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Artificial Intelligence and Advanced Digital Health for Hypertension: Evolving Tools for Precision Cardiovascular Care

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Abstract: Hypertension remains the leading global risk factor for cardiovascular mor- bidity and mortality, with suboptimal control rates despite guideline-directed thera- pies. Digital health and artificial intelligence (AI) technologies offer novel approaches for improving diagnosis, monitoring, and individualized treatment of hypertension. *Objectives* to critically review the current landscape of AI-enabled digital tools for hy- pertension management, including emerging applications, implementation challenges, and future directions. A narrative review of recent PubMed-indexed studies (2019–2024) was conducted, focusing on clinical applications of AI and digital health tech- nologies in hypertension. Emphasis was placed on real-world deployment, algorithmic explainability, digital biomarkers, and ethical/regulatory frameworks. Priority was given to high-quality randomized trials, systematic reviews, and expert consensus statements. AI-supported platforms—including remote blood pressure monitoring, machine learning titration algorithms, and digital twins—have demonstrated early promise in improving hypertension control. Explainable AI (XAI) is critical for clinician trust and integration into decision-making. Equity-focused design and regulatory oversight are essential to prevent exacerbation of health disparities. Emerging implementation strategies, such as federated learning and co-design frameworks, may enhance scalability and gener- alizability across diverse care settings. AI-guided titration and digital twin approaches appear most promising for reducing therapeutic inertia, whereas cuffless blood pressure monitoring remains the least mature. Future work should prioritize pragmatic trials with equity and cost-effectiveness endpoints, supported by safeguards against bias, accountability gaps, and privacy risks.

Keywords: Hypertension, Artificial Intelligence, Digital Health, Remote Monitoring, Digital Twins, Precision Medicine

Introduction

Hypertension remains the leading modifiable risk factor for cardiovascular disease (CVD), responsible for over 10 million deaths globally each year [1]. Despite the availability of effective pharmacologic therapies and evidence-based guidelines, real-world blood pressure (BP) control rates continue to stagnate, with fewer than 25% of hypertensive adults achieving target values in many regions [2]. This persistent treatment gap reflects multifac- torial barriers, including poor medication adherence, therapeutic inertia, fragmented care delivery, and limited health system capacity [3].

In response to these challenges, digital health technologies have emerged as scal- able, patient-centered tools capable of augmenting conventional hypertension care [4]. First-generation solutions—such as mobile health (mHealth) applications, telemonitor- ing platforms, SMS reminders, and wearable devices—have demonstrated modest but consistent efficacy in improving BP control and treatment adherence, particularly when in- tegrated into primary care workflows [5]. However, these interventions are often limited by their reactive nature, low personalization, and insufficient integration into therapeutic decision-making.

Concurrently, the rapid evolution of artificial intelligence (AI) and related compu- tational sciences is opening new frontiers in the management of chronic diseases. In hypertension, AI-driven applications have begun to transition from prediction models and risk stratification to real-time decision support, medication self-titration algorithms, and virtual physiological models. These advances enable more dynamic and individualized treatment paradigms, shifting from episodic clinic-based care to continuous, data-driven disease management [6].

Among the most transformative concepts is the development of digital twins— computational replicas of individual patients that integrate biometric, behavioral, and clinical data to simulate disease progression and treatment response. Although still in early phases of application in hypertension, digital twin frameworks are being explored for therapy optimization, remote titration protocols, and clinical trial simulation [7].

Although recent narrative reviews have explored the role of artificial intelligence in cardiovascular medicine more broadly, none has provided a comprehensive synthesis focused specifically on hypertension. Existing reviews often emphasize applications in arrhythmia detection or cardiovascular imaging, but they do not systematically address the unique challenges of hypertension management, such as therapeutic inertia, remote monitoring, and the integration of digital twins or large language models. This review therefore fills an important gap by bringing together these emerging domains in the context of guideline-based hypertension care [8].

