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The future of smart implants towards personalized and pervasive healthcare in Sub-Saharan Africa: Opportunities, barriers and policy recommendations

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ABSTRACT

Smart implants continue to evolve, posing tremendous opportunities to move towards personalized and pervasive healthcare in Sub-Saharan Africa (SSA). However, the adoption of smart implants is still nascent in SSA despite their tremendous benefits and the increasing demand to provide pervasive and personalized healthcare. Therefore, this study aimed to provide a comprehensive analysis of opportunities and potential challenges associated with the adoption of smart implants in SSA health systems as well as policy recommendations. The study adopted the PRISMA model to search and synthesize published literature about general implants and smart implants in SSA. The study revealed that smart implants present tremendous benefits including remote monitoring of patients, data management, disease diagnosis and treatment, monitoring of drug adherence, and effective family planning methods to reduce unplanned pregnancies. However, the adoption of smart implants faces implementation challenges such as poor technological infrastructure, cultural and religious barriers, health consequences and clinical challenges, legal and policy barriers, lack of manufacturing manpower, potential resistance by regulatory authorities and users, lack of political will and funding, data privacy and security concerns. Nonetheless, there is a need for SSA countries to develop strategies that will strengthen current implant services to stimulate the manufacturing of smart implants. This can be achieved through funding, public-private partnerships, training of healthcare professionals, sensitizing communities, increasing community engagement and most importantly the development of strategies and policies that will regulate the use of smart implants in healthcare settings. There is a need to investigate the privacy and security implications of smart implants in the provision of pervasive healthcare services.

1. Introduction

Emerging technologies present unprecedented opportunities to transform healthcare service delivery globally to deal with health uncertainties posed by infectious and non-communicable diseases. Such technologies like artificial intelligence, blockchain technology [1], nanotechnology, sensors, Internet of Things, Internet of Medical Things, machine learning, cloud computing, 5G/6G technology [2], cognitive computing [3], cognitive robots, drones [4] and virtual reality continue to evolve and revolutionize healthcare service delivery to improve the continuum of care. These technologies have been utilised in various healthcare systems, especially in developed nations, to improve disease diagnosis [5], surveillance and prevention, health monitoring, emotional state of patients [6], real-time collection of health data, maintenance of social distancing [7], treatment reminders, compliance and adherence. The shift towards smart techno-driven health service delivery has accelerated the demand for

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innovations and alternative strategies to integrate emerging technologies especially sensors in the development of smart implants and smart devices. Smart implants improve health monitoring for the tracking and diagnosis of physiological issues [8], early disease detection [9], prognostication and prevention, relies on ubiquitous and unobtrusive monitoring digital health systems [10]. The astonishing contribution of smart implants has been predominantly witnessed in managing chronic illnesses and conditions like cancer, cardiovascular diseases, cognitive impairment and most importantly in orthopaedics [11]. Such diseases cause a considerable burden on patients and healthcare systems and are major causes of reduced quality of life [12]. With smart implants integrated with sensors, the burden of diseases can be reduced by providing personalized virtual care [13]. As alluded to by Javaid et al. [14] and Haleem et al. [15], biosensors and nanosensors present great capabilities such as disease detection, retinal prostheses, contrast imaging, heart diagnosis, medical mycology and health monitoring. These sensors can be used to develop smart implants that could be deployed in the various continuum of healthcare to improve healthcare services.

1.1. Contribution of the study

Despite the benefits of smart implants evidenced in many health systems in developed countries, their adoption and utilization in sub-Saharan African (SSA) health systems is still nascent. The continent experiences limited health access [16], a shortage of healthcare workers [17] and high costs of disease burden exacerbated by communicable diseases such as HIV/AIDS, Ebola, tuberculosis (TB) and coronavirus disease 2019 (COVID-19) as well as the rising number of non-communicable diseases such as diabetes, cardiovascular disease, hypertension, cancer and trauma, among others. There is a great need to continue providing health care services despite the setbacks and restrictions imposed on the movement of people to reduce the catastrophic impact of COVID-19 and future pandemics. This can be achieved by incorporating non-invasive smart implants to build sustainable healthcare systems globally instead of completely relying on conventional interventions that support in-person care and physical consultations [18]. However, there has been significant progress in the utilization of contraceptive implants, substantially, and equitably in many sub-Saharan African countries [19], across almost all socio-demographic categories. Such promising gains pose a positive light towards the adoption of smart implants in the future for effective prevention, early detection [20], and minimally invasive management of diseases in SSA health systems. The adoption of contraceptive implants has been necessitated by combined efforts and key contributing factors such as sizeable reductions in commodity cost [21], much-increased commodity supply [22], greater government commitment to expand contraceptive method choices, and wider adoption of high-impact service delivery practices that broaden access and better reach underserved populations [23]. In contrast to contraceptive implants, smart implants adoption is still low in many SSA health systems. Therefore, this paper discusses the potential benefits of smart implants while exploring the potential challenges and barriers that may hinder their adoption in SSA health systems. Thus, this paper aimed to address the following research objectives:

