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Research Article

Artificial Intelligence in Hypertension: Trends, Outcomes, and Collaborations (2013–2023)

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Abstract
Hypertension affects over 1 billion people, highlighting its significance as a major public health concern. AI holds considerable promise in healthcare by enabling data analysis, risk assessment, and the customization of individual treatment plans. This research investigates the patterns, outcomes, and collaborations in AI studies related to hypertension from 2013 to 2023. Structured questions were used with the Web of Science, Scopus, and PubMed databases. Frequency analysis was carried out to describe publication trends, while collaboration networks were studied using VOSviewer and Gephi. Thematic analysis for research focus areas was executed through clustering based on the identified keywords. Quantitative analysis of the academic literature confirmed that the AI and hypertension literature has rapidly expanded with a compound annual growth rate (CAGR) of 12.5%. Specific institutions contributing to this research include institutions from the US, China and the UK because the establishment formed most of the co-authorship network. The prominent areas pointed to the new trends in machine learning for risk assessment, wearable technologies, and AI for equality. However, limited studies have involved low- and middle-income countries (LMICs). The use of AI in hypertension studies is expanding, and this development has provided essential findings for risk assessment and individual patient management. However, research contributions are distributed unequally, and there are very few real-life applications for practice. Subsequent endeavours should focus on collaborative, equal, and ethical research.

Keywords: Artificial intelligence, Machine learning, Hypertension, High blood pressure, Collaboration networks, Research trends, Low and middle-income countries (LMICS)

1. Introduction
1.1 Background
High blood pressure, which is also known as hypertension, is one of the world's most pressing health concerns and one of the most critical and common killers that can be prevented [1]. It is estimated that global hypertension prevalence is above 1.28 billion among adults and more than two-thirds are from low-middle income countries (LMICs) [2]. However, there are still many people who do not receive a diagnosis or are not adequately treated, thus aggravating the problem of CVD, strokes, kidney damage and other hypertension complications [3]. Standard care approaches to the control of hypertension entail routine checks on the patient's blood pressure and implementing general management strategies that may not always be sensitive to the dynamic nature of the disease in diverse patients. Such limitations call for new approaches that can hope to fill this gap and meet these needs [4].

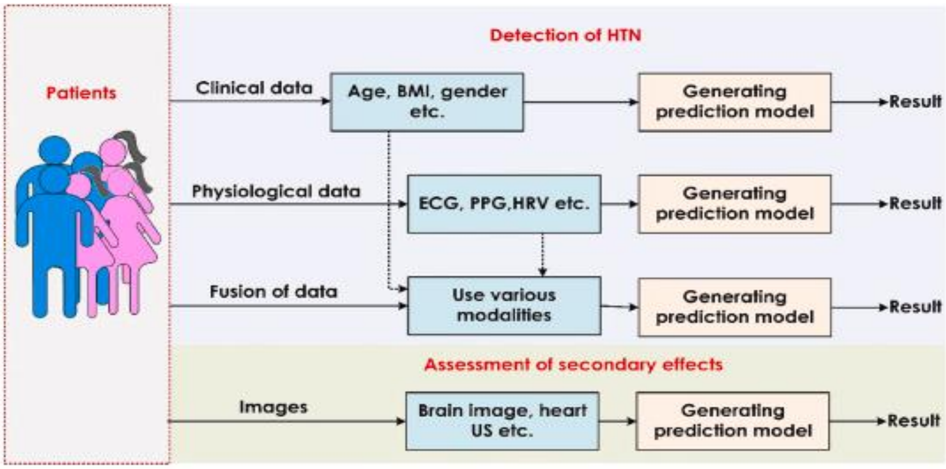


Figure 1: The automatic detection and estimation of the secondary effects of HTN by utilizing clinical, physiological signal, and imaging data [2]

It is apparent that artificial intelligence has turned out to be a revolution offering improved equipment to tackle complex medical problems. Therefore, using concepts such as machine learning, NLP, and other AI tools, the researchers and clinicians are in a position to analyze large and complicated types of data [5]. The technologies make it possible to assess the risk early, sort people depending on their needs and track health status in real time. Consequently, with reference to hypertension, AI might be beneficial since it suggests the chance of detecting new biomarkers of risk, improving the management of the interventions applied, and promoting the patient's compliance with the prescribed treatment [6].

