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Review Article

Breaking Barriers in Hypertension Care: The Role of AI

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ABSTRACT

Hypertension is also known as high blood pressure. In today's modern era, hypertension begins with understanding of the cardiovascular system. Wearable devices is revolutionizing and supplementing traditional methods like home and ambulatory blood pressure monitoring. These devices allow frequent, continuous blood pressure monitoring with little pain to the patient. Due to these advancements, we are able to detect abnormal blood pressure and masked hypertension with great accuracy and efficacy. The increasing incidence of hypertension highlights the critical need for improved awareness and prompt diagnosis, particularly in older populations. Artificial Intelligence(AI) is an emerging technology that can provide solutions for timely management of blood pressure . Through telemedicine, we can do analytical prediction and remote monitoring. AI powered devices allow continuous, non-invasive blood pressure monitoring when used in conjunction with wearable devices and smartphones. These devices take the information in real time and apply AI algorithms to identify risk factors , forecast risk predictions . By the help of AI, patients can receive timely medications, treatment. The integration of AI has also helped in reducing patients visit to a hospital. Therefore, this review focuses on the history of hypertension, encompassing how artificial intelligence has played a major role in monitoring hypertension . It focusses at the different kinds of hypertension, conventional monitoring techniques, and the use of AI for risk assessment, medication optimization, and real-time monitoring. This review also discusses how AI may advance hypertension treatment in the future, offering predictions on how it can strengthen precision medicine, boost patient outcomes, and revolutionize hypertension therapy in the years to come.

INTRODUCTION

Hypertension is also known as high blood pressure. Hypertension is considered as a major threat to human life as it is one of the factor that contributes to cardiovascular disease. Hypertension in today's world begins with the understanding of the cardiovascular system. In 1891, Samuel Siegfried Karl Ritter von Basch was the first person who invented sphygmomanometer. This invention proved to be of great help for physicians as they could easily diagnose hypertension with greater precision. In mid-20th

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century, as we came to know more about how hypertension grew and if it is left untreated it could cause major, serious health problems such as heart attack, kidney diseases, heart stroke and many more . In late 19th century and early 20th century many therapies and treatments were used for treating hypertension like rice diet but many were not successful . The major achievement we achieved was in 1950 which was the discovery of diuretics i.e. Chlorthiazide. After this many drugs came into the market which could treatment hypertension. Hypertension has affected more than 1.13 billon individuals in 2015 and is still continued to be a substantial contributor for cardiovascular illnesses. [1] Recent studies estimate that over 14 million people are unaware of their blood pressure level and subsequently, they are neither taking suitable drugs for it nor they are conducting any physical exercise so as to maintain their blood pressure normal. [2] Hypertension is defined as the medical condition in which the pressure of blood flowing through arteries is increased. It is measured in mm/Hg. The hypertension is recorded in two numbers i.e. systolic and diastolic. In hypertension the pressure is high than the normal blood pressure of the body i.e. 120/80 mm/Hg. Various causes of hypertension include smoke, stress , obesity , lack of physical activity .

AI can be defined as a branch of computer science that attempts to develop smart machines that are capable of improving their knowledge through an automated learning process that normally requires human intelligence. AI is an multidisciplinary science with numerous techniques such as reasoning which means making references using data, natural language processing which signifies the ability to read and understand human languages, planning i.e. the ability to act flexibly to develop a sequence of operations and then reach a final goal. [3] AI has proved to be a boon in the field of hypertension management because it offers new strategies, techniques for monitoring and controlling blood pressure. AI-driven technologies have the ability to enhance the accuracy, efficiency, and convenience of blood pressure monitoring. One of the significant advancement is the integration of AI with wearable sensors and smartphones, which enables continuous and real-time monitoring of blood pressure. The wearable devices can measure blood pressure non-invasively and provide valuable data to individuals. [4] AI algorithms can analyze the data and detect patterns, identify risk factors, predict hypertension-related complications. Remote monitoring through telemedicine platforms help patients by providing them timely information about their state so that they can timely receive interventions, personalized treatment plans without visiting the clinician. [5]

It is important to measure blood pressure because it helps us to plan accordingly that what further treatments we have to follow. It helps in early detection, diagnosis , prevention of cardiovascular disease .