(i) Analyse the current status of smart implants utilization in SSA health systems.
(ii) Identify and explain potential benefits and opportunities for adopting smart implants towards personalized and pervasive healthcare in SSA health systems.
(iii) Explore potential challenges and barriers to the successful implementation of smart implants in SSA health systems.
(iv) Outline policy recommendations to tackle challenges and barriers identified in (iii)

Therefore, the remaining sections of the paper are organized as follows. Section 2 presents the methodology adopted by this study. Section 3 discusses the potential benefits and opportunities for adopting smart implants in SSA health systems. Section 4 discusses potential challenges and barriers to the successful implementation of smart implants in SSA health systems. The policy recommendations to tackle challenges and barriers are presented in Section 5. Finally, Section 6 presents the conclusion and future work.

2. Materials and methods

This research used the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) model [24,25] to guide the systematic review. The main stages included are the search strategy, study selection, study eligibility criteria, quality assessment and risk of bias assessment.

2.1. Search strategy

Only quality, scientific and published literature was reviewed, searched from the following electronic databases – Scopus, Google Scholar, Science Direct, PubMed, Web of Science, IEEE Xplore Digital Library, ACM Digital Library, Wiley Library, Springer Link and African Journals Online. The searches were done between 25 October 2021 and 10 November 2021. The keywords used to compose the various query strings on the databases are “smart implants”, “implants”, “pervasive healthcare”, and “virtual healthcare”, all of which were combined with “Sub-Saharan Africa” using “and”. Snowballing was also used to ensure more relevant articles were retrieved.

2.2. Study selection

A total of 1045 articles were returned from the databases searches. Only peer-reviewed, published articles written in English or with English translations, and that were published by non-predatory outlets were considered. Excluded were non-peer-reviewed articles, articles published with predatory journals, preprints, opinions, letters to the editors and conference abstracts. Duplicates were also removed. Fig. 1 presents a summary of the steps followed and articles at each stage, showing how the reviewed articles were selected.

2.3. Eligibility criteria and quality assessment

The eligibility of papers was based on whether they were peer-reviewed, published by a non-predatory outlet, primary research, written in English (or have an English translation), empirical study, and focused on smart implants. The quality of the reviewed papers was a critical consideration by the researchers; hence, all reviewed papers were assessed for quality by independent researchers. A total of 19 papers were selected as shown in Fig. 1 and Table 1.

2.4. Analysis of risk of bias (RoB)

The included papers were analysed for risk-of-bias with the help of the Cochrane risk-of-bias tool for randomised trials. The analysis was conducted using the Review Manager software (version 5.4.1). The results of the analysis of RoB are presented in Fig. 2 and Fig. 3 under the Results analysis section.

3. Results analysis

3.1. Analysis of risk-of-bias

The researchers used the Cochrane's tool for analysis of risk-of-bias, using the Review Manager 5.4.1 software tool. The results of this stage are presented in Figs. 2 and 3, with the former presenting summarised results for all the included papers while the latter shows the results for each included article. Generally, the results show that the researchers

