World Journal of Biology Pharmacy and Health Sciences

eISSN: 2582-5542

Cross Ref DOI: 10.30574/wjbphs

Journal homepage: https://wjbphs.com/

(Review Article)

The future of wearable health technology: From monitoring to preventive healthcare

Chekwube Martin Obianyo [1, *], Victor Chiedozie Ezeamii [1], Benjamin Idoko [2], Tomilola Adeyinka [3], Ejembi Victor Ejembi [4], Joy Ene Idoko [5], Lilian Okwuonu Obioma [6] and Ogochukwu Judith Ugwu [7]

[1] *Jiann-Ping Hsu College of Public Health, Georgia Southern University, USA.*
[2] *Department of Nursing, University of Sunderland United Kingdom.*
[3] *Cygnet Wallace Hospital University of Sunderland.*
[4] *Department of Radiology, University College Hospital, Ibadan.*
[5] *Department of Biomedical Engineering, Faculty of Technology, University of Ibadan, Ibadan, Nigeria.*
[6] *Nursing department Wayne County Community College District Detroit Michigan.*
[7] *Department of Nursing, Ebonyi State University, Abakaliki Nigeria.*

World Journal of Biology Pharmacy and Health Sciences, 2024, 20(01), 036–055

Publication history: Received on 19 August 2024; revised on 28 September 2024; accepted on 30 September 2024

Article DOI: https://doi.org/10.30574/wjbphs.2024.20.1.0709

Abstract

Wearable health technology has undergone rapid development, evolving from simple fitness trackers to sophisticated medical devices that provide real-time monitoring and data collection. As these technologies become increasingly integrated into healthcare systems, their potential to shift from reactive treatment to proactive preventive care is gaining attention. This review paper explores the current state of wearable health devices, including the key technologies that enable monitoring and data analysis, and discusses the latest advancements such as AI integration, smart fabrics, and implantable wearables. The paper also delves into the significant role these technologies play in preventive healthcare by enabling continuous monitoring, early disease detection, and personalized health interventions. Furthermore, it addresses the challenges facing wearables, including issues of data accuracy, privacy, and user compliance. Finally, the paper explores future directions and ethical considerations, emphasizing the potential for wearables to reshape healthcare by promoting more accessible, equitable, and preventive healthcare solutions.

Keywords: Wearable health technology; Preventive healthcare; Real-time monitoring; Artificial intelligence; Chronic disease management; Biosensors; Personalized healthcare; Smart fabrics; Continuous monitoring; Healthcare data privacy; Predictive analytics; Telemedicine integration

1. Introduction

1.1. Background on Wearable Health Technology

Wearable health technology has its roots in the integration of digital tools with healthcare systems, a concept that has rapidly evolved over the past few decades. Initially designed for fitness and wellness tracking, such as monitoring heart rate or physical activity, these devices have grown into sophisticated medical tools capable of providing continuous health monitoring and personalized care. Wearables now encompass a broad range of devices, including smartwatches, fitness trackers, and medical-grade wearables that track vital signs such as heart rate, oxygen saturation, and glucose levels (Adeghe et al., 2024; Ezeamii et al., 2024).

The adoption of wearable health technology is driven by advances in biosensors, miniaturized electronics, and wireless communication, which enable real-time health data collection and analysis. These devices have become pivotal in both personal health management and clinical settings, offering advantages like early detection of health abnormalities, chronic disease management, and improved patient outcomes (Albín-Rodríguez et al., 2022; Ezeamii et al., 2024). For

* Corresponding author: Chekwube Martin Obianyo

instance, wearable devices are widely used to manage chronic diseases such as diabetes and cardiovascular diseases by continuously monitoring relevant biomarkers, allowing timely interventions that can prevent complications (Kalantari, 2017; Ezeamii et al., 2024).

Despite these advances, challenges remain, particularly in terms of data accuracy, interoperability, and privacy concerns. Nonetheless, the potential of wearable health technology to revolutionize both patient and preventive care continues to grow, especially as it becomes more integrated with artificial intelligence and healthcare systems (Smith et al., 2019).

Figure 1 The Evolution of Wearable Health Technology: From Fitness Trackers to Continuous Health Monitoring

Figure 1 showcases a modern wearable health device, specifically a smartwatch, which displays various real-time health metrics such as heart rate, oxygen saturation, and step count. The sleek design of the device and the data visualization on its digital interface emphasize its capacity for continuous monitoring. The setting includes a clinical environment, with digital health tools and AI-driven systems in the background, underscoring the integration of wearables into healthcare. This visual reinforces how wearable technology has evolved from simple fitness tracking to advanced health monitoring systems used in preventive healthcare.

1.2. Evolution of Wearables: From Fitness Trackers to Medical Devices

Wearable technology has undergone significant transformation since its inception, evolving from simple fitness trackers designed to monitor physical activity into sophisticated medical devices with the capacity for continuous health monitoring and real-time data analysis. The early stages of wearables, such as the Withings Pulse and Fitbit Flex, were focused primarily on encouraging physical activity by tracking daily steps and providing users with feedback on their fitness goals. These devices emphasized user satisfaction and accuracy, with studies showing that the Withings Pulse was considered one of the most user-friendly and precise fitness trackers available (Kaewkannate & Kim, 2016 Ezeamii et al., 2023).

Figure 2 illustrates the evolution of wearable health technology, starting from the invention of the pedometer in 1760, which enabled basic activity tracking. Over time, advancements such as the electrocardiogram (ECG) in 1895 and the pulse oximeter in 1935 allowed for the monitoring of heart activity and oxygen levels. The development of MEMS devices in 1955 further miniaturized electronic systems, leading to more sophisticated health tracking tools. In 2009, Fitbit released its first product, expanding the range of fitness measurements. In 2018, Apple introduced the Apple Watch with ECG capabilities, which tracks the heart's electrical activity and aids in potential diagnoses. This timeline showcases the increasing sophistication of health wearables, contributing to better patient awareness and health outcomes through continuous monitoring.

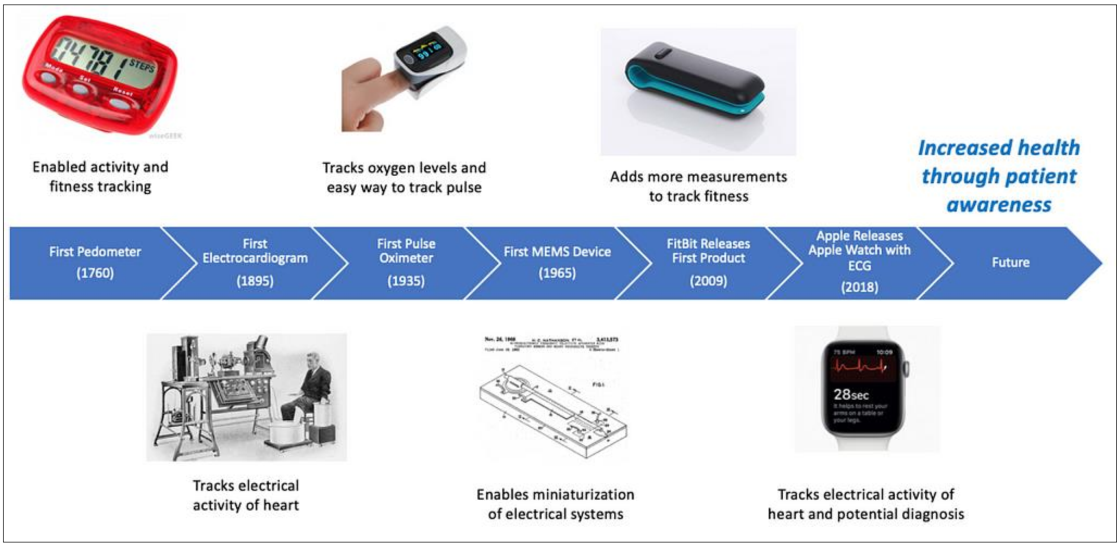

Figure 2 Evolution of Wearable Health Technology: From Pedometer to Advanced Fitness Tracking and ECG Monitoring (White, 2011)

As technology advanced, wearables began to incorporate more complex sensors capable of monitoring vital signs such as heart rate, oxygen saturation, and glucose levels. This shift has allowed wearable devices to move beyond fitness tracking and enter the realm of clinical healthcare, where they are now used to monitor chronic conditions, enhance patient safety, and provide real-time health data (Bez & Simini, 2018 Ezeamii et al., 2023). These advancements are particularly significant in managing chronic diseases like diabetes and cardiovascular conditions, where continuous monitoring can help prevent complications and improve patient outcomes.

Furthermore, modern wearables are increasingly integrated with AI and machine learning, enabling predictive analytics that can anticipate health issues before they arise. This evolution from basic activity tracking to comprehensive health monitoring has positioned wearables as critical tools in both personal health management and clinical care, with the potential to revolutionize the way healthcare is delivered (Monschein et al., 2021; Ezeamii et al., 2024).

