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Impact and Challenges of Artificial Intelligence Integration in the African Health Sector: A Review

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ABSTRACT

Artificial intelligence has proven to be a game-changing force in health sectors throughout Africa offering prospects for significant development. In sub-Saharan Africa, using AI in healthcare, especially in areas with limited resources, holds valuable promise in transforming and improving healthcare. This article takes an excellent look at how AI is being integrated into the African health sector, as well as examining policy frameworks, challenges and future possibilities. This article begins by giving an overview of AI and highlighting the groundbreaking impact of AI technologies in combating and addressing healthcare challenges that occur within African countries. Ranges from mobile-based diagnostics to precision medicine, artificial intelligence has proven its potential and capabilities in diagnosing, treating and improving healthcare operations by providing solutions to resource constraints and accessibility challenges. However, despite these advancements, there are still obstacles such as infrastructure limitations, concerns about data privacy and gaps in healthcare professionals' training that hinder the realization of AI's potential in African healthcare. This article envisions a future where the adoption of artificial intelligence is fully incorporated with community health initiatives and enhanced access to healthcare services for the betterment of healthcare across sub-Saharan African countries. While challenges and barriers like infrastructure and unequal access to healthcare persist, there is a need for governments and stakeholders to prioritize intelligence and digital health as catalysts for improving the healthcare sector in sub-Saharan Africa.

KEYWORDS

Artificial intelligence, sub-Saharan Africa, healthcare transformation, public health surveillance, disease detection, telemedicine

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INTRODUCTION

The healthcare sector in Africa stands as one of the most dynamic industries globally. Recent years have witnessed a renewed global health community focus on strengthening health systems, recognizing that systemic weaknesses significantly hinder the accomplishment of Millennium Development Goals (MDGs). Many nations especially those in sub-Saharan Africa still require substantial development in their healthcare industry, relying heavily on imports and seeking private investment support[1]. Enhancing the health workforce, securing funding for robust health system improvements and expanding health system knowledge would profoundly benefit the approximately 800 million people residing in the World Health Organization (WHO) Africa region. National governments, along with civil society organizations (CSOs), development partners and communities grapple with the challenge of providing healthcare across Africa. Intensified efforts in preventive and curative services, along with health promotion, have been evident since the inception of the MDGs[2]. According to Stothard *et al.*[3], malaria emerges as a prevalent health issue in sub-Saharan Africa, witnessing 225 million cases annually and resulting in approximately 781,000 deaths. To improve health service delivery in Africa, countries must increase access for the poor in peri-urban and urban areas.

The AI in healthcare encompasses the use of machine learning algorithms and cognitive technology within medical settings, representing the convergence of human and machine learning[4]. The use of AI in medicine dates back to the 1970s, with the development of medical expert systems that use Bayesian statistics and decision theory to diagnose and recommend treatments for conditions like glaucoma and infectious diseases[5]. As AI gains traction in various industries, including healthcare, it holds the potential to revolutionize patient care. Employing computer technology to simulate intelligent behaviour akin to human critical thinking, AI in healthcare is primarily utilized for diagnosing, prognosis and treating diseases[1].

This transformative technology analyzes extensive clinical documentation rapidly, aiding medical professionals in identifying disease markers and trends that might be overlooked through traditional methods. The groundbreaking emergence of AI in healthcare enhances the efficiency of healthcare systems, making them smarter and faster in providing care to millions of outcomes AI's use in hospitals and clinics is shaping the future, reducing costs for providers and improving health outcomes[6].

The integration of AI in healthcare significantly aids medical practitioners in various aspects of patient care, extending to administrative procedures. As of 2020, the adoption of AI in the USA and Canada has resulted in a 25% reduction in healthcare expenses in the former and a 12% decrease in the latter[7]. The potential of AI to revolutionize healthcare in sub-Saharan Africa is substantial, particularly in automating medical procedures and enabling health professionals to achieve more with limited resources. The AI's application extends to the evaluation of vast healthcare data, as demonstrated by a logistic regression-based prediction model automating early diagnoses of cardiac diseases with promising results[6]. Furthermore, AI technology has the potential to enhance patient care, leading to more precise diagnoses, including in surgical procedures. Noteworthy initiatives in Nigeria, such as the startup Ubenwa, utilize advanced technologies such as machine learning to improve the diagnosis of birth asphyxia in low-resource settings[7]. In Zambia, AI is employed for diagnosing diabetic retinopathy, the results obtained are significant and promising when compared to human assessment[8].

The AI is becoming increasingly prevalent in the healthcare industry, with applications ranging from detecting pulse rates to diagnosing cancer and providing therapy consultations. Today, there are continued developments, research and inventions in the application of AI across different branches of healthcare. Therefore, this study aims to investigate the impact and challenges of integrating artificial intelligence in the healthcare sector in sub-Saharan Africa.

