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DIGITAL MANAGEMENT OF HEART FAILURE IN AGING SOCIETIES: HEALTH SYSTEM TRANSFORMATION AND SOCIAL IMPLICATIONS - A NARRATIVE REVIEW

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ABSTRACT

Heart failure (HF) represents a multisystem syndromic challenge that imposes significant clinical and economic burdens on aging societies, with global costs estimated at US $284.17 billion. Conventional hospital-centered care paradigms are limited by episodic and reactive frameworks that frequently fail to detect physiological decompensation during critical post-discharge phases. This narrative review synthesizes evidence focusing primarily on the 2016-2026 period, while integrating foundational seminal studies dating back to 2006, to evaluate the interdisciplinary impact of digital health interventions on HF management. Empirical findings demonstrate a fundamental shift toward proactive, pathophysiology-driven care supported by remote patient monitoring, implantable sensors, and artificial intelligence. Key clinical outcomes include a hazard ratio of 0.80 for unplanned hospitalizations in landmark telemedical trials and a 92.5% diagnostic accuracy for neural network models. Organizationally, hybrid "Hospital-at-Home" models and transition-of-care coaching have demonstrated significant reductions in readmissions. This review concludes that a sustainable digital transformation is contingent upon achieving alignment between technological capability, longitudinal economic reimbursement models, and robust governance to resolve the technological equity ("Techquity") divide affecting high-risk aging populations.

KEYWORDS

Heart Failure, Remote Patient Monitoring, Digital Health, Artificial Intelligence, Health Equity, Aging

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1. Introduction

Heart failure (HF) is increasingly recognized as a global pandemic, representing a multisystem, progressive syndrome that imposes a profound and escalating strain on modern healthcare infrastructures (Noci et al., 2025). As noted by these authors, the clinical trajectory of HF is fundamentally defined by a fluctuating course of recurrent decompensation episodes, each of which significantly increases the risk of mortality and compounds the physiological challenges faced by the patient. Furthermore, current evidence characterizes the condition as a primary driver of global morbidity and healthcare expenditure, a reality largely precipitated by the high frequency of unplanned hospital admissions. Within the context of contemporary aging societies, HF has emerged as an urgent systemic concern, with its prevalence and associated disease burden concentrated heavily in individuals aged 65 years and older (Noci et al., 2025). The progressive nature of the syndrome, coupled with the demographic shift toward an aging population, has created a critical scenario where successive hospitalization events not only contribute to high all-cause mortality but also represent a significant and potentially unsustainable economic drain on health systems (Myhre et al., 2024; Paulson et al., 2023).

The economic strain of managing HF constitutes a critical dimension of this systemic burden. Global estimates place the economic cost of HF in 2021 at approximately US $284.17 billion, a figure that encompasses both direct medical expenditures and substantial indirect costs associated with lost productivity (Darvish et al., 2025). The majority of direct costs are generated by hospital admissions, which are reported to account for between 69.4% and 80% of total HF-related spending (Pathak et al., 2022; Seto, 2008). This financial concentration highlights the acute vulnerability of current health systems to the high rehospitalization rates characteristic of the disease. In addition to mortality risks, the frequency of these admissions serves as a primary metric for the failure of standard outpatient management to maintain clinical stability in advanced stages of the syndrome.

Traditional care models in HF management are predominantly characterized by an episodic, reactive, and hospital-centered paradigm (Noci et al., 2025; Singhal et al., 2021). These conventional strategies rely heavily on scheduled, intermittent clinical assessments conducted during infrequent outpatient visits (Noci et

al., 2025). Such a framework is fundamentally limited by its reliance on the patient's clinical manifestation of symptoms to trigger medical intervention. Consequently, traditional management frequently fails to detect physiological deterioration during the vulnerable phase following hospital discharge, when the risk of readmission is highest. Because decompensation is often identified only after significant pathophysiological changes have already occurred, these infrequent follow-ups result in delayed treatment adjustments and suboptimal outcomes (Noci et al., 2025).

The emergence of digital health interventions (DHIs) represents a fundamental pivot toward proactive and predictive management strategies (Obonna et al., 2025). These technologies - encompassing remote patient monitoring (RPM), implantable hemodynamic monitoring systems, wearable biosensors, and mobile health (mHealth) applications - enable the integration of continuous physiological data streams into clinical decision-making (Koehler et al., 2018; Noci et al., 2025). By facilitating the real-time monitoring of body weight, blood pressure, heart rate, and pulmonary artery (PA) pressure, digital tools provide a longitudinal view of the patient's status that traditional episodic visits cannot replicate (Abraham et al., 2016; Koehler et al., 2018). This shift allows for the earlier detection of clinical deterioration, creating a critical window of opportunity for intervention. Evidence suggests that subclinical physiological shifts can be identified several days before acute symptoms emerge, while certain wearable biosensors can predict hospitalization with a lead time ranging from 6.5 to 32 days (Noci et al., 2025).