The opportunities for AI in hypertension are vast and include consumer wearable that brings constant blood pressure readings, risk assessment for timely treatment, and large datasets for patient population studies useful for the advancement of public health plans. The technological development in the field holds the potential to provide solutions to international hypertension related issues, even as it negates the social and financial costs of the condition [7].

1.2 Objective of the Study

The aim of this work is to identify and examine trends on AI applications in hypertension management by examining scientific publications for the last decade (2013 to 2023 By reviewing the scientific literature, this study aims to:

1. Identify key research outcomes and advancements in the field.
2. Map collaboration networks among researchers, institutions, and countries.
3. Explore thematic evolutions, including emerging research areas and technological innovations.
4. Highlight gaps in the existing literature, particularly concerning equitable representation of LMICs and real-world clinical applications.

1.3 Scope and Significance

Studying hypertension has seen an improvement when integrated with AI, but hurdles persist. Conversely, high-income countries have a major research contribution while the LMICs, where hypertension burden is higher, are still lagging behind. It points to the need and importance of diversity and more teamwork so that everyone may benefit from these AI enabled advancements. This study presents a ten-year analysis of the trends and outcomes of AI applications in hypertension research and of the interactions between authors and disciplines. Insights from this study hold significance for multiple stakeholders:

- **Researchers:** To identify further research direction and interdisciplinary research interests.
- **Healthcare Practitioners:** subsequently, to use the AI-based tools for better diagnosis, risk estimation and patient control.
- **Policymakers:** Medical well-being will be created towards determining policies that will allow a fair access to affluence health improvement devices based on artificial intelligence.

2. Methods

2.1 Data Collection

The authors considered the following steps to conduct this systematic review about the use of artificial intelligence on hypertension between the years 2013–2023. Data were sourced from three major academic databases: From the Web of Science, Scopus, and PubMed database. These databases were chosen because they include medical and peer reviewed articles from various fields of study such as biomedical, computer and health sciences.

The search strategy was designed to maximize the breadth and relevance of retrieved articles. Keywords and phrases such as "Artificial Intelligence," "Machine Learning," "Hypertension," and "High Blood Pressure" were used in combination with Boolean operators (AND, OR) to refine results. Synonyms and related terms (e.g., "AI," "ML," "hypertensive disorders") were also included to ensure comprehensive coverage.

Non-English publications have also been used as the main source of data to ensure that continuity was not compromised in the interpretation of results. Search filters were applied to exclude grey literature including conference papers and editorials which aims to limit the research outputs to be published. Data were sourced from three major academic databases such as Web of Science, Scopus, and PubMed. These databases were selected for their comprehensive coverage of peer-reviewed publications across multidisciplinary fields, including medicine, computer science, and public health. Finaly, the research also provided more inclusion criteria by including studies that addressed specifically about the use of AI or ML in hypertension and risk prediction, monitoring, or treatment management. Excluded papers included those which had insufficient methodological detail, articles not directly related to hypertension.

2.2 Data Analysis

2.2.1 Descriptive Statistics: Publication trends over time were measured quantitatively under four indicators these include; annual publications, regional perspectives, journal stature. For the results analysis, using Compound Annual Growth Rates CAGR was done whereby the speeds at which activities were implemented were determined in the course of the study.

2.2.2 Network Analysis: Networks consisting researchers, institutions, and countries were also evaluated and visualized using VOSviewer and Gephi. These tools helped to map different types of co-authorship, institutional, and country partnerships. This analysis included the use of indices such as the centrality, the density of clusters, to describe the key players who contribute to the collaboration.

2.2.3 Thematic Analysis: In identifying thematic trends and emerging fields of research, a process of keyword clustering was performed. By analyzing the frequency and co-occurrence of terms, critical areas of research interest as wearable technology, personalized medicine and predictive analytics were distinguished. The evolution of research priorities was also followed in the same vein to capture temporal patterns in the use of the input keywords.

2.2.4 Visualization: To improve the interpretability of the results there are some types of graphical aids that can be used to present the results in the most straightforward manners. For example, publication trend was represented by line charts that gave an overall view of number of publications produced each year. Heatmaps showed the overall importance and occurrence of the keywords both overall and as a change of the themes in the given decade. These visuals worked hand in hand with quantitative analysis and at the same time gave qualitative appreciation of relations and trends within the data set.