OVERVIEW OF AI IN HEALTHCARE

Artificial Intelligence (AI) is a system that can precisely understand external data, assimilate knowledge from the data and employ the acquired learnings to achieve goals and tasks through adaptation[9]. The AI comes in different forms and one way to categorize it is by considering its level of cognitive capability. The three main types of AI classification include weak or limited artificial intelligence, often referred to as "functional" AI, which is engineered to efficiently execute specific tasks without the capability to reason generically or learn from novel situations[10]. This type of AI is tailored to solving particular problems and lacks the adaptability to generalize its behaviour across various contexts. It finds application in systems requiring repetitive tasks, such as filtering email spam, deriving generalizations from vast datasets, offering recommendations on streaming platforms and making decisions in e-commerce settings. A great example is Alexa, Amazon's AI-powered voice assistant, which is considered an instance of weak AI. Although, it exhibits apparent intelligence and responsiveness, its capabilities are limited to specific tasks like managing smart home devices, responding to voice commands, playing music, offering weather updates and setting reminders. However, Alexa is confined to a predetermined set of functions and cannot adapt to novel or unfamiliar situations, setting it apart from more advanced forms of AI[9].

General AI stands apart from weak AI by demonstrating a broad spectrum of cognitive abilities, including reasoning, learning and problem-solving, with the capability to adapt to new situations. It focuses on creating computing systems that can perform a wide range of tasks, closely emulating human intelligence. Examples of general AI include autonomous weapons capable of autonomous learning and adaptation, as well as advanced personal assistance systems like the GPT-3 chatbot, which offers highly rational and adaptively intelligent responses. Strong AI, synonymous with general AI, envisions intellect comparable to human capabilities, encompassing understanding, reasoning and adaptive actions under any circumstances. While some consider strong AI to be theoretical, debates arise on its existence, especially when self-awareness is considered a facet of human intelligence[9,11].

The last type of AI under this class is ASI (artificial super intelligence) also known as high-performance or strong AI, which possesses the capability to excel in virtually any task requiring human intelligence, surpassing humans in cognitive and learning abilities[11]. In medical research, high-performance AI plays a pivotal role in analyzing extensive medical datasets. An illustrative example is DeepMind, a company owned by Google, which developed AlphaFold. The AlphaFold aids in predicting protein structure and diagnosing and treating genetic diseases, such as Alzheimer's, Parkinson's, Huntington's and cystic fibrosis, that result from proteins folding incorrectly[9]. Incorrect protein folding can lead to various health issues. AlphaFold's detailed scrutiny of protein folding not only aids in precise disease diagnosis but also plays a crucial role in developing targeted treatments. Essentially, artificial super intelligence (ASI) is reshaping the field of medical research and healthcare by providing unprecedented insights and cutting-edge solutions.

The healthcare sector is experiencing a revolutionary change with the rapid advancements in analytics techniques and the abundant availability of healthcare data, there has been a surge in the healthcare industry, all fueled by the progress of artificial intelligence[12]. The AI has been engaged in the field of medicine since the 1950s when physicians initiated the earliest endeavours to enhance their diagnostic capabilities through computer-aided programs. In recent times, AI's impact on healthcare has sparked debates about replacing human doctors[10]. The AI also plays an important role in aiding physicians to enhance clinical decision-making. There is potential for AI even to take over certain specific functions in healthcare, such as radiology, dermatology and pathology, where it can contribute to improved accuracy and efficiency[13]. Other applications include the monitoring, evaluation and analysis of health status, health promotion and research in public health.

Secinaro *et al.*[14] discussed the application of virtual reality technology in rehabilitative medicine. The authors noted the main objective of rehabilitation is to improve and reinstate functional ability and enhance the quality of life for individuals dealing with physical impairments or disabilities. The AI and deep learning have the potential to assist medical and administrative personnel in extracting data, predicting outcomes and acquiring knowledge of medical representations. The AI techniques can reveal clinically pertinent information within extensive datasets, thereby aiding in clinical decision-making[11]. The AI has the potential to revolutionize patient monitoring and healthcare delivery, particularly in the field of wearable patient monitoring systems (WPMs). The AI platforms, now integral in public health initiatives, rely heavily on robust data systems for effective health emergency preparedness[12].

Despite this, Africa encounters challenges in accessing, analyzing and utilizing data for informed health determination. Access to population data is restricted in many countries and even those with access find it challenging to use it for program enhancements. With the rise in mobile phone ownership and usage in Africa, the region is now in a strong position to leverage AI technologies to enhance the adoption, access and utilization of health data[13-15].

Globally, there has been a consistent demand for technology solutions due to the COVID-19 pandemic. These solutions are used for tracking infections, minimizing direct human contact and screening populations. Notably, technology has played a critical role in safeguarding medical personnel by disinfecting controlled environments, reducing direct contact with patients and easy passage of public health and emergency messages. In Africa, digital technology has the potential to improve crisis management in the health sector, strengthen healthcare systems and enhance overall efficiency through effective digital mechanisms[14].