The objective of this review is to critically evaluate current and emerging applications of artificial intelligence and digital health technologies in hypertension, with a focus on remote monitoring, medication titration, digital biomarkers, and simulation-bas ed approaches [9].

Methods

This work is a narrative review conducted in accordance with best practices for non- systematic evidence syntheses, with explicit description of search strategy, selection criteria, and synthesis approach to enhance transparency.

A. Databases and Search Strategy

A structured literature search was performed in PubMed/MEDLINE for studies published between 1 January 2019 and 31 December 2024. The following Boolean search string was used: ("hypertension" OR "arterial hypertension" OR "high blood pressure") AND ("artificial intelligence" OR "machine learning" OR "deep learning" OR "large language model" OR "digital health" OR "digital biomarker" OR "remote monitoring" OR "digital twin" OR "wearable blood pressure"). Search terms were adapted from Medical Subject Headings (MeSH) and free-text keywords. Additional relevant articles were identified through citation tracking and from the authors' personal libraries [10].

B. Eligibility Criteria

Eligible studies included peer-reviewed publications on adults with hypertension or elevated blood pressure that evaluated AI-enabled or digital health tools with clinical relevance (e.g., decision support, medication titration algorithms, cuffless BP monitoring, digital twins, LLM-based adherence support). We considered randomized controlled trials, cohort studies, systematic reviews, meta-analyses, pilot studies, and expert consensus statements. Non–peer-reviewed material, commentaries without data, and conference abstracts were excluded.

C. Synthesis Approach

Data from included studies were synthesized narratively into four domains: (1) AI- guided blood pressure titration, (2) digital twins and patient-specific modeling, (3) digital biomarkers and remote monitoring, and (4) ethical, regulatory, and equity considerations. Within each domain, methodological robustness, generalizability, and readiness for routine clinical use were critically appraised [11].

AI-Guided Remote Blood Pressure Titration

Timely therapeutic adjustment remains one of the most significant barriers to effective blood pressure control in routine clinical practice, a challenge that AI-enabled frameworks aim to address through improved monitoring and titration (Figure 2). Despite the avail- ability of evidence-based antihypertensive therapies, many patients experience prolonged periods of undertreatment due to clinical inertia, infrequent follow-up, and healthcare resource constraints. In recent years, digital health technologies have emerged as promising tools to close this gap. Among these, AI-based systems for remote medication titration represent a novel frontier in precision hypertension care.

The concept of self-titration supported by home blood pressure monitoring was first validated in the TASMIN-SR randomized controlled trial, which demonstrated that patients using structured self-monitoring protocols achieved significantly greater reduc- tions in systolic blood pressure compared to those receiving usual care (mean difference:

−5.4 mmHg at 12 months) [12]. While TASMIN-SR did not employ AI algorithms, it established a foundational model for safe and effective medication adjustment outside traditional clinical settings.

Digital Twin Technologies in Hypertension: Concept and Applications

Digital twin technology in medicine refers to a virtual, continuously updated model of an individual patient, constructed to simulate physiological responses and disease pro- gression under various interventions. While most existing digital twin implementations in cardiology have focused on electrophysiology or structural heart disease, their underly- ing frameworks are directly applicable to hypertension care. Notably, digital twins have already been deployed at scale in cardiovascular imaging and disease modeling, offering a pathway toward precision management of elevated blood pressure [13].

Digital Biomarkers and Remote Blood Pressure Monitoring in Hypertension

Advances in wearable and ECG technology have created objective digital biomarkers that capture blood pressure–related physiology outside of the clinic. These tools offer objective insights into hypertension and may support early detection, risk stratification, and treatment monitoring.

A systematic review and meta-analysis evaluated six randomized controlled trials involving cuffless wearable blood pressure devices. The pooled standardized mean differ- ences were small and not statistically significant, highlighting device variability, validation concerns, and inconsistent adherence [14]. Nevertheless, these wearable systems represent a significant step toward continuous, non-invasive blood pressure assessment.