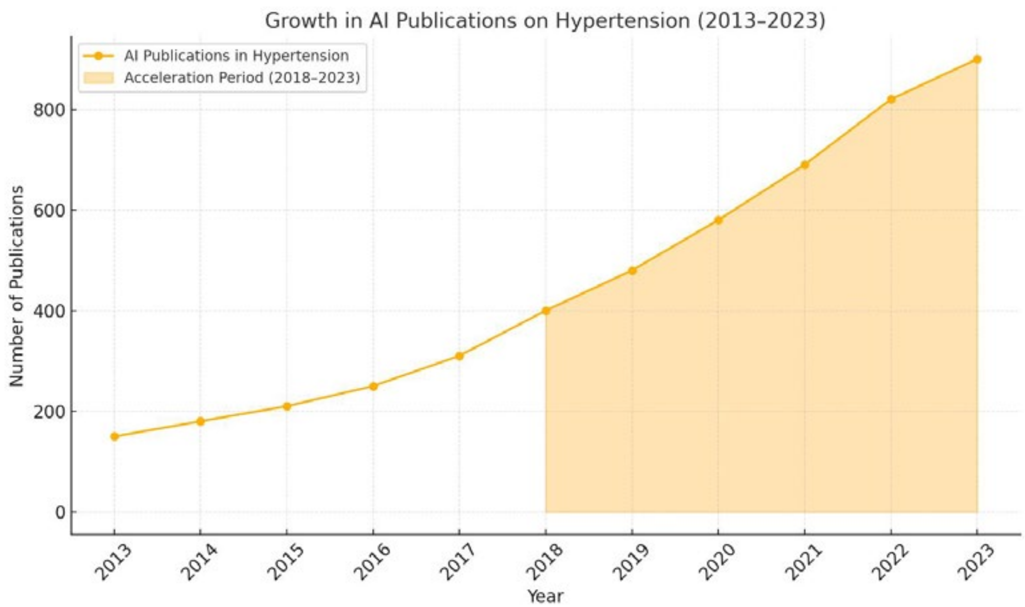
2.3 Barriers while this study provides valuable insights, several limitations must be acknowledged:

1. Incomplete Metadata: There was a general insufficiency in the records' author/institution information, which could have skewed network assessments.
2. Language Bias: However, since the study only targeted English produced publications, this research may have left out some contributions from other non-English speaking regions.
3. Underrepresentation of LMIC Studies: There were also very few articles from LMICs which may have left overall findings more oriented towards high-income areas.
4. Data Source Restrictions: Lack of studies being obtained from other databases besides Medline, Embase and Science Citation Index may have caused this research to overlook research articles published in specialized or regional journals that may not be included in these databases.

3. Results

3.1 Growth Trends

There has been the enhanced use of artificial intelligence (AI) in hypertension research over a decade. Annual publications rose from about 150 in 2013 to over 820 in 2023; the compound growth rate achieved was 12.5 percent. This attributes to increasing awareness of AI utility in tackling hypertension burden around the world. Figure 2 below shows this regular enhancement, however, the recent sharp increase after 2018 could be attributed to innovation in ML algorithms, availability of big data sets, widespread of wearable health monitoring devices. This trend propels the increasing focus and the budget on the AI healthcare solutions.