IMPACT OF AI INTEGRATION IN THE SUB-SAHARAN AFRICAN HEALTH SECTOR

Transformative power of AI in diagnostics and disease prediction: Introducing artificial intelligence in the African health sector portrays a major and important development, particularly in the aspect of diagnostics and disease prediction. This development is enhanced by an excellent understanding of machine learning algorithms and sophisticated AI models, that propel the best prospects for combating the complex issues of healthcare that are disturbing several continents[16]. In sub-Saharan Africa, where specialized healthcare resources are often hard to find and access, AI is a perfect solution for enhancing diagnostics. Because of its ability to process vast datasets, including medical structures and patient records, it optimally enhances the accuracy and efficacy of the detection of disease. This is particularly necessary in regions where early detection can be very crucial for successful treatment outcomes[4,5]. The adaptive nature of AI is advantageous for curbing the variations and unique disease patterns prevalent in several African regions. Diseases often manifest differently across continents and AI's capacity for progressive learning ensures that diagnostic abilities evolve, maintaining pace with the developing nature of diseases[16,17].

Ada Health's mobile application, a one-symptom checker for all medical problems powered by AI, is making substantial strides in diagnostics improvement in settings with limited resources. In areas with limited access to specialized medical experts, Ada Health utilizes machine-learning algorithms for symptom analyses and the provision of preliminary diagnoses. This helps individuals find timely medical care and attention and aids healthcare workers in making relevant informed decisions, thereby enhancing their overall diagnostic abilities[18].

Also, the Malaria Scope project, specifically for malaria prediction and mapping is a very good example of how AI can contribute to the prediction of disease, especially in the context of malaria outbreaks in Africa. The project revolves around making use of AI for the analysis of various datasets, ranging from

climate data and travel patterns, to historical malaria cases, to predict and map potential malaria outbreaks. This enables proactive measures and optimizes the allocation of resources for prevention and treatment strategies, solving the diverse challenges posed by malaria in different sub-Saharan African countries[19]. A published study in the Malaria Journal in 2010 also used the "Genetic Algorithm for Rule-set Prediction" (GARP) model to map malaria vector species in Africa based on actual findings[20]. These examples portray how AI and data analysis are being carried out to predict and map malaria outbreaks, optimally contributing to more effective prevention and treatment strategies in attacking malaria in Africa.

In South Africa, AI algorithms are being employed to analyze chest X-rays for early detection of tuberculosis. These algorithms, using a deep learning (DL) approach and already trained on various datasets, can recognize subtle patterns indicative of tuberculosis and aid healthcare workers in initiating treatment and early or timely diagnosis[21]. The use of AI for detecting tuberculosis in chest X-rays is a great development, especially in countries where tuberculosis remains a major health issue. The AI approaches in healthcare diagnostics are transforming the field through the provision of faster and more accurate analysis of medical data. Its ability to differentiate between cunning variations in medical data, especially in exploring intricate medical images and recognizing patterns that might go unchecked in traditional diagnostic approaches, enhances diagnostic accuracy and hastens the identification of potential health risks, aiding more timely and effective healthcare interventions[22].

Transformative influence of AI integration on treatment and personalized medicine: The intersection of AI and healthcare establishes a revolutionary era, redefining treatment modalities and ushering in a new age of personalized medicine. In the diverse landscape of the sub-Saharan African health sector, the evolution of AI promises profound impacts on the diagnosis and treatment of several diseases, with a major emphasis on infectious diseases[4]. The AI plays a major part in progressing precision medicine, offering a radical change in the understanding and curing of infectious diseases[23]. One of the potent tools empowered by AI is Nuclear Magnetic Resonance (NMR), which provides early detection capabilities that transcend conventional diagnostic timelines. The amalgamation of AI and radiological diagnosis, particularly in the context of pulmonary tuberculosis, amplifies diagnostic accuracy and expedites the identification of affected individuals. This precision-driven approach not only facilitates more nuanced and targeted treatment strategies but also holds the promise of curbing the spread of infectious diseases[4]. As 54 genes, a pharmaceutical company in Nigeria and LifeQ in South Africa use artificial intelligence to analyze genomic and biometric data to deliver personalized insights and recommendations for health and wellness[23,24]. The intersection of AI and precision medicine can transform healthcare by enhancing the personalization of treatment for each person. This requires access to massive amounts of data, such as data collected through projects like the UK Biobank and the "All of Us" project, to create personalized treatment plans focusing on individual exceptional characteristics[25].

