Chapter 20
The Future of Virology Diagnostics Using Wearable Devices Driven by Artificial Intelligence

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ABSTRACT

The utilization of the wearable devices (WDs) that are enhanced by artificial intelligence (AI) can have a notable potential in healthcare. This chapter aimed to provide an overview of the applications of AI-driven WDs in enhancing the early detection and management of virus infections. First, we presented examples to highlight the capabilities of WDs in very early monitoring of virus infections such as COVID-19. In addition, we provided an overview on the utility of machine learning algorithms to analyze large data for the detection of early signs of virus infections. We also

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overviewed the AI-driven WDs potential to enable real-time surveillance for effective virus outbreak management. We showed how this AI-driven WDs surveillance can be achieved via the collection and analysis of diverse real-time WDs' data across various populations. Finally, this chapter discussed the challenges and ethical issues that comes with AI-driven WDs in virology diagnostics, including concerns about data privacy and security as well as the issue of equitable access.

INTRODUCTION

Refining virology diagnostics in the context of global health security is an important and urgent issue. This importance stems from the continuous threats of emerging and re-emerging virus infections (Kessel, 2014; Kelly-Cirino et al., 2019; Hill et al., 2023). The traditional methods for virus infection diagnoses largely depend on clinical suspicion and subsequent laboratory confirmation. These approaches suffer weaknesses when rapid containment and management of virus outbreaks is needed (Burrell et al., 2017; Kretzschmar et al., 2020). The limitations of traditional diagnostic methods in virology were highlighted during the coronavirus disease 2019 (COVID-19) pandemic (Younes et al., 2020). The limitation of traditional diagnostic tools in virology was particularly evident in the early days of the COVID-19 pandemic, when countries faced diagnostic bottlenecks, precluding timely interventions and allowing virus spread to spiral unchecked (Martinez-Liu et al., 2021; Silva & Pena, 2021; Syal, 2021).

On the positive side, the COVID-19 pandemic showed the need for reassessment of the currently available virus infection diagnostic modalities (Cabrera et al., 2022; Li et al., 2022). In response, the field of virology diagnostics witnessed active attempts to adopt innovative technologies. For example, CRISPR-based diagnostic tools, such as SHERLOCK-Covid, STOP-Covid, AIOD-CRISPR, and DETECTR platform, emerged as promising tools during the pandemic, offering rapid, accurate detection of viral RNA with minimal infrastructure requirements (Rahman et al., 2021; Ebrahimi et al., 2022). Subsequently, these technologies can be adopted to reach efficient detection and response strategies to control future virus outbreaks (Broughton et al., 2020; Cassedy et al., 2021; Fernandes et al., 2022; Trinh et al., 2023).

Wearable Devices (WDs) emerged as promising tools that have the potential to improve healthcare diagnostics (Teixeira et al., 2021; Ahmed et al., 2022; Huang et al., 2022; Haghayegh et al., 2024). Additionally, the potential of Artificial Intelligence (AI) in virology can be extremely valuable. This value can be shown in multiple aspects including the early diagnosis, outbreak prediction, and effective coordination of public health responses to virus infection outbreaks (Guo et al., 2023; Padhi et al., 2023; Sallam, 2023, 2024; Zhao et al., 2024). Thus, further investigation of the potential of AI-driven WDs' diagnostics is a promising area in virology.

The evolution of diagnostics and therapeutics in virology has been marked by a significant shift toward new technologies. These technologies can offer real-time disease monitoring and in-depth data analysis (Patra & Mukhopadhyay, 2022; Zuo et al., 2024). The WDs that has traditionally been used for fitness and health monitoring, can be expected to be among the leading technologies in this evolution of virology diagnostics. Nevertheless, concerns arise regarding the reliability, privacy, and inclusivity of WDs (Kang & Exworthy, 2022; Shei et al., 2022; Longhini et al., 2024).

The WDs are defined as electronic devices designed to be worn on the body, equipped with sophisticated sensors capable of monitoring a wide spectrum of physiological parameters. These include, but are not limited to, body temperature, heart rate, respiratory rate, and biochemical markers (Kekade et al., 2018; Goergen et al., 2022; Xue et al., 2023). These devices provide a helpful range of diverse health data. In turn, the WDs' health data can be crucial for the early detection of virus infections that are often inapparent prior to its progression to more severe stages (Brakenhoff et al., 2021; Goergen et al., 2022; Mitratza et al., 2022; Quer et al., 2024).

