Artificial intelligence–enabled tools in cardiovascular medicine: A survey of current use, perceptions, and challenges

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BACKGROUND Numerous artificial intelligence (AI)-enabled tools for cardiovascular diseases have been published, with a high impact on public health. However, few have been adopted into, or have meaningfully affected, routine clinical care.

OBJECTIVE To evaluate current awareness, perceptions, and clinical use of AI-enabled digital health tools for patients with cardiovascular disease, and challenges to adoption.

METHODS This mixed-methods study included interviews with 12 cardiologists and 8 health information technology (IT) administrators, and a follow-on survey of 90 cardiologists and 30 IT administrators.

RESULTS We identified 5 major challenges: (1) limited knowledge, (2) insufficient usability, (3) cost constraints, (4) poor electronic health record interoperability, and (5) lack of trust. A minority of cardiologists were using AI tools; more were prepared to implement AI tools, but their sophistication level varied greatly.

CONCLUSION Most respondents believe in the potential of AI-enabled tools to improve care quality and efficiency, but they identified several fundamental barriers to wide-scale adoption.

KEYWORDS Artificial intelligence; Cardiology; Cardiovascular disease; Digital health tool; Electronic health records; Machine learning; Survey

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Introduction

Heart disease is the number 1 cause of death for US adults, with more than 650,000 deaths per year reported.[1] Artificial intelligence (AI) and machine learning have the potential to reduce the public health burden of heart disease in numerous ways, such as enabling the earlier detection of disease, risk-stratifying patients for targeted interventions, and identifying gaps and facilitating improvements in quality of care. Examples of these applications include the use of computer vision in retinal images for cardiovascular risk factor detection,[2–4] deep learning on electrocardiograms (ECGs) for detection of left ventricular dysfunction and other conditions,[5,6] and deep learning for early detection of rare causes of heart failure (HF), such as cardiac amyloidosis, with diagnosis codes, ECG, and echocardiogram (echo) data.[7–10]

The widespread adoption of electronic health records (EHRs); the creation of repositories of digitized cardiovascular tests (ie, ECG, echo) and other diverse electronic health data; the adoption of cloud-computing capabilities; and the development, testing, and U.S. Food and Drug Administration approval of several AI-enabled digital health tools have created the potential to embed these digital health tools into routine care in health systems. Although numerous tools have been developed and tested for diverse clinical tasks and settings, the impact of AI-enabled digital health tools on improving cardiovascular care, as well as other areas of medicine, has been limited to date. The US health system is in the early phase of development and validation of AI-enabled technologies in health care, and much additional work is needed to scale implementation and prospectively evaluate technologies in clinical trials.[11]

Before AI-enabled digital health tools can be adopted on a broad scale, numerous challenges and barriers must be overcome. These include substantial heterogeneity in the computational configurations and team structures used for AI clinical decision support tool development and implementation, clinicians' lack of trust in AI clinical decision support (owing in part to inadequate knowledge of AI and transparency of some AI tools), and absence of sufficient, high-quality evidence to support widespread adoption.[12–15]

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To better understand the barriers and opportunities associated with the adoption and implementation of AI solutions within clinical practice for large, integrated health systems and community-based practices, we undertook a mixed-methods study of clinicians and health information technology (IT) administrators. We focused on cardiovascular medicine, given the substantial impact of heart disease on the US adult population, the development of numerous AI-enabled technologies for various tasks to improve cardiovascular care and health, and the extensive interest in using AI to reduce the burden of cardiovascular disease in the cardiovascular community.[1,13,16]

Methods

Overall study design

In this study, qualitative focus group sessions and interviews were initially conducted in a small sample of cardiologists and health IT administrators to satisfy 3 main objectives: (1) to understand the current awareness, perceptions, and use of AI-enabled digital health tools in clinical practice, (2) to explore the perceived value and potential uses of AI technology in facilitating cardiac patient care, and (3) to identify the challenges related to the adoption and deployment of AI-enabled digital health tools. Results from the qualitative research were used to develop a quantitative survey, administered to a larger, more representative sample of cardiologists and health care IT administrators.

Qualitative focus group sessions/interviews

Participants and recruitment

Cardiologists (general cardiologists and cardiology subspecialists, including subspecialists in interventional, advanced HF, and transplant cardiology) and IT administrators were eligible to participate in the focus group sessions and interviews if they met the following criteria: (1) had been employed for 2–40 years in their respective roles; (2) worked in a large, integrated delivery network with ≥4 hospitals, a large hospital system with ≥500 total beds, or a large privately owned practice with ≥25 physicians; (3) used an EHR system that was integrated with and/or sharing data with other specialties, other cardiology practices, and/or other hospital systems; and (4) did not currently work for a pharmaceutical company. Eligible participants were recruited and selected by VPMR LLC (Kennett Square, PA) using available panels of cardiologists and IT administrators who were initially contacted via e-mail and invited to participate in market research.