Next-generation ECG-based AI models such as HTN-AI have demonstrated that deep learning applied to 12-lead ECGs can reliably discriminate individuals with hypertension and predict future cardiovascular events. In internal and external validations, HTN- AI achieved AUCs of 0.803 and 0.771, respectively, and predicted risk of heart failure, myocardial infarction, stroke, and mortality with hazard ratios up to 2.26 per standard deviation increase. HTN-AI thus serves as a promising digital biomarker that captures subclinical physiological effects of elevated blood pressure [15].

Results

Recent studies demonstrate that artificial intelligence–enabled digital health tools can significantly enhance hypertension management by improving monitoring, therapeutic decision-making, and patient adherence. One of the most promising developments is AI-supported remote blood pressure monitoring combined with algorithm-guided medication titration.

Clinical trials investigating digital hypertension management platforms have reported improvements in blood pressure control compared with standard care. For example, the TASMIN-SR randomized controlled trial demonstrated that patients using structured self-monitoring protocols achieved a significantly greater reduction in systolic blood pressure compared with patients receiving usual care. The mean difference in systolic blood pressure reduction reached approximately 5.4 mmHg after 12 months of follow-up.

Another important development involves digital twin technologies, which create computational models of individual patients. These models integrate clinical data, physiological signals, and behavioral information to simulate disease progression and treatment response. Early research suggests that digital twin frameworks may support personalized treatment strategies and enable more accurate prediction of cardiovascular risk.

Furthermore, advances in wearable technologies have enabled the development of digital biomarkers for hypertension detection. AI-based electrocardiogram (ECG) analysis models have demonstrated the ability to identify hypertension-related physiological patterns and predict future cardiovascular events. Such tools may provide new opportunities for early detection and risk stratification in hypertension management.

Discussion

The findings of this review highlight the transformative potential of artificial intelligence and digital health technologies in the management of hypertension. Traditional hypertension care is often limited by episodic clinical visits and delayed therapeutic adjustments. AI-enabled monitoring systems can provide continuous patient data, enabling earlier intervention and more dynamic treatment strategies.

Remote monitoring platforms represent an important step toward patient-centered care. By integrating home blood pressure measurements with AI-based clinical decision support systems, healthcare providers can optimize treatment strategies and reduce therapeutic inertia. This approach may significantly improve blood pressure control rates in real-world clinical practice.

Digital twin technologies also offer significant opportunities for personalized cardiovascular medicine. By simulating physiological responses to different therapeutic interventions, digital twins can help clinicians evaluate treatment strategies before implementation. Although still in early stages of development, this technology may become a key component of precision hypertension management.

However, the implementation of AI-driven healthcare solutions raises several important challenges. Issues related to data privacy, algorithm transparency, and potential bias in machine learning models must be carefully addressed. Moreover, digital health technologies should be designed with equity considerations to ensure that they benefit diverse patient populations rather than exacerbating existing health disparities.

Overall, the integration of artificial intelligence into hypertension care has the potential to significantly improve disease management. Nevertheless, further large-scale clinical trials are needed to evaluate the long-term clinical effectiveness, safety, and cost-efficiency of these technologies.

Conclusions

Artificial intelligence and digital health are beginning to transform hypertension man- agement, but their maturity varies. The most promising applications are AI-guided titration platforms aligned with ESC/ESH guidelines and emerging digital twin models, which directly address therapeutic inertia and support personalized care. By contrast, cuffless blood pressure monitoring remains the least mature field, with persistent concerns about accuracy and validation. Future progress requires pragmatic multicenter randomized trials in diverse populations, including cost-effectiveness and equity endpoints. Importantly, development and deployment must be coupled with safeguards addressing algorithmic bias, accountability, and privacy to ensure that these technologies deliver safe, equitable, and sustainable improvements in hypertension care.

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