Interestingly, the enhancement of WDs' technologies by incorporation of AI can result in a revolution in health care diagnostics (Shajari et al., 2023). This notable enhancement of AI-driven WDs is related to multiple aspects as follows. For example, AI algorithms allows the rapid analysis of large datasets with high precision. In addition, AI algorithms has the ability to identify early disease patterns that may elude experienced human eyes (Mijwil et al., 2022; Alowais et al., 2023). In the context of virology, AI-driven WDs can be utilized to meticulously detect subtle deviations from baseline physiological parameters. These subtle deviations may indicate an underlying virus infection in its outset (Goergen et al., 2022).

Importantly, when AI-driven WDs are networked across various communities, they can monitor and analyze data at a population level. Subsequently, this approach can be helpful in the Early Warning Systems (EWSs). The EWSs would enable the prompt detection of potential virus outbreaks before they reach the critical epidemiologic thresholds (Meckawy et al., 2022).

The potential of WDs was realized during the COVID-19 pandemic. Amid the COVID-19 pandemic, various forms of digital surveillance were employed to track the spread of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and implement health interventions efficiently (Channa et al., 2021; Cheong et al., 2022; Fallatah & Adekola, 2024). However, the applications of AI-driven WDs remain largely unexplored. Thus, the applications of AI-driven WDs represents a fertile ground for further exploration especially in virology diagnostics.

An application of AI-driven WDs in virology that is worth full consideration is virus outbreak detection and forecasting. Advanced AI models can help to enhance understanding of the data from WDs networked across various communities. These data in turn would enable forecasting of infection hotspots and future outbreak trends with a degree of accuracy previously hard to reach (Malik et al., 2021). This capability of AI-driven WDs could also be helpful in long-term virus pandemic preparedness via evidence-based public health policies and preventive measures (Syrowatka et al., 2021).

Moreover, the use of AI-driven WDs introduces new opportunities in the management of quarantine and isolation in virus outbreaks. Traditionally, the quarantine and isolation measures for virus control suffered from limitations and complications. These limitations include the unnecessary long quarantine and the negative psychological impact among the isolated individuals (Brooks et al., 2020; Wilder-Smith & Freedman, 2020). Such limitations can be overcome by AI-driven WDs. These devices would allow personalized health monitoring that can differentiate between individuals who may be at high risk of spreading a virus and those who are not; thus, providing a refined, risk-based outbreak control measures.

Based on this brief introduction, this chapter aimed to provide an overview of the potential of AI-driven WDs in virology diagnostics. Additionally, this paper aimed to address the challenges and limitations that can be associated with the widespread adoption of AI-driven WDs in virology. Issues such as data privacy, the potential for socioeconomic disparities in access to this technology, and the ethical considerations of surveillance are discussed in-depth.

Wearable Devices and Their Role in Virus Infection Detection

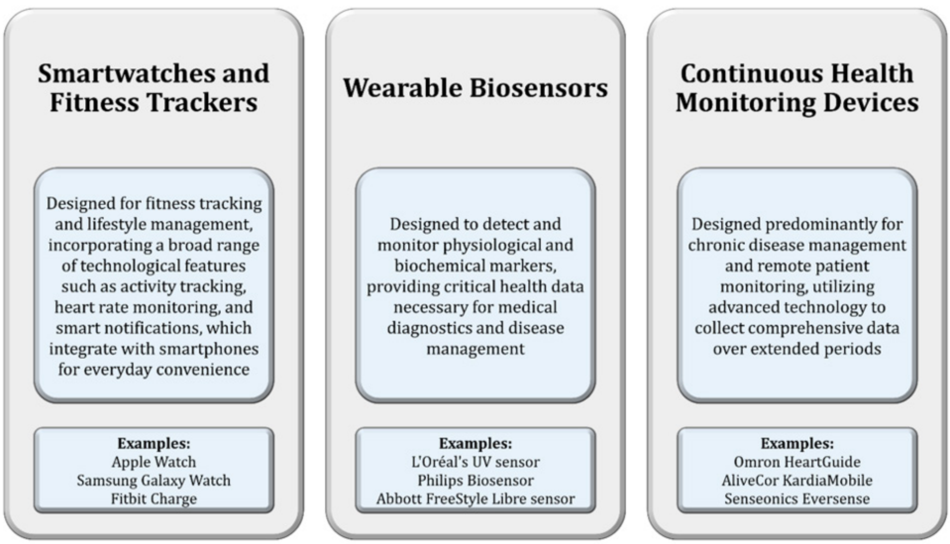
The introduction and widespread availability of WDs represented a significant milestone in health care diagnostics (Koydemir & Ozcan, 2018; Guk et al., 2019; Lu et al., 2020; Ometov et al., 2021). The WDs technologies can bridge the gap between traditional diagnostic modalities and real-time, personalized health tracking, enabling unprecedented opportunities for early disease detection and management (Pyper et al., 2023). As outlined briefly in (**Table 1**), WDs encompass a wide range of technologies with various health metrics they are capable of monitoring. The versatility of WDs lies in their ability to provide continuous, non-invasive monitoring across a variety of physiological parameters, thereby serving as an invaluable resource for tracking health trends over time (Teixeira et al., 2021).