The utilization of AI in early diagnosis and detection is very beneficial in the African health sector. By connecting the analytical prowess of AI algorithms, healthcare systems can scrutinize massive datasets to discern subtle patterns indicative of various infections. This proactive approach empowers healthcare providers to intervene swiftly, mitigating the contagious spread of diseases and significantly improving the prognosis for affected individuals. In the realm of viral upper respiratory infections, where rapid identification is pivotal, AI emerges as an indispensable ally in bolstering early diagnosis efforts[4,26]. The AI algorithms can accurately analyze medical images, such as MRIs, CT scans and X-rays, detecting subtle anomalies that may be missed by human observers. This capability has been instrumental in the early detection of conditions like cancer[26]. Additionally, AI can be used to monitor the vital signs of patients in real-time, detecting high-risk cases and allowing for early intervention, leading to improved outcomes, decreased healthcare costs and saved lives.

The AI's ability to analyze and interpret complex data sets, including patient health records, genetic information and treatment outcomes, positions it as a crucial factor in optimizing drug choices and treatment regimens. By analyzing diverse patient data, AI can discern optimal treatment options based on individual characteristics, thereby minimizing adverse drug effects while maximizing therapeutic efficacy[27]. This tailoring of interventions raises a more patient-centric and efficient healthcare paradigm[25]. The AI's integration into healthcare can lead to more effective treatment of common conditions or rare diseases and allow for optimization of the timing and dosage of medication for individual patients. This personalized approach could lead to earlier diagnosis, prevention and better treatment, saving lives and making better use of resources[27]. As these advancements gain momentum, the narrative of healthcare in Africa is poised to undergo a paradigm shift, marked by enhanced diagnostic precision, personalized treatment strategies and ultimately, improved health outcomes for diverse populations.

Streamlining healthcare operations in the sub-Saharan African health sector: Artificial intelligence (AI) has a high probability of improving the way healthcare works in sub-Saharan Africa, curing health-related problems and enhancing the overall effectiveness and efficacy of healthcare delivery. In Rwanda, Zipline, which is a US-based health logistics company, utilizes drones to overcome the hindrance of mountainous terrains, ensuring efficient delivery of medical supplies to rural health clinics[28]. This approach not only tackles accessibility issues but also establishes a precedent for using technology to surmount logistical obstacles in healthcare delivery. The AI technologies have also shown promise in various aspects of healthcare, presenting innovative solutions that can be particularly beneficial for resource-constrained settings such as those found in many parts of Africa. Across Africa, AI is aiding healthcare in important aspects such as overseeing medical data files in Morocco, the study of genomes in South Africa, COVID-19 tracking in Ethiopia and analyzing medical images in Ghana[29].

Because of the decrease in the availability of medical professionals across much of Africa, AI can probably fill voids left by doctors and other highly skilled health professionals. By 2030, it is estimated that AI will bring economic growth worth $1.2 trillion (about $3,700 per person in the US) to Africa. However, keeping AI projects within Africa is difficult as many doctors move to developed countries. Locally driven and owned AI solutions that prioritize safety, equity, transparency, reliability and societal benefit are essential. Governments in sub-Saharan African nations must develop legislation and policies that will govern AI's adoption in the healthcare sector[30]. The AI can significantly aid in optimizing the allocation of hard-to-find healthcare resources. In South Africa, AI-driven predictive analytics has been found as a way of determining pandemic symptoms and excellent distribution of medical resources in cases of public health emergencies. This technology, therefore, enables the analysis of data for the prediction of disease outbreaks, portraying high-risk areas and streamlining medical supplies, likewise, enhances resource management and sustainable farming practices such as monitoring crops, analyzing soil and optimizing supply chains[31].

These artificial intelligence tools can probably have considerable effects on public health surveillance and monitoring by providing real-time population health monitoring, thus facilitating rapid responses to epidemics as well as proactive public health measures. For example, the Kenyan government examined the use of AI for live disease surveillance that allows for timely intervention and containment efforts[32]. The AI could be useful in analyzing epidemiological data to identify patterns and trends hence providing a more precise and faster detection of disease outbreaks and informing targeted therapies. Additionally, AI may be applied in public health surveillance not just in specific regions but also elsewhere to enhance surveillance and response capacity[32]. The use of AI for public health surveillance can potentially improve disease detection, responses and general healthcare management. Therefore, using AI in public health surveillance holds promise for enhancing disease detection, response and overall public health management.