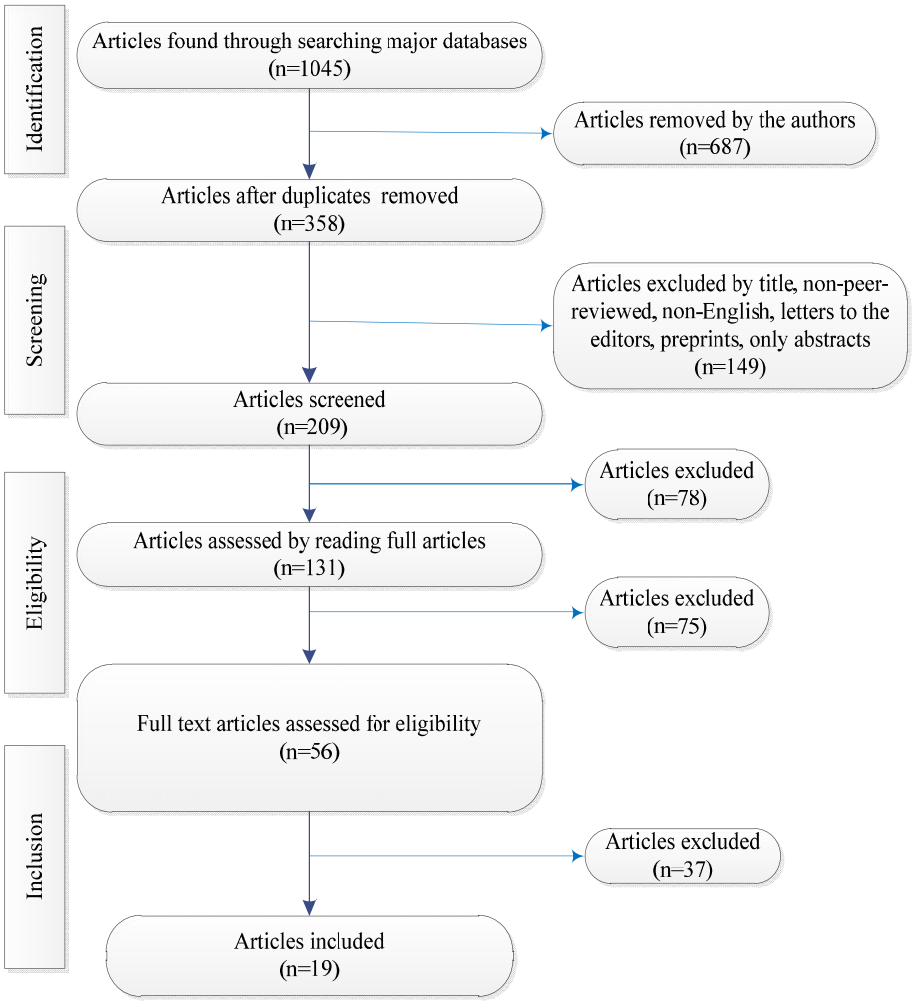

Fig. 1. PRISMA Flowchart.

strongly believe the included papers had minimal risk-of-bias. None of the included papers had no high risk of bias.

Table 1 shows several studies that investigated opportunities and challenges posed with implants deployed in various healthcare settings in various SSA countries. Therefore, the findings of this study are presented as follows; (i) potential opportunities and implications of smart implants in healthcare services in SSA, (ii) potential barriers and challenges associated with adoption and utilization of smart implants in SSA and finally, the policy recommendations for effective adoption of smart implants in SSA.

3.2. From convectional implants to smart implants: the potential transformative shift in sub-Saharan Africa

Table 1 shows that implants are not a new concept, however, they tremendously evolved with time to address emerging health challenges. For example, pacemakers and cochlear implants were introduced in the 1950s and 1970s, respectively [43]. A study conducted by Ref. [35] utilised Cochlear implants as an effective lifelong intervention for individuals with severe-to-profound hearing loss and rehabilitation. However, the high cost of Cochlear implants affects its uptake. Also, several studies including [22,27,31,32,36,38,40] show that implants are commonly used as a contraceptive method to provide family planning services that subsequently reduce unplanned pregnancies. SSA witnessed significant progress in the adoption and utilization of contraceptive implants, with a contraceptive prevalence rate (CPR) of 1.1% [22,26]. Contraceptive implants account for approximately 20% and 25% of all contemporary family planning methods in countries like Burkina Faso, Ethiopia, Ghana, the Democratic Republic of Congo, Kenya and Senegal [22]. The utilization of contraceptive implants in sub-Saharan Africa is expected to increase across socio-demographic classes, including single women, women with lower and higher income, young adults and older women, as well as women staying in rural areas. This is attributed to several interventions, such as commodity price reductions, increased supply and accessibility, increased government support and funding, wider World Health Organization eligibility guidance, and increased adoption of high-impact implants delivery practices. However, there is a notably low usage (below 1%) amongst nulliparous married women [22].