Table 1 From Fitness Trackers to Advanced Medical Devices: The Evolution of Wearable Health Technology

Aspect	Description	Key Devices	Advantages	References
Early Wearables	Initial fitness trackers like Withings Pulse and Fitbit focused on step tracking and user feedback.	Withings Pulse, Fitbit Flex	Encouraged physical activity, basic feedback	Kaewkannate & Kim, 2016
Sensor Integration	Advancement in sensors allowed wearables to track heart rate, oxygen saturation, and glucose levels.	Smartwatches, glucose monitors	Advanced monitoring of vital signs, real-time data	Bez & Simini, 2018
Medical Applications	Wearables are now used in clinical settings for chronic disease management and real-time health monitoring.	Medical-grade wearables	Improved patient safety, continuous monitoring	Bez & Simini, 2018
AI Integration	Modern wearables leverage AI and machine learning for predictive health analytics.	AI-powered devices	Predictive health analytics, anticipatory care	Monschein et al., 2021
Healthcare Impact	Wearables have shifted from fitness tracking to critical tools in personal health management and clinical care.	Integrated health platforms	Revolutionizing healthcare, preventing complications	Monschein et al., 2021

Table 1 summarizes the evolution of wearable health technology across five key aspects: Early Wearables, Sensor Integration, Medical Applications, AI Integration, and Healthcare Impact. Initially, wearables like the Withings Pulse and

Fitbit Flex focused on tracking physical activity and providing basic user feedback. With advancements in sensor technology, wearables began to monitor vital signs such as heart rate, oxygen levels, and glucose. These developments enabled their use in clinical settings for continuous health monitoring and chronic disease management. The integration of AI further enhanced wearables by enabling predictive health analytics, making them essential tools in both personal health management and preventive healthcare. Overall, wearables have shifted from fitness gadgets to critical healthcare devices, helping prevent complications and improving patient outcomes.

1.3. Importance of Wearable Technology in Modern Healthcare

Wearable technology has revolutionized healthcare by enabling continuous monitoring of vital signs and providing real-time health data, which can significantly improve patient outcomes. These devices, equipped with various sensors, have become integral tools for both healthcare professionals and patients, allowing for more efficient disease management and personalized care. Wearables provide crucial data that can enhance diagnostic accuracy and offer predictive insights into potential health issues, thus preventing severe medical conditions before they arise (Pentland, 2004; Ezeamii et al., 2024). For example, wearable devices such as smartwatches and medical-grade monitors are capable of tracking physiological parameters like heart rate, oxygen saturation, and glucose levels, contributing to the management of chronic diseases like diabetes and cardiovascular disorders (Zhang & Shahriar, 2020; Ezeamii et al., 2023).

Figure 3 outlines the key benefits of wearable technology in healthcare, emphasizing its transformative role in improving patient care and system efficiency. The first benefit is patient engagement, where wearables encourage individuals to actively participate in monitoring their health. Real-time monitoring allows for continuous tracking of vital signs, providing immediate data for both patients and healthcare providers. Wearables are multifunctional, capable of tracking various health metrics such as heart rate, physical activity, and more, all in one device. This enables proactive healthcare, allowing issues to be identified and addressed before they become serious. Lastly, wearable technology contributes to increased provider efficiency by streamlining data collection and making it easier for healthcare professionals to make informed decisions quickly. Overall, the image highlights how wearables are enhancing both the patient experience and healthcare delivery.

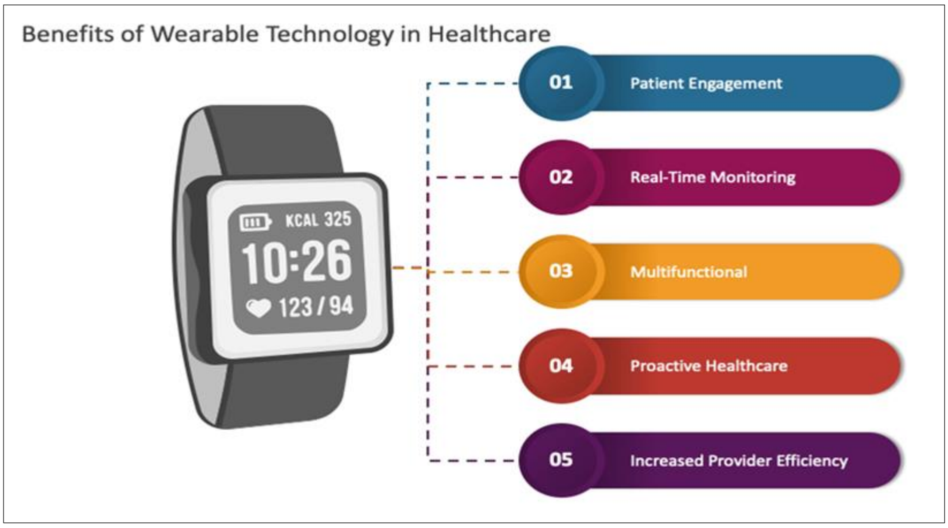

Figure 3 Key Benefits of Wearable Technology in Healthcare: Enhancing Patient Engagement and Efficiency (Collidu 2024)

In addition to chronic disease management, wearable technologies are also being used to improve the quality of life for the elderly population. These devices enable remote monitoring, reducing the need for frequent hospital visits and allowing healthcare providers to track patients' health from a distance. This is particularly important in aging populations, where continuous health monitoring can help in early diagnosis and timely intervention, ultimately reducing healthcare costs and improving patient outcomes (Lu & Xie, 2017). Moreover, wearable technology empowers patients by giving them access to their health data, fostering greater health awareness and encouraging proactive health management.

Despite these advantages, the adoption of wearable healthcare devices is not without challenges. Concerns about data privacy, device accuracy, and integration with existing healthcare infrastructure remain critical issues that need to be addressed to fully realize the potential of wearables in healthcare. Nonetheless, with ongoing advancements in sensor technology and artificial intelligence, wearable devices are poised to play an even more significant role in the future of healthcare, offering more personalized, efficient, and cost-effective care solutions (Zheng et al., 2013).

Table 2 The Critical Role of Wearable Technology in Enhancing Modern Healthcare Outcomes

Aspect	Description	Key Devices	Advantages	References
Continuous Monitoring	Wearables provide real-time monitoring of vital signs, improving diagnostic accuracy and offering predictive health insights.	Smartwatches, medical monitors	Real-time data collection, early detection of health issues	Pentland, 2004
Chronic Disease Management	Devices track physiological parameters like heart rate and glucose, crucial for managing chronic diseases like diabetes and cardiovascular disorders.	Heart rate monitors, glucose sensors	Efficient management of chronic conditions, reduced complications	Zhang & Shahriar, 2020
Elderly Care	Wearables allow remote monitoring, improving quality of life for the elderly by reducing hospital visits and enabling timely interventions.	Remote health monitoring devices	Better quality of life, reduced healthcare costs	Lu & Xie, 2017
Patient Empowerment	Patients gain access to their own health data, promoting proactive health management and greater awareness.	Wearable health trackers	Greater health awareness, proactive care	Pentland, 2004
Challenges	Privacy concerns, device accuracy, and integration with healthcare systems remain significant barriers to adoption.	Various wearables	Potential for improved healthcare efficiency	Zheng et al., 2013

Table 2 summarizes the importance of wearable technology in healthcare across five key aspects: Continuous Monitoring, Chronic Disease Management, Elderly Care, Patient Empowerment, and Challenges. It highlights how wearables enable real-time monitoring of vital signs, improving diagnostic accuracy and offering predictive health insights. In chronic disease management, wearables play a crucial role by tracking key physiological parameters, such as heart rate and glucose levels. For elderly care, wearables facilitate remote monitoring, reducing hospital visits and enhancing quality of life. Additionally, these devices empower patients by providing access to personal health data, promoting proactive health management. Despite these benefits, challenges such as privacy concerns, device accuracy, and integration with healthcare systems remain significant barriers to broader adoption.

1.4. Objectives and Scope of the Paper

The primary objective of this paper is to explore the evolution and future potential of wearable health technology, particularly its shift from basic monitoring devices to tools that play a significant role in preventive healthcare. The paper aims to examine current advancements in wearable technology and how these innovations are transforming patient care, enhancing early diagnosis, and contributing to more personalized health management.

In addition, the scope of the paper includes analyzing the challenges faced in the adoption and integration of wearable health devices, such as data privacy, security, and accuracy issues, as well as the technical limitations that need to be addressed. It also seeks to discuss how the integration of artificial intelligence and machine learning can further enhance the capabilities of wearable devices, enabling predictive healthcare and more efficient management of chronic diseases.

This paper will provide an in-depth review of existing wearable technologies, highlight cutting-edge developments in the field, and project future trends, emphasizing the role of wearables in preventive healthcare and their potential to revolutionize healthcare delivery. By doing so, it aims to offer valuable insights for researchers, healthcare providers, and policymakers.

1.5. Organization of the Paper

This paper is organized into five key sections:

- Introduction: The first section provides an overview of wearable health technology, its evolution, and its significance in modern healthcare. It outlines the objectives and scope of the paper, setting the foundation for the discussion that follows.
- Current State of Wearable Health Technology: This section discusses the major wearable devices currently in use, the technologies behind them, and their applications in healthcare. It also addresses the challenges related to data accuracy, privacy, and user compliance in wearable technology.
- Advancements in Wearable Health Technology: The third section explores emerging trends and innovations in wearable technology, such as advances in sensors, AI integration, and the development of smart fabrics. It also highlights real-world case studies showcasing the latest developments in wearable health devices.
- Wearables and Preventive Healthcare: This section focuses on the role of wearable technology in preventive healthcare, discussing how continuous monitoring, early detection, and personalized interventions can help reduce the burden of chronic diseases and improve patient outcomes. It also examines the integration of wearables with healthcare systems and telemedicine.
- Future Directions and Ethical Considerations: The final section looks ahead to the future of wearable health technology, addressing potential technological advancements and ethical concerns. It emphasizes the importance of overcoming current barriers, such as privacy and data security, and discusses the societal implications of widespread wearable adoption in healthcare.