Table 1: Impacts of AI integration in the sub-Saharan African health sector

AI integration	Specific countries	References
Diagnosis and disease prediction		
Mobile-based diagnostics (ADA mobile health application)	Swahili-speaking countries (Kenya, Tanzania and Uganda)	Ellahham[18]
Malaria prediction and mapping	sub-Saharan African countries (South Africa, Gambia and Kenya)	Santosh and Gaur[29]
Tuberculosis detection in chest X-rays	South Africa	Rajakumar *et al.*[21]
Treatment and personalized medicine		
Precision medicine (NMR, 54 gene, LifeQ)	Nigeria and South Africa	Otaigbe[4], Schork[23] and Fatumo *et al.*[24]
Early detection and diagnosis (upper respiratory tract infections)	Tanzania	Otaigbe[4]
Optimizing drug choice and treatment regimens	South Africa	Johnson *et al.*[25]
Streamlining healthcare operations		
Zipline logistics company	Rwanda	Amukele[28]
Resource allocation optimization	South Africa	Chilunjika *et al.*[31]
Public health surveillance and monitoring	Kenya	Taylor-Robinson[32]
Strengthening public health systems		
Telemedicine and remote patient monitoring (M-Tiba mobile health platform)	Kenya	Betjeman *et al.*[35]
Healthcare workforce support (babylon chat-bot)	Rwanda	Santosh and Gaur[29]
Drug discovery and personalized medicine	South Africa and Nigeria	Mak *et al.*[38]
AI and infectious disease surveillance (EpiAFRIC)	Nigeria	Otaigbe[4]

Barriers to AI integration in the sub-Saharan African health sector

Strengthening public health systems in the sub-Saharan African health sector: The integration of AI in the sub-Saharan African healthcare sector has the potential to revolutionize healthcare delivery, enhance efficiency and improve patient outcomes. Table 1, details the impacts of AI integration in this region. The African healthcare landscape is faced with numerous challenges, including limited resources, insufficient infrastructure and a high burden of infectious and non-communicable diseases. The AI presents an opportunity to curb these issues[7,33]. The AI plays a significant role in expanding access to healthcare through Remote Patient Monitoring (RPM) and Telemedicine. The RPM contributes to the improvement of health outcomes, especially for patients with neurological and cardiovascular diseases[34]. Also, healthcare professionals can organize virtual consultations and remotely monitor patients' vital signs by utilizing AI-driven telehealth platforms, leading to improved access to healthcare services and more effective management of chronic conditions. The M-Tiba mobile health platform in Kenya uses AI to facilitate telemedicine consultations and remote monitoring, enabling patients to consult with healthcare professionals through their mobile phones[35]. The AI algorithms help in tracking and managing chronic conditions, ensuring timely intervention and decreasing the need for consistent physical hospital visits, majorly in remote and underdeveloped areas where there is limited access to medical facilities[36].

The shortage of healthcare professionals in many African countries is a significant challenge. The AI can act as a force multiplier by supporting the existing healthcare workforce. The AI applications, for example, chatbots and virtual health assistants, can provide information and offer basic medical advice, thereby easing the burden and improving the efficiency of healthcare delivery[37]. Babylon Health's AI-driven chatbot has been integrated into the healthcare system in Rwanda, providing instant medical information, advice and assistance to patients. The chatbot helps to relieve some of the pressure on healthcare professionals and improve access to basic healthcare information for the population. The adoption and development of AI chatbots in Africa have been influenced by several significant global health trends and AI chatbots have been used in some parts of Africa to effectively fight the Ebola virus[29].

Also, the African Drug Discovery Foundation (ADDF) uses AI algorithms to accelerate drug discovery for diseases prevalent in sub-Saharan Africa, such as malaria and tuberculosis. By analyzing genetic data and simulating molecular interactions, AI expedites the identification of potential drug candidates, leading to more efficient drug development processes. The use of AI in drug discovery processes is transforming the traditional resource-intensive and time-cost methods[38]. The AI's integration in drug discovery is projected to enter a new age, with the global market estimated to be worth $4.9 billion (about $15 per person in the US) by Paul *et al.*[39]. Several significant global health trends have influenced the adoption and development of personalized medicine in Africa and it has been used in some parts of Africa to optimize the choice of drug and dosage while avoiding adverse effects for the specific patient. The concept of personalized medicine in sub-Saharan Africa is still developing and it is vital to apply it to overcome various challenges[40]. The use of AI in personalized medicine can help in the analysis of patient data to develop personalized care plans, leading to more effective treatment outcomes[38,40].

Recently, in Nigeria, the EpiAFRIC organization has utilized AI in disease surveillance by analyzing diverse datasets, including social media, climate information and travel patterns. The EpiAFRIC's AI algorithms contribute to the early detection of infectious disease outbreaks, allowing for rapid response and containment strategies[4,41]. The employment of AI in disease surveillance has proven valuable in various infectious diseases surveillance and control, such as tuberculosis, malaria, Ebola viral hemorrhagic fever and HIV/AIDS. The integration of AI in disease surveillance promises to revolutionize healthcare delivery, enhance efficiency and improve patient outcomes strategies[41]. These examples demonstrate how AI technologies are actively aiding the improvement of healthcare in Africa, curbing specific challenges and providing innovative solutions that bring progress to the overall effectiveness and efficiency of public health systems on the continent. The employment of AI holds immense ability to transform healthcare delivery, optimally contributing to better health outcomes and the well-being of African populations.

