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Research paper

The pursuit of health equity in digital transformation, health informatics, and the cardiovascular learning healthcare system

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ABSTRACT

African Americans have a higher rate of cardiovascular morbidity and mortality and a lower rate of specialty consultation and treatment than Caucasians. These disparities also exist in the care and treatment of chemotherapy-related cardiovascular complications. African Americans suffer from cardiotoxicity at a higher rate than Caucasians and are underrepresented in clinical trials aimed at preventing cardiovascular injury associated with cancer therapies. To eliminate racial and ethnic disparities in the prevention of cardiotoxicity, an interdisciplinary and innovative approach will be required. Diverse forms of digital transformation leveraging health informatics have the potential to contribute to health equity if they are implemented carefully and thoughtfully in collaboration with minority communities. A learning healthcare system can serve as a model for developing, deploying, and disseminating interventions to minimize health inequities and maximize beneficial impact.

1. Introduction

Health inequity is one of the greatest injustices in our time. At the dawn of the digital era, there is an opportunity to chart an impactful course to improve outcomes in racial and ethnic minorities. The health of our nation and the world is not only measured by the individuals with the best outcomes, but the optimization of health and well-being in all. While we cannot guarantee ideal cardiovascular health for each human being, we can still strive towards a goal of equitable healthcare in which individuals have autonomy over their health outcomes. We would like to reject disparities as the norm and take meaningful steps towards achieving health equity. Now more than ever before, we have incredible innovations in health informatics, digital transformation, and learning healthcare systems at our fingertips. How do we leverage health informatics for digital transformation in learning healthcare systems to improve health equity?

There are startling disparities between African American and Caucasian patients in cardiovascular medicine, including higher rates of morbidity and mortality and lower rates of receiving specialty consultation and therapy [1,2]. For example, hydralazine and nitrite combination therapy improves survival and reduces hospitalization from heart failure among African American patients [3]. However, this dual therapy is underused, despite its known effectiveness in improving survivorship. In one study, only 13 % of qualifying African American patients received this combination therapy [4]. The persistent racial disparities within heart failure treatment and in the management and prevention of cardiovascular disease and risk factors among African American patients contribute to morbidity and decreased survival [1,2]. These disparities

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extend into the care and treatment for adverse cardiovascular effects from chemotherapy treatments [5–7]. African Americans have higher frequencies of cardiotoxicity compared to Caucasians and are infrequently included in clinical trials to prevent cardiovascular injury from cancer therapies [8–15].

An interdisciplinary and innovative approach will be required to alleviate racial and ethnic disparities in cardiotoxicity prevention [15]. Telemedicine can help overcome impediments to healthcare related to transportation, caregiving needs, out-of-pocket costs, and time away from work [5]. However, challenges including access to reliable broadband Internet and computer devices must be addressed first. Additionally, telemedicine approaches can integrate patient-generated health data to allow for remote monitoring of chronic conditions, increase access to healthcare, improve continuity of care, and enable more efficient, personalized care for patient populations by augmenting patient engagement and the quality of patient-provider communication [16,17]. Health inequities and disparate health outcomes are the results of intersecting factors such as race, gender, socioeconomic status, disability, and geography because of different opportunities for health [18]. Structural inequities shunt individuals into areas with unequal resource distributions and are perpetuated in systems of housing, education, employment, and criminal justice [18,19]. These differences disproportionately impact African American patients, as demonstrated in New York City during the COVID-19 pandemic when ZIP codes that experienced the greatest increases in the number of out-of-hospital sudden deaths included those with a higher proportion of African American residents [20]. Virtual visits and remote information exchange may mitigate these disparities by allowing for more equitable access to specialist medical care to which geography, cost, mobility-impairment, long waits, and other considerations may otherwise be barriers. Further, as digital transformation is implemented, it has the potential to be intentionally developed with a focus on equity, diversity, and inclusion at its inception so that these aims can be woven into its framework rather than added retrospectively.

New technologies in informatics, data usage, and patient engagement in continuous learning health systems are effective tools for countering, managing, and preventing cardiovascular disease in racial and ethnic minorities [22,23]. A learning healthcare system applies scientific knowledge at the time of clinical care while also gathering insights from that care to drive innovation in optimal healthcare delivery and inspire new investigations [22]. To optimally implement this, the existing healthcare system must focus on partnerships between patient populations and health professionals, in the context of a culture of continuous learning [23]. A learning healthcare system can serve as a model for establishing the evidence base for developing, deploying, and disseminating interventions through the measurement and evaluation of population cardiovascular health parameters [23]. The American Heart Association released a Scientific Statement advocating for this approach, asserting that we must maximize the impact of clinical outcomes in learning health systems [23]. Many health-care organizations fund efforts to hasten the transfer of knowledge into practice [24], but to minimize health inequities and maximize helpful impact, doing so in the setting of learning healthcare systems in cardiovascular care will be key [22,23].