Each section builds upon the previous one to provide a comprehensive review of the current state, advancements, and future directions of wearable health technology.

2. Current state of wearable health technology

2.1. Overview of Major Wearable Health Devices

Wearable health devices have rapidly become an integral part of healthcare, offering continuous monitoring and real-time data collection to aid in the diagnosis, treatment, and management of various medical conditions. These devices are classified into four primary application areas: health and safety monitoring, chronic disease management, disease diagnosis and treatment, and rehabilitation. Their design allows for versatile usage, with wearables being worn on different parts of the body, such as the wrist, chest, or even as implantable devices (Lu et al., 2020). For instance, devices like smartwatches and medical-grade monitors can track vital signs such as heart rate, oxygen saturation, and glucose levels, proving essential for chronic disease management.

Figure 4 provides a comprehensive overview of various wearable devices that are integrated with modern technology, showcasing their potential in enhancing everyday life. It features a range of wearable technologies, including smart rings, smart glasses, smart watches, and smart shoes, which offer functionalities such as tracking, monitoring, and connectivity. Additionally, devices like smart belts, smart shirts, and smart socks are designed to monitor health metrics such as heart rate and activity levels. The inclusion of Bluetooth key trackers and GPS-enabled devices illustrates how wearables are not just for fitness but also serve practical purposes like security and navigation. These wearables represent the growing integration of technology into clothing and accessories, driving a shift towards more connected and health-conscious lifestyles.

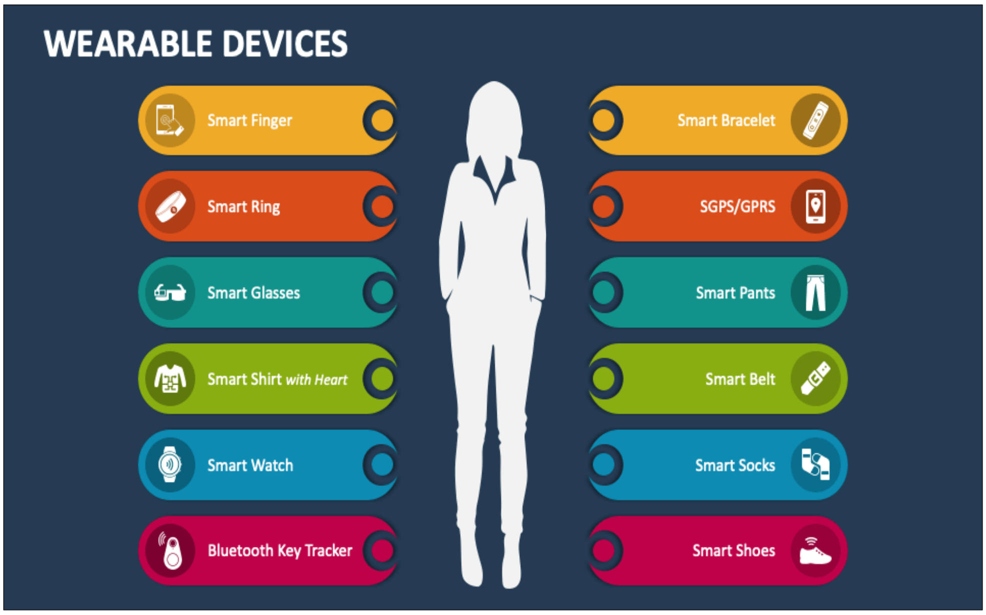

Figure 4 Comprehensive Overview of Wearable Devices in Modern Technology

In cardiovascular medicine, wearable devices have shown tremendous potential in monitoring heart conditions such as arrhythmias and heart failure. These devices collect continuous data, providing clinicians with a more comprehensive understanding of a patient's condition, which is often not possible with traditional, episodic monitoring methods. By analyzing long-term behavioral and physiological data, wearable devices can predict potential health risks and inform more personalized treatment plans (Hughes et al., 2023). This capability makes wearables invaluable for improving patient outcomes and reducing hospital readmissions.

Despite their significant benefits, challenges still limit the widespread clinical use of wearable devices. Issues related to user-friendliness, data privacy, and the lack of standardized protocols for data interpretation and device regulation are major barriers. As the adoption of these devices grows, overcoming these challenges through collaboration between healthcare providers, manufacturers, and regulatory bodies will be crucial in realizing the full potential of wearable health technology (Verma et al., 2023).

Table 3 Key Aspects of Major Wearable Health Devices in Modern Healthcare

Aspect	**Description**	**Key Devices**	**Advantages**	**References**
Application Areas	Health and safety monitoring, chronic disease management, diagnosis, and rehabilitation.	Wrist-worn, chest-worn, implantable wearables	Improves safety, enhances chronic disease management	Lu et al., 2020
Key Functions	Continuous monitoring of vital signs, real-time data collection, long-term condition tracking.	Smartwatches, heart monitors	Provides real-time health data, long-term tracking	Hughes et al., 2023
Major Devices	Smartwatches, medical-grade monitors, implantable devices.	Medical-grade devices	Enables better health insights, early detection	Verma et al., 2023
Challenges	User-friendliness, data privacy, lack of standardized protocols.	Various health wearables	Requires overcoming privacy, usability, and regulatory issues	Lu et al., 2020
Future Potential	Improving patient outcomes, reducing hospital readmissions, personalized treatment.	Next-generation wearables	Personalized care, predictive healthcare	Hughes et al., 2023

Table 3 provides a concise summary of the key aspects of major wearable health devices used in modern healthcare. It highlights the primary application areas, such as health and safety monitoring, chronic disease management, diagnosis, and rehabilitation. The key functions of these devices include continuous monitoring of vital signs and real-time data collection. Major devices, such as smartwatches and medical-grade monitors, are identified, along with challenges like user-friendliness, data privacy, and lack of standardized protocols. The future potential of these devices is also emphasized, focusing on improving patient outcomes, reducing hospital readmissions, and enabling personalized care through next-generation wearables.

2.2. Key Technologies: Sensors, Data Collection, and AI Integration

Wearable health devices are underpinned by several key technologies, including advanced sensors, data collection systems, and artificial intelligence (AI) integration. Sensors, which are the foundation of wearable technology, are designed to monitor various physiological parameters such as heart rate, temperature, blood pressure, and sleep patterns. These sensors are often flexible, biocompatible, and non-invasive, allowing continuous monitoring without disrupting the user's daily activities (Wang et al., 2019). The data collected by these sensors is crucial for real-time health tracking and early disease detection.

Figure 5 illustrates the integration of wearable health sensors with the Internet of Things (IoT) for remote health monitoring. Various sensors, including ECG, blood pressure, insulin pump, EMG, and motion sensors, are connected to a central control unit, which communicates with a base station or an access point through 3G/4G or Wi-Fi. This setup allows for real-time transmission of health data over the internet, enabling continuous monitoring and remote healthcare services. The connectivity to the cloud ensures that the data is accessible to healthcare providers, facilitating timely intervention and management of medical conditions. This system exemplifies how wearable technology, combined with IoT, enhances patient care by providing real-time, continuous monitoring.

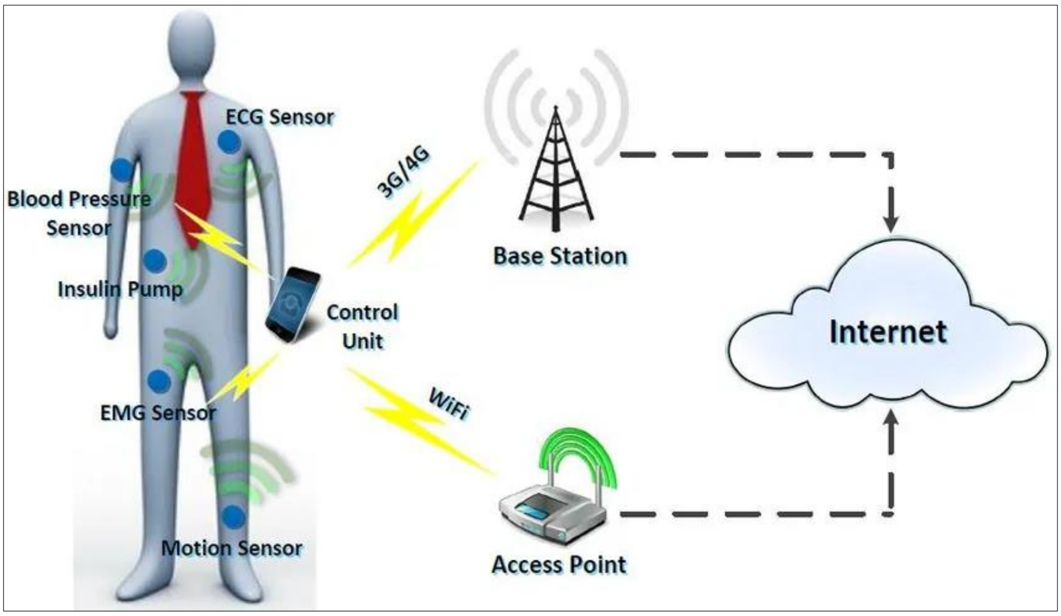

Figure 5 Integration of Wearable Sensors with IoT for Remote Health Monitoring(Qureshi 2014)

Data collection in wearable devices relies on robust and energy-efficient systems that ensure long-term monitoring. Miniaturized sensors collect and transmit data to health monitoring platforms, where it is analyzed for trends and anomalies. Efficient data transmission and battery management are critical challenges in this process, particularly for long-term use. Low-power designs and energy-saving techniques, such as edge computing, are being developed to enhance the functionality and usability of these devices without compromising user comfort (Basaklar et al., 2021).