Infrastructure and technology challenges: Infrastructure and technology challenges pose significant barriers to the implementation of AI in sub-Saharan Africa. The challenges in assessing bias in AI algorithms are made more difficult because many of these algorithms are considered 'black boxes'. This means that it's harder to determine if they are biased or not. However, some researchers are trying to assess biases by testing how well the algorithms predict outcomes when they randomly change key variables for individuals[42]. The lack of adequate ICT infrastructure, including low internet penetration rates and limited access to high-performance computers, makes it difficult for healthcare systems to adopt and implement AI systems[43].

The cost of purchasing, maintaining and upgrading high-performance computers is often prohibitively expensive for healthcare systems that rely on funding[42]. Many sub-Saharan African countries lack policies to direct e-health development and dissemination in public hospitals, affecting digital health adoption[42]. The progression of technology frequently outpaces regulatory frameworks, which can hinder the adoption of digital health initiatives. A recent investigation into e-health policies across four African nations revealed that the strategic objectives were ambiguous and lacked cohesive strategies. The lack of clear policies for e-health development in African countries has been identified as a significant barrier to the adoption of digital health solutions[5].

In sub-Saharan Africa, particularly in rural areas, low internet penetration rates and limited access to high-performance computers pose significant challenges to the deployment of AI applications in healthcare settings[5]. For instance, in rural Uganda, sparse internet connectivity hinders the implementation of AI-powered telemedicine platforms, limiting the reach of remote healthcare services to underserved communities. According to Statista, the number of internet users in Uganda is forecast to amount to 7.48 million in 2024, with an estimated internet penetration of 14.99%[44-46]. The data underscores the

notable gap in digital access and the hurdles linked to internet availability in the area. These obstacles profoundly affect the capacity to utilize AI innovations in healthcare, given the dependence on strong internet connections and advanced computing capabilities[44,45].

The financial constraints associated with the acquisition, installation and maintenance of high-performance computers present formidable challenges for healthcare systems across sub-Sahara Africa, particularly those heavily reliant on donor funding[37]. A poignant example of these financial barriers is evident in Nigeria, where the scarcity of financial resources has significantly impeded the integration of AI-driven diagnostic tools within public health facilities[16]. Addressing infrastructure and technology challenges in Africa will require significant investment in ICT infrastructure, digital skills training for healthcare professionals and the development of policies and frameworks to support the integration of AI-based solutions into health systems[43].

Data privacy and security concerns: An individual's personal identity number, mobile number, voice, image and other forms of identity are frequently included in the healthcare database. Many data points including sensitive personal information are needed to develop an AI-powered medical gadget, however, getting hold of such sensitive data could result in privacy-related legal problems[47]. Additionally, the lack of transparency regarding how companies handle patient data raises concerns about the potential misuse of patient information. These security concerns highlight the need for proactive measures to safeguard patient data and ensure transparency in data handling practices within the healthcare industry[48]. The absence of clear policies and legislation to safeguard privacy while enabling critical analysis of health data is identified as a constraint in the Kenyan health sector[49]. However, Kenya has taken measures to address data privacy issues by issuing new guidelines and establishing an Office of the Data Protection Commissioner to enforce compliance with data privacy laws. Challenges related to the handling of patient information and the need for robust data protection measures are part of a broader context of utilizing digital health to overcome Africa's health issues[49].

Also, the 2019 data breach in South Africa's health database exposed millions of sensitive information, including personal identity numbers and medical records[50]. The incident portrayed immediate threats to data privacy and underrated the benefits and importance of the need for strict security measures in handling healthcare data. The breach occurred on Jigsaw Holdings, the server of a property company, which was traced through an IP address. The incident is a reminder that strong security measures are crucial for protecting sensitive healthcare data and maintaining individual privacy. The study emphasizes the need to address ethical considerations, particularly privacy when using and deploying AI applications in healthcare. This can help healthcare companies understand the AI market and obtain different indications of how stable, profitable and valuable it is to provide better services to their customers[51].

Healthcare workforce and training acceptance: The integration of AI in the African health sector encounters significant barriers as outlined in Table 2. One of the foremost challenges is the lack of specialized expertise and digital skills among healthcare workers. It is challenging to implement mobile health smart applications in developing nations with limited resources since many healthcare practitioners lack knowledge and skills related to digital health. The integration of AI-based models into health systems is similarly hampered by inadequate frameworks and policies that facilitate the integration of data-driven AI-based solutions[38]. A study conducted in rural Uganda revealed that low levels of computer knowledge among health workers hinder the successful adoption of electronic clinical decision support systems (CDSSs)[52]. The findings in this study stated that health workers have limited computer knowledge, with proficiency only in Microsoft Word. The study also revealed that health workers faced challenges in using ICT when they were assigned the task of obtaining Tax Identification Numbers alongside other staff. The lack of computer knowledge among health workers in rural areas has proven to be a significant barrier