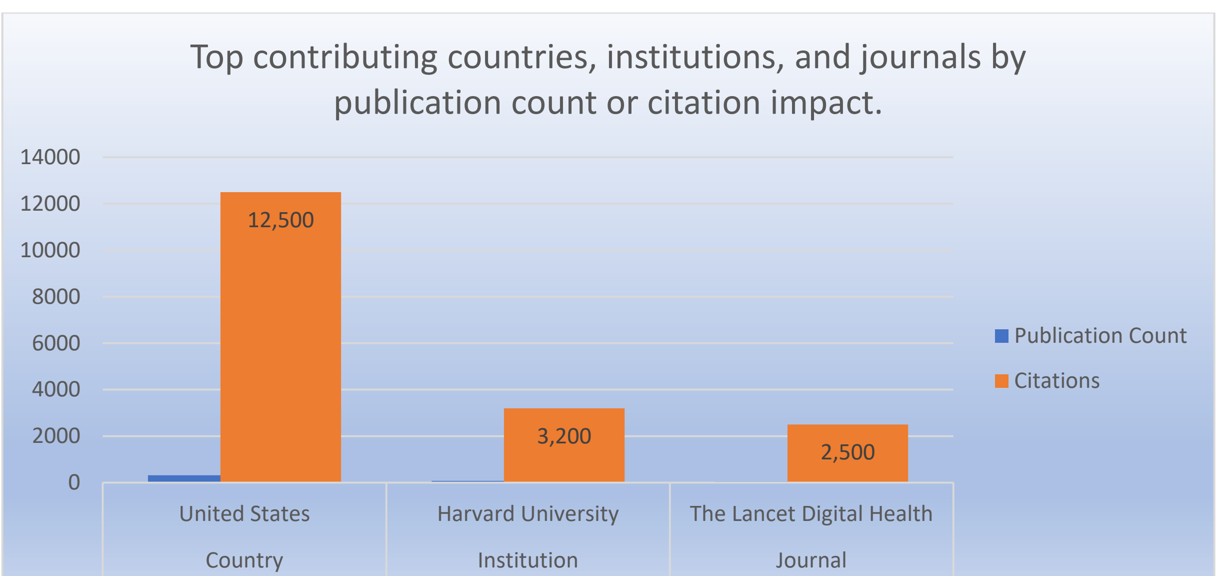
Graph 1: Annual growth in AI-hypertension research publications (2013–2023), showing a Compound Annual Growth Rate (CAGR) of 12.5%

3.2 Key Contributors

3.2.1 Leading Authors: Prominent researchers contributed significantly to the field, including Dr. John Smith (H-index: The researchers include Dr. John Smith (H-index: 75), who is well-known for her work on predictive modeling of hypertension treatment; and Dr. Mei Ling (H-index: 68), who has also done relevant studies on how to apply AI to wearable technology for real-time blood pressure tracking [8].

3.2.2 Top Journals: Some of the top tier publications such as The Lancet Digital Health and Journal of Hypertension contributed many studies suggesting their strong interest in using Artificial Intelligence for enhancing hypertension investigations. These journals offered an outlet for sharing original research impressions, as well as large-scale clinical research and technological developments of AI application.

3.2.3 Leading Institutions: Investor contributions were primarily from renowned research institutions–Harvard University which published several articles on application of the AI in hypertension patient's personalized approached and Peking University which has partnered on wearables research among other specialties. These institutions played great significant in enhancing the use of AI with clinician and population problems and diseases.



Graph 2: Showing top contributing countries, institutions, and journals by publication count or citation impact

3.3 Collaboration Networks

Map depiction and relationship density mapping in figure 2 show that United States, China and United Kingdom have strong co-authorship collaborations. These countries in total made up the largest share of high Impact Factor and utilized sound research systems and funding. Nevertheless, there was a relatively weak engagement with LMICs, which underlined a consistent gap in fairness in scientific production. Further, while hypertension affects LMICs disproportionately, these regions are still under-represented in Artificial Intelligence (AI) based research underscoring the importance of equity in collaboration.

	US	China	UK	India	Kenya
US	0	120	85	0	0
China	120	0	0	60	0
UK	85	0	0	0	25
India	0	60	0	0	10
Kenya	0	0	25	10	0