The integration of AI into wearable devices has revolutionized their capabilities, allowing for the analysis of vast amounts of health data in real time. AI algorithms can detect patterns and make predictions based on the data collected, enabling personalized health interventions and predictive healthcare solutions. This combination of sensors, data collection, and AI allows wearables to move beyond basic monitoring and become proactive tools in managing chronic diseases and improving overall health outcomes (Tarafder, 2023).

2.3. Current Applications: Fitness, Chronic Disease Management, and Monitoring

Wearable technology has become a significant tool in healthcare, with applications ranging from fitness tracking to chronic disease management and continuous health monitoring. In fitness, wearable devices like smartwatches and fitness trackers are designed to track physical activity, including steps taken, calories burned, and heart rate. These devices promote physical activity by providing real-time feedback, helping users improve their health and maintain an active lifestyle. Studies have shown that wearable fitness devices can significantly increase physical activity, especially for individuals with chronic conditions such as hypertension and diabetes, where regular activity is crucial for disease management (Yu et al., 2023).

In the context of chronic disease management, wearable devices play a vital role by providing continuous monitoring of patients' vital signs. For example, smartwatches and specialized medical-grade wearables can track blood glucose levels, heart rate, and oxygen saturation, allowing for early detection of health anomalies. These devices enable patients to manage their conditions more effectively by offering real-time data to healthcare providers, thus improving disease control and reducing hospital readmissions (Yang & Gong, 2021). The ability to collect and analyze health data over time allows for more personalized treatment plans and interventions, enhancing patient outcomes.

Wearable technology is also transforming healthcare by supporting long-term health monitoring. Continuous monitoring of physiological parameters enables clinicians to assess patient health more comprehensively, particularly in critical cases like heart failure or respiratory issues. This real-time data is invaluable for making informed decisions, enabling timely interventions, and preventing complications. The integration of wearables with healthcare systems can streamline patient care by reducing the need for frequent in-person visits and allowing remote monitoring, thus lowering healthcare costs and improving patient quality of life (Pentland, 2004).

Table 4 Key Applications of Wearable Technology in Fitness, Chronic Disease Management, and Health Monitoring

Aspect	Description	Key Functions	References
Fitness Tracking	Wearable devices track physical activity like steps, calories, and heart rate, promoting healthier lifestyles.	Real-time feedback on fitness goals, encouraging physical activity.	Yu et al., 2023
Chronic Disease Management	Wearables continuously monitor vital signs (e.g., glucose, heart rate), helping patients manage chronic diseases more effectively.	Continuous tracking of vital signs, providing real-time data to healthcare providers.	Yang & Gong, 2021
Health Monitoring	Real-time monitoring of physiological parameters allows clinicians to make informed decisions and timely interventions.	Continuous health monitoring, offering comprehensive insights into patient health.	Pentland, 2004
Key Devices	Smartwatches, fitness trackers, medical-grade monitors for chronic conditions and long-term monitoring.	Tracking physiological data for fitness and disease management.	Yu et al., 2023
Advantages	Promotes physical activity, enhances disease management, enables personalized healthcare, and reduces hospital visits.	Improved patient outcomes, remote monitoring, and cost reduction.	Yang & Gong, 2021

Table 4 provides an overview of the key applications of wearable technology across three primary areas: fitness tracking, chronic disease management, and health monitoring. It highlights how wearable devices, such as smartwatches and fitness trackers, help monitor physical activity by providing real-time feedback on steps, calories burned, and heart rate, encouraging healthier lifestyles. In chronic disease management, wearables continuously monitor vital signs like glucose and heart rate, offering valuable data to healthcare providers for better disease control. Additionally, wearables enable real-time health monitoring, allowing clinicians to make informed decisions and timely interventions. The table emphasizes the benefits of these devices, including promoting physical activity, enhancing disease management, enabling personalized care, and reducing hospital visits.

2.4. Challenges: Data Accuracy, Privacy, and User Compliance

Wearable health technology faces several critical challenges that affect its widespread adoption, particularly in the areas of data accuracy, privacy, and user compliance. One of the most significant challenges is ensuring the accuracy of data collected by wearable devices. Inaccurate readings can lead to incorrect health assessments, which may compromise patient care. To address this, advances in sensor technology and data calibration methods are essential. However, even with improved technology, factors such as device placement, user movement, and environmental conditions can still affect the accuracy of the data (Seçkin et al., 2023). Thus, continuous development is needed to ensure that wearable devices provide reliable and actionable health insights.

Privacy concerns also pose a substantial barrier to the adoption of wearable health technology. The collection and transmission of personal health data expose users to potential privacy violations, particularly if the data is accessed by unauthorized parties or misused. Current privacy regulations, such as HIPAA in the U.S., often do not cover data collected by commercial wearable devices, leaving gaps in protection. Solutions such as implementing stronger encryption protocols, differential privacy techniques, and user consent mechanisms are necessary to mitigate these risks (Mone & Shakhlo, 2023). Additionally, users often lack awareness of the potential privacy risks associated with wearables, highlighting the need for better education on protecting personal health information (Cilliers, 2020).

User compliance is another challenge that affects the long-term effectiveness of wearable devices. Many users stop wearing these devices due to discomfort, lack of engagement, or concerns about data privacy. Ensuring user compliance requires developing more user-friendly designs, enhancing battery life, and integrating wearables seamlessly into daily routines. Additionally, providing clear benefits and value through personalized health insights can help maintain user engagement and compliance (Li et al., 2022).

Table 5 Key Challenges and Solutions in Wearable Health Technology: Data Accuracy, Privacy, and User Compliance

Aspect	Description	Key Issues	References
Data Accuracy	Inaccurate readings from wearables can lead to incorrect health assessments, affecting patient care.	Device placement, user movement, environmental factors impact data accuracy.	SeÃ§kin et al., 2023
Privacy Concerns	Personal health data collected by wearables is vulnerable to misuse and unauthorized access.	Lack of regulatory protection for data collected by commercial devices.	Mone & Shakhlo, 2023
User Compliance	Users often discontinue wearing devices due to discomfort, lack of engagement, or privacy concerns.	Engagement drops over time due to usability and privacy issues.	Cilliers, 2020
Solutions	Improving sensor technology, implementing encryption protocols, and educating users can enhance data accuracy and privacy.	Better sensors, encryption, and user education for secure and accurate data collection.	Li et al., 2022
Challenges	Addressing device placement, battery life, and ensuring long-term user engagement are critical challenges.	Enhancing comfort, battery life, and demonstrating value to ensure compliance.	SeÃ§kin et al., 2023

Table 5 summarizes the key challenges and solutions related to wearable health technology, focusing on data accuracy, privacy concerns, and user compliance. It highlights how inaccuracies in data collection, often caused by device placement or environmental factors, can impact patient care. Privacy issues are a major concern, as personal health data collected by wearables may be vulnerable to misuse due to insufficient regulatory protection. User compliance is also a challenge, with many discontinuing device use due to discomfort, lack of engagement, or privacy concerns. To address these challenges, the table suggests solutions such as improving sensor technology, implementing encryption protocols, and enhancing user education to ensure secure data collection and long-term engagement.

3. Advancements in wearable health technology

3.1. Emerging Trends in Wearable Technology

The landscape of wearable technology is evolving rapidly, with new innovations poised to revolutionize healthcare by providing more personalized and efficient patient care. One significant trend is the advancement of wearable medical devices, which are now being recognized for their ability to monitor patients in real-time, facilitate early diagnosis, and offer personalized treatments. These devices have moved beyond basic tracking tools to become critical components in managing chronic diseases and enhancing patient outcomes (Zheng et al., 2013).

Another emerging trend is the integration of artificial intelligence (AI) and machine learning into wearable devices. These technologies are transforming how health data is processed, analyzed, and utilized. AI-driven wearables can predict health events by analyzing vast datasets, helping clinicians make proactive interventions. The incorporation of AI into wearable technology offers more accurate, real-time health monitoring and enables a shift towards predictive and preventive healthcare (Pentland, 2004).

Moreover, wearable technology is advancing through the development of smart fabrics and flexible electronics, allowing for more seamless and comfortable integration into daily life. These innovations are enabling continuous health monitoring with minimal disruption to users' activities. The miniaturization of sensors and advancements in battery life are also addressing the challenges of long-term wearability, making these devices more accessible and practical for everyday use (Lu & Xie, 2017).

3.2. Advances in Sensors and Biometrics

Recent advances in sensors and biometrics are significantly transforming wearable health technology. Modern wearable sensors, designed to be flexible and non-invasive, can continuously monitor physiological parameters such as heart rate, temperature, and glucose levels. These sensors utilize a range of technologies, including electrochemical, optical, and mechanical mechanisms, to capture critical health data from body fluids like sweat, saliva, and blood (Dkhar et al., 2022). This real-time data collection enables a more comprehensive understanding of a patient's health, enhancing the potential for early diagnosis and timely intervention.