Table 2: Barriers to AI integration in the African health sector

Barriers	Specific countries	References
Infrastructure and technology challenges		
Low internet penetration and limited access to High-performance computers	Uganda and Kenya	Owoyemi *et al.*[5]
Prohibitive cost of high-performance computers	Nigeria	Takuwa *et al.*[46]
Lack of clear policies for e-health development	Kenya	Owoyemi *et al.*[5]
Data privacy and security concerns		
Concerns about patient information handling	Kenya	Mbuthia *et al.*[49]
Health database reach	South Africa	Neto *et al.*[50]
Healthcare workforce and training acceptance		
Lack of confidence, knowledge and skills in using ICTs	Ghana and Uganda	Yagos *et al.*[52], Johnson[53] and Peprah *et al.*[54]

to the successful adoption of AI-driven healthcare solutions[53]. It is important to have a specially designed operating system that is user-friendly and adapted for local rural health workers to effectively utilize AI-driven healthcare solutions. Additionally, there is a need for specific investment in ICT infrastructure development for rural health centres to support this[52].

Also, the study conducted in Ghana demonstrated that despite limited computer knowledge, rural care providers exhibited positive attitudes toward technology[54]. This finding focuses on the readiness of healthcare professionals to embrace technological solutions, portraying a potential for successful integration with proper training and support. A study conducted in the rural areas of Northern Uganda, which experienced post-war conflict, also revealed that health workers lacked confidence, knowledge and skills in using ICTs. However, health workers had positive opinions about the benefits that ICTs could bring to health service delivery[52]. These findings suggest that with the right training and support, healthcare professionals in rural areas are willing to embrace and use technology for healthcare purposes. The lack of skilled AI experts in sub-Saharan Africa is a big worry. As a result, many healthcare systems are finding it difficult to handle the growing demand for services while also dealing with severe shortages of necessary medications and qualified healthcare personnel[37].

EMERGING TRENDS IN AI HEALTHCARE TECHNOLOGIES IN THE SUB-SAHARAN AFRICAN HEALTH SECTOR

This section briefly looks at the emerging trends in AI healthcare technologies in the African health sector (Table 3). The current state of integrating AI technologies in the healthcare sector of Africa is still in its early developmental phase[38]. Although, Africa is globally positioned at a low rank in AI and its associated activities[55], the significance of its influence on African healthcare systems cannot be undermined. According to research conducted by Owoyemi *et al.*[5], the application of AI in African healthcare settings has primarily been limited to a small set of pilot projects and test cases. Nevertheless, there is growing interest and increased investment in deploying AI technologies to enhance diverse facets of healthcare delivery within the African context[38]. Emerging trends in African healthcare AI technologies encompass a range of advancements including the rapid HIV testing in South Africa in which deep learning algorithms have been used for rapid HIV testing in rural South Africa[56].

This technology enables faster and more accurate diagnosis, leading to timely treatment and care. Also, autonomous drones for medical supply delivery in Rwanda (Zipline drones) have been deployed to facilitate rapid delivery of medical supplies to remote areas. This technology reduces delivery time and enhances access to essential medical provisions[57]. In Nigeria, a startup named Ubenwa employs machine learning and signal-processing techniques to enhance the detection of birth asphyxia in low-resource environments[5]. This technology aids in the early identification and intervention of better neonatal care. In Kenya, rural health clinics across the community also use a smartphone-based diagnostic tool integrated with AI has been used to perform cervical screening[58]. This technology enables early detection of cervical cancer in women, leading to immediate treatment and improved outcomes.

Table 3: Emerging trends in AI healthcare technologies in the African health sector

Emerging trends	Countries	References
Deep learning algorithms for rapid HIV testing	South Africa	Turbé *et al.*[56]
Autonomous drones for medical supply delivery (Zipline drone)	Rwanda	Ackerman and Strickland[57]
Improved detection of birth asphyxia	Nigeria	Owoyemi *et al.*[5]
Smartphone-based cervical screening	Kenya	Manyazewal *et al.*[58]
Sophia AI for clinical genomics	Morocco, Cameroon and South Africa	Aljurf *et al.*[59]
Counterfeit drug detection in Nigeria	Nigeria	Owoyemi *et al.*[5]

In Morocco, Cameroon and South Africa, Sophia, an AI system, has also been incorporated into medical institutions. It analyzes patient genomic data for clinical genomics and maps disease-causing mutations in their genomic profiles, thereby enabling precise care[59]. A group of high school girls from Nigeria created an application using MIT open-source software to identify counterfeit drugs. This technology has proven to be a valuable asset for the pharmaceutical industry in Nigeria, as it ensures the safety and efficacy of medications[5]. These examples demonstrate the potential of AI technologies to improve healthcare access, diagnosis, treatment and delivery in Africa, while the current level of integration is still in its nascent stages, there is growing interest and investment in deploying these technologies to improve healthcare systems in the region.