Propagation of health inequity is a risk with most new innovations and can dampen excitement [25]. However, health informatics and digital transformation in learning health systems introduce novel possibilities to produce groundbreaking research findings that may be among the missing links in achieving health equity. In this article, we describe various perspectives with commonalities that include the

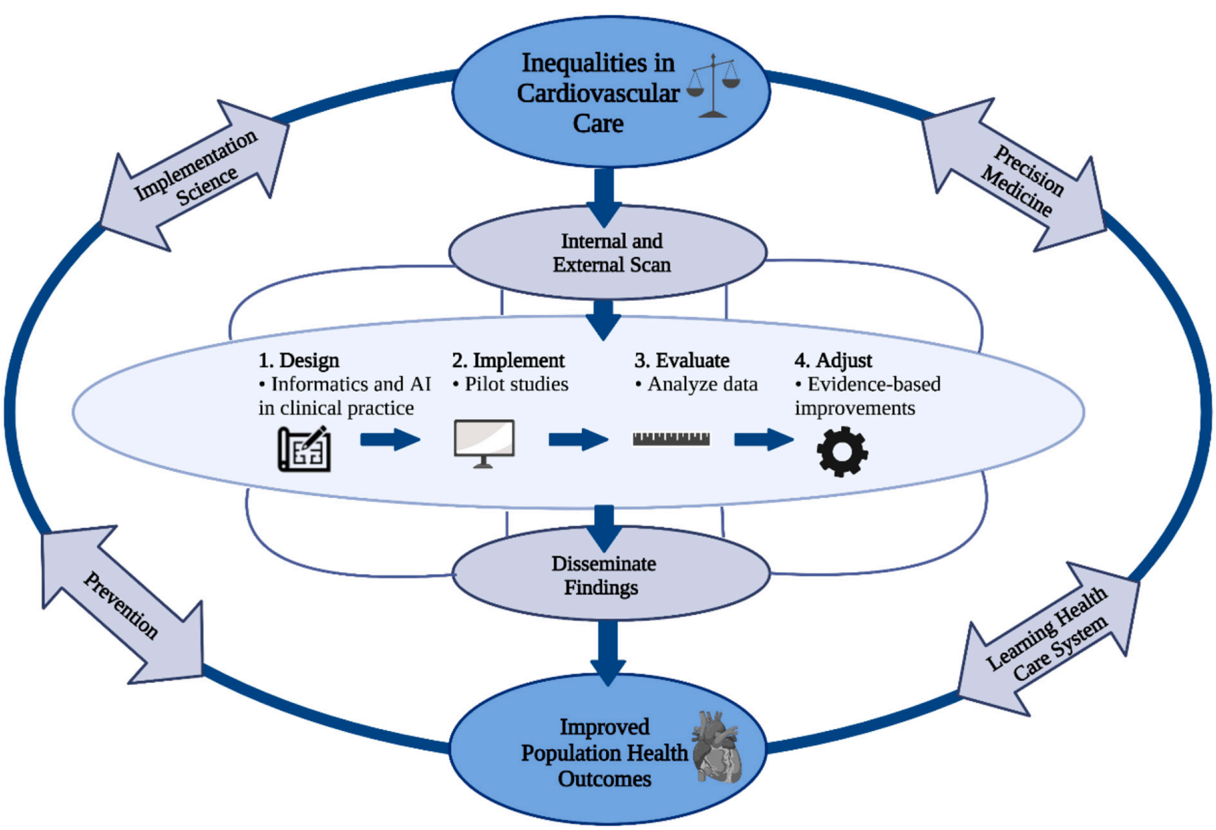


Fig. 1. Promoting Health Equity in Cardiovascular Health, Leveraging Health Informatics for Digital Transformation in a Learning Health System, with Interplay of Precision Medicine and Implementation Science. Interdisciplinary partnerships nurture and support education, clinical practice, and translation of health informatics research into evidence-driven team-based care.
Data in part derived from [23,89,97,102] and used with permission. Created with BioRender.com.

pursuit of health equity in digital transformation, leveraging of health informatics in learning health systems, and the amelioration of racial and ethnic disparities (Fig. 1).

2. Digital transformation

As a rising number of hospitals look to expand their digital footprints to improve efficiency, prevent medical errors, and improve patient communication, there is increasing concern for patients who have limited access to digital health advancements [26,27]. According to the Pew Research Center, 77 % of Americans own a smartphone [26]. A closer examination of the remaining 23 % reveals historically disadvantaged racial and ethnic minority populations who may now be at risk of increasing segregation as healthcare, including cardiology, embraces the digital revolution [26]. Thus, efforts at digital transformation in healthcare, particularly in cardiology and cardio-oncology, should emphasize equitable transformation.