Biometric sensors have evolved to become highly biocompatible, biodegradable, and, in some cases, self-healing. These features make them ideal for long-term monitoring without causing discomfort or adverse reactions in patients. Smart wearable sensors, which integrate multiple functionalities, are increasingly being used in medical devices for continuous health monitoring, offering precise and reliable data on vital signs. Such advancements have paved the way for more personalized and responsive healthcare solutions, especially in chronic disease management (Wang et al., 2019; Idoko et. al., 2024).

Moreover, nanotechnology has played a crucial role in the development of advanced wearable sensors, making them smaller, more efficient, and capable of functioning in various environmental conditions. However, challenges such as power supply limitations, data transmission security, and the integration of wearable sensors with healthcare systems remain hurdles that need to be addressed to fully realize the potential of these devices (Nasiri & Khosravani, 2020; Idoko et. al., 2024). As the technology continues to evolve, wearable sensors are expected to play an even more significant role in predictive healthcare and personalized medicine.

3.3. Integration of Wearables with AI and Machine Learning for Predictive Analytics

The integration of artificial intelligence (AI) and machine learning (ML) with wearable health technology has revolutionized how healthcare data is collected, analyzed, and applied. AI allows wearable devices to process vast amounts of health data in real-time, enabling predictive analytics that can detect early signs of health deterioration. Wearable devices embedded with AI systems can continuously monitor physiological parameters and detect patterns that may indicate potential health risks, enabling timely interventions. This capability has significantly improved chronic disease management, especially for conditions like heart failure, diabetes, and hypertension (Shumba et al., 2023; Idoko et. al., 2024).

Machine learning algorithms are increasingly used to enhance the accuracy and efficiency of wearable devices by analyzing users' health data to offer personalized recommendations. For instance, AI-powered wearables can track user behaviors, such as physical activity or sleep patterns, and suggest personalized changes to improve overall health. Furthermore, edge computing combined with AI helps in reducing the latency of data processing, ensuring that wearables provide instant feedback to users and healthcare providers without relying on cloud-based systems (Dai & Zhou, 2023; Idoko et. al., 2024).

Despite the benefits, integrating AI into wearable health devices presents challenges, such as data privacy concerns, compatibility with healthcare infrastructure, and user trust. Many patients remain skeptical about the transparency of AI-driven healthcare decisions, raising the need for Explainable AI (XAI) to foster trust and enhance the interpretability of AI's role in diagnostics and care recommendations. As wearable technology continues to evolve, the integration of AI and ML will remain a cornerstone in transforming preventive and personalized healthcare (Pawar et al., 2020; Idoko et. al., 2024).

3.4. Smart Fabrics and Implantable Wearables

Smart fabrics and implantable wearables represent the next frontier in healthcare innovation, offering seamless integration of health monitoring into everyday life. Smart textiles are designed to facilitate health management by embedding sensors within the fabric, allowing continuous monitoring of physiological parameters such as heart rate, temperature, and even respiratory patterns. These textile-based systems enable real-time data collection, providing insights that can enhance personal health management and improve patient outcomes, especially in areas like chronic disease management and elderly care (Patwary et al., 2015; Idoko et. al., 2024).

One of the key advantages of smart fabrics is their ability to create a more comfortable and familiar healthcare environment. By blurring the boundary between hospital and home, these textiles make medicalization more "cozy," transforming surveillance into a friendly, non-invasive form of care. This aligns with broader trends in healthcare that seek to integrate medical monitoring into daily life, reducing the need for hospital visits and allowing patients to be continuously monitored from the comfort of their homes (Joyce, 2019; Idoko et. al., 2024).

Implantable wearables further push the boundaries of continuous health monitoring. These devices are inserted under the skin or within the body, providing constant tracking of critical health metrics, such as glucose levels in diabetes patients or cardiac function in those with heart conditions. The integration of implantable wearables with advanced AI and communication technologies ensures that real-time data is transmitted directly to healthcare providers, enabling timely interventions and a more personalized approach to treatment (Al-Siddiq, 2019).

4. Wearables and preventive healthcare

4.1. Role of Wearables in Early Disease Detection

Wearable health technology plays a crucial role in the early detection of diseases by enabling continuous monitoring of physiological parameters, thereby allowing healthcare providers to intervene before conditions worsen. These devices offer real-time tracking of health markers, such as heart rate, temperature, and respiratory patterns, which can help in detecting anomalies that may indicate the onset of chronic diseases. One key application of wearable technology is in the early detection of neurodegenerative diseases like Parkinson's disease. A recent study demonstrated that wearable sensors could monitor gait and tremor in individuals with Parkinson's, allowing for the early identification of disease progression outside of clinical environments (Adams et al., 2021; Idoko et. al., 2024).

Moreover, wearable devices equipped with biosensors are now capable of non-invasively monitoring physiological markers found in body fluids like saliva, sweat, and breath. These biosensors can detect biomarkers associated with conditions such as cardiovascular diseases, diabetes, and respiratory disorders, providing critical insights into a patient's health status. This non-invasive approach to health monitoring improves early diagnosis while reducing the need for more invasive procedures (Sharma et al., 2022; Idoko et. al., 2024).

In addition to their application in chronic disease management, wearables are also being used for the early detection of infectious diseases and other acute health conditions. For example, during the COVID-19 pandemic, wearable devices such as the Oura Ring helped healthcare workers by monitoring body temperature and other vital signs, enabling the early detection of potential infections (Shiba et al., 2023; Idoko et. al., 2024). By providing continuous and accurate health data, wearable technology is reshaping the way diseases are detected and managed, ultimately improving patient outcomes.

4.2. Personalization of Preventive Healthcare via Wearables

Wearable technology has significantly enhanced the personalization of preventive healthcare by allowing continuous monitoring of individual health data, enabling tailored interventions that address specific patient needs. These devices collect real-time data on various physiological parameters, such as heart rate, sleep patterns, and physical activity levels, and use this information to provide personalized health recommendations. One key aspect of successful wearable implementation in healthcare is the focus on delivering a "personalized experience," which encourages patient engagement and adherence to health plans (Smuck et al., 2021; Idoko et. al., 2024). This personalization enables a more proactive approach to preventive healthcare by identifying potential health risks before they become critical.

The integration of wearable sensors and mobile health applications (mHealth) further enhances the ability to offer personalized care. These technologies facilitate long-term tracking of patients' health status, enabling healthcare providers to adjust treatment plans and lifestyle recommendations in real-time. Although evidence regarding their effectiveness in driving behavior change is still emerging, wearable technologies hold great promise for motivating healthier lifestyle choices, particularly when integrated with behavior change techniques within primary healthcare settings (Alós & Puig-Ribera, 2021; Idoko et. al., 2024).

Furthermore, wearables have shown to be particularly beneficial in geriatric care by supporting personalized, patient-centered approaches. Studies indicate that elderly patients using wearables experience fewer mental health issues, such as depression and anxiety, which are common in older adults. This reduction in psychological distress is linked to the ability of wearables to provide real-time health insights and reassurance, empowering patients to take control of their health (Elkefi & Asan, 2022). As such, the use of wearables in personalized preventive healthcare is transforming patient engagement, improving outcomes, and fostering a more tailored approach to health management.

4.3. Continuous Monitoring for Predictive and Preventive Care

Continuous health monitoring through wearable technology is transforming healthcare by providing real-time data that can predict potential health issues and enable timely preventive interventions. Wearable devices equipped with sensors can continuously track vital signs such as heart rate, oxygen levels, and activity patterns, which allows healthcare providers to detect anomalies early, leading to more effective preventive care. This constant stream of data improves patient outcomes by reducing the time between the detection of a health problem and intervention (Anjum et al., 2023).

One of the significant benefits of continuous monitoring is its potential for predictive healthcare. Machine learning algorithms applied to data collected by wearables can predict adverse health events, such as seizures or heart attacks, by recognizing patterns in the data before symptoms become apparent. A study utilizing the K-nearest neighbors (KNN) algorithm in wearable devices demonstrated its effectiveness in predicting seizures through continuous monitoring of EEG and ECG signals. This system enabled timely interventions, highlighting the importance of predictive analytics in enhancing healthcare delivery (Raja Suguna et al., 2024).

However, continuous monitoring can also lead to information overload, especially for healthcare professionals managing large amounts of real-time data. To avoid clinician burnout and ensure effective use of wearables, it is critical to balance data collection with efficient alert systems, ensuring that only relevant and significant health changes trigger alarms. This approach optimizes healthcare providers' responses to potential health issues while maintaining the benefits of continuous monitoring (Zahradka et al., 2022).

4.4. Wearables and Behavioral Health: Nudging Healthier Habits

Wearable health devices are increasingly being used to influence behavioral health by nudging users towards healthier habits. These devices offer continuous tracking of physical activity, sleep patterns, and other health metrics, providing users with feedback that encourages positive behavior changes. By offering real-time data, wearables empower individuals to take control of their health, promoting increased physical activity, better sleep hygiene, and weight management. A study highlighted that wearables, such as Fitbit and Withings devices, showed strong validity in measuring steps and sleep duration, motivating users to adopt more active lifestyles (Ferguson et al., 2015).