Table 1. Examples of wearables and health parameters it can monitor.

Wearable type	Parameters monitored	Examples
Wrist-mounted devices	Cardiovascular signals: heart rate, blood pulse; Sweat contents: glucose, sodium	Wristband, watch
Head-mounted devices	Salivary contents: lactate, uric acid, glucose	Mouth guard
E-textiles	Sweat contents: glucose, lactate	Textiles with electrode
E-textiles	Cardiovascular signals: heart rate, temperature	Leg calf

In this section, we provide an overview of widely used WDs and explore how AI can enhance their capabilities, thus converting scattered raw health data into meaningful in-depth insights aiding in public health responses to viral diseases. The discussion will encompass smartwatches and fitness trackers, wearable biosensors, and continuous health monitoring devices, highlighting their roles in advancing virology diagnostics. This arbitrary classification was chosen based on function, technological features, and the scope of data collected by these WDs (**Figure 1**).

Figure 1. Wearable Devices' classification with examples.



Smartwatches and Fitness Trackers

Nowadays, smartwatches and fitness trackers are among the most commonly used WDs (Shei et al., 2022). These devices were initially used for fitness tracking and basic health monitoring; however, their capabilities extended to include providing medical information (Scheid et al., 2023). Smartwatches and fitness trackers can continuously track vital signs such as body temperature, pulse rate, blood oxygen levels, and respiratory rates—each of which may be influenced by the onset of a virus infection (Costa et al., 2023). The strength of smartwatches and fitness trackers lies in their ability to provide real-time health monitoring (Tang et al., 2020; Masoumian Hosseini et al., 2023).

For example, during the COVID-19 pandemic, Mishra *et al*. suggested that tracking the vital signs by smartwatches could precede the manifestations of clinical symptoms of COVID-19 by several days (Mishra et al., 2020). Additionally, Alavi *et al*. demonstrated that a smartwatch-based alert system could detect COVID-19 pre-symptomatically, with key signals becoming apparent at a median of three days before the onset of COVID-19 symptoms (Alavi et al., 2022). Moreover, the DETECT-AHEAD trial demonstrated the early feasibility of prompting at-home respiratory virus testing via smartwatch sensors and symptom tracking, leading to pre-symptomatic detection of respiratory viruses (Quer et al., 2024).

In a scoping review, Cheong *et al*. demonstrated that smartwatches and fitness trackers were effective for early COVID-19 diagnosis (Cheong et al., 2022). The review which involved 40 articles, highlighted models with up to 100% sensitivity and 95.3% specificity demonstrating the applicability of smartwatches and fitness trackers in virology diagnostics (Cheong et al., 2022).

Wearable Biosensors

Wearable biosensors (e.g., glucometers, pulse oximeters) represent a more advanced example of WDs compared to smartwatches and fitness trackers (Haghayegh et al., 2024). Unlike smartwatches and fitness trackers, wearable biosensors are equipped to detect and analyze specific biochemical markers (Buekers et al., 2019). Additionally, wearable biosensors have undergone significant miniaturization, facilitating their integration into devices such as armbands and wristbands (Tricoli et al., 2017; Lu et al., 2020; Sharma et al., 2021; Parrilla et al., 2022). This progress enabled wearable biosensors to continuously and autonomously monitor critical physiological parameters such as oxygen saturation (Buekers et al., 2019).

In the context of virology, a study by Ka-Chun Un *et al*., demonstrated the utility of wearable biosensors among patients with COVID-19 (Un et al., 2021). In this study, COVID-19 patients were monitored remotely through an integrated system including wearable biosensors, a patient-facing smartphone application, secure cloud storage, and a clinician-accessible web dashboard (Un et al., 2021). The primary wearable biosensor, Everion, worn on the upper arm, continuously tracked vital signs for real-time analysis and the resulting Biovitals Index, derived through machine learning (ML), accurately predicted clinical deterioration and hospitalization needs, surpassing the established early warning score systems (Un et al., 2021).

Additionally, a review by Ayan Chatterjee *et al*. showed the value of wearable biosensors in virology diagnostics during the COVID-19 pandemic (Chatterjee et al., 2023). The review highlighted the role of employing technologies such as wearable biosensors to monitor patients remotely. In turn, this monitoring facilitated real-time data collection aiding in the containment of SARS-CoV-2 (Chatterjee et al., 2023).

Continuous Health Monitoring Devices

Continuous health monitoring devices constitute a significant advancement in wearables' technology. These devices offer continuous and extensive data collection across various physiological parameters (Kazanskiy et al., 2024; Khan & Kim, 2024).