Smart implants have been used in orthopaedic surgery such as knee arthroplasty [34], hip arthroplasty, spine fusion, fracture fixation and spinal fusion surgery, mostly in developed countries [43]. The current uses of smart orthopaedic implants include measuring physical parameters from inside the body, including pressure, force, strain, displacement, proximity and temperature [34]. Smart implants present unprecedented opportunities in providing personalized and pervasive healthcare in Sub-Saharan Africa such as remote patients' monitoring and early disease detection [44], facilitating pervasive healthcare, and improving clinical practices [34]. Pervasive healthcare changes the healthcare paradigm

Table 1
From convectional implants to smart implants in SSA.

Ref	Implant	Opportunities	Barriers/Challenges
[26]	Contraceptive Implant	• Improve access to different contraceptive methods • Provision of family planning services to reduce unwanted pregnancies	• Cultural and religious barriers including misconceptions, misinformation and myths towards implants use • Huge funding gaps to develop implants locally • Lack of awareness through information, education and communication.
[22]	Contraceptive Implant	• Revised expert guidance supportive of wider client eligibility to receive an implant. • Greater country commitment to ensuring broad access to implants	• Implant removal services are not always readily available. • Cost/financing challenges
[27]	Contraceptive Implant	• Contraceptive availability, promotion and preventing pregnancy	• Limited availability of (long-acting reversible contraceptive) LARC methods • Huge investment is required to improve LARC availability and affordability • Training and strategies are required to increase LARC uptake. • Higher prices for LARCs limit access
[28]	Contraceptive Implant	• Awareness of the implant has spread rapidly • Implant's overall level of use and its share of use have both risen sharply	• Lack of trained providers • Misconceptions about health risks
[29]	Contraceptive Implant	• Ensuring long-term sustainable access to implants • Facilitate implants mobile outreach programmes	• Lack of adequate infrastructure and frequent commodity stockouts • Lack of skilled providers hinder public-sector provision, lack of commodity supply chains and financing mechanisms • Lack of provider supply for scaling-up implant service delivery
[30]	Dental Implants – South Africa	• Remote monitoring and provision of dental care	• Carbon contamination
[31]	Contraceptive Implant	• Improves convenience and offer up to 3–5 years of extremely reliable contraceptive protection • Provide a wider provision of contraceptive implants	• Lack of adequate infrastructure • Huge investment is required • Lack of policies on utilization of emerging contraceptive implants
[32]	Contraceptive Implant – South Africa	• Expanding the contraceptive method mix • Availability of long-acting reversible methods in the public sector	• Lack of training and support on insertions and removals of implants • Cultural or personal issues relating to side-effects of implants
[33]	Contraceptive Implant – South Africa	• Confidence and competence to deliver new contraceptive methods • Improving family planning services	• Misconceptions on side-effects and implant removals • Lack of follow-up support and undertake implants removals
[32]	Long-acting Antiretroviral Implants	• Consistent and predictable drug release • HIV treatment and prevention • Protection from poor adherence	• Requires insertion and removal by well-trained personnel, which are sometimes scarce. • Lack of clinical dose-finding and safety studies in antiretroviral implants.
[34]	Smart Implants in Orthopedic Surgery	• Smart implants have been used to improve healthcare services in knee arthroplasty, hip arthroplasty, spine fusion, fracture fixation • Measuring the physical parameters from inside the body remotely	• Creating hollow cavities alters the properties of the implant and ultimately jeopardizes the implant's performance • The sensor sizes and signal conditioning circuits need to be reduced. • High power consumption, communication range, data transfer rates, robustness and cost.
[35]	Cochlear Implant	• Effective lifelong intervention for individuals with a severe-to-profound hearing loss. • Rehabilitation	• High cost of Cochlear implant • Lack of funding models to reduce the cost of the implant.
[36]	Contraceptive Implant	• Family planning and ensuring long-term sustainable access to implants	• Poor insertion technique results in difficult implant removal • Removal training and services have lagged behind
[37]	Contraceptive Implant - Rwanda	• Improve family planning services among HIV-positive women to reduce unplanned pregnancies	• Limited access
[38]	Contraceptive Implant - SSA	• Improve the provision of family planning services to reduce unwanted pregnancies	• Commodity cost, which historically limited implant availability in low-resource countries. • Changes in menstrual bleeding patterns
[39]	Contraceptive Implant – South Africa	• Enabling pregnancy planning	• Side effects and inadequate health care training. • Lack of counselling services in health facilities in rural communities.
[40]	Contraceptive Implants - Kenya	• Family planning • Prevention of child transmission of HIV and reduction of maternal/ infant morbidity and mortality	• Insufficient resources to manufacture implants • Lack of policies and strategies guiding local manufacturing implants • Lack of awareness strategies
[41]	Hormonal Implants - Nigeria	• Effective family planning methods	• Menstrual problems • Culture and religious barriers • Weight changes, mood swings and abdominal bloating
[42]	HIV PrEP Implant	• HIV pre-exposure prophylaxis (PrEP) with potential for high adherence and long-acting protection	• Implants' side effects and efficacy • Implant robbery stories that emerged in Cape Town(South Africa) affect implant uptake.