Transformation of healthcare is the result of a unified vision among a wide variety of stakeholders (Fig. 2). Together, stakeholders build a future version of healthcare delivery and construct new models that are patient-centered and evidence-driven and prioritize value over volume [28]. Innovative technological advances are key components of this transformation [28]. Insight is needed to better determine the extent of the challenges facing new healthcare innovations and to effectively overcome these challenges. To inform digital transformation, the American College of Cardiology (ACC) assembled a Healthcare Innovation Summit to listen to concerns and perspectives of various stakeholders across healthcare, including patient advocacy groups, clinicians, investigators, policy, entrepreneurship, and industry [28]. The resulting ACC Health Policy Statement includes a list of healthcare policies and initiatives relevant to emerging healthcare advances [28]. The statement indicates that digital transformation will likely require a convergence of methods that connects the various stakeholders aiming to enhance care delivery [28]. Organizing breakthroughs in digital health, big data, and precision health relevant to research and patient care, as well as sharing resources through stakeholder participation and collaborations will be essential for demonstrating value and exploring effects of these innovations on clinical practice in the greater healthcare community [28].

Among these innovations, a growing range of digital health advances offer physiologic measures accessible to health professionals and allow patients to monitor mobile diagnostic tests [26]. Patients are empowered to collect crucial health data and contribute clinically essential information to physicians as the 'digitization of healthcare' progresses [26]. Indeed, a wide range of new technologies has emerged, such as smartphone-connected devices, wearable and wireless technologies, lab-on-a-chip and new point-of-care human genome-sequencing devices, and data analytics with cloud computing and artificial intelligence, all as part of this transformation [26]. These technologies can provide patients and professionals with near-instant diagnoses and prediction of current health and disease patterns [26]. However, while many of these advancements have the potential to improve patient care, they also have the potential to propagate inequity. The drivers for digital health can be viewed from two perspectives: those of patients and consumers who want to engage in their own health and have data that can inform their clinical interactions by acquiring new digital health tools; and those of healthcare practitioners who need new digital tools and data analytics to reduce healthcare costs, improve outcomes, and increase the efficiency of healthcare delivery by acquiring new digital tools and data analytics [26,29]. For optimal solutions for both perspectives, we need to ensure

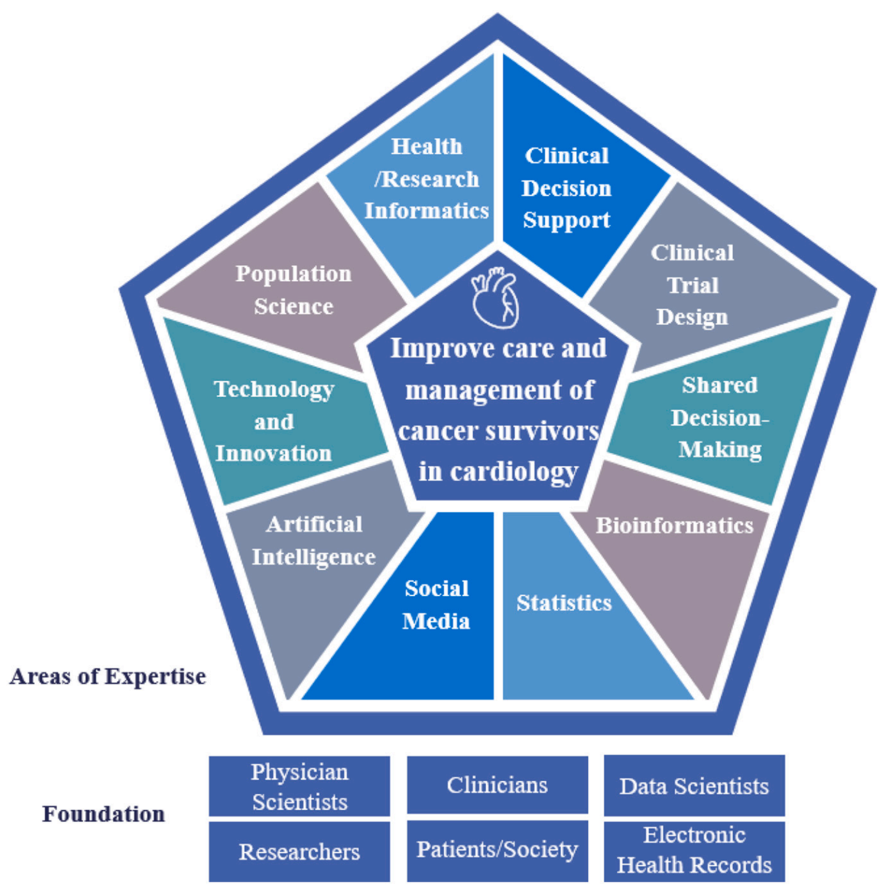


Fig. 2. Foundational stakeholders and expertise to digitally transform care for cancer survivors in cardiology using health informatics for patient care, research, and education. Templates from Infograpia were used in the making of this graphic.

that the voices of racial and ethnic minority populations are heard and invited as key drivers of the process of digital transformation.