Parallel to these monitoring capabilities, the integration of artificial intelligence (AI) and predictive analytics is reconfiguring the diagnostic landscape of HF management. AI-driven neural network models have attained diagnostic accuracies as high as 92.5% in identifying early-stage symptoms, providing clinicians with sophisticated tools to interpret complex data from wearable sensors and electronic health records (Udoy & Hassan, 2025). These technologies facilitate precise risk stratification and support targeted therapeutic strategies by interpreting non-linear interactions within physiological data. The shift from reactive to predictive care is thus predicated on the constant availability of data, allowing for interventions to be initiated in response to subclinical markers of congestion rather than waiting for the manifestation of end-stage clinical symptoms.

However, the digitalization of HF management is increasingly recognized not merely as a technical upgrade, but as a profound structural transformation of the healthcare system. This transformation involves a significant organizational redesign, as seen in the development of "Hospital-at-Home" (HaH) models and advanced care programs that decentralize high-acuity treatment (Bosman et al., 2025; Paulson et al., 2023). These hybrid models reconfigure the home environment as a formal clinical workspace, supported by virtual command centers that provide 24/7 specialized oversight (Paulson et al., 2023). Such a shift redefines the clinical workflow and necessitates a fundamental redistribution of labor. The success of digital management relies on "invisible work" - the unrecognized technical and administrative adjustments made by both clinicians and patients to manage daily data flows (Trupia et al., 2021). Patients are transitioned from passive recipients of care into active "co-producers" of health data, a role that introduces a new cognitive and domestic labor burden (Trupia et al., 2021).

The economic restructuring associated with digital HF management also introduces a complex time-horizon tension. While these programs demonstrate potential through a reported return on investment (ROI) of 22.2% and net savings per patient-year, long-term cost-effectiveness is often contingent on extended horizons of up to 20 years (Darvish et al., 2025; Grustam et al., 2018; Zhang et al., 2025). This creates a conflict between the long-term needs of aging societies and the short-term political and budgetary cycles of most health systems. Furthermore, the large-scale implementation of these technologies introduces significant social and governance challenges. Digital health innovations may inadvertently widen existing health disparities through the "Techquity" divide (Johnson et al., 2023), where access to care is moderated by digital literacy, socioeconomic status, and geography (Kim et al., 2024). Barriers such as digital literacy and sensory or cognitive deficits in the oldest-old population can impede equitable access, as evidenced by the finding that 72% of patients over age 85 report difficulties with video-based digital tools (Masterson Creber et al., 2023; Myhre et al., 2024).

Ethical and regulatory concerns further complicate this systemic transformation. The deployment of AI is constrained by risks of algorithmic bias, where training data may not be representative of diverse demographics, potentially leading to diagnostic unfairness in low-resource settings (Cau & Pisu, 2025; Joseph, 2025). Jurisdictional fragmentation, specifically the jurisdictional divide between data access rights under frameworks like the EU General Data Protection Regulation (GDPR) and US Health Insurance Portability and Accountability Act (HIPAA), poses a challenge to the institutional legitimacy and interoperability of digital health systems (Cohen et al., 2020). Additionally, the connectivity of medical devices introduces documented cybersecurity risks, such as the

unauthorized alteration of medication doses in connected infusion pumps (Ok, 2025). These interdisciplinary dimensions highlight that clinical efficacy is inextricably linked to the structural determinants of health and the legal-regulatory frameworks governing their implementation (Singhal et al., 2021).

The aim of this narrative review is to critically assess how digital technologies are transforming HF management in aging societies by integrating clinical, economic, organizational, and social dimensions. Specifically, this review evaluates the structural sustainability of proactive care models, the redistribution of labor within clinical workflows, and the equity implications of the digital divide. By synthesizing evidence from landmark trials, economic evaluations, and sociological frameworks, this paper seeks to identify the conditions necessary for a responsible and equitable systemic transformation. Ultimately, this review aims to provide a multidimensional analysis of digital HF management, ensuring that the quest for clinical precision remains grounded in the pursuit of diagnostic fairness and health equity.

2. Methodology

2.1 Study Design

The present study utilizes a comprehensive narrative review methodology to synthesize the interdisciplinary landscape of digital HF management within the context of rapidly aging global societies. This research design was selected as the most appropriate framework for addressing the multidimensional nature of the topic, which necessitates the integration of evidence from diverse fields, including clinical cardiology, health economics, organizational sociology, and medical law. Unlike a systematic review, which is typically constrained to answering a narrow clinical question through quantitative aggregation, the narrative approach facilitates an interpretative and thematic synthesis. This allows for a holistic evaluation of how technological innovations, such as RPM and AI, drive broader health system transformations and produce complex social implications. The primary objective of this methodology is to provide a cohesive narrative that connects clinical efficacy with structural sustainability, economic feasibility, and equity-focused governance.