Semi-structured focus groups/interviews and analysis

A semi-structured interview guide (Supplemental Appendix A) was developed based on a review of the literature and author expertise in AI, biomedical informatics, learning health systems science, and mixed-methods research methodology. VPMR LLC (interviewer: L. Durkin, MBA, an independent researcher) conducted 4 90-minute focus group sessions with 12 cardiologists (3 cardiologists per session) and 8 60-minute in-depth interviews with 8 IT administrators (1 administrator per interview) via video conferencing between September 7, 2021, and September 16, 2021. The interviewer regularly asked follow-up questions to encourage participants to elaborate on their comments. The focus group sessions and interviews were recorded, transcribed, and analyzed using Strauss and Corbin grounded theory framework to identify major themes.[17]

Analyses

For the qualitative research, we used a grounded theory approach for the analysis; that is, we identified emerging ideas with codes that succinctly summarized the concepts, rather than attempting to fit them into an existing body of theory or to assess the validity of a hypothesis. Codes were grouped into higher-level categories and themes. Interviews and focus groups were audio-recorded, and the recordings were transcribed, de-identified, and entered into an Excel worksheet for content analysis and coding. Codes were developed to summarize common ideas and concepts mentioned during the interviews. The VPMR qualitative team performed a line-by-line and question-by-question review; iteratively identified and applied codes to text; and reviewed each interview to categorize, summarize, and examine them for patterns and themes.

Quantitative survey

Participants and recruitment

The eligibility criteria and recruitment strategy for participation in the quantitative survey were similar to those for the qualitative focus groups/interviews. Planned enrollment was 90 cardiologists (30 general cardiologists and 60 cardiology subspecialists) and 30 health IT administrators.

Survey questions, administration, and analysis

Twenty-minute online surveys were developed for cardiologists and health IT administrators based on the major themes and information identified from the qualitative interviews. The surveys (Supplemental Appendix B) covered the following topics: (1) the current state of AI in cardiovascular medicine and potential use cases, (2) attitudes about AI tools in cardiovascular care, and (3) deployment processes and AI-related challenges in cardiovascular medicine. Surveys were completed between November 26, 2021, and December 17, 2021. Standard descriptive statistics were used to summarize the survey results.

Results

Qualitative focus group sessions/interviews

Participant characteristics.

The focus group sessions and interviews included 12 cardiologists and 8 health IT administrators (Table 1). Participating cardiologists had the following subspecialties: general (n = 4), interventional (n = 4), and advanced HF and transplant (n = 4). The roles of the participating IT administrators within their organizations were as follows: chief information officer (n = 5), director of IT (n = 1), head of biomedical/clinical engineering (n = 1), and health record system administrator (n = 1).

Participant-identified challenges

As summarized in Table 2 and described below, 5 major challenges were identified during the qualitative interviews with cardiologists and health IT administrators:

(1) Digital health tools are pervasive, but cardiologists' knowledge of AI is limited. Cardiologists and IT administrators indicated that digital health tools were commonly used in hospital settings for a variety of tasks, including (1) risk stratification for adverse outcomes (ie, readmissions and clinical deterioration); (2) EHR integration of patient-generated health data; (3) EHR alerts for medical contraindications, preventive screening, and medical coding; (4) interpretation of ECG, telemetry, and sensor data; and (5) automation of workflows and image refinement in imaging studies. However, although some of these tools were thought to be useful for increasing care efficiency and quality, cardiologists expressed uncertainty regarding which, if any, of the currently used digital health tools were using true AI. Many of these tools were relatively new and tended to be primarily deployed in the hospital setting.

(2) Difficulties related to the usability of cardiovascular-based AI tools and their integration into clinical workflows are also barriers. Several cardiologists (n = 7) stated that their health systems were collecting data from patient wearable devices, such as data on glucose levels, step counts, and heart rate and rhythm. However, unless a sensor was being used for hospitalized patients, few cardiologists reviewed the data. These data were also rarely compiled and scanned for patterns at large scale for clinical care.

Cardiologists and IT administrators identified several potential opportunities for using AI in cardiovascular care, including (1) faster diagnosis of rare or commonly missed conditions; (2) faster and more reliable risk stratification; (3) rapid data integration of diverse, longitudinal data with clinical decision alerts; (4) integration of genomic, epigenetic, and other "omic" data; (5) advancing care into "preventive cardiology"; (6) increasing patient engagement; and (7) increasing efficiency of patient intake processes. Cardiologists also cited the following specific use cases as opportunities for AI to improve cardiovascular care: (1) analysis of imaging, ECGs, and sensor data; (2) modifying therapy or discussing treatment regimens with patients as needed (ie, without an in-office visit); (3) monitoring real-time therapeutic progress; (4) rapid identification of the need for medication changes; (5) using risk stratification tools for shared decision-making about treatment (eg, implantation of a cardiac defibrillator); and (6) using natural language processing to capture patient–clinician conversations and automatically document important parts in the EHR.