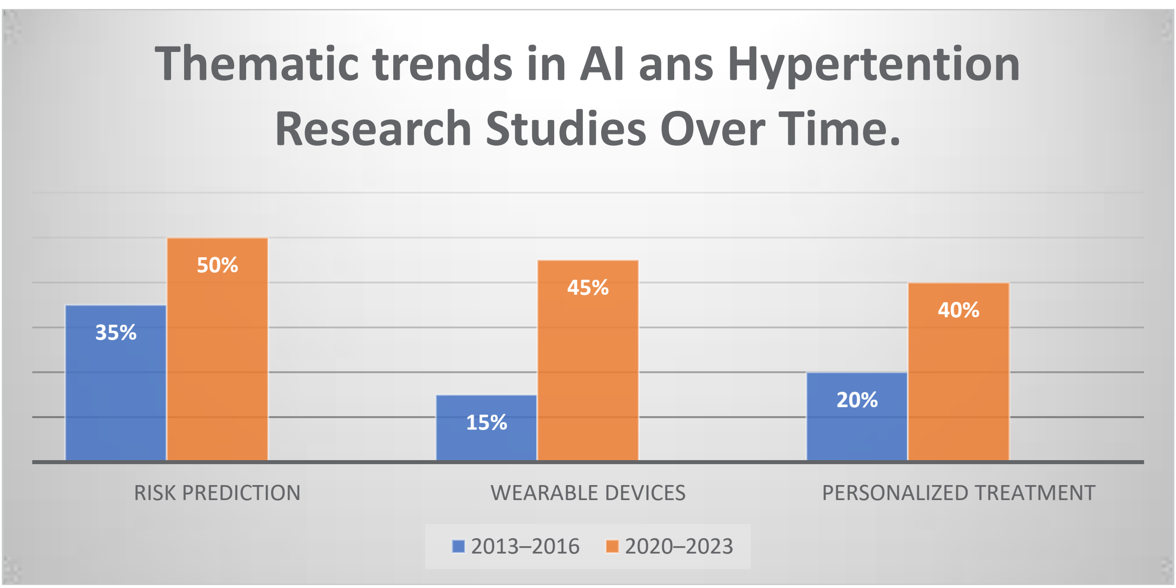
Figure 2: An Illustration of the research collaborations distribution between countries from 2013 to 2023. The gradient highlights significant disparities, with dominant collaborations seen among high-income countries, while LMICs exhibit limited research partnerships

3.4. Thematic Trends

Thematic analysis identified three dominant research trends:

3.4.1 Risk Prediction: Papers focused on how to apply ML models to identify hypertension risks with the help of varied data, including EHR and genetics. For instance, using the logistic regression and deep learning models yielded accurate early-onset hypertension prediction to facilitate preventive measures [9].

3.4.2Wearable Devices: Wearable technologies by using AI were newly introduced which gave real time blood pressure management and improved patients' interaction. New devices like smart watches with PPG sensors also offered continuous, noninvasive, would enhance patients' compliance and deliver remote care [10].



Graph 3: The bar chart shown above using thematic trend depicts of AI and hypertension research from the year 2013 to 2023. It puts into perspective the percentage of studies in three major themes which include Risk Prediction, Wearable Devices, and Personalized Treatment from two periods: (2013–2016 and 2020–2023)

3.4.3 Personalized Treatment

AI application in hypertension management improved ways of introducing appropriate therapeutic strategies. Patient data were tailored concerning each patient's lifestyle, comorbidities, and pharmacogenomics of drugs to maximize therapeutic effect and reduce side effects [11]. These thematic trends thereby reveal the creative aspect of changing the means and methods used in hypertension and the potential role of AI in future developments of the field.

3.4.4 Clinical Trials and Real-World Validation

Research on hypertension featuring AI applications shows good accuracy for predicting hypertension risk but seeks essential proof in clinical practices. Most AI-hypertension research a few studies reach the level of clinical trials to determine patient results while testing device usability and long-lasting practicality.

Trial Name	Country	Technology Used	Study Status
AI-Based Hypertension Risk Prediction in Telehealth	USA	Machine Learning Algorithms	Ongoing
Wearable AI-Integrated BP Monitoring	UK	AI-powered Smartwatches	Completed
AI-Driven Hypertension Management in Rural Clinics	India	Deep Learning-based Risk Stratification	Recruiting

Table 1: Summarizes ongoing or recently completed AI-driven hypertension clinical trials

The research shows the necessity for global expansion of AI-based trials while validating hypertension risk prediction models in various real-life medical environments [12].

4. Discussion

4.1 Key Findings

This study showed a radical increase in hypertension research articles with the AI application from 2013 to 2023, which depicts the increasing importance of AI in the global hypertension issue. Such an increase in the number of publications may be explained by the growing interest in AI applications in healthcare, including in hypertension prediction, monitoring, and management, with the annual publication growth rate of 12.5%. The results showed that HICs such as USA, China, and UK published a greater number of articles with 75-80% of the global total. These nations have established strong research infrastructure and funding for the advancement this field, few of the prominent institutions for this domain are Harvard University and Peking University.