Continuous health monitoring devices can be crucial for detecting early signs of virus infections. This ability is related to the continuous recording of physiological data and the identification of subtle deviations that may indicate an infection's onset prior to overt clinical manifestations (Ming et al., 2020). The efficacy of these devices in virology has been demonstrated through real-life applications and studies. An example is the identification of COVID-19 cases before patients experience full-blown symptoms (Ates et al., 2021; Jiang et al., 2022).

Utility of AI-driven WDs in Virology Diagnostics

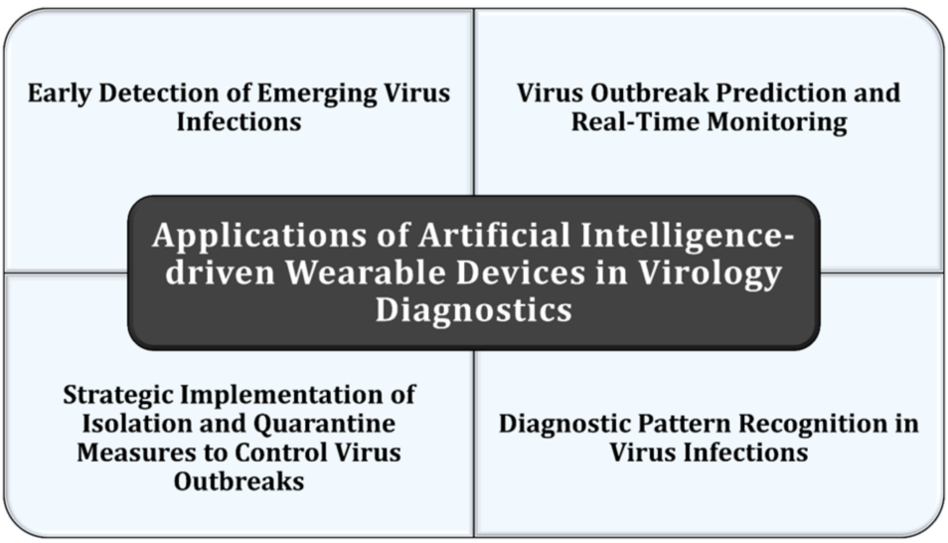
The integration of AI with WDs can revolutionize virology diagnostics. This ability is facilitated by shifting the health approaches from reactive to proactive diagnosis and management (D'Haese et al., 2021; Padhi et al., 2023; Shajari et al., 2023; Ashique et al., 2024). This revolution is expected based in the AI's ability to swiftly process massive datasets. In turn, this feature would allow for real-time analysis of biometric data from WDs (Shajari et al., 2023; Marvasti et al., 2024).

Through advanced pattern recognition, AI can help to analyze variations in vital signs and biometric data. This analysis would help to differentiate between normal fluctuations and those signaling a potential virus infection (Badidi, 2023). In addition, the predictive power of AI extends to involve monitoring the progress of virus infections and its response to treatment. Thus, AI predictive monitoring offers insights that are important for health care and public health decisions.

By predicting infection trends and potential occurrence of outbreaks, AI-driven WDs can aid in epidemiological surveillance and response strategies. For example, a study by Conroy *et al.*, explored the potential of AI-driven WDs to mitigate workforce impacts during the COVID-19 pandemic (Conroy et al., 2022). In this study, the researchers developed a prototype tool that provided real-time infection risk scores using data from WDs worn by 9,381 United States Department of Defense personnel (Conroy et al., 2022). The tool which tracked 201 million hours of data, successfully predicted infections before diagnostic confirmation showing increased risk scores up to six days before testing (Conroy et al., 2022).

Thus, the WDs' capabilities strengthened by AI can result in massive transformation of how to manage public health resources efficiently. Additionally, AI-driven WDs can help in the preemptive responses to virus outbreaks. Consequently, this can be seen as substantial positive shift in global health security. In this section, we outline the potential of AI-driven WDs in virology diagnostics as shown in (**Figure 2**).

Figure 2. Examples of the applications of artificial intelligence (AI)-driven wearable devices (WDs) in virology diagnostics.



Early Detection of Emerging Virus Infections

Significant challenges remain in virology diagnostics and predictive epidemiologic modeling. These challenges are related to the difficulty in the identification of early signs of emerging infections such as novel or zoonotic diseases (Glennon et al., 2021). AI-driven WDs' data have the potential to improve the early detection and management of novel pathogens, serving as key tools in preemptive surveillance. Continuous monitoring of a wide range of physiological parameters through AI-driven WDs can help to establish comprehensive databases of baseline physiological ranges (Kher & Patel, 2021). These valuable data can allow for the detection of significant deviations as a result of virus infections. In turn, these deviations could indicate infections from unknown pathogens before any specific symptoms become clinically apparent.