Patients, clinicians, and institutions are all committed to starting a digital transformation process that will affect all aspects of healthcare delivery [26]. While existing efforts are vital, clinicians, their patients, and medical professional organizations should take a more active role to ensure that health equity is a central focus at all stages, from designing new technology to engaging in the development of evidence [26]. We may then be better able to answer essential questions, increase our understanding of significant disputes, and communicate information on the technologies that may eventually expand access and close the digital health divide for all populations [26]. The framework must emphasize the ongoing involvement of interdisciplinary and diverse teams of stakeholders, including patients, clinicians, academia, industry, and hospitals, to support research into new insights and develop integration and interoperability methods within current healthcare systems [26]. The need for data transparency and incorporating diverse patient populations early in the development of new devices – factors that could result in better device designs and the application of practical and applicable technologies to a wide range of patient populations – must be promoted [26].

The ACC has advocated for incorporating emerging healthcare innovations such as digital health, big data, and precision medicine into research and patient care [26]. Transformational approaches that employ human-centered design principles for how new innovations are applied within healthcare delivery have been proposed [26]. Supporting clinical validation in a way that is geared towards translating the evidence of those technologies that provide sufficient diagnostic accuracy, effective integration, and cost-effectiveness have also been encouraged [26]. The technologies include telemedicine, digital health, and electronic health records, with anticipated communication among all three. The lack of adequate neighborhood broadband and Internet access, in particular, highlights the creation of a digital gap in electronic health record patient portal utilization [26]. Access to electronic health records by way of patient portals has been used by only 30 % of care beneficiaries at an extensive integrated health system with a statewide sample of >240,000 patients [26,30]. Compared to commercially insured patients, ethnic minorities and those with lower socioeconomic position had considerably lower rates of use [26]. If ubiquitous computer or smartphone technology and Internet connectivity are required for the usability of new digital health solutions, the development, integration, and clinical practice patterns that leverage digital health solutions must address these crucial constraints [26]. We must implement advances in digital health with broad inclusion of urban and rural practices caring for diverse patient populations as we adopt digital transformation [26].

High economic and human resource costs are required in providing digital transformation to individuals in resource-poor neighborhoods. Streamlined funding processes are lacking for establishing transformative health technology initiatives in these areas. However, some grant and loan programs are available with a preference for initiatives to improve healthcare quality and access, including infrastructure (broadband and Internet), community development, affordability, and partnerships in these communities [32–35]. For instance, a telemedicine coverage waiver put into practice during the COVID-19 pandemic had the highest odds of utilization by individuals in the most socioeconomically disadvantaged neighborhoods and increased access to telemedicine for all Medicare populations [21]. Health innovations also require workforces possessing skills and cultural and linguistic competency specific to the communities they serve. In a study assessing workforce-related barriers to rural primary care practices across 13 states implementing and using electronic health records and health information technology, approximately two thirds required more training [36]. Other barriers were affordable access to skilled vendors, consultants, and qualified staff. Additionally, access to the Internet posed a challenge to a quarter of rural practices and almost a fifth of small rural practices [36].

Digital health interventions may help buttress efforts at improving cardiovascular health in minority populations [37–41]. If applied carefully and thoughtfully in partnership with minority communities, digital transformation can potentially revolutionize health equity and play a key role in eradicating health disparities. One factor to be considered is broadband Internet access which has evolved into a social determinant of health. Patient portals, electronic medical records, telemedicine, and remote health monitoring, among other initiatives focused on improving patient health literacy, engagement, and support, are all part of ongoing strategies to improve health care through innovative technologies [42]. Despite these efforts, ethnic and racial minorities still experience health inequities [43]. An observational study of 243,248 adult patients at a large urban public healthcare system reported a disparity in access to patient portals among ethnic and racial minorities essentially based on a lack of broadband and Internet access [43,44]. Another strategy to minimize inequities involves behavioral intervention technologies. These are individualized solutions with real-time, formalized, and tiered information targeting highly motivated participants living with chronic diseases with effective and sustainable self-management tools. In a randomized controlled trial comparing behavioral intervention technology for cardiovascular disease in African American individuals with poor cardiovascular health, 53 % of all participants experienced improvements in BMI, blood glucose, and systolic blood pressure [45]. In a second randomized controlled trial, a smartphone-based application used blood pressure self-monitoring, an electronic medication tray, and culturally tailored messages for hypertensive Hispanic adults. At the nine-month timepoint, 92 % of those using the application met Joint National Committee cutoffs for systolic blood pressure control, compared to only 28 % in the control group [46]. Finally, the All of Us Research Program by the National Institutes of Health is poised to reduce health inequities by providing researchers and healthcare providers with an ethnically and racially diverse database providing inclusive data to foster representative research and precision medical care that transcends beyond ethnicity and race.