Themes revealed three growing trends, use of Machine Learning (ML) model for risk prediction, wearable technology for monitoring and personalized approach to management. The use of AI through sensors, for instance, PPG in smartwatches also had promising potential in enhancing patient compliance and the possibility of home-based health delivery [13]. Research also showed ways that ML algorithms in individual patient characteristics were used to improve the efficiency and safety of treatments.

4.2 Research Gaps

Despite the promising advancements, the study identified critical gaps that hinder the equitable and effective application of AI in hypertension management:

4.2.1 Language and publication Biase: Almost all researched papers on AI applications in hypertension available for study originated from English language publications thus creating a language and publication bias. The analysis excludes significant findings from areas where hypertension affects populations heavily since these regions typically use non-English languages including China, Russia, Latin America and the Middle East.

Future research should utilize multilingual AI models to perform literature reviews and text analysis for the purpose of reducing language-based research bias. Google's BERT multilingual model in combination with deep learning-based translation tools enables the evaluation of non-English research papers extracted from databases that include CNKI (China National Knowledge Infrastructure) and LILACS (Latin American and Caribbean Health Sciences Literature) as per Gasparyan et al. (2021). AI researchers together with medical professionals who publish outside English can enhance understanding of hypertension management through their regional knowledge and language-related expertise.

4.2.2 Underrepresentation of LMICs: Among the reviewed studies, just under a quarter (12%) were from LMICs settings even as these settings experience a significantly higher burden of hypertension. There are also concerns that little research has come out of LMICs and therefore conclusions may not be broadly applicable; furthermore, health disparities persist. Some of the causes of such an imbalance include the following; lack of funding, poor research facilities, and scanty competent AI expertise in those areas.

4.2.3 Real-World Applications: Most of the researches were mostly concerned with the development of the algorithms or cohort reviews while less attention was paid to randomized control studies which determine the effectiveness and clinical outcomes of the approaches in a specific timeframe. For example, despite the fact that supreme results for hypertension risk prediction were achieved in developed models, further research concerning their application in various, real-world populations is still very limited. Currently, there is limited evidence based on large-scale implementation studies that qualify successfully developed AI innovations for usual clinical care [14].

4.2.4 Lack of Methodological Details: Limited methodological details, however, excluded several of the AI-hypertension studies in this study. In a plethora of studies, there were also no clear descriptions of their AI models, validation techniques, or patient demographics, hindering one's ability to assess the reliability and applicability of them.

Future research can follow established AI-specific reporting frameworks, like the AI based risk prediction models; TRIPOD

(Transparent Reporting of a multivariable prediction model for Individua Prognosis or Diagnosis). Secondly, researchers should implement the CONSORT-AI (Consolidated standards of reporting trials–AI Extension) for reporting randomized clinical trials involving AI driven interventions [15].

4.3 Opportunities

Addressing these gaps presents significant opportunities to enhance the impact of AI in hypertension research and management.

4.3.1 Bridging AI Research and Application in LMICs: The development of hypertension prediction systems using AI has progressed, yet their application in medical practice remains limited. Research mainly focuses on the creation of AI systems and evaluations of past medical data, but only a handful of clinical trials have confirmed the effectiveness of AI technology in hospital settings [5].

i. Future research should mix data analytics and vital disease verification in real medical contexts.

ii. Hypertension risk evaluation becomes faster from using AI systems that help doctors make medical decisions.

iii. Researchers tested AI-powered blood pressure monitoring devices in numerous medical centers during randomized studies.

iv. Research teams should monitor patient adherence and health results through extended projects that examine AI's effects on patients with hypertension.

v. Our strategic steps will help technical advancements in AI become accepted treatments for hypertension patients.

4.3.2 Building More Cohesive International Partnerships: Evaluating equitable relations between HICs and LMICs to enable creation of research collaborations can help in closing the knowledge and resource gap. Practical partnerships, including both capacity enhancement and funding support, can ensure that the LMIC researchers make valuable research contributions.