Types of Hypertension

There are two types of hypertension -

1. **Primary Hypertension**
2. **Secondary Hypertension**

- Primary Hypertension – is also known as essential hypertension. Most of the individuals suffer from this type of hypertension. This hypertension does not have a known cause. It is thought to be a combination of genetics, age, lifestyle, diet. [6]
- Secondary Hypertension – This type of hypertension has a known and identifiable cause. Nearly 5% of the people have this kind of hypertension. Young age people suffer from this kind of hypertension. Causes of this type of hypertension include – constriction of the aorta, narrowing of the arteries that supply blood to the kidney, hormone abnormalities. [7]

The subtypes of Primary and Secondary Hypertension are –

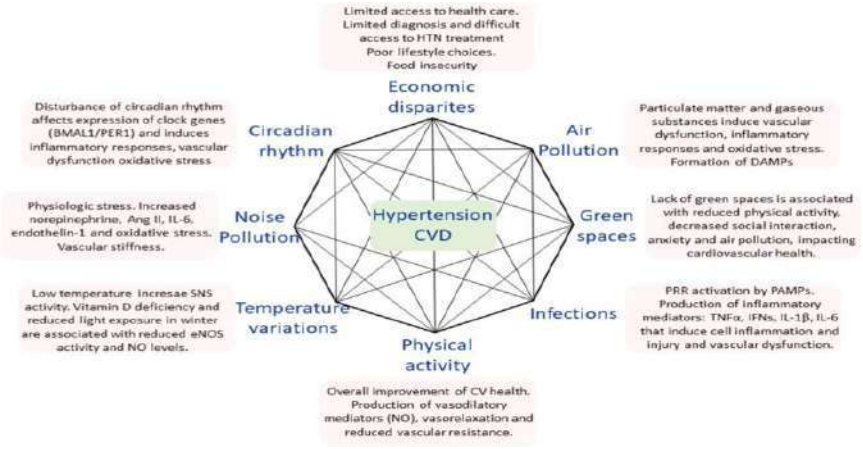
1. Resistant hypertension
2. Malignant hypertension
3. Isolated systolic hypertension

- Resistant Hypertension is defined as the high blood pressure i.e. difficult to manage, requires multiple medications. In this case our blood pressure remains higher than our treatment target even when we are taking three different types of blood pressure lowering medications including a diuretic then also blood pressure is not lowered, such a condition is referred to as resistant to treatment. People who are having resistant hypertension may have secondary hypertension with a cause but that has not been identified. Mostly, resistant hypertension can be treated with many drugs or by identifying the secondary cause. [8]
- Malignant hypertension refers to that type of high blood pressure that causes damage to our organs. This should be treated as urgent importance. In this type of hypertension, the systolic blood pressure is usually found to be 180 mm/Hg or higher and diastolic pressure is found to be higher than 120- 130 mm/Hg. Despite rise in blood pressure the organs also get damaged. [9]
- Isolated systolic hypertension – In this type of hypertension, systolic blood pressure is above 140 mm/Hg and diastolic blood pressure is below 90 mm/Hg. This type usually affects older people. People of young age can also develop this kind of hypertension. [10]

Etiology of Hypertension

Hypertension is a major disease with many etiological factors. The cause of primary hypertension is not known but this type of hypertension includes the combination of genetic and environmental factors. Risk factors like age, obesity, family history play an important role in development of hypertension. [11] Secondary hypertension has a known cause out of which renal disease is the most common and other causes include sleep apnea, pregnancy and drug use.

The etiology of hypertension involves a complex interplay between genetic, environmental, and pathophysiological factors. [12] Some of the factors that affect hypertension are – diet, obesity, physical inactivity. Firstly a diet containing high amount of salt intake, low potassium intake and excessive consumption contribute to be as one of the factors that contribute to hypertension. Secondly obesity or overweight increases our risk of hypertension. In obesity, adipose tissue gets deposited and visceral fat can release pro – inflammatory cytokines and disrupt the normal endocrine function of the body leading to development of hypertension. [13] Moreover physical inactivity can be considered as one of the factors that contributes to hypertension. Regular physical activity is necessary because it helps in maintaining good health , keeps our blood pressure in normal range and also keeps us healthy . Lack of physical activity contributes to inactiveness, obesity which indirectly leads to hypertension . The most important is age . Blood pressure continues to rise as we grow older . With increasing age the arterial walls gets stiffened and elasticity within the arteries is lessened due to which there is difficulty in flowing of blood as pressure is increased and therefore this ultimately leads to development of hypertension. [14] Environmental factors that contribute to hypertension are Air Pollution , Traffic Noise , Climate Change , Temperature . The environmental factors affecting hypertension are explained in the below image



