline involvement were underrepresented, the magnitude of change reported here should not be extrapolated to the entire cohort or to unselected pediatric myocarditis populations, and the proportion of patients with persistent LGE may differ in such populations.

Cardiac magnetic resonance plays a central role in the diagnosis of acute myocarditis by enabling comprehensive assessment of myocardial inflammation, edema, and injury[12,22]. The updated Lake Louise Criteria, incorporating parametric mapping techniques such as native T1, T2, and ECV, have substantially improved diagnostic accuracy compared with conventional imaging approaches[12,15,23]. These techniques allow detection of both focal and diffuse myocardial involvement, overcoming the limitations of LGE, which primarily reflects regional injury[12,15]. In pediatric populations, where clinical presentation may be heterogeneous and noninvasive diagnostic tools are particularly important, CMR provides a valuable framework for diagnosis and disease characterization[2,20,24]. Our findings, demonstrating a high prevalence of abnormal tissue characterization parameters at baseline, further support the value of multiparametric CMR in capturing the extent of myocardial involvement in acute pediatric myocarditis.

LGE has been consistently associated with myocardial injury and has emerged as an important imaging marker with potential prognostic implications in acute myocarditis[12,25]. Previous studies have shown that the presence and extent of LGE may be associated with adverse clinical outcomes, including persistent ventricular dysfunction and the development of chronic myocardial damage[20,26]. In pediatric populations, although long-term outcome data remain limited, persistent LGE on follow-up imaging has been reported even in patients with clinical recovery, suggesting that residual enhancement may be observed even after clinical recovery[19,21,27]. Our findings support the concept that LGE represents a dynamic process reflecting ongoing myocardial remodeling rather than a static marker of irreversible injury, particularly in the early phase of recovery. Because clinical outcomes were not assessed, the prognostic significance of the residual enhancement observed in our cohort cannot be determined, and its persistence should not be equated with an adverse prognosis in the absence of outcome data.

Beyond their descriptive value, our tissue-characterization findings were associated with circulating markers of myocardial injury and wall stress. After adjustment for age, higher peak troponin and CRP were associated with greater LGE burden, and higher NT-proBNP was associated with higher native T1 and T2 and greater LGE extent, supporting a biological link between the intensity of the acute inflammatory insult and the degree of detectable myocardial involvement[18,19]. Higher baseline troponin was also associated with greater residual LGE at follow-up, consistent with the concept that more severe acute injury predisposes to residual replacement fibrosis[16,26]. Because age was strongly associated with both native T1 and peak troponin in our cohort, consistent with reports of age-related variation in pediatric myocardial T1[28], these associations were adjusted for age; unadjusted analyses were confounded by age and would have yielded biologically implausible inverse correlations, underscoring the importance of age adjustment in pediatric CMR studies. These associations should be regarded as exploratory, and quantitative LGE assessment in children remains constrained by dependence on the thresholding technique, partial-volume effects in the thin pediatric myocardium, and the absence of validated age-specific reference ranges[13,23].

Despite the growing use of CMR in the evaluation of acute myocarditis, data regarding the comprehensive assessment of both baseline and follow-up multiparametric CMR findings in pediatric populations remain limited. Most available studies have focused either on diagnostic performance or on selected imaging markers, with relatively few addressing the temporal evolution of myocardial tissue characteristics using a multiparametric approach[19-21,27,29]. In this context, our study provides a detailed evaluation of functional and tissue-level changes, integrating ventricular function, mapping parameters, and LGE characteristics in a pediatric cohort. The combined assessment of baseline abnormalities and their evolution over time offers a more comprehensive understanding of myocardial involvement and recovery patterns in children with acute myocarditis. These findings may help inform follow-up imaging strategies, although prospective studies with longer follow-up and systematically collected clinical outcomes are required before persistent imaging abnormalities can be used for risk stratification. Although our study did not specifically evaluate clinical outcomes, the observed improvement in imaging parameters alongside persistent LGE may provide insight into ongoing myocardial remodeling and may warrant further investigation.

Study Limitations

This study has several limitations. Its retrospective, single-center design may limit generalizability. Because CMR—including the tissue markers used in the Lake Louise Criteria—contributed to the diagnosis, the reported prevalences of CMR abnormalities reflect incorporation bias rather than diagnostic accuracy. The cohort also represents a CMR-imaged subset of all clinically diagnosed patients. Patients who underwent follow-up CMR had greater baseline myocardial abnormality (higher

LGE prevalence and T2 values), indicating that follow-up preferentially included more severely affected patients; the follow-up findings may therefore overrepresent patients with greater baseline involvement and not generalize to the full cohort. The follow-up interval was also not standardized, which may have influenced the degree of recovery observed. Methodologically, left ventricular function by echocardiography was estimated using the M-mode Teichholz method, which, together with a higher normal reference range, greater sensitivity, and a different threshold of CMR, likely explains the lower prevalence of systolic dysfunction on echocardiography; ventricular volumes and some mapping parameters were not available in all patients; CMR was interpreted by a single reader, so interobserver reproducibility was not assessed. The retrospective categorization of admission electrocardiograms may underestimate transient abnormalities. Most importantly, long-term clinical follow-up data—including functional status, arrhythmic events, hospitalization, and the need for heart failure therapy—were not available. Therefore, the residual LGE observed at follow-up cannot be related to clinical outcome, and its prognostic significance in this cohort remains undetermined; this, together with the exploratory nature of the association analyses, should be taken into account when interpreting the persistent imaging abnormalities reported here.

Conclusion

Multiparametric CMR imaging provides a comprehensive assessment of myocardial involvement in pediatric acute myocarditis. Significant improvement in ventricular function and tissue characterization parameters is observed over time. However, residual abnormalities, particularly LGE, may persist during follow-up. These findings suggest that imaging recovery may lag behind the recovery of ventricular function. CMR may therefore be a valuable tool not only for diagnosis but also for follow-up evaluation in this patient population, although the optimal timing and the prognostic value of persistent imaging abnormalities require prospective evaluation.

Ethics

Ethics Committee Approval: Ethical approval was obtained from the Ethics Committee of University of Health Sciences Türkiye, Başakşehir Çam and Sakura City Hospital (approval no: 2025/355, date: November 26, 2025).

Informed Consent: Informed consent was not required due to the retrospective nature of the study.

Footnotes

Authorship Contributions

Surgical and Medical Practices: Kangel D, Oğuz AS, Genç HZ, Öztürk E, Concept: Kangel D, Özkök S, Tanıdır İC, Öztürk E, Design: Kangel D, Kartal YC, Tanıdır İC, Data Collection and/or Processing: Kangel D, Oğuz AS, Özkök S, Tanıdır İC, Analysis and/or Interpretation: Oğuz AS, Öztürk E, Literature Search: Kangel D, Genç HZ, Writing: Kangel D, Tanıdır İC.

Conflict of Interest: The authors declare no conflicts of interest concerning the authorship or publication of this article.

Financial Disclosure: This research received no specific grants from any funding agency in the commercial or not-for-profit sectors.

Supplementary Tables: https://d2v96fxpocvxx.cloudfront.net/beb8919b-f013-4ea1-b1c8-40332e840fe1/content-images/46c5218b-0dde-47c8-89f3-b4bbfc8e29d8.pdf

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