Table 1 Characteristics of participants in the focus groups and interviews

Characteristic	Cardiologists (n = 12)	IT administrators (n = 8)
Setting, n (%)		
Large, integrated delivery network	4 (33.3)	5 (62.5)
Large, hospital-owned health system (≥500 beds)	8 (66.7)	2 (25.0)
Privately/independently owned	0	1 (12.5)
Medical specialty,[†] n (%)		
General cardiology	4 (33.3)	—
Interventional cardiology	4 (33.3)	—
Advanced heart failure and transplant cardiology	4 (33.3)	—
Time in practice/role, mean (range), y	9 (6–17)	13 (6–20)

IT = information technology.
[†]Board certified or board eligible.

According to the participating IT administrators, several new projects in AI are being initiated, but most will not be available for years.

(3) The cost of AI tools often poses a challenge owing to budget constraints. Cost was the most common barrier to AI-enabled digital health tool implementation. Hospitals and larger practices often do not have budget for AI tools, even if the tools appear to improve care delivery and/or reduce costs. Barriers to the purchase of cardiology-specific AI tools also exist, as hospitals frequently only acquire such tools when their costs can be spread across multiple departments.

In addition to cost-effectiveness, cardiologists and IT professionals need to justify the costs of any AI tool to procurement and value assessment committees. The champions of the tool need to demonstrate a substantial reduction in hospital or clinical practice costs and/or improvement in patient outcomes. However, many tools lack sufficient data to support a strong case for the tool's value.

(4) The integration of AI tools into EHR and incompatibility of tools from different vendors are major concerns. Integration of AI tools into the EHR can be challenging, raising concerns about usability. Tools from different vendors frequently are incompatible with one another. However, although Cloud or iOS residence is convenient and less burdened by integration needs, and allows for easier data sharing, most cardiologists and IT administrators expressed a preference for EHR-based systems based on several concerns: (1) uncertainty about how Cloud-based AI could protect patient information, (2) cardiologists' need for "one-stop shopping," ie, the ability to trigger prescriptive algorithms while reviewing the raw data themselves, and (3) IT administrators' ability to

Table 2 Challenges in the deployment of AI-enabled digital health tools in cardiovascular medicine

Challenge	Quotations from interview participants
1. *Limited knowledge of AI/failure to reach consistently high level of AI use* Cardiologists had a low level of understanding of which EHR-based and digital tools within their clinical practice used AI algorithms. Some expressed frustration about not achieving a consistently high level of AI use that would improve time pressures for cardiologists.	"I don't really know what's going on as far as generating risk scores for something like [ATTR-CM]. The majority of the time, we look at the detailed data graph and use trends…I know there are scoring systems for drug withdraw though." –Cardiologist "We do use 3D imaging…where we take the image and use AI. But data mining, we do do it, but not to the level we should. That's one of my pet peeves, that you know how we can do it, because it's still to this day, physicians who I work with in clinical settings, they are pressured due to time." –Cardiologist
2. *Problems related to AI tool usability and integration into clinical workflows* Participants identified the inability to use cardiovascular-focused AI tools efficiently and integrate them into clinical workflows as important barriers.	"I've seen many studies coming out recently in which the ability for the machine learning to make predictions about patient's condition, even patient's age and things like that, is pretty impressive. So I think there is a lot of potential with it. But clinically, we're not really there with it yet, at least in the current setting." –Cardiologist "I think it has to pull from the [health] record without you doing anything...you don't have to go and put the data into it yourself." –Cardiologist "Sometimes when you get all of these risk calculators…and EPIC, it becomes more information, which is not better. We're pretty busy as clinicians. I think information that's not actionable or helpful, it just slows us down and we ignore it." –Cardiologist
3. *Cost constraints* Hospitals and large clinical practices often do not have the budget for AI tools regardless of its benefits. Cardiologists and IT administrators must justify the costs of tools to procurement and value assessment committees.	"…we showed them that [cost in] the long term is better or as good, and that actually the hospital saves money…we showed them with a group of cases that are using AI a lot to prevent heart failure." –Cardiologist "Implementation of some of these new concepts is very expensive, and most of the hospitals in the United States are known for profit; that means they have to allocate only so much money towards technology…so that is the key to getting any prescriptive technology in place." –IT administrator
4. *Difficulty of integrating AI tools into EHR and incompatibility of tools from different vendors* AI tool integration into EHRs is perceived as challenging. Moreover, participants recognized that tools from different vendors are often incompatible with each other.	"…[to] see how something in a proof of concept would work in an institution, it needs to be integrated. And…we have months of backup from the IT folks to integrate anything." –Cardiologist "Obviously, every entity that you're getting that data from is going to be different. It's not uniformly given to you the same in every context. So that's where you have to train it. And that's where it takes time to be able to teach it, that it's not something that can be done overnight, that if you're getting it from one source, you're getting it from hundreds, if not thousands of sources." –IT administrator
5. *Lack of trust in AI tools* Participants cited a lack of trust in human–AI collaborations as a barrier to use. They expressed concern about the use of AI to dictate clinical decisions, the validity of data, and the protection of patient data privacy. They did not have confidence in tools developed by third-party vendors, who, in their experience, had not delivered on promises of prescriptive AI.	"What worries me is that administration—who are not physicians and have no idea of our value or what goes into truly personalized care—would attempt to replace many of our important tasks with AI, not realizing how essential physicians are." –Cardiologist "I'm always scared when I say security, I'm scared of artificial intelligence making the wrong decision. But then also where's the data being stored? That is a concern about patient data. We need to be HIPAA-compliant." –Cardiologist "We've had real problems, frankly, finding vendors who can really help us generate actionable intelligence from all that data as opposed to, really, just providing more data that we then, in turn, have to analyze by hand, when what we need is the analytics." –IT administrator