Genetic Factors play an important role in development of hypertension . Some of the genes that are responsible to increase hypertension are - LDRL (low-density lipoprotein receptor),APOA5 (Apo lipoprotein A-V),LPL (lipoprotein lipase), MIA3, ADAMTS7 (a disintegrin and metalloproteinase with thrombospondin motifs-7) etc. [15] Genetic factors include the following- Vascular Dysfunction: In vascular dysfunction there is impaired endothelium-dependent vasorelaxation which leads to increased vascular remodeling further which leads to inflammation which then causes reduced distensibility, and finally leading to stiffening of arteries which indirectly causes hypertension. [16] Some other factors include-

- Renal Dysfunction: In renal dysfunction there is fluid retention which leads to increased blood volume which leads to increased blood pressure.
- Sympathetic Nervous System Activation: Activation of the sympathetic nervous system causes increased heart rate, peripheral vascular resistance resulting in high blood pressure.
- Oxidative Stress: The body's inability to neutralize reactive oxygen species (ROS) production causes vascular dysfunction, cardiovascular remodeling, and hypertension.

Therefore, a complex interaction exists between genetic, environmental and pathophysiological factors.

Pathogenesis of Hypertension

Pathogenesis of hypertension is multifaceted and the factors that contribute to hypertension are genetic and epigenetic factors, neuro-hormonal factors , cardiac factors , vascular pathophysiology etc. Genetic and Epigenetic Factors - Genetic factors that contribute to hypertension include variations in DNA regulatory sequences and single genetic mutations. Approximately 30% of hypertension cases are inherited through a single genetic mutation, and 30 to 50% of variation is influenced by genetic factors. Hypertension can be influenced by epigenetic factors, which are stable changes in DNA function that are not determined directly by the sequence of the DNA. Lifestyle and environmental factors may influence these changes. [17] Epigenetic mechanisms that play a role in hypertension include- DNA methylation, Histone modifications, Noncoding RNA that regulates transcription, Chromatin conformation . Neurohormoral Regulation – The important function of neurohumoral regulation is to maintain cardiovascular homeostasis. The two pillars of neurohormonal regulation are - autonomic nervous system (ANS) and the renin-angiotensin-aldosterone system (RAAS). The ANS can be divided into sympathetic nervous system SNS and peripheral nervous system PNS . SNS is generally activated under stress while PNS prevails during rest . RAAS is divided into two counteractive systems – classical and alternative . The classical sytem involves angiotensin converting enzyme (ACE) , angiotensin (Ang), ANG II type 1 receptor , aldosterone and mineralocorticoid receptor . [18]

The alternative RAAS system involves ACE2 , Ang 1-7 and MAS receptor . Chronic activation of RAAS can lead to maldaptive changes contributing to cardiac detoriation and increased neurohormonal imbalance . Vasular Dysfunction - Vascular dysfunction is associated with hypertension and can involve endothelial dysfunction and arterial stiffness, contributing to the pathogenesis of hypertension. Endothelial dysfunction may precede the development of hypertension and is associated with increased cardiovascular risk. [19] It is characterized by vasoconstriction, cell proliferation, and a shift towards a pro-inflammatory and prothrombotic state. Endothelial dysfunction can lead to increased peripheral vascular resistance, vascular inflammation, remodeling. [20] Additionally, excessive reactive oxygen species (ROS) derived from NADPH oxidases (NOXs) and mitochondria contribute to vascular oxidative stress and dysfunction in hypertension-related disorders .

The hallmark of hypertension is oxidative stress. O_2/H_2O_2, 8-isoprostaglandin F2α (8-iso-PGF2α), oxidized low-density lipoprotein (ox-LDL), and protein carbonyl are the biomarkers of oxidative stress that are elevated in oxidative stress. Additionally, hypertension-related disorders exhibit vascular oxidative stress, with increased production of $O_2\bullet-$ and H_2O_2 in vascular cells in experimental models of hypertension. [21] Oxidative stress promotes aberrant cell signaling and vascular remodeling, which contributes to hypertension development . Kidney Function and Fluid Balance – The kidneys play a crucial role in maintaining sodium balance, which directly impacts blood pressure regulation. Impaired kidney function can lead to reduced sodium excretion in urine, resulting in sodium retention and salt-sensitive hypertension .

