Koşuyolu Heart Journal

Koşuyolu Heart J 2026;29(2):150–152
DOI: 10.51645/khj.2026.605

Review Article

Digital Technologies and Hypertension

Alparslan Şahin

Department of Cardiology, Bakırköy Dr. Sadi Konuk Training and Research Hospital, İstanbul, Türkiye

Abstract

Hypertension is one of the most prevalent chronic diseases, and with advances in technology, various digital solutions have long been explored for its management. Mobile applications, telemedicine systems, digital blood pressure monitoring devices, and, more recently, artificial intelligence-assisted systems are intended to achieve effective blood pressure control, prevent adverse outcomes, and improve cost-effectiveness.

Keywords: Artificial intelligence; hypertension; telemedicine.

Dijital Teknolojiler ve Hipertansiyon

Özet

Hipertansiyon en sık görülen kronik hastalıklardan biridir, teknolojinin gelişmesi ile birlikte yönetiminde farklı dijital çözümler uzun yıllardır denenmektedir. Mobil uygulamalar, teletıp sistemleri, dijital kan basıncı ölçüm cihazları ve bir süredir kullanılan yapay zeka destekli sistemler, etkin kan basıncı kontrolü, kötü sonlanımların önlenmesi ve maliyet etkinliğinin arttırılmasını hedeflemektedir.

Anahtar sözcükler: Yapay zeka; hipertansiyon; teletıp.

Introduction

Hypertension is one of the most common chronic diseases in the general population and is defined as office blood pressure values above 140/90 mmHg.[1] Standard management includes dietary modification, lifestyle interventions, and antihypertensive medications.[1] Despite more than a century of efforts to combat hypertension, diagnosis and treatment rates, as well as the proportion of treated patients achieving target blood pressure levels, remain below desired levels.[2] Numerous digital solutions with varying content and methodologies have long been used and investigated in the diagnosis, monitoring, and treatment of hypertension. The growing number of patients, limitations in access to healthcare services, technological advances, and the COVID-19 pandemic have accelerated digital integration in the management of chronic diseases such as hypertension.[3] Digital solutions are intended to enable more effective patient follow-up, improve the effectiveness of existing treatments, and enhance patient adherence.[4]

Digital blood pressure monitoring devices, real-time blood pressure tracking, data transmission via mobile applications, telephone, or the internet, telemedicine platforms, healthcare professionals who manage or supervise these systems, and artificial intelligence are among the main components of the digital transformation in hypertension management.[5] Different countries and healthcare systems, as well as public and private institutions, provide these services using various models and content structures. The effectiveness of these systems in achieving blood pressure control is determined by the services they provide and the methods they employ. Blood pressure monitoring plays a fundamental role in hypertension management and in the evaluation of treatment efficacy. Because lower blood pressure levels are associated with a reduced risk of cardiovascular events, effective blood pressure control is essential.[6]

Cite This Article: Şahin A. Digital Technologies and Hypertension. Koşuyolu Heart J 2026;29(2):150–152.

Address for Correspondence:
Alparslan Şahin

Department of Cardiology, Bakırköy Dr. Sadi Konuk Training and Research Hospital, İstanbul, Türkiye

E-mail: dralpsahin@gmail.com

Submitted: April 7, 2026
Accepted: May 13, 2026
Available Online: June 08, 2026

In recent years, home blood pressure monitoring has gained increasing prominence because it enables more regular and longer-term blood pressure assessment.[1,7] Digital solutions further enhance the effectiveness of this individualized blood pressure monitoring.[1,7] Digital solutions used in hypertension management include real-time blood pressure monitoring, treatment planning based on blood pressure values, and personalized recommendations for dietary and lifestyle modification; in delivering these functions, they may also incorporate artificial intelligence support in addition to oversight by a healthcare professional.[4]

The TASMINH4 study compared the effects of standard hypertension follow-up, home blood pressure monitoring, and telemonitoring-supported home blood pressure monitoring on blood pressure levels. Compared with standard treatment, the home monitoring group had significantly lower blood pressure values at both 6 and 12 months. The addition of telemedicine to home monitoring resulted in a further reduction in blood pressure, although this difference was not statistically significant.[8] In the HOROSCOPE study, which compared standard treatment with telephone-based remote monitoring, the remote monitoring group had significantly lower blood pressure values at the 6-month assessment.[9] Meta-analyses have likewise shown that telemedicine interventions are associated with significant reductions in blood pressure compared with standard treatment.[10–12]