AI = artificial intelligence; ATTR-CM = transthyretin amyloid cardiomyopathy; EHR = electronic health record; HIPAA = Health Insurance Portability and Accountability Act; other abbreviations as in Table 1.

create better automated algorithms with centralized data collected on the same operating system platforms, in the same format.

(5) Lack of trust in AI tools represents a significant barrier to adoption. In addition to a poor understanding of AI, lack of trust in human–AI collaborations was also a commonly cited barrier to broader adoption. Hospital administrators are reluctant to invest in a new AI tool if cardiologists and other health care providers will not use it to its full potential. Their apprehension is based in part on the

concerns of health care providers about a "super AI" tool superseding their clinical judgment, generating resistance to tool adoption. Although they would like all systems to be fully inter- and intra-operational, several cardiologists expressed concerns about their hospital networks' IT departments reaching beyond data compilation, retrieval, and other descriptive informatics, and controlling their treatment decisions. Cardiologists emphasized the need for AI tools to be well validated before adoption and expressed concern about using tools developed by third-party vendors.

Quantitative survey

Participant characteristics

In total, 90 cardiologists (30 general cardiologists and 60 cardiology subspecialists) and 30 IT administrators completed the online survey (Table 3). Participating IT administrators had the following roles within their organizations: chief information officer (n = 10), chief medical information officer (n = 4), IT director (n = 15), and health record system administrator (n = 1). The majority of general cardiologists, cardiology subspecialists, and IT administrators characterized themselves as early (47%, 38%, and 43%, respectively) or average (43%, 62%, and 57%) adopters of technology.

Current state of AI in cardiovascular medicine and potential use cases

When asked to rate the health care sector's sophistication level in using AI to support clinical practice or health care delivery organizations, 30% of cardiologists and 24% of IT administrators gave a below average rating (Figure 1A). When asked to rate their own organization's sophistication level, 32% of cardiologists and 16% of IT administrators gave a below average rating (Figure 1B).

Current use of AI-enabled digital health tools to support either clinical decision-making or clinical practice management was not common, particularly in general cardiology practices (Figure 2A). Across applications, current use of AI tools was least common among general cardiologists (7%–27%), followed by cardiology subspecialists (7%–35%), and most common among IT administrators (20%–60%). AI tools that help screen for rare cardiovascular conditions (eg, cardiac amyloidosis) were the least-often used applications among general cardiologists and cardiology subspecialists (7% each) and IT administrators (20%); those that assist with patient communication were the most-often used applications among these groups (27%, 35%, and 60%, respectively).

In addition to lower levels of current use than cardiology subspecialists, lower proportions of general cardiologists are currently prepared to begin using the applications in clinical practice than cardiology subspecialists and IT administrators (Figure 2B). Current preparedness for employing these tools was least common among general cardiologists (20%–33%),

Table 3 Characteristics of participants in the survey

Characteristic	Cardiologists (n = 90)	IT administrators (n = 30)
Setting, n (%)		
Large, integrated delivery network	34 (37.8)	9 (30.0)
Large, hospital-owned health system (≥500 beds)	46 (51.1)	19 (63.3)
Privately/independently owned	10 (11.1)	2 (6.7)
Medical specialty,[†] n (%)		
General cardiology	30 (33.3)	—
Interventional cardiology	46 (51.1)	—
Advanced heart failure and transplant cardiology	14 (15.6)	—
Time in practice/role, mean (SD), y	14.7 (7.6)	15.5 (6.1)

SD = standard deviation; other abbreviations as in Table 1.
[†]Board certified or board eligible.

followed by IT administrators (23%–43%), and cardiology subspecialists (35%–50%).

Attitudes about AI tools in cardiovascular care

A majority of general cardiologists, cardiology subspecialists, and IT administrators believed that AI can be used effectively to screen large amounts of data to detect abnormalities (85%–87%), increase diagnostic efficiency (77%–83%), and help clinicians avoid missed diagnoses and/or false-negatives (73%–83%) (Figure 3A). More than half of general cardiologists and cardiology subspecialists believed that AI-generated flags in clinical data would require their attention (57% and 68%, respectively), even if the flags are unlikely causes for concern. Fewer than half agreed that AI applications would result in a loss of clinicians' control (40% and 42%, respectively) or too-frequent false alarms (37% and 42%), and lower proportions indicated that AI poses an additional burden for clinicians (27% and 40%).