Utilizing advanced pattern recognition and ML, the AI-driven WDs can analyze patterns of variation. Additionally, AI-driven WDs can learn from extensive datasets collected across various individual demographics and different world regions (Giacobbe et al., 2023; Al Meslamani et al., 2024). This ongoing analysis would help to enhance the ability of WDs to distinguish between normal fluctuations due to everyday activities and anomalies that may signal a potential health threat due to an emerging virus infection (Agrebi & Larbi, 2020; Zhao et al., 2024).

Such AI capabilities are crucial for identifying the early presence of a hypothetical "Pathogen X" enabling health authorities to effectively implement rapid response strategies (Anjaria et al., 2023; Olawade et al., 2023; Zhao et al., 2024). AI-powered predictive models can further utilize this data to assess and forecast the risk of virus spread via integrating epidemiological factors like travel patterns and population density to anticipate and localize potential outbreaks (Zhang, 2022; Ankolekar et al., 2024).

The integration of wearable technology data enhanced by the strong AI potential with global health monitoring systems would ensure a coordinated response across international borders, which would help to enhance the global preparedness and response capabilities to the threat of virus infections. Thus, AI-driven WDs' data are not merely adjunct tools but can be central to the innovation in global health security (Zuhair et al., 2024).

The data provided by AI-driven WDs can offer a proactive framework for combating emerging viral threats before escalation into widespread public health emergencies. Additionally, one of the most significant implications of AI in virology diagnostics is its potential to reduce the strain on healthcare systems, particularly during the peak times of a pandemic (Chang et al., 2021; Farhat et al., 2023; Singh et al., 2024). By detecting infections early and accurately predicting disease progression, AI-driven WDs' data can help prioritize medical resources and interventions for those at greatest risk. This proactive management helps prevent hospital systems from becoming overwhelmed, maintaining higher levels of care and improving patient outcomes.

Outbreak Prediction and Real-Time Monitoring

The integration of AI with WDs can significantly enhance the capability for virus outbreak prediction as well as the real-time monitoring of the outbreak. This advanced application of AI enables the synthesis and analysis of physiological data collected from millions of WDs, facilitating the early detection of an emerging virus outbreak and tracking its trajectory.

In a seminal study, Tejaswini Mishra *et al*. demonstrated how WDs, continuously measuring vital signs, could be used for the pre-symptomatic detection of COVID-19 (Mishra et al., 2020). Analyzing physiological and activity data from 32 infected individuals within a cohort of nearly 5,300 participants, the study found that 81% exhibited alterations in heart rate, daily steps, or sleep patterns. Remarkably, 88% of these cases with available symptom information showed detectable physiological changes before or at symptom onset, with four cases identified at least nine days earlier (Mishra et al., 2020).

In another relevant study, Emilia Grzesiak *et al*., evaluated the use of non-invasive, wrist-worn WDs to detect presymptomatic virus infections and predict severity among participants exposed to H1N1 influenza virus and human rhinovirus (Grzesiak et al., 2021). Conducted with intranasal inoculations of viruses in controlled settings, the models identified presymptomatic infections with high accuracy; 92% for H1N1 and 88% for rhinovirus, and were able to predict infection severity 24 hours before symptoms with 90% accuracy for H1N1 and 89% for rhinovirus (Grzesiak et al., 2021). These findings highlight the potential of WDs in early intervention and monitoring the spread of virus infections.

Moreover, the real-time data processing facilitated by AI tools would ensure that the monitoring of health patterns is continuous, allowing for immediate public health responses. The ongoing refinement of these AI models, achieved through ML, enhances their predictive accuracy by adapting to new viral strains and changing epidemiological patterns (Piccialli et al., 2021).

In this context, Riaz *et al*. introduced iPREDICT, an innovative AI-based framework designed to enhance pandemic prediction through data from connected and wearable biosensing devices (Riaz et al., 2024). This framework can detect early infection signs by analyzing anomalies in biomarkers and correlating them across a community (Riaz et al., 2024). Utilizing AI for anomaly detection and spatiotemporal analysis, the framework aimed to identify potential pandemics in near real-time (Riaz et al., 2024). The system has graph neural networks to set thresholds based on demographic, social, and geographical factors, assessing the likelihood of an outbreak escalating into a pandemic (Riaz et al., 2024).

Overall, the strategic use of AI with WDs will not only improve the efficiency of public health responses but also would revolutionize how we prepare for and manage infectious disease outbreaks on a global scale. This proactive approach, powered by AI, holds the potential to significantly reduce the impact of future pandemics, saving lives and stabilizing health care systems worldwide. Additionally, by predicting potential hotspots and infection trends, AI-driven WDs can enable health care systems to prepare and respond more effectively, allocating resources in anticipation of increased demand (Zhu et al., 2020).