Salt sensitivity refers to the physiological trait where blood pressure changes in response to alterations in salt intake. Increased salt consumption leads to an expansion of extracellular fluid volume and increased cardiac output which could result in an increase in blood pressure. In salt-sensitive individuals, the kidneys retain the most of the salt because of an abnormal sympathetic nervous system over reactivity and impaired nitric oxide synthesis in the endothelium. This abnormal kidney reaction contributes to hypertension. [22] Additionally, factors such as age, gender, chronic kidney disease, and insulin resistance can influence salt sensitivity and hypertension. Lifestyle Factors Obesity is a worldwide disorder that is common to children, adolescents, and adults. Obesity is associated with many health problems, including insulin resistance, cardiovascular disease, hypertension . Obesity, especially visceral obesity, is a contributing factor to the development of hypertension and cardiovascular diseases High blood pressure and arterial stiffness are more likely to be seen in obese people. Obesity increases intravascular inflammation, alters endothelial function and reduces diameter of arteries. [23] Sleep Apnea – Obstructive Sleep apnea (OSA) is a common sleep disorder breathing condition that often coexists with hypertension. OSA is characterized by a multifactorial process involving different mechanisms, including sympathetic activation, baroreflex impairment, and chemo reflex impairment. These factors contribute to cardiac and vascular damage, increasing the risk of cardiovascular disease. [24] OSA is characterized by recurrent episodes of apnea which results in intermittent hypoxia and causes various autonomic, hemodynamic, and biochemical changes that contribute to the pathophysiology of hypertension. [25] This includes increased activity of sympathetic nervous system, activation of the renin-angiotensin-aldosterone system, endothelial dysfunction, inflammation, and metabolic dysregulation. Therefore pathogenesis of hypertension involves the following factors.

Traditional Methods Of Monitoring Hypertension v/s Modern Method Of Monitoring Hypertension

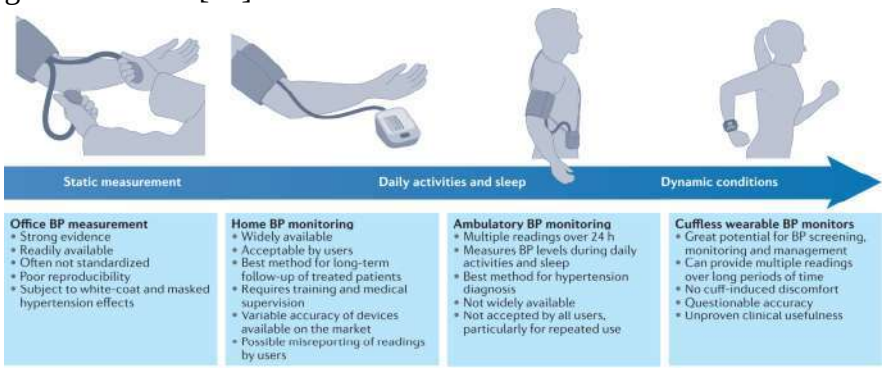
The traditional method of monitoring hypertension is one of the oldest methods. In-office blood pressure measurements, ambulatory blood

pressure monitoring (ABPM), and home blood pressure monitoring (HBPM) are some of the traditional methods of monitoring hypertension [26] while modern method includes automated detection systems that use physiological signals such as electrocardiography (ECG), photoplethysmography (PPG), heart rate variability (HRV), and ballistocardiography (BCG). These signals are analyzed using advanced techniques like machine learning and deep learning to provide early detection and continuous monitoring of hypertension. [27]

- **Traditional Methods of Monitoring Hypertension**

Ambulatory blood pressure monitoring (ABPM) is a technique in which patients wear a small device that is connected to an arm cuff and it measures their blood pressure over a 24-hour period, including during nighttime sleep. It provides a more comprehensive assessment of an individual's blood pressure by capturing fluctuations throughout the day and has been recommended as the method of choice for assessing blood pressure and guiding the use of antihypertensive drugs. [28] ABPM helps to identify conditions like white-coat hypertension and masked hypertension. Office blood pressure measurement, also known as conventional blood pressure measurement, is typically taken using either auscultatory or semi-automated oscillometric devices. It is typically done using a sphygmomanometer in a clinical or screening setting. It is considered the gold standard of blood pressure measurement techniques and involves taking measurements after a few minutes of rest, either twice or thrice, and then averaging these values. [29] This method was recommended by some organizations like American Heart Association Guidelines, the European Society of Cardiology, etc.

Automated office blood pressure (AOBP) measurement is another technique that uses a fully automated oscillometric device to record multiple readings while the patient rests in the examination room and these provide more accurate readings for the diagnosis and treatment of hypertension. [30] Home blood pressure monitoring (HBPM) is a practical, less expensive option than ambulatory blood pressure monitoring (ABPM). Accuracy and Reliability of HBPM necessitate the use of validated equipment and consistent methods, combined with training and good patient information. These days, semi-automatic HBPM devices can take our blood pressure periodically while we sleep. When compared to ABPM, HBPM has a number of benefits, such as being widely available, having the capacity to take numerous daily readings over an extended period of time, identification of masked hypertension and blood pressure variability, enhanced hypertension treatment as a result of immediate feedback and patient involvement, and relatively low cost. [31] The auscultatory technique is also a traditional approach for measuring blood pressure. It uses Korotkoff sound for measuring blood pressure . Secondly, Oscillometric method is also a method for measuring blood pressure. Marey in 1876 firstly established this approach. It was seen that when the oscillations of pressure in a sphygmomanometer cuff are recorded during gradual deflation, the point of highest oscillation is correlated to the mean intra-arterial pressure.