Across all study groups, a majority (77%–80%) agreed that they need to fully understand the predictors used in the AI model to trust its output, and that well-validated AI applications can dramatically improve outcomes (77%–83%) (Figure 3B). Approximately half of general cardiologists and cardiology subspecialists believed EHR vendors' AI applications do not provide real insights that improve patient management (57% and 48%, respectively) and would be hesitant to use an AI tool developed by a big pharmaceutical company (47% and 57%). Just under half of general cardiologists and cardiology subspecialists were doubtful of the clinical value of AI tools developed with patient populations other than their own (43% and 47%), and lower proportions believed that using race or ethnicity as predictors perpetuates structural racism (33% and 40%).

Deployment processes and AI-related challenges in cardiovascular medicine

More than half of the participants reported that their organizations had specific processes for evaluating new AI

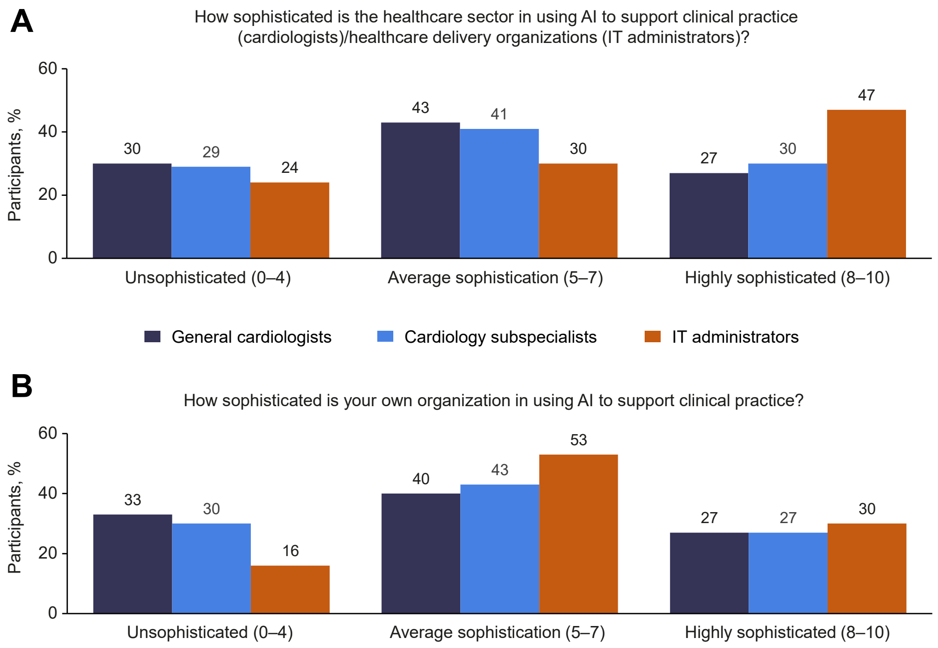

Figure 1 Use of artificial intelligence (AI) in health care. Participants' views of the sophistication of the health care industry in general (**A**), and of their respective organizations (**B**), in using AI. IT = information technology.

technology for potential use in delivering health care (53%–77%) (Figure 4A). When an organization first considers a clinical AI application, clinicians within the clinical department/specialty who will use it are most likely to champion the idea (43%–53%). While more than half of participants reported that chief medical officers or chief medical information officers are more likely than not to have a role regarding the initial evaluation/consideration of an AI application (60%–63%), higher proportions reported that clinical department heads are more likely to be involved in such a decision (77%–80%). Half or fewer reported that leadership changes were likely to hinder the evaluation and adoption of AI technology in their organizations (30%–43%).

Across all study groups, a majority believed that their organizations would only support a new AI application if it were capable of automatically integrating results into the EHR (73%–90%) and if it was associated with net revenue improvement (57%–73%) (Figure 4B). Concerns about the Health Insurance Portability and Accountability Act were common among respondents, even when deploying an AI tool using de-identified patient data (62%–77%). Half or fewer reported that AI tools were too expensive for their organizations to implement (43%–53%), and their organizations would not adopt an AI application for cardiologists because EHRs are too complex and must address the needs of a broad range of users (27%–40%).

Discussion

In this mixed-methods study, we evaluated the current awareness, perceptions, and use of AI-enabled digital health tools in clinical practice, as well as barriers and challenges to their adoption. In interviews with small groups of cardiologists and health IT administrators, we identified several major themes that helped guide our subsequent quantitative research. Specifically, participants recognized that digital health tools are pervasive, but few had a deep understanding of AI-enabled tools. Concerns about the usability of AI tools, their integration into EHRs and clinical workflows, the incompatibility of tools provided by different vendors, and cost were cited as barriers to adoption. Finally, participants indicated that a lack of trust in AI-enabled digital health tools, including their use to assist clinical decision-makers rather than to dictate clinical decisions, and the validity and security of AI-generated data also represent a substantial challenge to the deployment of these tools in cardiovascular medicine.