2.2 Evidentiary Corpus and Scope

The evidence base for this review is derived from a defined corpus of peer-reviewed academic materials, comprising approximately 88 unique documents provided for forensic analysis. The literature selection strategy focused primarily on the decade between 2016 and 2026 to capture the most recent advancements in digital acceleration, sensor miniaturization, and AI-driven predictive analytics. However, foundational seminal trials and cost-analysis frameworks (e.g., Coleman et al., 2006; Seto, 2008) were selectively included to provide necessary longitudinal context for health system transition models and the evolution of economic evaluation in telehealth.

This evidentiary corpus was specifically curated to reflect the interdisciplinary scope of the research problem, encompassing high-impact randomized controlled trials (RCTs), health-economic evaluations, retrospective cohort analyses, pilot implementation studies, and governance-focused reviews. By prioritizing both landmark trials that provide the clinical backbone of the review (such as TIM-HF2 and CHAMPION) and contemporary implementation science, the review ensures that the synthesis is grounded in a robust set of empirical data without claiming the exhaustive, external database search protocols characteristic of systematic methodologies.

2.3 Analytical and Thematic Framework

The synthesis of the identified corpus was structured through a socio-technical systems perspective, recognizing that the digitalization of HF care is a complex interaction between technological capabilities and social or organizational structures. Consequently, the analysis was organized into five core thematic pillars: digital technologies in HF management, health system organization, economic cost-effectiveness, social implications in aging societies, and ethical and regulatory considerations. These themes were not pre-defined in a rigid manner but emerged through an iterative process of reading and analytical integration of the corpus.

This thematic framework allows for a multi-layered interpretation of the data. For instance, clinical outcomes regarding mortality reduction are analyzed in conjunction with organizational findings on labor redistribution and the "invisible work" required to sustain such outcomes. Similarly, economic findings on ROI are evaluated alongside social findings regarding the "Techquity" divide and the specific usability barriers faced by the oldest-old population. This approach ensures that the review remains analytically rigorous while fulfilling its goal of providing a systemic interpretation of how DHIs reconfigure the foundations of cardiovascular care.

2.4 Data Extraction and Synthesis Approach

Data extraction was performed with a focus on capturing both high-precision quantitative metrics and nuanced qualitative insights. From the clinical and economic literature, key outcomes - including Hazard Ratios (HR), Incidence Rate Ratios (IRR), Incremental Cost-Effectiveness Ratios (ICER), and ROI - were extracted directly to ensure the empirical density of the Results section. Special attention was paid to subgroup data, particularly those involving comorbid conditions like diabetes or specific age-stratified barriers, to highlight the heterogeneous impact of digital interventions.

The synthesis approach was primarily narrative and interpretative. No statistical re-analysis or meta-analysis was conducted; instead, the study prioritized internal coherence and the structural interpretation of documented findings. Qualitative evidence regarding workflow redesign, transition coaching, and patient adherence was synthesized to illustrate the systemic shifts in care delivery. By integrating these varied data types, the review constructs a "thick description" of the digital transformation process, emphasizing the conditions under which technological efficacy translates into sustainable health system improvements.

2.5 Methodological Limitations

As a narrative review, several methodological limitations must be acknowledged to maintain academic transparency. First, the review is interpretative by nature, meaning that the synthesis reflects a specific analytical perspective on the socio-technical landscape of HF. Second, the evidentiary corpus, while extensive, is non-exhaustive; it contains the most significant landmark trials and interdisciplinary frameworks available in the provided materials but does not represent the entirety of the global HF literature. Furthermore, the review includes a high degree of heterogeneity in study designs, ranging from multi-center RCTs to small-scale pilot cohorts, which limits the ability to draw uniform conclusions across all healthcare settings.

Finally, this review did not employ a formal risk-of-bias assessment or a systematic screening protocol (such as PRISMA), as its goal was the integration of established evidence rather than the exhaustive mapping of a clinical field. These selection constraints are inherent to the narrative format but are mitigated by the rigorous forensic verification of the data presented and the explicit focus on interdisciplinary transparency. The methodology thus serves as a reliable, grounded framework for evaluating the complex systemic shifts currently defining HF management in aging populations.

3. Results

3.1 Digital Technologies in Heart Failure Management

Synthesis of the clinical evidence suggests that a core paradigm shift is occurring in HF management, moving away from episodic and reactive models toward predictive strategies centered on physiological drivers. The integration of RPM, AI applications, and implantable hemodynamic sensors serves as the primary foundation for this evolution. A pivotal study in this transition is the Telemedical Interventional Management in Heart Failure II (TIM-HF2) trial, which was an unmasked, prospective, randomized controlled trial that recruited 1,538 participants from 165 cardiology practices and hospitals throughout Germany (Koehler et al., 2018). The trial included patients in New York Heart Association class II or III, with a left ventricular ejection fraction (LVEF) of 45% or less, or those with an LVEF higher than 45% if they had been hospitalized for HF within the previous 12 months. Under the study protocol, participants were required to perform daily assessments of heart rate, weight, blood pressure, and ECG, while concurrently utilizing a tablet-based interface to report their general health status.