Modern Methods Of Monitoring Hypertension

Modern methods of monitoring hypertension are gaining importance nowadays. These methods provide accurate readings with less defects. These methods are still under study . This methods involves use of automated devices like watches , mobile health care apps for measuring blood pressure. [32] Modern method includes Hypertension telemonitoring , Home-based physical training programs , Cuff-less and wearable devices , Mobile health, Physical training Hypertension Telemonitoring involves telemonitoring of blood pressure and cardiovascular risk factors such as sedentary lifestyle, diet. Home-based physical training programs involve supervised cardiac rehabilitation using telemonitoring and text messaging, which has been shown to improve physical fitness and quality of life. [33] Cuff-less and wearable devices provide continuous BP . Mobile health involves the use of smartwatches, smartphone apps, and online software to monitor physical activity and other cardiovascular signals. Regular physical training is a must because it can reduce blood pressure and cardiovascular risk factors . Automated unattended office blood pressure (AOBP) measurement is also one of the method for measuring blood pressure . In this blood pressure readings are taken with a fully automated device in the absence of healthcare personnel. Modern Methods therefore uses cuffless blood pressure sensors , wearable devices , remote monitoring technologies, wireless smartphone-enabled upper arm blood pressure monitors and mobile applications .

Role of AI In Monitoring Hypertension

AI also known as Artificial Intelligence plays an important role in monitoring of hypertension. AI is being employed in hypertension monitoring using blood pressure telemonitoring (BPT) systems. BPT is a branch of telemedicine that intends at collecting and transmitting BP readings, related information on patients health state. [34] Machine learning models are also being used in applications based on m-health and making use of wearables or smartwatches. These applications are particularly promising for the future. AI is being used to monitor hypertension through the use of wearable devices that can continuously monitor blood pressure. [35] AI can also be used to predict hypertension through large data sets and to suggest treatment protocols. AI is being used to monitor hypertension through the use of machine learning (ML) to predict non-invasive blood pressure (NIBP) measurements. [36] This is done through the use of pulse arrival time, pulse transit time, pulse wave velocity, and ML. These techniques are used to continuously monitor blood pressure and can be used to predict hypertension. Most notably the tools which leverage AI play a vital role as they can be utilized to create novel ideas and clinical classifications about the biology of hypertension. [37] They can also assist utilize possible actional insights obtained by DNA and RNA sequencing which can lead to the discovery of potential pathways and target molecules for which medications or treatments can be designed and tested. [38] Some other important roles of AI in monitoring hypertension are - Enhanced Data Analysis , Predictive Analytics , Personalized Treatment , Improved Medication Adherence , Automated Alerts and Notifications, Comprehensive Health Monitoring , Clinical Decision Support, Behavioral Insights, Patient Education and Support, Research and Innovation.

Increased data analysis with AI algorithms has been made possible through real-time monitoring as well as pattern recognition. Consequently, AI algorithms analyze real-time information from wearable gadgets or home BP monitors which provide feedback immediately and alert when readings appear unusual. [39] Additionally, they are able to view trends and patterns in blood pressure measurements over a period of time showing slight changes that suggest deteriorating high blood pressure or other underlying disorders. Moreover, artificial intelligence models predicting the onset of hypertension based on the history of past health records as well as lifestyle can be used for such purposes. This allows for early response

and personalized prevention methods. By using AI-driven apps, reminders about taking medicines can be sent as well as therapy compliance monitored and medication usage feedback provided; thus ensuring adherence to prescribed treatment plans. AI systems can analyze lifestyle and behavioral data to provide tailored recommendations on diet, exercise, and stress management. AI tools can assist doctors in diagnosing hypertension by analyzing data from blood pressure readings, medical history, and other diagnostic tests. This can help in identifying patterns and making more informed decisions. [40]