In a survey of a larger number of cardiologists and IT administrators, we found that tools employing AI were being used by only a minority of cardiologists in larger practices, health systems, and integrated delivery networks, but many more were prepared to implement them. Many respondents believed AI has value in a wide range of clinical decision support and practice management use cases. However, the frequency of use varied widely across applications. Among cardiologists, current use was highest for AI tools supporting radiographic imaging for pathology and patient communication, whereas it was lowest for AI tools that support screening for rare cardiovascular diseases. The latter findings are likely related to the lack of hospital funding for technology that cannot be used across multiple departments. The participants in this survey recognized that numerous challenges and barriers exist, including cost, security and privacy concerns, poor usability, lack of EHR integration, and absence of high-quality evidence supporting the adoption of these technologies as part of clinical care. Findings from this research also underscored differences in the knowledge base, needs,

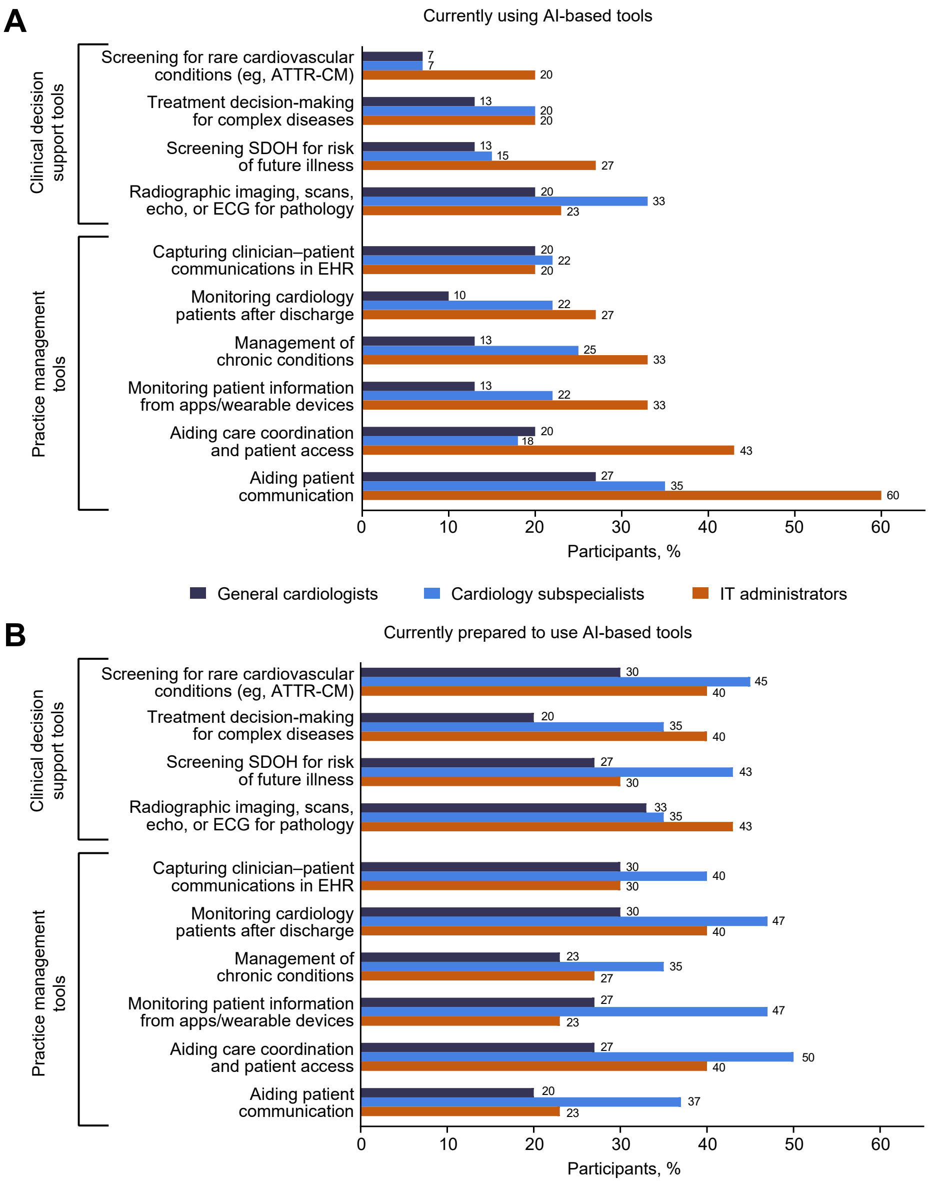

Figure 2 Use of artificial intelligence (AI)-based tools in cardiac care. **A:** Participants who are currently using AI-based tools in cardiac care. **B:** Participants who are currently prepared to use AI-based tools in cardiac care. ATTR-CM = transthyretin amyloid cardiomyopathy; ECG = electrocardiogram; echo = echocardiogram; EHR = electronic health record; IT = information technology; SDOH = social determinants of health.

and attitudes of general cardiologists and cardiology subspecialists, which may represent an additional barrier to broader adoption of AI-enabled digital health tools in the field of cardiovascular medicine.