In addition to tracking health data, wearable devices often incorporate behavioral nudges through notifications and rewards systems. These features are designed to prompt users to move, exercise, or rest, thereby reinforcing healthy habits. Research has shown that wearables can successfully increase physical activity among users, especially when paired with incentives such as rewards from health insurers or fitness challenges. These nudges are particularly effective in driving behavior change and promoting long-term adherence to health goals (Adebesin, 2019).

Wearable technology has also proven to be an effective tool in preventive health strategies by promoting primary preventive healthcare. For example, wearables help reduce the risk of chronic diseases by motivating individuals to maintain consistent physical activity and monitor their health metrics regularly. As more consumers integrate wearables into their daily routines, the potential for these devices to encourage healthier behaviors and improve overall well-being continues to grow (Lewis et al., 2019).

5. Future directions and ethical considerations

5.1. The Future Landscape of Wearable Health Technologies

The future of wearable health technologies holds immense potential for revolutionizing healthcare by making it more personalized, proactive, and preventive. Advances in sensors, artificial intelligence (AI), machine learning, and data analytics are driving the evolution of wearables, enabling more accurate and comprehensive health monitoring. Wearable devices will not only track basic physiological parameters such as heart rate and physical activity but will also monitor more complex biomarkers, such as glucose levels, hormonal fluctuations, and even mental health indicators. This expanded functionality will allow for more detailed insights into an individual's overall health, leading to earlier interventions and better health outcomes.

The integration of AI and machine learning will further enhance the predictive capabilities of wearables, allowing for real-time analysis of large datasets and the detection of patterns that may indicate potential health issues before symptoms even arise. This shift toward predictive and preventive care will significantly reduce the burden of chronic diseases and acute medical conditions by allowing healthcare providers to take timely action based on continuous data.

Additionally, the future of wearables is likely to see greater interoperability with other healthcare technologies, such as telemedicine platforms, electronic health records, and diagnostic tools. This seamless integration will enable a more holistic approach to patient care, where wearables provide critical data that can be used alongside other medical information to deliver personalized treatment plans. Moreover, the use of smart fabrics, implantable devices, and even nanotechnology will push the boundaries of what wearable health technology can achieve, making health monitoring more discreet, comfortable, and efficient.

As wearable health technologies continue to advance, there will also be a growing emphasis on addressing the challenges of data privacy, user compliance, and regulatory oversight. Ensuring that wearable devices meet stringent standards for accuracy, security, and ethical use will be critical to their widespread adoption and success in the healthcare industry. The future of wearables promises a more connected, informed, and health-conscious society, with individuals empowered to take charge of their own health through continuous, real-time data and actionable insights.

5.2. Overcoming Technological Barriers: Battery Life, Connectivity, and Interoperability

As wearable health technology continues to evolve, overcoming several key technological barriers will be crucial to fully realizing its potential in healthcare. Among the most significant challenges are battery life, connectivity, and interoperability. These issues not only affect the user experience but also determine the effectiveness and sustainability of wearable devices in providing continuous health monitoring and data analysis.

5.2.1. Battery Life

One of the most persistent challenges in wearable technology is extending battery life without compromising device performance. Most wearable devices are designed to be compact and lightweight, limiting the space available for batteries. However, users expect their devices to operate continuously, particularly in healthcare settings where interruptions in monitoring can have serious consequences. To address this, researchers and manufacturers are exploring various solutions, such as developing more energy-efficient sensors and processors, optimizing power consumption through software, and exploring alternative power sources like solar energy or kinetic energy from the user's movements. Extending battery life is essential for improving the reliability and usability of wearables, especially in long-term healthcare applications.

5.2.2. Connectivity

Continuous monitoring requires constant data transmission between wearable devices and healthcare systems. However, ensuring reliable and uninterrupted connectivity, especially in remote or low-bandwidth areas, remains a challenge. Wearables rely on wireless communication technologies, such as Bluetooth, Wi-Fi, and cellular networks, to transmit data. While these technologies have advanced significantly, factors such as signal interference, distance limitations, and power consumption can still hinder connectivity. Future wearables will need to leverage advancements in 5G networks and edge computing to ensure stable and secure data transmission. Additionally, improving device-to-cloud and device-to-device communication protocols will be crucial for enabling real-time health monitoring without connectivity disruptions.

5.2.3. Interoperability

Another key barrier is the lack of standardization and interoperability across different wearable devices and healthcare platforms. Currently, many wearables operate in isolation, with data stored in proprietary systems that are not easily integrated into broader healthcare networks or electronic health records (EHRs). This fragmentation limits the ability to create comprehensive health profiles for patients and hinders the potential for personalized, data-driven care. Achieving true interoperability requires developing standardized data formats, open APIs, and universal protocols that allow wearables to communicate seamlessly with various healthcare systems. It also necessitates collaboration between device manufacturers, healthcare providers, and regulatory bodies to establish common guidelines for data exchange and system integration.

Addressing these technological barriers will be critical in advancing the functionality and accessibility of wearable health devices. By enhancing battery life, connectivity, and interoperability, wearables can become more effective tools for continuous health monitoring, predictive healthcare, and personalized treatment, ultimately improving patient outcomes and the overall healthcare experience.

5.3. Ethical and Legal Issues: Privacy, Data Security, and Consent

As wearable health technology becomes increasingly integrated into healthcare, ethical and legal concerns surrounding privacy, data security, and informed consent have gained significant attention. These issues are critical to ensuring that the widespread adoption of wearable devices aligns with the rights and interests of users while maintaining the integrity and confidentiality of their personal health information.

5.3.1. Privacy

One of the foremost ethical concerns with wearable health technology is the potential for privacy violations. Wearable devices continuously collect sensitive health data, including physiological metrics, behavioral patterns, and, in some cases, location information. The collection, storage, and transmission of such vast amounts of personal data create significant risks of unauthorized access, misuse, or even surveillance by third parties. Users may not always be fully aware of the extent of data being collected or how it is being used, which can lead to feelings of vulnerability and mistrust. To address these concerns, it is imperative that wearable manufacturers implement robust privacy policies and transparent data usage agreements that clearly outline what data is being collected, how it will be used, and who will have access to it.

5.3.2. Data Security

The security of health data collected by wearables is another major issue. As wearable devices transmit data wirelessly, they are vulnerable to cyberattacks, hacking, and data breaches. Such incidents could expose sensitive health information, leading to identity theft, financial fraud, or unauthorized access to medical records. Ensuring that wearable devices are equipped with strong encryption protocols, secure data storage systems, and multi-factor authentication is essential to safeguarding user data. Furthermore, manufacturers must stay ahead of emerging cybersecurity threats by continuously updating device software and security measures to prevent vulnerabilities from being exploited.

5.3.3. Informed Consent

Informed consent is a foundational principle in healthcare and medical research, and its relevance extends to the use of wearable devices. Users must provide explicit consent before their data can be collected and used, and they should fully understand the scope of data collection and its potential implications. This is particularly important in clinical and research settings, where wearable data may be used to inform medical decisions or contribute to scientific studies. Ensuring that consent processes are clear, accessible, and ongoing is crucial to maintaining user autonomy and trust. Consent should also be dynamic, meaning that users should have the ability to withdraw consent at any time and opt out of certain data-sharing practices if they wish.

Additionally, the increasing use of wearable health devices raises concerns about data ownership and control. It remains unclear who legally owns the health data generated by wearables: the individual user, the device manufacturer, or the healthcare provider. Resolving this ambiguity will require the establishment of clear legal frameworks that delineate ownership rights and responsibilities, ensuring that users retain control over their personal health information.

As wearable technology continues to evolve and play a larger role in healthcare, addressing these ethical and legal issues will be essential to maintaining public trust and ensuring that wearable devices are used responsibly. Stronger regulations, user-centered policies, and greater transparency in data collection and usage practices will help safeguard the rights of individuals while allowing wearable technology to achieve its full potential in transforming healthcare.

5.4. Societal Implications: Accessibility and Equity in Healthcare through Wearables

The integration of wearable health technology into modern healthcare systems has the potential to transform healthcare delivery by making it more personalized, data-driven, and proactive. However, these advancements also bring with them important societal implications, particularly regarding accessibility and equity. For wearable health technology to truly revolutionize healthcare, it must be made accessible to diverse populations, including those from underserved or marginalized communities, and must address broader issues of health equity.

5.4.1. Accessibility

One of the major concerns surrounding wearable health technology is ensuring that these devices are accessible to all segments of the population, not just those who can afford them. Many wearable devices, such as smartwatches and fitness trackers, come with high costs that may be prohibitive for low-income individuals or families. This creates a digital divide, where only certain groups have access to the benefits of wearable technology, such as continuous health monitoring and personalized care. Ensuring that wearable devices are affordable and widely available will be critical to achieving health equity. This may involve government subsidies, insurance coverage, or partnerships with healthcare organizations to provide devices at reduced or no cost to underserved populations.

5.4.2. Digital Literacy and Inclusivity

Another key factor in ensuring accessibility is digital literacy. For wearable health devices to be effective, users must have a certain level of technological competence to operate and understand the data provided by these devices. Populations such as the elderly, individuals with limited education, or those in rural areas may face barriers in using wearables due to lack of familiarity with the technology. Healthcare providers, device manufacturers, and policymakers must work together to improve digital literacy through educational programs and user-friendly device designs that accommodate individuals with varying levels of technological proficiency.