At the 365-day median follow-up point, the TIM-HF2 trial demonstrated a significant decrease in the primary endpoint, which represented the percentage of days lost to all-cause mortality or unplanned cardiovascular-related hospitalizations. In comparison to the 24.2% days lost in the usual care group, the RPM group recorded 17.8%, resulting in a HR of 0.80 (95% CI 0.65 to 1.00; $p = 0.046$). Furthermore, all-cause mortality was absolute and notably lower for the RPM cohort at 8% (61 of 765 participants) versus 11% (87 of 773 participants) for those receiving standard care (Koehler et al., 2018). Further pre-specified subgroup analyses confirmed that these clinical benefits were maintained across the LVEF spectrum. Specifically, the IRR values for the primary endpoint were 0.72 (95% CI 0.58 to 0.89) for patients with heart failure with reduced ejection fraction, 0.85 (95% CI 0.55 to 1.31) for heart failure with mildly reduced ejection fraction, and 0.93 (95% CI 0.66 to 1.31) for heart failure with preserved ejection fraction (Kerwagen et al., 2023). Additionally, a post-hoc analysis of 654 patients from the same trial with comorbid diabetes demonstrated an HR for all-cause mortality of 0.52 (95% CI 0.33 to 0.82; $p = 0.004$), suggesting that the RPM intervention may be particularly efficacious in managing complex, multi-morbid phenotypes (Koehler et al., 2024).

Evidence from the CHAMPION trial provides a parallel perspective on invasive monitoring, specifically regarding the CardioMEMS™ HF System and its implantable PA pressure-guided sensor. Over an 18-month randomized phase, the trial demonstrated a 33% reduction in hospital admissions related to HF (HR 0.67; 95% CI 0.55 to 0.80; $p < 0.0001$) (Abraham et al., 2016). Peer-reviewed follow-up of the trial cohort confirmed a robust safety profile, reporting high freedom from device - or system-related complications and an absence of sensor failures throughout the study duration (Abraham et al., 2016). The mechanism of action for such systems involves identifying subclinical increases in PA pressure that precede clinical symptoms of congestion, facilitating pre-emptive medication adjustments to maintain stability (Abraham et al., 2016).

The field of non-invasive monitoring has similarly progressed through the deployment of mHealth applications and wearable biosensors. Findings from the HEART-HF study indicate that smartwatches utilized for monitoring subclinical physiological changes can predict HF-related hospitalizations with a lead time ranging from 6.5 to 32 days (Noci et al., 2025). The SMART-CARE study protocol emphasizes a multisensory approach, integrating data from the EmbracePlus wristband and Polar H10 chest sensors to achieve a targeted 20% reduction in hospitalizations through early decompensation detection (Ciccarelli et al., 2025). Accuracy in symptom recognition is further enhanced by AI; neural network models have attained a diagnostic accuracy of 92.5% in identifying early-stage HF symptoms (Udoy & Hassan, 2025). However, clinical heterogeneity remains a factor, as some meta-analyses of broader RPM implementations show relative risk reductions of 20% in HF-related hospitalizations (RR = 0.80; 95% CI 0.77 to 0.84; $p < 0.0001$), while others note varied effects depending on the intensity of the telemedical support (Ezimoha et al., 2025).

3.2 Impact on Health System Organization

The integration of DHIs facilitates a structural reorganization of healthcare systems, moving care away from hospital-centered crisis management and toward community-based, longitudinal maintenance. This transformation is driven by the shift from scheduled, periodic clinical visits to data-driven clinical decision-making. Synthesis of the evidence suggests that this integration creates a window of opportunity to intervene several days before hemodynamic decompensation leads to acute symptoms requiring emergency admission (Noci et al., 2025).

One of the most distinct organizational shifts identified in the corpus is the emergence of hybrid care models, specifically HaH and advanced care programs. The DZThuis pilot study, a retrospective single-center cohort evaluation involving 47 patients, reported that home-based intravenous diuretic treatment for acute HF decompensation was both feasible and safe. The study observed a 30-day readmission rate of 6% in the HaH group compared to 17% in a conventional in-hospital comparator group (Bosman et al., 2025). Similarly, the Mayo Clinic's Advanced Care at Home (ACH) program utilized a virtual command center staffed by physicians and nurses to coordinate high-acuity care across urban and rural sites. This program reported 0% mortality during the intervention period and a 30-day readmission rate of 9.7% (Paulson et al., 2023).

Structural transformation is also evident in transition-of-care models. The Care Transitions Intervention trial, which enrolled 750 community-dwelling adults aged 65 and older, demonstrated that transition coaching led to significantly lower rehospitalization rates at 30 days (8.3% vs. 11.9% in usual care) and maintained benefits at 180 days (Coleman et al., 2006). These organizational changes necessitate a redistribution of clinical labor and the recognition of "invisible work" - the unrecognized technical and administrative adjustments made by clinicians and patients to manage daily data flows and device technicalities (Trupia et al., 2021). The organizational redesign required to support these flows often involves telemedical centers that provide 24/7 specialized oversight, as seen in the TIM-HF2 model, where specialized nurses and physicians acted as a bridge between the patient and their primary care provider (Koehler et al., 2018).