4.3.3 Population Health Management –An Opportunity to Build on Existing AI Experience: The utilization of AI in hypertension care at populations' level may be useful in the global control of the disease. Using big data from different populations AI will be able to find out the most vulnerable people, allocate resources effectively, and help in making healthy policies to provide equal health care.

4.3.4 Equity-Focused Interventions: The utilization of AI in the community health programs in LMICs could enhance hypertension care especially in the communities that poorly covered. There is indication that innovative telehealth systems and affordable wearable technologies could enhance timely diagnosis and active follow-up, two important factors of access.

4.4 Comparative Analysis

Comparing hypertension research to other chronic diseases like diabetes and kidney disease, Moghani Lankarani, and Assari [16-19] show that AI applications in hypertension have less implementation of real-world clinical trials. For instance, AI-enabled glucose tracker devices and algorithms for early detection of chronic kidney disease are well tested in clinical practice, and hence popular. On the other hand, hypertension research continues to be investigated in circulating and retrospective analysis only continuously shifting the advancement in artificial intelligence solution from laboratories to clinics.

Domain	Key AI Application	Implementation	Real-World Trials
Hypertension	Wearable BP monitors	Limited	Few
Diabetes	Glucose monitoring systems	Widespread	Extensive
Kidney Disease	Risk prediction models	Moderate	Moderate

Table 2: Contrasting AI adoption in hypertension with diabetes and kidney disease

This difference underlines why the study of implementation science needs urgent attention in hypertension research. From a research perspective, large-scale, multi-site studies in different populations may assist in establishing the applicability of developed AI methodologies in actual practice. The findings of this study stress the positive impact of AI in hypertension control but also state the existing lack of gender, ethnic, and application-related studies. It becomes evident that there are approachable solutions to the problem at hand to help fill the existing gaps and capitalize on opportunities to innovate equitably for the benefit of inclusion of all the targeted populations into the field of AI.

5. Ethical Considerations in AI-Driven Hypertension Management

Healthcare practices integrating AI systems create major ethical issues when applying the technology for hypertension risk assessments and remote patient monitoring responsibilities. Research must solve three primary ethical problems.

i. AI models become biased when they are based primarily on Western data sets. They cannot efficiently be applied to low-and medium-income populations. Using AI for hypertension risk assessment through biased methods frequently results in incorrect medical decisions and unbalanced healthcare results (Obermeyer et al., 2019).

ii. AI-based wearable devices continuously collect data on patient health, presenting HIPAA and GDPR compliance issues related to data protection and security.

iii. The accessibility of AI-powered hypertension management should focus on achieving equality by making both devices and services cost-effective and widely available in lower-middle-income countries.

6. Conclusion

6.1 Summary

Recent advances in hypertension artificial intelligence (AI) have focused on predictive modelling, wearable technology, and customized plans. These innovations have pointed out an opportunity to shift tackling of hypertension through early detection, real-time monitoring of the condition and individualized prescription. However, there are established crucial issues; for example, a minority of research contributions originated from LMICs; the advancement of artificial intelligence solutions is hindered by the lack of its adoption in real-life practice. To ensure that these advantages of AI-supported health services can be distributed among all population categories, it is necessary to resolve some issues and avoid specific prejudices.

6.2 Research and Policy Conclusions

To enhance AI's role in hypertensive management globally, it is mandatory to address the imbalance in collaborations between policymakers, funding agencies, and researchers regarding inequality and research-to-practice gaps. This includes engaging diverse and exclusion-less approaches to incorporate LMIC researchers in modelling AI tools to fit LMIC populations, self-sustaining large-scale clinical trial studies to ascertain the generalization of AI tools in the LMIC populace and mapping strategies for scaling up ALS interventions in context-restricted LMIC settings.

6.3 Policy Recommendation

Implementing AI into national hypertension guidelines requires the adoption of these policy recommendations:

i. National health agencies must create official standards and regulatory approvals for AI-based blood pressure monitoring devices that ensure operational safety and meet specific quality guidelines.

ii. Translating AI into Primary Care involves implementing AI risk assessment systems for hypertension screenings to provide judgment support and individualized treatment to medical professionals during diagnosis.

iii. AI deployment in hypertension management needs international best practice regulatory frameworks through policymaking that follows FDA AI/ML-based software as a Medical Device (SaMD) guideline for safe deployment.

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