5.4.3. Health Equity

Wearable technology has the potential to exacerbate existing health disparities if its use remains concentrated among more affluent, tech-savvy individuals. For example, people in rural areas or developing countries may not have reliable internet access or the necessary infrastructure to support the use of wearable devices, limiting their ability to benefit from these technological advancements. Additionally, wearable devices that cater primarily to lifestyle monitoring (e.g., fitness and activity tracking) may overlook the needs of individuals with chronic health conditions, disabilities, or specific cultural contexts. To promote health equity, wearables must be designed and implemented with the needs of diverse populations in mind, ensuring that they address a wide range of health conditions and are adaptable to various cultural and socioeconomic contexts.

5.4.4. Bridging the Gap

To bridge the gap in accessibility and equity, healthcare systems and policymakers must focus on integrating wearable health technology into public health initiatives. This could involve incorporating wearables into large-scale health programs that target chronic disease prevention, maternal health, or elderly care. Partnerships between governments, healthcare providers, and tech companies can help ensure that wearables are distributed and utilized in a way that benefits all individuals, regardless of their financial or social status. Additionally, the development of open-source platforms and low-cost wearable devices could help democratize access to wearable health technology, enabling more widespread adoption in underserved communities.

By addressing the challenges of accessibility and equity, wearable health technology can play a significant role in reducing health disparities and improving healthcare outcomes for diverse populations. When implemented thoughtfully, wearables have the potential to empower individuals from all backgrounds to take control of their health and access high-quality, data-driven healthcare. Ensuring that these technologies are inclusive, affordable, and user-friendly will be critical to realizing their full potential in transforming global healthcare systems.

6. Conclusion

Wearable health technology has evolved significantly from basic fitness trackers to advanced medical devices capable of continuous health monitoring, early disease detection, and personalized healthcare interventions. These innovations, including AI integration, biosensors, and smart fabrics, hold great potential to transform healthcare by making it more proactive and preventive. However, challenges such as data privacy, accuracy, and user compliance remain critical barriers that need to be addressed. By overcoming these obstacles, wearable technology can greatly enhance healthcare delivery and improve patient outcomes, benefiting society through more accessible and efficient healthcare solutions. Moving forward, interdisciplinary collaboration among technologists, healthcare providers, and policymakers is essential to ensure the successful integration of these technologies into everyday healthcare.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Adams, J. L., Dinesh, K., Snyder, C. W., Xiong, M., Tarolli, C. G., Sharma, S., Dorsey, E., & Sharma, G. (2021). A real-world study of wearable sensors in Parkinson's disease. *NPJ Parkinson's Disease*, 7(1), 1-10. https://doi.org/10.1038/s41531-021-00248-w

[2] Adebesin, F. (2019). Not missing a step: South Africans taking control of their personal wellbeing using wearable health devices. *Journal of Healthcare Informatics*, 6(1), 23-31.

[3] Adeghe, E. P., Okolo, C. A., & Ojeyinka, O. T. (2024). A review of wearable technology in healthcare: Monitoring patient health and enhancing outcomes. *Open Access Research Journal of Multidisciplinary Studies*, 7(1), 142–148. https://doi.org/10.53022/oarjms.2024.7.1.0019

[4] Albín-Rodríguez, A., López-Ruiz, J. L., & Espinilla-Estévez, M. (2022). Past, present, and future of research on wearable technologies for healthcare: A bibliometric analysis using Scopus. *Sensors*, 22(22), 8599. https://doi.org/10.3390/s22228599

[5] Alós, F., & Puig-Ribera, A. (2021). Uso de wearables y aplicaciones móviles (mHealth) para cambiar los estilos de vida desde la práctica clínica en atención primaria: Una revisión narrativa. *Applied Psychology Research*, 100122. https://doi.org/10.1016/j.appr.2021.100122

[6] Al-Siddiq, W. (2019). Next generation wearables: Achieving a value-based care system. *Wearable Technologies*, 1(1), 5–8.

[7] Anjum, G., Hasan, Z., Prasad, R., & Yadav, R. (2023). Real-time monitoring and predictive analytics in healthcare: The role of IoT technologies. *International Journal of Innovative Research in Computer and Communication Engineering*, 11(6), 6080. https://doi.org/10.15680/ijircce.2023.1106080

[8] Basaklar, T., Tuncel, Y., An, S., & Ogras, Ü. Y. (2021). Wearable devices and low-power design for smart health applications: Challenges and opportunities. *IEEE International Symposium on Low Power Electronics and Design*, 9502491. https://doi.org/10.1109/ISLPED52811.2021.9502491

[9] Bez, M., & Simini, F. (2018). Wearable devices and medical monitoring robot software to reduce costs and increase quality of care. *2018 International Conference on Advances in Computing, Communications and Informatics (ICACCI)*. https://doi.org/10.1109/ICACCI.2018.8554646

[10] Cilliers, L. (2020). Wearable devices in healthcare: Privacy and information security issues. *Health Information Management Journal*, 49(1), 42–49. https://doi.org/10.1177/1833358319851684

[11] Dai, W., & Zhou, H. (2023). Wearable design innovations enabled by artificial intelligence: A technical review. *Proceedings of the 2023 International Conference on Advanced Design Research and Innovation*, 4056. https://doi.org/10.1145/3614008.3614056

[12] Dkhar, D. S., Kumari, R., Mahapatra, S., Divya, C., & Chandra, P. (2022). Engineering design, implementation, and sensing mechanisms of wearable bioelectronic sensors in clinical settings. *Electroanalysis*, 34(10), 1–13. https://doi.org/10.1002/elan.202200154

[13] Elkefi, S., & Asan, O. (2022). Wearable devices' use in geriatric care between patient-centeredness and psychology of patients. *Digital Health*, 8, 2327857922111025. https://doi.org/10.1177/2327857922111025

[14] Ezeamii, V. C., Okobi, O. E., Wambai-Sani, H., Perera, G. S., Zaynieva, S., Okonkwo, C. C., ... & Obiefuna, N. G. (2024). Revolutionizing Healthcare: How Telemedicine Is Improving Patient Outcomes and Expanding Access to Care. *Cureus*, *16*(7).

[15] Ezeamii, V., Adhikari, A., Caldwell, K. E., Ayo-Farai, O., Obiyano, C., & Kalu, K. A. (2023, November). Skin itching, eye irritations, and respiratory symptoms among swimming pool users and nearby residents in relation to stationary airborne chlorine gas exposure levels. In *APHA 2023 Annual Meeting and Expo*. APHA.

[16] Ezeamii, V., Adhikari, A., Caldwell, K. E., Ayo-Farai, O., Obiyano, C., & Kalu, K. A. (2023, November). Skin itching, eye irritations, and respiratory symptoms among swimming pool users and nearby residents in relation to stationary airborne chlorine gas exposure levels. In *APHA 2023 Annual Meeting and Expo*. APHA.

[17] Ezeamii, V., Jordan, K., Ayo-Farai, O., Obiyano, C., Kalu, K., & Soo, J. C. (2023). Dirunal and seasonal variations of atmospheric chlorine near swimming pools and overall surface microbial activity in surroundings.

[18] Ezeamii, V. C., Gupta, J., Ayo-Farai, O., Savarese, M., & Adhikari, A. (2024). Assessment of VOCs and Molds Using CDC/NIOSH developed tools in Hurricane Ian affected Homes.

[19] Ezeamii, V., Ayo-Farai, O., Obianyo, C., Tasby, A., & Yin, J. (2024). A Preliminary Study on the Impact of Temperature and Other Environmental Factors on VOCs in Office Environment.

[20] Ezeamii, V., Ayo-Farai, O., Obianyo, C., Tasby, A., & Yin, J. (2024). A Preliminary Study on the Impact of Temperature and Other Environmental Factors on VOCs in Office Environment.

[21] Here is the reference for the article in APA style based on the image:

[22] Ezeamii, G. C., Idoko, F. A., & Ojochogwu, O. J. (2024). Biosensors and technological advances in monitoring marine pollution in the USA. *Global Journal of Engineering and Technology Advances, 20*(3), 133–149. https://doi.org/10.30574/gjeta.2024.20.3.0174

[23] Ferguson, T., Rowlands, A., Olds, T., & Maher, C. (2015). The validity of consumer-level activity monitors in healthy adults worn in free-living conditions: A cross-sectional study. *International Journal of Behavioral Nutrition and Physical Activity*, 12(1), 1-9. https://doi.org/10.1186/s12966-015-0201-9

[24] Hughes, A., Shandhi, M., Master, H., Dunn, J., & Brittain, E. (2023). Wearable devices in cardiovascular medicine. *Circulation Research*, 122(3), 322–389. https://doi.org/10.1161/CIRCRESAHA.122.322389

[25] Idoko, B., Alakwe, J. A., Ugwu, O. J., Idoko, J. E., Idoko, F. O., Ayoola, V. B., ... & Adeyinka, T. (2024). Enhancing healthcare data privacy and security: A comparative study of regulations and best practices in the US and Nigeria. *Magna Scientia Advanced Research and Reviews*, *11*(2), 151-167.

[26] Idoko, B., Idoko, J. E., Ugwu, O. J., Alakwe, J. A., Idoko, F. O., Ayoola, V. B., ... & Adeyinka, T. (2024). Advancements in health information technology and their influence on nursing practice in the USA. *Magna Scientia Advanced Research and Reviews*, *11*(2), 168-189.