Wearable blood pressure monitoring devices have emerged as one of the leading consumer health technologies in recent years. Blood pressure is measured using indirect methods such as photoplethysmography, pulse transit time, and applanation tonometry.[13–15] These devices enable continuous, regular, and periodic blood pressure measurement. By providing data on blood pressure fluctuations, variability, periodic changes, and upper and lower limits, wearable blood pressure devices may facilitate more effective blood pressure monitoring and management. They may also generate data that could enable intervention before abrupt elevations in blood pressure occur.[16] However, wearable blood pressure devices are not yet recommended for use in hypertension management because of the lack of adequate validation studies, as well as unresolved issues related to standardization, calibration, and certification.[7,17]

As in many other areas of medicine, an increasing number of studies and applications based on artificial intelligence are being reported in the diagnosis and management of hypertension. The use of artificial intelligence in hypertension began with prediction models and risk stratification protocols and has since expanded to include real-time decision-making, drug dosing, virtual physiological modeling, digital biomarkers, and digital twin technologies.[18,19] Similar to other digital solutions, artificial intelligence applications aim to transform disease monitoring and treatment from a cyclical process into one that is continuous and uninterrupted.[20]

Artificial intelligence can support antihypertensive drug dosing by integrating multiple data sources, including the patient's medical history, ethnicity, living environment, previous medication experiences, and blood pressure monitoring records, with the aim of achieving effective blood pressure control and preventing potential cardiovascular events.[20] Furthermore, artificial intelligence may enable the prediction of impending blood pressure elevations before their onset and facilitate their prevention through preemptive pharmacologic intervention (anticipation medicine). A wide range of patient-specific data, including prior clinical records, blood pressure trajectories, fluctuations and variability, daily activities, geographic location, and seasonal characteristics, can be analyzed to construct predictive models. Such models may enable the delivery of fully personalized preemptive pharmacologic therapy (anticipatory medicine), tailored in form, content, and timing before the onset of an event, thereby helping to mitigate blood pressure instability and associated cardiovascular outcomes.[20]

Leitner et al.[21] reported that artificial intelligence-based autonomous digital health interventions incorporating personalized lifestyle modification recommendations were associated with significant reductions in systolic and diastolic blood pressure at weeks 12 and 24, as well as a significant increase in the proportion of patients achieving blood pressure control. Artificial intelligence applications in hypertension may facilitate diagnosis through indirect markers other than direct blood pressure measurements and may additionally provide prognostic information. In a study by Al-Alusi et al.,[22] a deep learning system trained on 12-lead electrocardiograms successfully identified hypertension. Furthermore, the HTN-AI score derived from this model enabled risk stratification in hypertensive patients, with higher scores being associated with adverse cardiovascular outcomes.

Beyond conventional treatment strategies, digital therapeutics are increasingly being explored in the management of hypertension. These interventions aim to lower blood pressure by providing individualized app-based recommendations tailored to the patient's current status, including guidance on salt intake, exercise, diet, alcohol consumption, sleep quality, and stress management. In a study by Kario et al.[23] conducted in Japan, newly diagnosed hypertensive patients not receiving antihypertensive medication were assigned to either standard lifestyle modification advice or personalized daily digital therapeutic recommendations. At weeks 12 and 24, mean systolic, office systolic, and home systolic blood pressure values were significantly lower in the digital therapeutics group.[23]

Another important objective of implementing digital solutions in the management of chronic diseases such as hypertension is to improve cost-effectiveness. However, the available evidence remains inconsistent. This variability is largely attributable to differences among countries in healthcare delivery and drug pricing, as well as the heterogeneity in the components and costs of telemedicine programs. Consequently, some studies have demonstrated cost-effectiveness, whereas others have not.[24] In a study conducted in Singapore, Wang et al.[25] compared the Singapore hypertension telemedicine program with standard hypertension management and found that the program was cost-effective at both 6 and 12 months when device acquisition and system maintenance costs were excluded. When these costs were included, the program was cost-neutral at 6 months and cost-effective at 12 months.

Conclusion

In the near future, personal health technologies, telemedicine applications, and artificial intelligence are likely to play an increasingly important role in the management of chronic diseases, particularly hypertension. However, before this potential can be fully realized, telemedicine applications must be standardized, the current challenges related to the standardization, calibration, and certification of wearable devices must be addressed, and additional studies with more robust evidence are needed to clarify the effects of these approaches on blood pressure control and healthcare costs.

Disclosures

Conflict of Interest Statement: The author declare that there is no conflict of interest.

Funding: The author declared that this study received no financial support.

Use of AI for Writing Assistance: The author declared that artificial intelligence was not used in the study.

Peer-review: Externally peer-reviewed.

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