3.3 Economic Consequences and Cost-Effectiveness

HF represents a substantial global economic burden. In 2021, the global cost was estimated at US $284.17 billion, comprising 48.16% direct costs and 51.84% indirect costs (Darvish et al., 2025). Hospital admissions remain the primary cost driver, representing 69.4% to 80% of total direct HF-related expenditures (Pathak et al., 2022; Seto, 2008). Economic evaluations of digital interventions show varied results depending on the perspective and time horizon. An analysis of the TIM-HF2 trial from a payer perspective found that RPM was associated with an average gross saving of €3,125 per patient-year. After accounting for the costs of the telemedical intervention, the net saving remained €1,758 per patient-year (Sydow et al., 2022).

For invasive technologies, cost-effectiveness analyses using data from the CHAMPION trial reported ICERs ranging from $12,262 to $29,593 per quality-adjusted life-year (QALY). These values meet established willingness-

to-pay standards in the United States (Martinson et al., 2017). Observational evaluations of regional programs, such as the HerzMobil Tirol in Austria, showed that patients gained an average of 42 additional days free of hospitalization and 40 extra days of life over a one-year period (Egelseer-Bruendl et al., 2024).

Long-term economic sustainability is often assessed through Markov modeling. One systematic review and Markov simulation indicated that home telemonitoring reached cost-effectiveness at a threshold of approximately €14,000 per QALY over a 20-year horizon (Grustam et al., 2018). Additionally, specialized remote monitoring programs have reported a potential ROI of 22.2% (Zhang et al., 2025). Despite these positive trends, decision uncertainty remains a factor; meta-analyses of 38 trials indicate that healthcare cost reductions vary widely, from 1.6% to 68.3%, emphasizing that the economic impact is highly dependent on the health system's existing infrastructure and reimbursement models (Seto, 2008).

3.4 Social Implications in Aging Societies

The social impact of digital HF management is characterized by a tension between technological potential and the structural barriers of aging. Access to digital care is frequently moderated by digital literacy and the Techquity divide (Johnson et al., 2023). Evidence indicates that 72% of patients over age 85 report difficulties with video-based telehealth due to sensory or cognitive deficits (Masterson Creber et al., 2023; Myhre et al., 2024). This demographic stratification suggests that digital innovations may inadvertently widen health disparities based on age and socioeconomic status (Kim et al., 2024).

Adherence and usability are critical metrics for success in older populations. A study of older adults with a mean age of 65 reported that adherence to wireless wristwatch-based monitoring remained stable at 77% over six months (Evans et al., 2016). Perceived usefulness was identified as the primary driver of adoption intention (standardized regression weight $\beta = 0.33$), followed by social influence ($\beta = 0.17$) and perceived ease of use ($\beta = 0.16$) (Cajita et al., 2017). Psychological effects are also documented; digital health use in rural settings was associated with increased patient anxiety in 40% of trials analyzed in one systematic review, likely due to a perceived loss of direct clinical contact (Azizi et al., 2024).

Health literacy is an independent risk factor for mortality in HF, yet it is rarely assessed formally in digital health trials (Ionescu et al., 2025). In regions characterized by social exclusion, supervised monitoring has been associated with improved functional capacity and significant changes in quality of life (QoL) (Wańczura et al., 2025). A systematic review of 14 studies found that nine reported statistically significant improvements in QoL after digital intervention, frequently measured by the Minnesota Living with Heart Failure Questionnaire (MLHFQ), where a 5-point change is considered clinically meaningful (Obonna et al., 2025).

3.5 Ethical, Regulatory, and Equity Considerations

Ethical and governance challenges are central to the large-scale implementation of AI and digital monitoring. The deployment of AI in HF management is constrained by algorithmic bias, particularly in low-resource settings where training data may not represent local demographics (Cau & Pisu, 2025; Joseph, 2025). Skewed data can lead to incorrect symptom recognition in diverse ethnic groups, potentially exacerbating health inequalities (Cau & Pisu, 2025).

Regulatory frameworks face challenges regarding medical liability. The "black box" nature of AI algorithms creates ambiguity as to whether responsibility for diagnostic errors lies with the software developers, the clinicians, or the healthcare institution (Cestonaro et al., 2023). Regulatory efforts to address these gaps include the EU Artificial Intelligence Liability Directive and the AI Act (Cestonaro et al., 2023). Jurisdictional fragmentation also persists; the EU GDPR and California Consumer Privacy Act (CCPA) grant patients broader raw data access than the US HIPAA Privacy Rule (Cohen et al., 2020).