Although digital transformation in healthcare is still in early phases, customers, patients, and practitioners will become exposed to more digital environments as time goes on [26]. The key will be to guide how this happens – how we drive 'evidence-based' digital transformations to benefit patients, professionals, and the healthcare system in which all interact [26]. As we implement digital health, patient portals, telemedicine, and other components of digital transformation, we will need to ensure that individuals, families, and communities – populations of people – have direct and equitable access, narrowing the health inequity gap [31].

3. Health informatics

Contributions to health information research integrate both health and information sciences and can lead to well-formed and well-founded clinical research initiatives [47]. Researchers in training, research teams, and researchers and practitioners in the fields of information, health, and other disciplines can all benefit from exposure to health informatics [47]. Health informatics is made up of three components: data, information, and knowledge [48]. While data was once the domain of computer science, today data science in health informatics touches such interdisciplinary sectors as healthcare, economics, media and communication [49]. Hierarchically, data is at the bottom of the model and serves as the foundation for establishing information and, in turn, potentially generating knowledge [48]. Optimal application of health informatics incorporates principles, goals, and tasks of evidence-based medicine [48], ensuring that the knowledge gained from assessing the information provided in the data can be translated to patient care. The technology acceptance model in health informatics is commonly used to understand the adoption of technology by clinical staff and patients, and in the development and implementation of health informatics systems [50]. The model can potentially be applied to a wide range of health information applications, such as best practices alerts and clinical decision aids incorporated into electronic health records to identify and manage individuals at highest risk for adverse cardiovascular events from cancer therapies. The model can also be applied to the adoption of information and communication technology frequently used in medicine, such as telemedicine and mobile health applications [50].

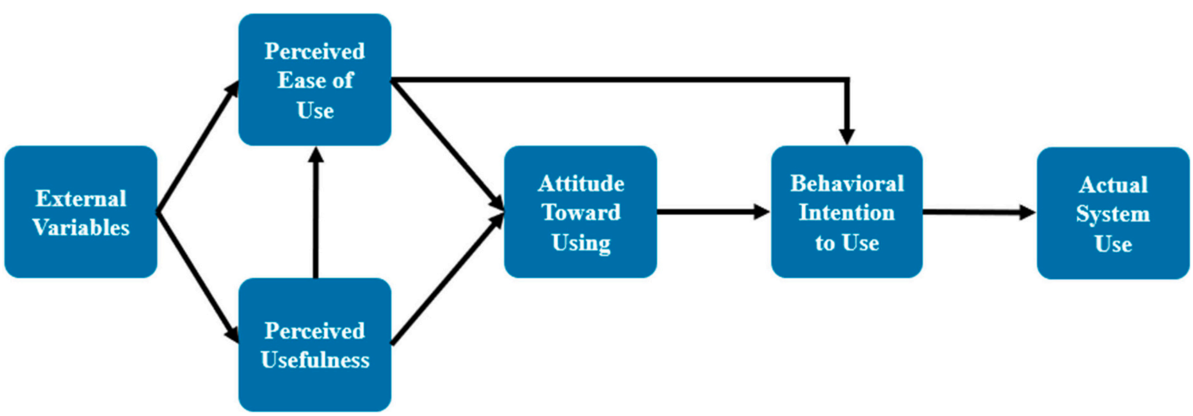
The technology acceptance model may be used as a framework to pursue health equity in health informatics (Fig. 3). Health professional and community representatives and patient advocates from racial and ethnic minorities should assist racially and ethnically diverse researchers with selecting, adapting, and applying appropriate tools to assess perceived ease of use (defined as an individual's belief that using a specific technology will require no effort [51]), perceived usefulness (defined as an individual's belief that using a specific technology will enhance/increase job performance [51]), and attitude towards using specific health informatics technologies (defined as an individual's evaluation/impression towards the use of the technology [52]), as well as behavioral intention to use (defined as an individual's intention/willingness to use the technology [53]), and actual system use (defined as an individual's actual use of technology [53]).