Strategic Implementation of Isolation and Quarantine Measures to Control Virus Outbreaks

The strategic implementation of isolation and quarantine measures plays a critical role in controlling infectious disease outbreaks, particularly during pandemics (Hellewell et al., 2020; Wong et al., 2020). The integration of AI with WDs can significantly enhance these control strategies by enabling early detection and continuous monitoring of virus infections. Wearables equipped with AI can identify infected individuals before they show symptoms or become contagious, allowing health authorities to implement isolation or quarantine measures preemptively and effectively mitigate virus spread (Lim & Abdul Ghani, 2022; Gheisari et al., 2024).

In addition, the AI-driven WDs continuous monitoring of the health status of quarantined individuals with real-time data analysis can give important insights into the progression of an infection (Chang et al., 2021). This continuous monitoring can indicate the need for early medical intervention, potentially reducing the severity of the virus infection and preventing its complications (Goergen et al., 2022). Moreover, AI can determine when individuals are no longer contagious, optimizing isolation duration and minimizing unnecessary disruptions to personal lives and the economy (Nurkahfi et al., 2022).

Diagnostic Pattern Recognition in Virus Infections

In general, AI has demonstrated a great capacity to recognize and interpret diagnostic patterns in various health contexts including virus infections (El-Bouzaidi & Abdoun, 2023; Padhi et al., 2023; Rabaan et al., 2023; Sallam, 2023; Khalifa & Albadawy, 2024; Sallam, 2024; Zhang et al., 2024). This capability is critical for understanding the progression of infections and tailoring treatment strategies to individual patient needs. AI excels in tracking and analyzing the progression of viral symptoms across diverse populations (Padhi et al., 2023). By examining real-time data collected from WDs, AI algorithms can identify the trajectories of virus infections, such as the progression rates of specific symptoms, the progression from mild to severe stages, or the progression from acute to chronic stages (Agrebi & Larbi, 2020; Zhao et al., 2024). This diagnostic pattern recognition would provide personalized insights into virus disease severity and patient response to treatments, allowing the tailoring of health care interventions to be more precisely suited to the patient current state (Johnson et al., 2021).

Moreover, in the face of rapidly mutating viruses such as influenza, Ebola virus, and coronaviruses, the role of AI tools becomes even more important (Farhat et al., 2023). These viruses frequently undergo mutations that can significantly alter the virus disease course and treatment responses. The ability of AI algorithms to quickly identify patterns in how different virus strains affect patients would help to enhance the efficiency of health care responses (Alsulimani et al., 2024).

Additionally, AI-driven WDs can prioritize patient care by identifying which virus strains are most likely to cause severe disease or complications (Cheong et al., 2022; Kang et al., 2023; Maleki Varnosfaderani & Forouzanfar, 2024). This predictive capability is invaluable, as it aids health care providers to focus resources and medical attention on cases that pose the highest risk to patient health and public safety.

Challenges and Ethical Considerations of Implementing AI-Driven WDs in Virology Diagnostics

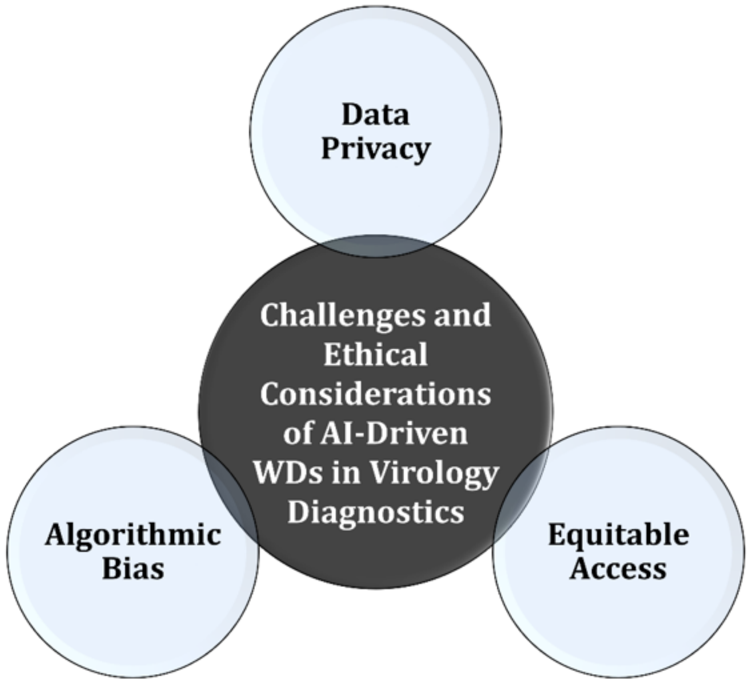
The use of AI-enhanced WDs in virology diagnostics is expected to be associated with significant challenges and limitations (Dobson et al., 2023; Sui et al., 2023; Bala et al., 2024). The AI-driven WDs continuously collect extensive personal health information. While beneficial to monitor health patterns and predict medical conditions, this process raises privacy concerns (Ali et al., 2024). Thus, it is important to ensure the security of the collected data through these AI-driven WDs. This step is important to prevent breaches that would compromise individual privacy rights (Soni & Rasad, 2025).