Other studies have evaluated the current landscape of adoption of AI-enabled tools into clinical practice. In structured interviews with health IT team members at 20 sites, Kashyap and colleagues[14] found a wide range of computational configurations, each with trade-offs, for the development and deployment of AI-enabled tools. In another recent study, in which 37 health stakeholders in AI-enabled digital health tools from health systems were interviewed, Gonzalez-Smith and colleagues[18] found that health system adoption of AI-enabled tools is driven by a range of factors, including "clinical utility, ease of use, and patient safety, but also hospital priorities, interoperability/ease of software integration, physician champions, payment models, and market dynamics." Our study extends these findings by providing more granular data on specific cases, perceptions, and organizational challenges for the adoption of AI-enabled cardiovascular tools in a larger, more diverse sample of health systems and clinical practices.

This study has several noteworthy limitations and strengths. First, we focused on cardiovascular AI tools in medium-to-large health systems and practices, which means our findings may not be generalizable to other settings, eg, smaller systems and practices or non–cardiovascular care settings. Second, the sample included cardiologists and health IT administrators who had previously volunteered for market research and may not be representative of the broader

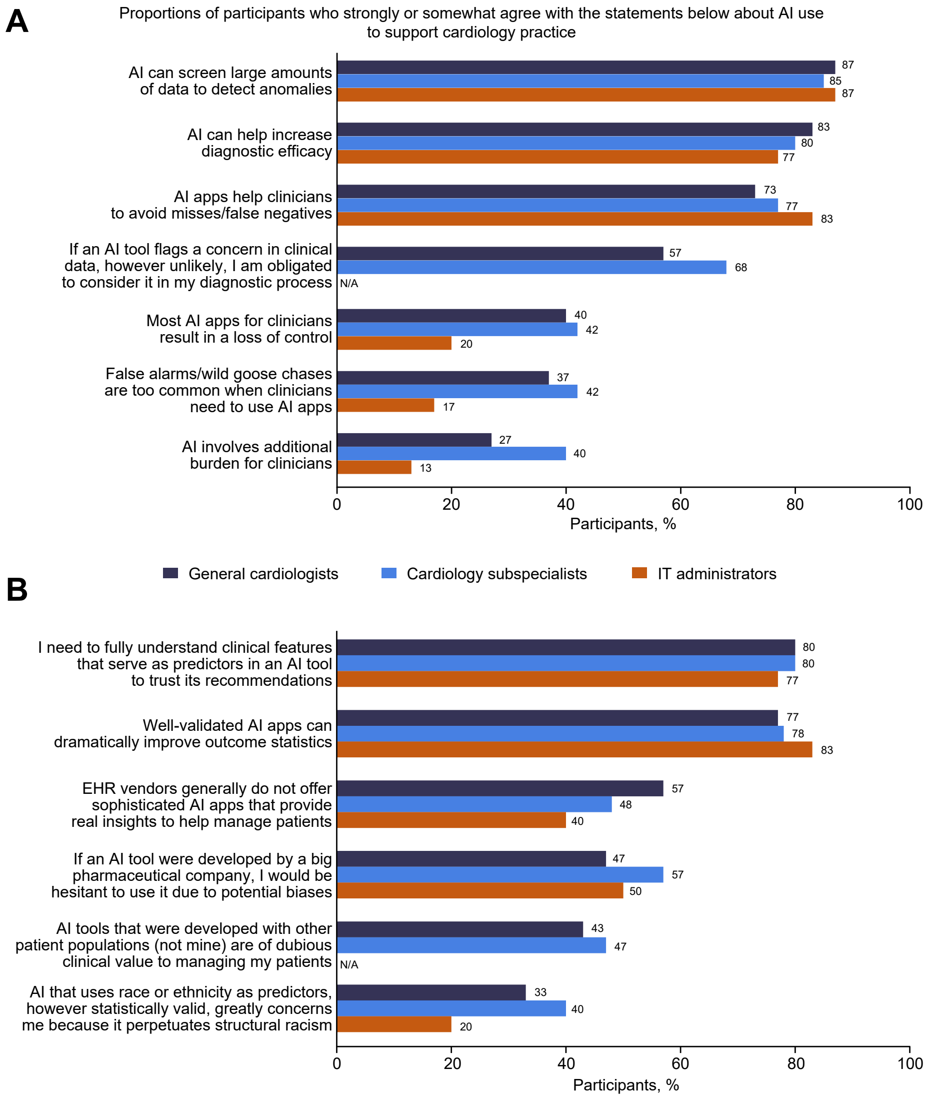

Figure 3 Attitudes about artificial intelligence (AI) efficiency in health care. Participants' attitudes about (**A**) the efficiency of AI tools and clinician control and (**B**) other strengths and limitations of AI tools in clinical practice. app = application; EHR = electronic health record; IT = information technology; N/A = not available.

populations. Third, collecting detailed budget information from participants to further characterize the cost barrier was beyond the scope of this study. Strengths include the relatively large sample size compared to other studies, with data from in-depth interviews of 20 cardiologists and health IT administrators and survey data from 120 cardiologists and health IT administrators.