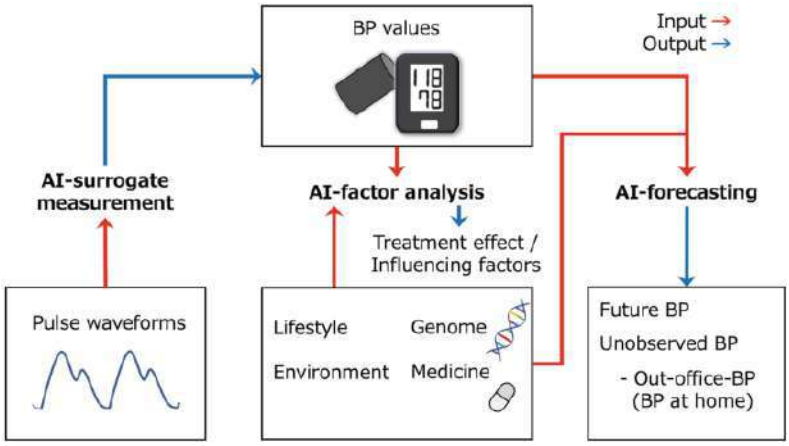
AI Applications In Monitoring Hypertension

AI has various applications in monitoring hypertension. AI can be used to monitor hypertension by using wearable biosensors and portable devices. By developing an AI-based fuzzy assisted Petri net (AI-FAS) method for stress assessment on HR and BP monitoring, AI can be used to manage hypertension. [41] The transitory duration of each pulse serves as a basis for the AI-FAS stress assessment tool, which is used for heart rate tracking and stress management.Deep learning, the exponential increase in processing power, and the availability of massive datasets have propelled the "AI revolution". Deep learning is a subclass of machine learning that creates final input without human assistance by using multilayered neural networks to learn representations of the input data at different levels of abstraction. [42] Deep learning-based image recognition has garnered substantial interest, particularly in the domains of pathology, radiology, cardiology, etc. The use of AI technology in healthcare will enhance diagnostic performance and lessen the amount of work that physicians have to do to diagnose and analyse patient data. In addition, AI has enormous potential to advance precision medicine. Deep learning algorithms are able to support clinical judgements in a range of diseases by predicting clinical risks based on patient datasets in the form of EMR or EHR data. [43]

An AI-enhanced blood pressure monitoring wristband has been developed to monitor hypertension. Piezoelectric Nano generators based on the basis of the wristband's sensors, have a high signal-to-noise ratio of 29.7 db. The wristband has ability to monitor blood pressure readings using the transformer deep learning model, and its loss value is less than 4 mmHg. In addition to being lightweight and having a significant impact on the prevention and treatment of hypertension, the blood pressure monitoring wristband has numerous potential uses in the aerospace, medical, and military industries. [44] The aorta diameter can be measured using artificial intelligence (AI) to help detect blood pressure abnormalities, such as disguised hypertension. AI-powered applications can be used to monitor hypertension. [45] The application monitors symptoms and risk factors through the use of artificial intelligence (AI), digital therapies, and an integrated virtual care platform. The application also uses remote monitoring capabilities to transform the provision of long-term care. [46] Although physiological signals like electrocardiography (ECG), photoplethysmography (PPG), heart rate variability (HRV), and ballistocardiography (BCG) are not directly related with blood pressure readings but can be used to assess health status. Using these physiological signs, the manual identification of hypertension is laborious and prone to human mistake. As a result, numerous systems for computer-aided diagnostics have been created. [47] A smart home health monitoring system has been developed to predict hypertension. The system uses a combination of machine-learning approaches and conditional decision-making to predict hypertension. The system uses supervised machine learning algorithms to train the system and predict the patient's hypertension status. The system has been developed as a desktop application that will help in analyzing blood pressure readings and send notifications to physicians for further diagnosis. It also has an alarm feature through which a patient can notify their physician via email. [48]

Hypertension can also be measured by using a machine learning approach based on photoplethysmography and clinical data. [49]

AI-powered Remote Patient Monitoring (RPM) systems can monitor hypertension by analyzing real-time data from wearable devices and sensors. [50] Based on artificial intelligence, RPM systems are capable of monitoring blood pressure and heart rate in individuals suffering from cardiovascular conditions, predicting possible heart attacks or strokes and facilitating timely therapies.



Why AI is needed in monitoring hypertension

AI is needed in monitoring hypertension because it can detect minor patterns that humans cannot detect . It can help by eliminating time-consuming data monitoring methods. [51] It has the potential to improve clinical practice by incorporating individualized preventative and treatment techniques, such as setting optimal and patient-specific blood pressure objectives, selecting the most effective antihypertensive medication regimen for an individual . It exhibits the ability to detect risk factors and phenotypes of hypertension, forecast the likelihood of incident hypertension, diagnose hypertension, estimate blood pressure, develop novel cuff less methods for blood pressure measurement. [52] The application of AI in monitoring hypertension is needed to assist forecast the development of hypertension in a general population. This can be done by identifying persons at risk of developing hypertension and allowing early intervention with techniques such as lifestyle modification to avoid future hypertension development. [53] It is needed in monitoring hypertension because it can help to improve the quality of life for patients with the condition. AI can be used to monitor hypertension by collecting data from sensors and other devices, such as smart watches and then using machine learning algorithms to analyse the data.