[27] Idoko, I. P., Ayodele, T. R., Abolarin, S. M., & Ewim, D. R. E. (2023). Maximizing the cost effectiveness of electric power generation through the integration of distributed generators: wind, hydro and solar power. *Bulletin of the National Research Centre*, *47*(1), 166.

[28] Idoko, I. P., Ayodele, T. R., Abolarin, S. M., & Ewim, D. R. E. (2023). Maximizing the cost effectiveness of electric power generation through the integration of distributed generators: wind, hydro and solar power. *Bulletin of the National Research Centre*, *47*(1), 166.

[29] Idoko, I. P., Ijiga, O. M., Harry, K. D., Ezebuka, C. C., Ukatu, I. E., & Peace, A. E. (2024). Renewable energy policies: A comparative analysis of Nigeria and the USA. *World Journal of Advanced Research and Reviews*, *21*(1), 888-913.

[30] Idoko, I. P., Ijiga, O. M., Akoh, O., Agbo, D. O., Ugbane, S. I., & Umama, E. E. (2024). Empowering sustainable power generation: The vital role of power electronics in California's renewable energy transformation. *World Journal of Advanced Engineering Technology and Sciences*, *11*(1), 274-293.

[31] Idoko, I. P., Ijiga, O. M., Agbo, D. O., Abutu, E. P., Ezebuka, C. I., & Umama, E. E. (2024). Comparative analysis of Internet of Things (IOT) implementation: A case study of Ghana and the USA-vision, architectural elements, and future directions. *World Journal of Advanced Engineering Technology and Sciences*, *11*(1), 180-199.

[32] Idoko, I. P., Igbede, M. A., Manuel, H. N. N., Ijiga, A. C., Akpa, F. A., & Ukaegbu, C. (2024). Assessing the impact of wheat varieties and processing methods on diabetes risk: A systematic review. *World Journal of Biology Pharmacy and Health Sciences*, *18*(2), 260-277.

[33] Idoko, I. P., Ijiga, O. M., Enyejo, L. A., Ugbane, S. I., Akoh, O., & Odeyemi, M. O. (2024). Exploring the potential of Elon musk's proposed quantum AI: A comprehensive analysis and implications. *Global Journal of Engineering and Technology Advances*, *18*(3), 048-065.

[34] Idoko, I. P., Igbede, M. A., Manuel, H. N. N., Adeoye, T. O., Akpa, F. A., & Ukaegbu, C. (2024). Big data and AI in employment: The dual challenge of workforce replacement and protecting customer privacy in biometric data usage. *Global Journal of Engineering and Technology Advances*, *19*(02), 089-106.

[35] Idoko, I. P., David-Olusa, A., Badu, S. G., Okereke, E. K., Agaba, J. A., & Bashiru, O. (2024). The dual impact of AI and renewable energy in enhancing medicine for better diagnostics, drug discovery, and public health. *Magna Scientia Advanced Biology and Pharmacy*, *12*(2), 099-127.

[36] Joyce, K. (2019). Smart textiles: Transforming the practice of medicalisation and health care. *Sociology of Health & Illness*, 41(7), 1289–1302. https://doi.org/10.1111/1467-9566.12871

[37] Kalantari, M. (2017). Consumers' adoption of wearable technologies: Literature review, synthesis, and future research agenda. *International Journal of Technology Marketing*, 12(3), 274–307. https://doi.org/10.1504/IJTMKT.2017.084486

[38] Kaewkannate, K., & Kim, S. (2016). A comparison of wearable fitness devices. *BMC Public Health*, 16, 433. https://doi.org/10.1186/s12889-016-3059-0

[39] Lewis, Z. H., Sypes, E., JeanMarie-Tucker, M., Picazo, A.-L., & Pritting, L. (2019). Research and commercial utilization of wearables among healthy adults: An exploratory comparative analysis. *Medicine & Science in Sports & Exercise*, 51(Suppl 6), 699. https://doi.org/10.1249/01.mss.0000562991.40344.ec

[40] Lu, L., Zhang, J., Xie, Y., Gao, F., Xu, S., & Ye, Z. (2020). Wearable health devices in health care: Narrative systematic review. *JMIR mHealth and uHealth*, 8(11), e18907. https://doi.org/10.2196/18907

[41] Lu, Y., & Xie, H. (2017). [Application of wearable devices in medical field]. *Chinese Journal of Medical Instrumentation*, 17(3), 120–125. https://doi.org/10.3969/j.issn.1671-7104.2017.03.015

[42] Monschein, T., Leutmezer, F., & Altmann, P. (2021). Anwendung von Wearables bei Multipler Sklerose. *Nervenarzt*, 92, 72–80. https://doi.org/10.1055/a-1351-8552

[43] Nasiri, S., & Khosravani, M. (2020). Progress and challenges in fabrication of wearable sensors for health monitoring. *Sensors and Actuators A: Physical*, 312, 112105. https://doi.org/10.1016/j.sna.2020.112105

[44] Patwary, S., Farhana, K., & Ahmed, S. (2015). Smart textiles and nanotechnology: A general overview. *Journal of Textile Science & Engineering*, 5(1), 181. https://doi.org/10.4172/2165-8064.1000181

[45] Pawar, U., O'Shea, D., Rea, S., & O'Reilly, R. (2020). Explainable AI in healthcare. *2020 IEEE Cyber Science and Artificial Intelligence Conference*, 9139655. https://doi.org/10.1109/CyberSA49311.2020.9139655

[46] Pentland, A. (2004). Healthwear: Medical technology becomes wearable. *IEEE Computer*, 37(5), 42–49. https://doi.org/10.1109/MC.2004.1297238

[47] Raja Suguna, M., Nithisha, J., Babu, A. R., Ananda, M. H., Venkatesan, R., & Malathi, N. (2024). Advanced seizure prediction system for wearable health management devices using KNN algorithm. *2024 International Conference on Intelligent Systems and Communication*, 10563606. https://doi.org/10.1109/ICIPTM59628.2024.10563606

[48] Seçkin, A., Ateş, B., & Seçkin, M. (2023). Review on wearable technology in sports: Concepts, challenges and opportunities. *Applied Sciences*, 13(18), 10399. https://doi.org/10.3390/app131810399

[49] Sharma, A., Mahajan, P., Singh, A., & Arya, S. (2022). Detection of physiological markers via wearable devices for human healthcare. *ECS Transactions*, 107(1), 20265. https://doi.org/10.1149/10701.20265ecst

[50] Shiba, S. K., Temple, C. A., Krasnoff, J., Dilchert, S., Smarr, B. L., Robishaw, J., & Mason, A. (2023). Assessing adherence to multi-modal Oura Ring wearables for COVID-19 detection among healthcare workers. *Cureus*, 15(9), e45362. https://doi.org/10.7759/cureus.45362

[51] Shumba, A., Montanaro, T., Sergi, I., Bramanti, A., Ciccarelli, M., Rispoli, A., Carrizzo, A., & Patrono, L. (2023). Wearable technologies and AI at the far edge for chronic heart failure prevention and management: A systematic review and prospects. *Sensors*, 23(15), 6896. https://doi.org/10.3390/s23156896

[52] Smuck, M., Odonkor, C., Wilt, J., Schmidt, N., & Swiernik, M. A. (2021). The emerging clinical role of wearables: Factors for successful implementation in healthcare. *npj Digital Medicine*, 4(1), 1-9. https://doi.org/10.1038/s41746-021-00418-3

[53] Tarafder, N. (2023). Functions and applications of wearable technology - A review. *Journal of Modern Manufacturing*, 1(11), 1111–15. https://doi.org/10.48001/jomm.2023.1111-15

[54] Wang, L., Lou, Z., Jiang, K., & Shen, G. (2019). Bio-multifunctional smart wearable sensors for medical devices. *Advanced Intelligent Systems*, 1(7), 1900040. https://doi.org/10.1002/aisy.201900040

[55] Yu, S., Chen, Z., & Wu, X. (2023). The impact of wearable devices on physical activity for chronic disease patients: Findings from the 2019 Health Information National Trends Survey. *International Journal of Environmental Research and Public Health*, 20(1), 887. https://doi.org/10.3390/ijerph20010887

[56] Zhang, C., & Shahriar, H. (2020). The adoption, issues, and challenges of wearable healthcare technology for the elderly. *Proceedings of the 11th ACM Conference on Bioinformatics, Computational Biology, and Health Informatics*, 319–325. https://doi.org/10.1145/3368308.3415454

[57] Zheng, J., Shen, Y., Zhang, Z., Wu, T., & Lu, H. (2013). Emerging wearable medical devices towards personalized healthcare. *BodyNets 2013*, 253725. https://doi.org/10.4108/ICST.BODYNETS.2013.253725

[58] White, D. A. (2011, September). Pedometers 101. Retrieved from https://www.foodnetwork.com/healthyeats/2012/04/pedometers-101.

[59] Collidu. (2024). *Wearable technology in healthcare* [Presentation]. Collidu. https://www.collidu.com/presentation-wearable-technology-in-healthcare

[60] Qureshi, K. N., Abdullah, A. H., & Anwar, R. W. (2014, April). The evolution in health care with information and communication technologies. In *Proceeding of 2nd International Conference of Applied Information and Communications Technology-2014. ELSEVIER, Oman*.