Cybersecurity is a documented risk, as medical device connectivity exposes systems to potential threats. Specific risks include the unauthorized alteration of medication doses in connected infusion pumps (Ok, 2025). Furthermore, pervasive surveillance through continuous monitoring may infringe upon patient autonomy, leading to calls for transparency dashboards to maintain trust (Muller et al., 2025). Finally, the legal divide in clinician licensing often restricts the ability to provide telehealth services across different state or national borders, presenting a significant barrier to the interdisciplinary and cross-regional care delivery required for managing aging populations (Singhal et al., 2021).

4. Discussion

4.1 Structural Reorganization of Care

The results of this synthesis demonstrate that HF management is moving toward a state of infrastructural medicine, where the locus of care shifts from hospital-centered crisis intervention to community-based, longitudinal surveillance. This transition is not merely a change in technical equipment but a profound reconfiguration of the healthcare system's temporal and spatial logic. The traditional model, characterized by reactive responses to symptomatic decompensation, is being replaced by a predictive framework supported by RPM, implantable sensors, and AI. This shift is evidenced by the predictive windows identified in the data, where subclinical physiological changes are detectable several days before acute symptoms emerge, and in some wearable contexts, up to 32 days prior to hospitalization (Noci et al., 2025). This expansion of the clinical gaze into the domestic environment effectively transforms the patient's home into an active node within the healthcare infrastructure.

The emergence of HaH and advanced care models like the Mayo ACH program represents the most mature form of this structural transformation. By utilizing virtual command centers to coordinate high-acuity care, these models prove that the hospital is no longer the sole environment capable of managing acute decompensation. The significant reduction in 30-day readmission rates - 6% in the DZThuis HaH pilot compared to 17% in-hospital - indicates that community-based care, supported by digital oversight, may provide a safer and more stable environment for recovery (Bosman et al., 2025). Furthermore, the role of telemedical centers as a bridge between the patient and primary care providers suggests that health systems are moving toward a tiered, data-driven workflow where clinical interactions are triggered by physiological necessity rather than rigid, periodic scheduling (Koehler et al., 2018).

This reorganization necessitates a profound embedding of monitoring technologies into daily life, which effectively redefines the clinical workflow. Transition evidence highlights that clinical efficacy in a digitalized system depends on successful navigation between different care environments. The organizational redesign required to support these flows is intensive, demanding 24/7 specialized oversight and a technical infrastructure that can support continuous physiological data streams. Consequently, the transformation of care delivery is characterized by a move toward pathophysiology-driven strategies that rely on the constant availability of data to guide clinical decision-making.

4.2 The Risk Stratification Paradox

The findings present a Risk Stratification Paradox: while digital tools significantly enhance the precision of risk detection, they simultaneously introduce new mechanisms of exclusion that may disproportionately affect the most vulnerable populations. On one hand, the predictive accuracy of neural network models (92.5%) and the specific efficacy of RPM in complex phenotypes - such as the mortality reduction in patients with comorbid diabetes - demonstrate an unprecedented capability for personalized risk management (Koehler et al., 2024; Udoy & Hassan, 2025). On the other hand, the Techquity divide serves as a structural moderator that limits the reach of these benefits, reinforcing the inequities originally conceptualized within the Techquity framework (Johnson et al., 2023). The fact that 72% of patients over age 85 struggle with basic digital interfaces indicates that clinical precision is currently being developed for a demographic that may be structurally incapable of accessing it without significant intervention (Masterson Creber et al., 2023).

This paradox is further complicated by the intersection of age-related usability barriers and health literacy. Since health literacy is identified as an independent risk factor for mortality, its limited assessment in digital health trials suggests a critical blind spot in current implementation strategies (Ionescu et al., 2025). Digital innovations may inadvertently widen existing health disparities, as the benefits of remote management - such as the IRR of 0.72 for HFrEF patients - are contingent upon the patient's ability to navigate the digital environment (Kerwagen et al., 2023). The stratification of adoption drivers suggests that older adults prioritize clinical utility, yet the 40% increased anxiety reported in rural settings indicates that the socio-technical friction of digital care can have counterproductive psychological implications (Azizi et al., 2024; Cajita et al., 2017).

Sustainable transformation requires addressing these structural determinants of health that moderate clinical effectiveness. In regions of social exclusion, supervised monitoring has been shown to improve functional capacity, suggesting that human-supported digital care may be necessary to overcome the literacy and usability gaps identified in the Results (Wańczura et al., 2025). The Risk Stratification Paradox therefore highlights that the quest for higher diagnostic accuracy must be balanced with an equal focus on inclusive design and equitable access to ensure that the evolution of care does not leave the highest-risk aging populations behind.

4.3 Economic Time-Horizon Tension

The economic results reveal a fundamental tension between short-term fiscal constraints and long-term sustainability modeling. The global cost of HF provides a powerful mandate for cost-reduction strategies, particularly since 69.4% to 80% of direct costs are tied to the hospitalizations that digital interventions aim to prevent (Darvish et al., 2025; Pathak et al., 2022). However, the varied results of economic evaluations create a state of decision uncertainty for health system administrators (Seto, 2008). Short-term payer perspectives, such as the €1,758 net saving per patient-year in the TIM-HF2 trial, provide immediate evidence of feasibility, but they may not account for the extensive infrastructure and labor costs required to sustain such systems (Sydow et al., 2022).