Additionally, it is important to highlight another issue regarding the quality of data collected via AI-driven WDs. This important issue is the susceptibility of AI-driven WDs data to noises and artefacts (Böttcher et al., 2022). The erroneous or missing data points can arise from various issues. Examples include sensor malfunction, improper device placement on the body, WD adherence issues, or external environmental factors that can interfere with the WDs' sensors (Williamson et al., 2015; Heikenfeld et al., 2018; Cho et al., 2021; Chan et al., 2022). Thus, continuous improvement of AI-driven WDs and careful handling of data are necessary to address these issues. These improvements are important to enable WDs to provide reliable health monitoring in real-world scenarios.

Another major concern of AI-driven WDs the vulnerability of sensitive health data to breaches. These breaches can come from unauthorized access or cyberattacks (Ali et al., 2024; Guma & Mijwil, 2024). These devices, which continuously collect and transmit personal health information, are potential targets for cyberattacks. Such attacks could compromise patient privacy and security (Silva-Trujillo et al., 2023; Shojaei et al., 2024; Sifaoui & Eastin, 2024). Thus, there is an urgent need for clear and comprehensive regulations for AI-driven WDs in healthcare. These regulations are important to govern the ownership, usage, and sharing of health data collected by WDs.

Addressing the challenges that comes with application of AI-driven WDs require a collaborative effort. This involves the policymakers, researchers, and technology developers. Together, all these stakeholders must develop and enforce international standards for data privacy that respect and protect individual rights. Furthermore, the inclusivity of AI training processes must be enhanced. This enhancement is needed to prevent biases in data handling and ensure equitable access to these beneficial health technologies. Ensuring that AI-driven WDs advance in a manner that respects individual rights and promotes health equity is crucial to realize their full potential in virology diagnostics. Only then can we maximize their acceptance and efficacy in addressing global health challenges. A brief summary of the challenges expected with AI-driven WDs' adoption in virology diagnostics is outlined in (**Figure 3**).

Figure 3. The major challenges facing implementing AI-driven WDs in virology diagnostics.



Data Privacy

A major concern of AI-driven WDs' utility is the potential breaches in data privacy (Sifaoui & Eastin, 2024). By their nature, WDs collect a continuous stream of personal health information. This data are invaluable for monitoring and predicting health patterns such as the early stage of virus infections. However, these data poses a significant risk if not properly protected (Thapa et al., 2023; Pool et al., 2024).

Ensuring the security of collected data through WDs is critical. This critical aspect arises as breaches or misuse of WDs could lead to severe violations of individual privacy rights (Arora et al., 2014; Paul et al., 2023). The challenge lies in implementing robust security measures. These measures can shield this sensitive data from unauthorized access, cyber-attacks, and other forms of exploitation (Jaime et al., 2023; Silva-Trujillo et al., 2023; SaberiKamarposhti et al., 2024).

Anaya *et al*. revealed that WDs users express significant concerns about privacy and overwhelmingly consider informed consent to be crucial when sharing their information with third parties (Segura Anaya et al., 2018). The urgent need for educating users on the privacy and security implications of using WDs has been shown by Liezel Cilliers that revealed a significant lack of awareness about privacy and security risks among users (Cilliers, 2020).

Thus, there is an urgent need for clear regulations that define the ownership, use, and sharing of WDs data, ensuring that patients' rights are protected while encouraging innovation in health care practice (Bouderhem, 2023). These regulations should clearly define data ownership to make sure that individuals retain control over their personal health information (Sifaoui & Eastin, 2024). This ownership must extend to granting or revoking consent for data sharing, whether for clinical, research, or commercial purposes (Brückner et al., 2023). Simultaneously, the regulations and policies should address data stewardship, outlining responsibilities for the secure storage, ethical use, and appropriate anonymization of WD-derived datasets (Digital Regulation Platform, 2024).

Algorithmic Bias

Algorithmic bias presents a significant challenge in the deployment of AI-driven WDs in virology diagnostics. Since AI algorithms are dependent on the data they are trained on, biases would be expected if the training datasets lack diversity (Sallam, 2023; Varsha, 2023; Ferrara, 2024). This can result in diagnostic inaccuracies that disproportionately affect different demographic groups (Celi et al., 2022; Koçak et al., 2024).