There is a gravitation toward precision and innovation in cardio-oncology, such as studying the use of artificial intelligence technologies to personalize health care, and offering a way for cardio-oncology to optimize risk assessment and care for patients. As these health informatics technologies are adopted and implemented, it will be imperative to avoid the perpetuation of health disparities. Since artificial intelligence systems are often trained on real-world data, the underrepresentation of various racial and ethnic communities in datasets creates a gap of knowledge within these technologies that can propagate healthcare disparities based on race and ethnicity. Therefore, we must be cautious and further investigate the underpinnings of these disparities within healthcare and applied artificial intelligence algorithms to optimize precision care for all racial/ethnic groups [54,55].

As the interdisciplinary cardio-oncology field develops, overcoming health inequities while incorporating innovative health informatics technologies poses a complex problem that will continue to require interdisciplinary solutions. Health informatics curricula have been created to develop skills in at least three types of professionals: applied health informaticians (who implement information technologies), research and development health informaticians (who create novel concepts, methods, and solutions), and clinician health informaticians (who use health informatics functionalities to assist in their health-related jobs) [56–62].

4. Learning healthcare system

A critical public health problem of our day is improvement of the healthcare system to achieve better health outcomes for all [63]. One possible solution is advocating for learning healthcare systems, which align clinical care, science, informatics, and culture for continuous improvement, innovation, and research; capture new knowledge as a byproduct of care; and reliably and seamlessly embed evidence in the delivery process [63] (Fig. 1). Substantial gains in outcomes for healthcare transformation can be achieved, providing valuable research and learning opportunities [63]. Defining this framework and probable mechanisms of action will aid research in testing and refining ideas, as well as guiding practice in developing and optimizing this promising approach to healthcare system improvement [64]. A learning healthcare system is one that seeks to generate and apply evidence, innovation, quality, and value in health care on a continuous basis [65]. Learning healthcare systems carry many opportunities for addressing clinical implementation, practice, and policy [65]. Learning health systems are complex adaptive systems in which all stakeholders can work together to develop and share resources to meet a wide range of demands [64].



Variable	Definition
Core Variables	
Perceived Ease of Use	An individual's belief that using specific technology will require little to no effort (52)
Perceived Usefulness	An individual's belief that using specific technology will enhance/increase job performance (52)
Attitude Toward Using	An individual's impression regarding the use of specific technology (53)
Outcome variables	
Behavioral Intention to Use	An individual's intention/willingness to use the technology (54)
Actual System Use	An individual's actual use of the technology (54)

Fig. 3. Technology Acceptance Model - A conceptual model of elements leading to technological system acceptance.
Used with permission [50].

These results may have an effect on both research and practice [64].

To create a learning healthcare system, communities focused on improving health outcomes with quality improvement methodologies, data collection, closed feedback loops, and community-participatory techniques, supported by information, regulatory, and cultural infrastructures are needed [66]. Building solid infrastructures and teaching a broad range of stakeholders to participate in these unique socio-technical systems are essential to realizing this vision [66]. To encourage advances in the development and adoption of learning health systems, health professionals, researchers, patients and the general public will need to be informed and engaged [67]. Health professional, patient, and community perspectives will need to be gleaned at all stages of the process [67].

Learning health systems have also been proposed as a key strategy for improving value in healthcare, with the goal of leveraging advances in science, technology, and practice to improve health system performance at a lower cost [68]. Learning cycles for evidence-based patient care are employed to strike an optimal balance of impacts on patient and provider experience, population health, and health system costs [68]. The goal is to improve health system performance and deliver greater value in health systems [68] – greater value for all. In spite of the efforts of learning health systems to improve value-based health outcomes, disparities in health outcomes continue [69].

Specifically in cardio-oncology, learning health systems may help facilitate continuously studying and aiming to provide equitable healthcare to all patients. Cancer survivorship continues to rise [70–73], as does the cost of care associated with managing cardiovascular adverse effects of cancer therapies [74]. African Americans have three-fold higher rates of cardiotoxicity in some studies and lower 5-year survival than Caucasians; however, when treated comparably for similar stage cancers, cancer-specific difference between African Americans and Caucasians can be minimal [3,75–77]. Underpinning cancer stage at presentation and also subsequent treatment are themes such as structural racism, implicit and explicit bias, and historically disadvantaged socioeconomic status [15,78].