In contrast, long-term Markov modeling suggests that the true value of home telemonitoring is realized over extended horizons, reaching cost-effectiveness at thresholds like €14,000 per QALY over 20 years (Grustam et al., 2018). This creates a temporal conflict: while the healthcare needs of aging societies require 20-year policy horizons, budgetary cycles and reimbursement models often prioritize immediate ROI. The reported 22.2% ROI in specialized programs indicates that digital management can be economically productive, yet its success is highly dependent on existing reimbursement structures and the ability of a system to shift resources away from traditional hospital-based expenditures (Zhang et al., 2025).

For invasive technologies like the CardioMEMS system, the ICERs are well within the willingness-to-pay standards of high-income countries (Martinson et al., 2017). The tension between ROI and high infrastructure costs is a central theme; while regional programs like HerzMobil Tirol demonstrate significant gains in life-days and hospitalization-free survival, the scalability of such models depends on resolving the uncertainty surrounding long-term funding (Egelseer-Bruendl et al., 2024). The economic impact of digital HF management is thus a factor of the system's ability to transition from a reactive, hospital-centered spending model to a proactive, community-based investment strategy.

4.4 Labor Redistribution and Cognitive Burden

Digitalization reconfigures the clinical labor market by redistributing responsibility and creating new forms of work. The Results identify "invisible work" as a critical component of digital HF management - unrecognized technical and administrative labor performed by both clinicians and patients to manage data flows (Trupia et al., 2021). In the RPM framework, the patient is transitioned from a passive recipient of care to an active "co-producer" of health data. This shift places a significant workload on the patient, which is reflected in the 77% stable adherence rate; the effort required to maintain this level of engagement represents a form of domestic clinical labor that is often excluded from traditional efficiency metrics (Evans et al., 2016; Koehler et al., 2018).

For clinicians, the shift to data-driven decision-making leads to a workflow intensification. The need for 24/7 specialized oversight creates a data interpretation burden and the potential for alert fatigue. The redistribution of labor is essential for creating early intervention windows, but it also increases the cognitive load on the healthcare workforce (Trupia et al., 2021).

The redistribution of labor also extends to informal caregivers, although the evidence primarily highlights the patient’s role in daily measurements. Transition coaching and supervised monitoring are often required to support the patient’s clinical labor, suggesting that the success of a digital system is as much about human support as it is about technological accuracy (Coleman et al., 2006). Therefore, the efficiency gains associated with digital care are partially offset by the new administrative and cognitive burdens placed on the patient-clinician dyad, making invisible work a critical variable in the sustainability of digital health transformations.

4.5 Governance, Trust, and Algorithmic Responsibility

The large-scale implementation of AI and digital monitoring introduces significant ethical and regulatory tensions that center on trust and algorithmic responsibility. AI deployment is fundamentally constrained by algorithmic bias, where training data that is non-representative of local demographics leads to incorrect symptom recognition in diverse groups (Cau & Pisu, 2025; Joseph, 2025). This bias represents a structural threat to diagnostic fairness, as skewed data may exacerbate existing health inequalities in low-resource settings. The governance of these systems is further complicated by the black box nature of algorithms, which creates a liability ambiguity regarding who is responsible for a diagnostic error (Cestonaro et al., 2023).

Regulatory fragmentation serves as a significant barrier to the interdisciplinary care delivery required for aging populations. The jurisdictional differences in raw data access - contrasting the EU GDPR and CCPA

with the US HIPAA Privacy Rule - limit the interoperability of digital health systems and complicate the patient's right to data access (Cohen et al., 2020). Furthermore, clinician licensing barriers restrict the ability of telemedical centers to provide cross-regional care, a limitation that stands in opposition to the borderless nature of digital technology (Singhal et al., 2021). These regulatory barriers are compounded by documented cybersecurity risks, such as the unauthorized alteration of medication doses in connected devices, which underscore that technical connectivity can introduce systemic vulnerabilities (Ok, 2025).

Maintaining institutional trust in a system characterized by pervasive surveillance requires transparency. The call for transparency dashboards is a response to the risk that continuous monitoring may infringe on patient autonomy (Muller et al., 2025). The governance of digital HF management must therefore address the intersection of technical security, algorithmic fairness, and legal interoperability. Without a robust regulatory framework that addresses liability ambiguity and bias, the systemic transformation of HF care risks losing the trust of the very populations it aims to protect.

4.6 Integrated Socio-Technical Synthesis

The digital management of HF represents a fundamental socio-technical evolution where clinical efficacy, economic sustainability, and social equity are inextricably linked. The transition from reactive to predictive care is made possible by high-accuracy technologies, but the real-world success of these tools is moderated by structural social determinants (Noci et al., 2025; Udoy & Hassan, 2025). The clinical benefit seen in the TIM-HF2 trial is the outcome of a complex interaction between the technology itself, organizational models that allow for home-based intervention, and the patient's willingness to engage in "invisible work" (Koehler et al., 2018; Trupia et al., 2021).