AI can be used to monitor blood pressure and heart rate, and then use this data to predict the likelihood of a heart attack or stroke. This can help doctors to make more informed decisions about treatment and can also help patients to manage their condition more effectively. [54] AI is used in monitoring hypertension because it can produce early and accurate results, helping doctors make early decisions to save the life of patients. [55] AI is needed in monitoring hypertension because it can help to improve the quality of patient care, increase the productivity, efficiency, and accessibility of health care provision. [56] AI can also help in monitoring hypertension in elderly and old age patients and improve the quality of care. [57] Artificial Intelligence (AI) can be used to monitor hypertension by using predictive analytics to identify potential cardiac events faster than a clinician. [58] Many sensors, communication networks, wearable devices, and portable gadgets have made it possible to collect various types of data that could help in hypertension diagnosis.

AI integration with hypertension monitoring also enhances patient involvement and treatment plan adherence. Real-time feedback from AI-powered gadgets might warn users of possible health

hazards or remind them to take their medicine. Constant interaction increases adherence to recommended therapy and encourages the adoption of healthier lifestyle choices, empowering patients to take a more active role in their own health care. [59] AI is being used in the management of hypertension not only for individual patients but also for population-level health. Through the analysis of data trends, including lifestyle characteristics, genetic predispositions, and environmental effects, AI can identify high-risk individuals among the overall population. Therefore, AI is needed in monitoring hypertension because it can help to diagnose and manage the condition. AI can be used to monitor blood pressure and detect any changes that may indicate hypertension. It can also be used to track the effectiveness of treatment and make adjustments as needed. [60] AI is used in monitoring hypertension because it can help individualize changes in medication doses to increase patient compliance and secondarily improve health outcomes. [61] AI is needed in monitoring hypertension because it allows for extensive data analysis, prognosis, and precise health recommendations based on people's biometric data collected daily. AI-driven personal health monitoring devices can provide real-time data, analysis, and health-based recommendations, which can help the person make informed health decisions. Through the constant accumulation and analysis of health information, they help in the identification of possible health complications so as to influence proactive measures when it comes to medical attention. [62]

Future Prospects of AI

Artificial intelligence (AI) and machine learning (ML) are the upcoming technologies that have the potential to transform the way hypertension is being managed and monitored. [63] One of the most promising tools for helping in clinical decision-making and enhancing disease treatment is artificial intelligence (AI). AI helps to handle, interpret and use multiple data collected on individual patients. [64] AI technology has the potential to revolutionize the landscape of hypertension management and research. The application of AI to hypertension healthcare and research, or digital hypertension, can provide further insights into the pathophysiology and therapeutic targets of hypertension. It can also enable predictive, personalized, and preemptive approaches in clinical practice. [65]

AI-powered smart healthcare systems can provide cost-effective solutions for the increasing number of older adults affected by chronic diseases. These systems can remotely identify abnormalities in vital signs, such as body temperature and heart rate, by using wearable technology and smartphone apps. Machine learning algorithms can interpret and present predictive analytics, including the prediction of illnesses and the tracking of chronic conditions like hypertension. Additionally, AI can assist in creating ambient assisted living environments for older adults, integrating smart healthcare techniques for better care without human intervention. [66]

Artificial intelligence (AI) can be used to revolutionize medical diagnosis, treatment, risk prediction, clinical care. It can be used to analyze raw image data from cardiac imaging techniques (such as echocardiography, computed tomography, cardiac MRI) and electrocardiogram recordings. [67] It has potential to be a powerful tool for monitoring hypertension. In the field of cardiology, AI has been used to interpret echocardiograms, automatically identify heart rhythms from an ECG. [68] AI-powered personal health monitoring devices are gradually becoming acknowledged as significant improvements in the medical field. These devices can provide real-time data, analysis, and health-based recommendations, helping individuals make informed health decisions. Through the constant accumulation and analysis of health information, these devices can identify potential health complications, allowing for proactive medical attention. [69] The integration of AI with telemedicine and other digital health applications enhances the accessibility of healthcare services. Continuous

screenings and early diagnosis increase the chances of early treatment, resulting in more efficient management of chronic diseases. AI has played an essential part in healthcare, and its implementation has evolved from simple designs to more complex and smart systems.