Learning health systems must evolve and perform in ways that explicitly emphasize ways to combat and avoid disparities, in order to achieve and maintain health equity [69] in medicine, cardiology, and cardio-oncology. Learning health systems could achieve tremendous benefits for equity, if these systems are created with the focus of promoting and achieving health equity in mind [22]. An effective learning health system needs to collect, organize, and analyze an abundant amount of clinical information to provide meaningful insights into healthcare decisions and delivery. For efficient predictive analysis, big data technologies applied to clinical information in health informatics can facilitate healthcare decisions informed by massive pools of clinical data [49]. Yet, the vast potential of learning health systems and health informatics is often compromised by challenges with interconnections among technology, human characteristics, and the socioeconomic environment [47,79]. Health informatics models frequently encounter persistent structural healthcare inequities and disparities, compounded by limited pursuit of data gathering from minority populations [3]. African Americans continue to die from cardiovascular diseases at a higher rate than Caucasians, demonstrating the persistence of racial and ethnic disparities in medicine [80–82]. The comparison of disease rates in cities also indicates health disparities and inequities based on location and socioeconomic class, such as in the city of Milwaukee, Wisconsin, which has higher cardiovascular disease rates particularly among African Americans than other nearby Wisconsin cities [83]. These statistics are alarming, especially with the goal of learning health systems to provide every patient with quality care. While learning health systems can be transformative, these systems must focus on and pursue equity in healthcare.

Limited roadmaps exist for designing, implementing, and evaluating learning health system initiatives, however, a composite guide to system operationalization has recently been synthesized [24] (Table 1).

Table 1
Elements of a learning healthcare system (LHS) development pathway including foundational structure, process components, and impact measures. Constituents identified and explained by [24].

Foundational structure [24] Measurable components vital to the implementation of an LHS [24]	Process components [24] Primary actions and deliverables deriving the value of an LHS [24]	Impact measures [24] Metrics assessing alignment with quadruple aim and effective investment [24]
Personnel & collaborations [24] Individuals and partnerships fostering learning within the organization as well as in connection with external entities [24,91]	Field gap assessment [24] Internal scan and external research of existing procedures and gaps to find areas for improvement and applicable solutions [24]	Evidence to practice delay [24,92] Duration between research innovation and evidence-based practice adoption [24]
Health data system [24] Digital data storage and access system created through compiled clinical care inputs which supplies live access to knowledge and information for clinical application [24,91]	Literature search and application [24] Compile and condense the academic evidence to support the application of these findings to the identified gap [24,93]	Integration of best practices [24] Performance data collection to evaluate system intervention impacts [24,94]
Organization goal alignment [24] Development of actionable organizational objectives at each level within the system to achieve overarching goals [24,91]	Information analysis [24] Synthesize useful conclusions and future research directions using data modeling and investigation [24,95]	Negative-impact practice elimination [24] Removal of system processes found to be wasteful, harmful, inefficient, or ineffective [24,96]
Financing [24] Securing funding for each element of the systemic plan and long term needs to optimize initiative outcomes [24,91]	Care methods [24] Plan best practices that will be practical, pertinent, and based on relevant evidence [24,91,97]	Health outcomes [24] Population health outcomes and methods evaluation [24]
Optimization framework [24] Culture, terms, and structure to facilitate ongoing optimization efforts [24,98]	Stakeholder involvement [24] Involve patients and families to incorporate beliefs, considerations, and viewpoints [24,99]	Patient satisfaction [24] Experience evaluations by persons receiving care [24]
Regulatory oversight [24] Authoritative guidance regarding ethics and quality improvement in clinical and research realms [24,91]	Intervention integration [24] Support implementation of interventions into clinical sites [24,99]	Usage and expense relationship [24,100] Measure of the use of the system by patients multiplied by the cost to facilitate services including equipment, products, and medications [24]
	Revision [24] Accumulate data to evaluate efficacy of interventions and optimize efforts [24,97]	Care team experience [24,85,86] Staff and provider retention, burnout, and satisfaction measures for care and research employees [24]
	Result distribution [24] Disseminate results to share care-improvement strategies [24,97]	Equity outcomes and projects [24,87] Number of projects measuring socioeconomic outcomes and evaluating fairness [24]
	Expert counsel [24] Consultation with field experts to facilitate	Outcome-cost interrelation [24] The program-associated expenses over the

(continued on next page)

Table 1 (*continued*)

Foundational structure [24] Measurable components vital to the implementation of an LHS [24]	Process components [24] Primary actions and deliverables deriving the value of an LHS [24]	Impact measures [24] Metrics assessing alignment with quadruple aim and effective investment [24]
	discovery and education [24,101]	outcomes achieved in education, equity, health, team satisfaction, and care costs throughout the system [24]