RECOMMENDATIONS FOR OVERCOMING CHALLENGES

The implementation of AI in sub-Saharan Africa is hindered by a variety of obstacles, including limited access to data, the absence of regulatory frameworks, inadequate infrastructure and networking connectivity, as well as a scarcity of talent and expertise in advanced AI[16]. To overcome these challenges, Owoyemi *et al.*[5] suggested a need to accelerate ongoing improvements in African infrastructure, particularly in electricity and internet accessibility, which could help in the generation and analysis of data required for advanced mechanization of processes that have to do with patient care. López *et al.*[60] stressed the need for AI models to be trained and organized under a robust legal and regulatory framework to meet the public health system requirements of low and middle-income countries (LMICs). Luo *et al.*[61] further highlighted the secondary use of data health to overcome barriers to data availability, which could help the researcher uncover novel insights and advancement in medical science. Finally, Ibeneme *et al.*[15] urged the government and all stakeholders to convene to facilitate the necessary focus on artificial intelligence and digital health in the advancement of the healthcare sector in Africa.

OPPORTUNITIES FOR COLLABORATION AND PARTNERSHIPS

Artificial Intelligence (AI) possesses the potential to significantly enhance healthcare in Africa, presenting various opportunities for collaboration and partnerships in this sector. Several noteworthy instances of partnerships and initiatives include google for startups growth academy, a health program designed for companies situated in Europe, the Middle East and Africa, this program concentrates on the responsible advancement of AI solutions in the health and well-being industry. Selected startups engage in tailored workshops and receive long-term Google mentorship and support[62]. Another one is the ACET and Convergence AI partnership in Accra. The objective of the collaboration between the African Center for Economic Transformation (ACET) and Convergence AI is to propel AI research forward, improve collaboration, share knowledge, create solutions driven by impact and advocate for responsible AI development in Africa. By leveraging the expertise of both organizations, the partnership endeavours to push the boundaries of innovation and address critical challenges confronting Africa[63].

Also, Vantage Health Technologies, a non-profit organization focused on public health and development, is joining forces with Nigeria's Health Systems Strengthening (NHED) to harness the power of AI and long-term in-country contextual expertise in health advocacy. The partnership aims to enhance healthcare system performance and attain Universal Health Coverage by 2030[64].

Another example involves a partnership between Helix Biogen Institute, a prominent translational biomedical research center in Nigeria and Univercells, an international life sciences firm headquartered in Belgium. This collaboration aims to collectively enhance the creation, refinement and manufacturing of mRNA vaccines using artificial intelligence and bioinformatics tools, with a focus on tackling and adapting to healthcare challenges worldwide[65]. The collaboration between LifeBank and Bensh AI partnership seeks to employ AI to enhance patient outcomes in hospitals throughout Africa. By harnessing the power of AI, the partnership aims to optimize patient care and streamline hospital operations[66]. All these partnerships and initiatives serve as evidence of the increasing interest and potential of AI in enhancing healthcare outcomes and systems in Africa. By nurturing collaboration and knowledge sharing, these endeavours can contribute to the development of innovative and impactful AI solutions for the healthcare challenges facing the continent.

CONCLUSION

The integration of AI in the sub-Saharan African health sector holds promise, varying across countries due to infrastructure and policy variations. The AI's transformative impacts in diagnostics, treatment and healthcare operations address challenges like limited resources and accessibility. Examples include mobile-based diagnostics, malaria prediction and precision medicine. However, barriers such as infrastructure challenges, data privacy concerns and healthcare workforce training gaps hinder the progress. The healthcare sector's challenges, including malaria prevalence, are linked to AI's potential benefits in diagnostics. Addressing these gaps is crucial for ensuring ethical deployment and consumption, marking a paradigm shift in healthcare delivery. Healthcare in sub-Saharan Africa holds potential future improvement through technology adoption, community health initiatives and increased access to medical services. Challenges like infrastructure limitations and healthcare inequality need addressing for sustainable progress. Finally, the government and all stakeholders are urged to convene to facilitate the necessary focus on AI and digital health in the advancement of the healthcare sector in sub-Saharan Africa.

SIGNIFICANCE STATEMENT

This study underlines the significance of integrating artificial intelligence across the healthcare systems in sub-Saharan Africa. It elucidates AI's transformative potential to address myriad challenges in healthcare, from disease surveillance to the optimization of treatment, amidst resource constraints. This study highlights the crucial role of AI in improving healthcare access, diagnosis and delivery in sub-Saharan Africa through the examination of barriers, emerging trends and recommendations. The main findings emphasize the urgency of overcoming infrastructure limitations and workforce gaps and underscore the promising partnerships and collaborations driving AI innovation in African healthcare.

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