Remote healthcare monitoring services powered by AI help hospitals in quickly discharging patients from the hospital. Analytical prediction makes it simple to develop a risk stratification model, which frees up more time to manage a patient group with high risk indicators. [70] The future of AI in monitoring hypertension looks set to focus on the development of non-invasive, continuous blood pressure monitoring systems. Wearable and ambulatory technology will emerge as reliable, accurate technology in the future. The potential for real-time risk factor adjustment based on lifestyle, system biology, and electronic health record data will be made possible by these technologies. [71] AI techniques such as machine learning and deep learning can improve medical knowledge and assist physicians in making better clinical decisions. AI can be combined with telemedicine and mobile health to provide a universal healthcare solution. It helps elderly , chronic patients by allowing them to receive medical care at home without visiting hospitals and also improves their quality of life. Using AI in cardiology has the potential to bring wide possibilities for personalized care, change the way cardiology is practiced. [72] Artificial Intelligence (AI) is extensively employed in the healthcare industry to produce early, accurate results. The prediction of diseases helps doctors in making early decisions upon how to save the lives of patients. AI-based machine learning techniques make predictions early, accurate, timely, and easy. Therefore, The future of AI in monitoring hypertension looks set to be driven by smart health monitoring (SHM) systems, which use deep learning and artificial intelligence to analyse health data and achieve multiple targets. SHM systems have been shown to help with the early detection of chronic diseases, including hypertension, which was not possible with traditional healthcare systems. AI can be used in predicting cardiovascular outcomes , identify coronary artery disease , detection of malignant arrhythmias and can also be used in predicting outcomes for heart failure patients . [73]

CONCLUSION

The incorporation of Artificial Intelligence (AI) into hypertension therapy promises a radical change with the ability to address fundamental obstacles in controlling this prevalent and often chronic ailment. As hypertension continues to rise internationally, driven by factors such as aging populations, lifestyle changes, and increased stress, traditional techniques of diagnosis and management are becoming increasingly insufficient. AI offers revolutionary ways to better hypertension management through non-invasive monitoring, thorough data analysis, and individualized treatment options.The global prevalence of hypertension poses a considerable issue for healthcare systems, exacerbated by a substantial proportion of untreated cases. AI-driven technology, particularly non-invasive wearable devices, promise to transform the way hypertension is monitored. By delivering continuous and real-time blood pressure measures, these devices can detect early indicators of hypertension and track trends over time, ensuring that more individuals are recognized and treated immediately. This change from periodic to continuous monitoring minimizes the likelihood of missed diagnoses and allows for prompt actions, thereby relieving the stress on healthcare facilities and experts.AI's ability to evaluate large data sets and give actionable insights will drastically change how hypertension is controlled. Integration with Electronic Health Records (EHRs) provides for comprehensive data analysis, enabling healthcare practitioners to adapt treatment programs based on a patient’s unique health profile. AI can identify future health concerns and offer personalized interventions, leading to more effective and individualized care. This tailored approach not only increases treatment efficacy but also

enhances patient involvement by offering real-time feedback and actionable recommendations. Early illness detection and continued monitoring assist prevent consequences, such as cardiovascular events and kidney damage, thereby improving long-term health outcomes for patients. The financial ramifications of hypertension are enormous, with costs connected with long-term care, hospitalizations, and complications. AI offers substantial cost-saving potential by automating healthcare processes and decreasing the need for frequent in-person visits. Automated solutions for routine monitoring and data analysis reduce administrative hassles and free up healthcare resources, allowing for more efficient distribution. AI-driven predictive models can detect high-risk patients and prioritize interventions, reducing costly emergency treatments and hospital admissions. By enhancing drug adherence and reducing the occurrence of severe hypertension-related consequences, AI contributes to overall cost reductions in the healthcare system. Looking ahead, the continued progress of AI technologies promises more breakthroughs in hypertension care. Non-invasive blood pressure monitoring technologies are likely to become more sophisticated, giving even more accurate and convenient solutions for patients. Integration with EHRs will promote a more integrated approach to controlling hypertension, with AI delivering deeper insights into patient data and enabling more proactive care. The development of smart health monitoring systems, powered by deep learning and powerful AI algorithms, will better chronic illness management by giving real-time, tailored health insights and suggestions.In summary, AI is set to play a major role in the future of hypertension therapy. By resolving present constraints, increasing patient outcomes, and promoting cost-efficiency, AI technologies offer a complete approach to managing this ubiquitous illness. The integration of AI into hypertension care not only promises to transform how the condition is monitored and treated but also holds the potential to greatly improve quality of life for patients and reduce the global healthcare burden associated with hypertension. As these technologies continue to progress, their impact on hypertension therapy will likely become even more profound, propelling a new era of precision medicine and proactive health management.

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