Additionally, curricula can be designed to address core competencies identified for researchers who are part of learning health systems [84]. The organization-level development guide charts a path to starting learning healthcare systems, understanding how components of learning healthcare systems interact in applied practice, and reviewing essential practice and research models and approaches to impact measurement [24]. This pathway is based upon the Kaiser Permanente Washington (KPWA) Learning Healthcare System Logic Model and incorporates the foundational structure, process components, and impact measures for the creation of a successful learning health system (Table 1) [24]. The foundational structure comprises vital organizational components which can be tangibly measured to assess preparedness for conversion to a learning health system [24]. Process components are undertakings that produce deliverables through a development practice [24]. Finally, impact measures consist of outputs by the system, which are quantified and assessed for alignment with evidence-based practice objectives derived from health equity, quadruple aim, and project investment measures [24,85–87]. This literature can provide practical guidance for healthcare professionals and organizations developing, implementing, and assessing learning health systems [24].

5. Ethics, governance, challenges, and solutions

Seven practices for pursuing equity through learning health systems also offer guidance to ensure that newly incorporated health systems do not propagate racial and health disparities [69]. These core practices based on theory, data, and experience include: positioning equity as an essential focus of the learning health system; measuring equity; ensuring people with lived experience are leading the work; co-producing output; redistributing power; practicing a growth mindset; and engaging stakeholders and mentors even beyond the healthcare system. Ultimately, adherence to these principles may ensure a sustainable and equitable learning healthcare system in medicine, cardiology, and cardio-oncology.

The World Health Organization (WHO) has also provided core principles to guide the ethical use of new technologies in healthcare, with a focus on artificial intelligence [88]. According to the WHO, artificial intelligence technologies as an example pose an ethical dilemma to the healthcare field. The six core principles to be promoted regarding the ethical use of artificial intelligence technology in healthcare include: protect autonomy; promote human well-being, human safety, and the public interest; ensure transparency, explainability, and intelligibility; foster responsibility and accountability; ensure inclusiveness and equity; and promote artificial intelligence that is responsive and sustainable. While the WHO developed these principles for artificial intelligence technologies, it is imperative that these principles are also applied to other health informatics technologies and implemented in learning healthcare systems for predictive analytics and digital transformation. Any technology that can predict and inform decision-making presents this ethical dilemma, including learning healthcare systems, and designers of these systems should embody these principles to ensure that these systems are ethical and sustainable for advancing equity.

Applications of artificial intelligence can potentially beneficially impact public health by improving diagnosis and narrowing the healthcare accessibility gap. Yet, there is an ethical dilemma that coincides with these benefits. The WHO recognized that a strong commitment must be made to overcome biases embedded in data used to train algorithms in healthcare systems and services based on race, ethnicity, age, and sex [88]. The rapid proliferation of artificial intelligence technologies has also created a new space that is largely unregulated. Incorporation of these technologies into learning healthcare systems could facilitate situations in which patients and healthcare providers are unaware of how artificial intelligence technology arrives at a decision, leading to blind followership. This complete dependency on artificial intelligence technologies to reach healthcare decisions is especially concerning if the model is trained on data that contains existing biases. Focused efforts should be made to eliminate bias in medicine, cardiology, and cardio-oncology, and especially in algorithms with potential to overcome rather than advance perpetuate racial and ethnic disparities and health inequities. Increasing the accessibility of technologies for cardio-oncology care among racial and ethnic minorities will increase the representation of these marginalized groups and provide more data that learning healthcare systems can use to address health equity in cardio-oncology. Persistent and collaborative efforts will be key to continue to study and provide excellent care for all patient populations.

6. Conclusion

Effectively leveraging technology to achieve health equity is a golden opportunity in biomedical research. In this paper, we propose three core strategies to ensure that technology is a key player in eradicating, not exacerbating, racial and ethnic health disparities. Clinicians and scientists should be exposed to health informatics curricula, with an emphasis on recognizing and addressing health disparities, and encouraged to integrate these approaches into their own specialties. Learning healthcare systems that align clinical care, science, and informatics and allow for continuous evaluation, measurement, and growth will allow identification of disparate outcomes, and encourage development of solutions. Centering ethical considerations and engaging stakeholders beyond the healthcare system are critical. High-quality and efficient care based on artificial intelligence, precision medicine, and other health informatics advances will depend on collaboration among researchers, physicians, and other health care professionals and stakeholders embracing the learning health care system concept and investing time and resources to bring it to fruition [89]. Although precision medicine and many other forms of health informatics crucial to digital transformation and personalized care are in their infancy, implementation in learning health care systems can potentially turn the overarching vision for health equity from attractive ideas to an actual reality for improving both individual and population health around the world [89,90] (Fig. 1).

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Author contributions

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Interpretation of data: SAB, CH, AH, GB, KL, JO.
Critical revision: SAB, JO.
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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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