Conclusion

In summary, in a mixed-methods study, we found that cardiologists and health IT administrators see potential value in the adoption of AI-enabled tools, although numerous challenges and barriers exist. Obstacles such as a lack of standardized approaches to evaluate value to the health system, difficulties with usability and integration into the EHR and workflows, lack of trust in tools by clinicians, and concerns with data privacy and security need to be addressed to support broader adoption of these important resources. Future work is needed to better characterize barriers in diverse care settings and create interventions to address barriers and facilitate the implementation of AI-enabled digital health tools. Additional evidence supporting the clinical or operational value of these technologies is also needed.

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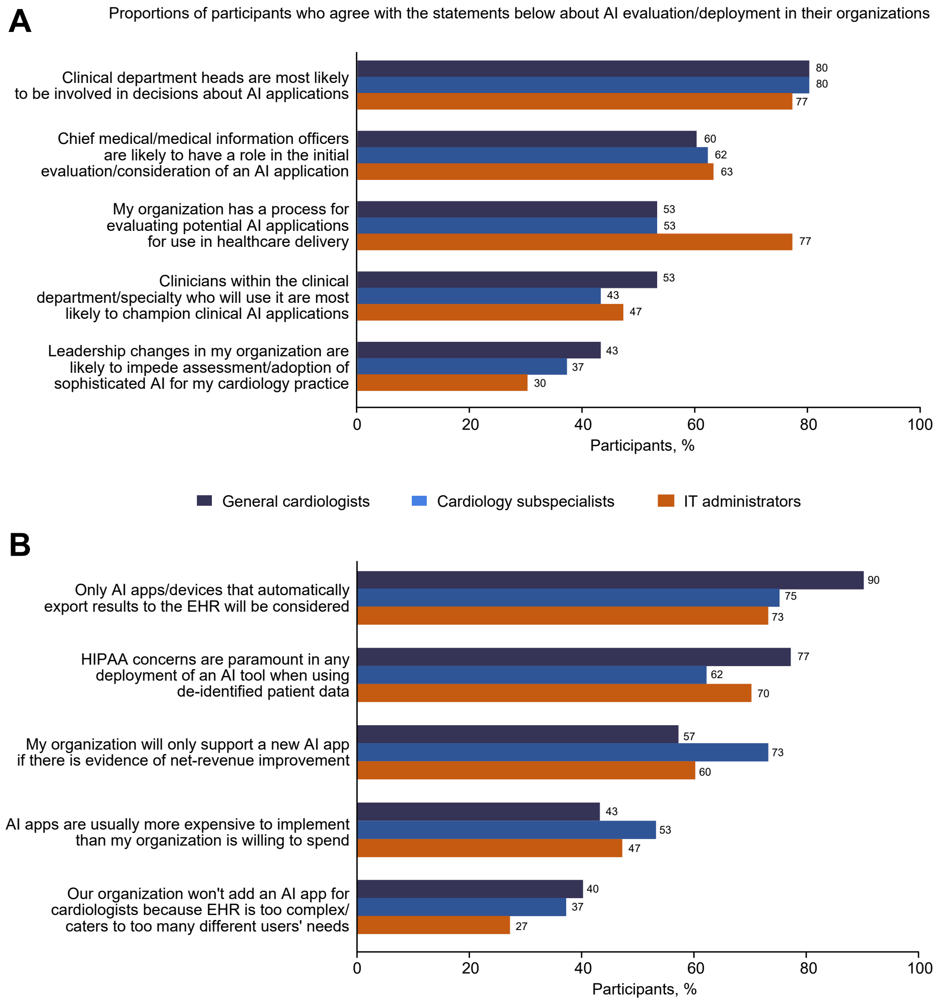

Figure 4 Attitudes about artificial intelligence (AI) evaluation/deployment in health care. Participants' attitudes about **A:** processes and decision-makers involved in AI evaluation and deployment in their organizations and **B:** concerns and features considered when evaluating AI for deployment. app = application; EHR = electronic health record; HIPAA = Health Insurance Portability and Accountability Act; IT = information technology.

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Disclosures

The authors declare no competing nonfinancial interests but the following competing financial interests: Drs Schepart, Burton, and Bhambri are full-time employees of Pfizer and hold stock and/or stock options in Pfizer; Mr Durkin, Ms Fuller, and Ms Charap are employed by an independent research consulting firm, which was contracted by Pfizer to conduct the study; Dr F.S. Ahmad was supported by grants from the National Institutes of Health/National Heart, Lung, and Blood Institute (K23HL155970) and the American Heart Association (AHA number 856917) and has received consulting fees from Pfizer and Teladoc Livongo.

Ethics Statement

This study was determined to be exempt from review by the Advarra Institutional Review Board.

Authorship

Dr F.S. Ahmad wrote the initial draft of the manuscript. All the authors assisted with the interpretation of the data, provided critical revisions for important intellectual content, and approved the final version. All authors attest they meet the current ICMJE criteria for authorship.

Appendix

Supplementary data

Supplementary data associated with this article can be found in the online version at https://doi.org/10.1016/j.cvdhj.2023.04.003

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