Such AI algorithms' biases could have serious health implications, especially when managing diseases that significantly impact diverse populations (Nazer et al., 2023). For example, if an AI algorithm is predominantly trained on data from younger, healthier populations in high-resource settings, it may fail to accurately diagnose or predict infections in older adults or individuals in low-resource regions (Norori et al., 2021; Celi et al., 2022; Chu et al., 2023).

To counteract possible AI algorithmic bias, it is essential to ensure that training datasets are representative of the global population with employment of subpopulation calibration to fine-tune these AI algorithms (Barda et al., 2021; Huang et al., 2024). Specifically, AI training datasets must be representative of the global population, encompassing diverse demographics, including age, ethnicity, geographic location, and socioeconomic status (Arora et al., 2023). This inclusivity is essential to ensure that the AI tools can generalize their predictions across varied contexts (Shams et al., 2023). Additionally, implementing subpopulation-specific calibration is essential to fine-tune algorithms for particular groups, enhancing diagnostic accuracy and fairness (Afrose et al., 2022). In addition, ongoing evaluation of AI tools' performance is imperative to detect and address biases post-deployment (Gichoya et al., 2023). Regular audits, coupled with transparent reporting mechanisms, can identify patterns of diagnostic inaccuracies and prompt iterative improvements (Karalis, 2024). Collaborative efforts among researchers, technologists, and public health experts are key to ensure that these corrective measures are implemented effectively (Mennella et al., 2024).

This approach would help to maintain the accuracy and fairness of AI diagnostics in virology across all demographic groups. Thus, addressing algorithmic bias in AI-driven WDs requires a collaborative effort to enhance the inclusivity of AI training processes and the ongoing evaluation of AI integration into WDs.

Equitable Access

The challenge of ensuring equitable access to AI-driven WDs is particularly important in low-resource settings, which are often the hardest hit by infectious disease outbreaks (Gashaw et al., 2021; Sarantopoulos et al., 2024). The high costs of these advanced AI-driven WDs' technologies, coupled with the infrastructure required for their operation, can make it difficult for these regions to benefit from such innovations as shown by Stefany Cruz *et al*. demonstrating that the needs of populations in these regions were not considered in the design of current WDs (Cruz et al., 2024).

Importantly, AI-driven WDs require the initial purchase cost besides the ongoing expenses for data management and device maintenance, which can be unaffordable for under-resourced healthcare systems (Osei & Mashamba-Thompson, 2021; Canali et al., 2022; Khanna et al., 2022). To address these cost barriers, more efforts are needed to make AI-driven WDs more accessible. This would include developing cost-effective WDs tailored to the needs and economic realities of these regions, enhancing local healthcare infrastructure to support the integration of such technologies, and providing comprehensive training for healthcare providers to effectively utilize these tools (Canali et al., 2022).

Initiatives like the one proposed by Wang *et al*. via affordable shoe system for monitoring plantar pressure in diabetics are crucial (Wang et al., 2021). Partnerships between non-governmental organizations (NGOs) and technological companies could facilitate the distribution of low-cost WDs in low-income areas. Such collaborations ensure that wearable technology benefits are equitably accessible worldwide, enhancing public health while upholding individual rights.

CONCLUSIONS

The integration of WDs with AI has promising prospects in virology diagnostics. AI-driven WDs have the ability to analyze diverse and large datasets in real-time providing valuable insights in virology. These AI-driven WDs offer exceptional capabilities for early detection of virus infections. AI-driven WDs can also help to predict virus outbreaks and personalize health interventions with subsequent improvement in the precision and timing of public health responses. Additionally, AI-driven WDs would enable continuous health monitoring, with detection of subtle bodily changes that may indicate early stages of virus infections that occur before symptoms appear. This capability will improve the effectiveness of virus outbreak containment measures and facilitate targeted public health interventions. Moreover, the insights provided by AI-driven WDs' data can help to refine quarantine measures. This capability would significantly reduce the socio-economic impacts associated with traditional infectious disease quarantine strategies.

However, the widespread implementation of AI-driven WDs faces challenges. These challenges include data privacy concerns, the issue of equitable access, and the potential for algorithmic bias. Robust privacy protections, algorithmic fairness, and widespread accessibility are essential to reach the full potential of AI-driven WDs in virology diagnostics.

Abbreviations

AI: Artificial Intelligence
COVID-19: Coronavirus disease 2019
EWS: Early Warning System
ML: Machine Learning
NGOs: Non-governmental organizations
SARS-CoV-2: Severe acute respiratory syndrome coronavirus 2
WD: Wearable Device

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Conflicts of Interest

The authors declare no conflict of interest.

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