Sustainable transformation is contingent upon health systems' ability to bridge the gap between technological potential and the structural barriers of aging. The tensions identified in stratification and economic modeling suggest that clinical success is not a purely technical achievement but a factor of systemic alignment. For digital HF management to be sustainable, economic reimbursement models must evolve to support long-term time horizons, and governance frameworks must address the algorithmic bias and jurisdictional divides that threaten diagnostic fairness (Grustam et al., 2018; Joseph, 2025). Ultimately, the digitalization of cardiovascular care in aging societies is a systemic transformation that requires a rigorous commitment to closing the divide between high-precision capability and inclusive design.

5. Conclusions

The evidence and interpretation synthesized in this review confirm that the digital management of HF represents a fundamental socio-technical evolution, reconfiguring the clinical, economic, and organizational foundations of cardiovascular care in aging societies. The core empirical findings demonstrate a systemic transition from a reactive, hospital-centered model toward a predictive framework grounded in infrastructural medicine. By integrating RPM, implantable hemodynamic sensors, and AI, health systems have gained the capacity to replace episodic clinical assessments with longitudinal, pathophysiology-driven oversight. This shift is validated by documented reductions in mortality and hospitalization across diverse patient phenotypes, including complex comorbid cases such as those with diabetes. The decentralization of monitoring effectively moves the locus of care into the community, enabling interventions during a critical window of opportunity identified by subclinical physiological shifts rather than the late-stage manifestation of symptoms.

The structural transformation of HF management is most visible in the emergence of hybrid care models and the reconfiguration of clinical workflows. Programs such as HaH and virtual command centers demonstrate that high-acuity maintenance can be safely conducted outside traditional institutional boundaries. However, this organizational redesign is not merely a technological upgrade but a profound redistribution of clinical labor. It necessitates the recognition of "invisible work" - the unrecognized technical and administrative adjustments required by both clinicians and patients to manage continuous data flows. The patient has been transitioned from a passive recipient of care to an active "co-producer" of health data, a shift that introduces significant cognitive and domestic labor burdens. Furthermore, the operational success of these models depends on an intensive infrastructure of 24/7 specialized oversight, bridging the gap between the domestic environment and professional clinical decision-making.

Despite the clear clinical efficacy of these technologies, this review identifies critical systemic tensions regarding equity and sustainability. Conflict exists where digital tools provide unprecedented precision in risk detection but simultaneously introduce new mechanisms of exclusion. The divide moderated by digital literacy and age-related usability barriers suggests that the populations at the highest clinical risk - specifically the

oldest-old and those in regions of social exclusion - are often the most vulnerable to digital marginalization. Diagnostic fairness must therefore be treated as a primary metric of success alongside clinical accuracy. Economic sustainability is similarly characterized by a time-horizon tension, where documented short-term fiscal savings and ROIs are often at odds with the long-term horizons required for robust cost-effectiveness. The transition to a proactive care model remains highly dependent on the ability of health systems to move beyond reactive budgetary cycles and toward value-based, longitudinal reimbursement structures.

Governance and regulatory challenges remain significant inhibitors of a seamless digital transformation. The black box nature of AI algorithms introduces liability ambiguities and necessitates new frameworks for algorithmic responsibility and transparency. Ethical concerns regarding pervasive surveillance and patient autonomy have led to calls for more transparent data dashboards to maintain institutional trust. Furthermore, regulatory and jurisdictional fragmentation - including variations in raw data access rights - presents a barrier to the cross-regional and interdisciplinary care delivery necessitated by aging populations. Cybersecurity risks associated with connected medical devices further underscore the need for a robust regulatory environment that integrates technical security with clinical safety.

This review also reinforces several research and implementation gaps identified in the literature. Methodological limitations, such as the inherent heterogeneity of implementation models and the lack of representative training data for AI in diverse or low-resource settings, remain unresolved. The decision uncertainty in economic evaluations highlights the need for more standardized infrastructure assessments. Moreover, the social determinants of health, particularly health literacy, remain under-assessed in formal digital trials, suggesting that implementation science must prioritize the human-technical interface to overcome socio-technical friction.

In final synthesis, the sustainable transformation of HF management depends on achieving alignment between technological capability, economic structures, and social equity. Digital management offers a pathway to proactive health maintenance that supports the "aging-in-place" paradigm, but its success is not a purely technical achievement. It is an organizational and social process that requires a rigorous commitment to closing the digital divide and resolving the temporal tensions in economic modeling. Ultimately, the digitalization of cardiovascular care represents a systemic shift where clinical precision serves as an equitable foundation for public health, provided that the structural barriers to access and the cognitive load of data-driven care are addressed through inclusive design and robust governance.

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