from the traditional reactive, event-driven model to a proactive, patient-centric model in which patients manage their own health [45], presenting new healthcare opportunities. However, the optimal value of smart implants in pervasive healthcare provision lies in their integration with application-specific technologies, allowing remote interaction between the implants and healthcare professionals. Despite the potential uses of smart implants, their integration in clinical practice remains elusive [34].

3.3. Opportunities and potential implications of smart implants in healthcare services in SSA

The adoption of smart implants in SSA's healthcare presents unprecedented opportunities to move towards personalized and pervasive healthcare services delivery. Such transformative shift requires strategies and policies to strengthen current implant services in order to realise the benefits of smart implants, including remote health data collection and

management, disease diagnosis and treatment, remote disease monitoring and progression, drug adherence and effective family planning method, as shown in Fig. 4.

3.4. Remote patient health data management

Smart implants can be effectively utilised to collect patients' data remotely. Such data can be accessed through electronic health records (EHR) [46], online health data portals and secure cloud-based platforms. As such data increase in terms of volume and size to become big data, computational intelligence techniques, such as deep learning and machine learning models can be applied to analyse and extract meaning patterns and further assist policymakers to make informed decisions. For instance, a study conducted by Ref. [47] applied intelligence-based computational techniques on the COVID-19 dataset for classification and early differential diagnosis. However, remote access of health data using digital means require robust and secure digital health systems to protect health data from security vulnerabilities and data leakages. Therefore, there is a need to investigate the privacy and security implications of smart implants in the provision of pervasive healthcare services.

3.5. Remote monitoring and diagnosis of diseases

Smart implants can be effectively used to diagnose and monitor chronic diseases remotely. For instance, smart implants can diagnose diseases by monitoring physiological activities [48], tracking, early disease detection [13], prognostication and prevention [18]. Such emerging health intervention supports smart health monitoring that relies on ubiquitous and unobtrusive monitoring digital health systems [49]. This can tremendously improve healthcare service delivery in SSA heath systems. Also, smart implants can be used across remotely chronic conditions and diseases such as cardiovascular disease, dental ailments, orthopaedics abnormalities, diabetes and blood glucose level abnormalities [9]. Additionally, smart implants, due to their *in vivo* status, afford the early detection of disease for early treatment and monitoring drug adherence. For example, smart implants can be used in the treatment of heart disease and enable electrocardiogram measurements [50] and heartbeat rhythms [51]. Conventional medicine often involves invasive medical procedures such as biopsies, for cell and tissue-specific diseases such as cancer. Smart implants, especially the non-invasive bypass such procedures, sparing patients with repeated surgeries that would otherwise be mandatory in conventional medicine.

3.6. Remote monitoring of progression of diseases

Smart implants collect patients' biological information, enabling healthcare professionals to monitor disease progression in real-time virtually [52,53]. This allows the medical professionals to make recommendations, especially during the coronavirus disease 2019 (COVID-19) because of social distancing guidelines and imposed travel restrictions. Therefore, under such circumstances, smart implants become indispensable resourceful for the continued provision of healthcare services. Generally, many health systems in SSA still hinged on doctor-to-patient physical interaction which becomes difficult and increases the risk of COVID-19 infection. This is not always in developed countries as evidenced by the use of biosensors and smart materials to detect SARS-CoV-2, even at extremely low concentrations [54]. As the outbreak of future pandemics like COVID-19 are inevitable, there is a need to incorporate smart implants in SSA health systems to alleviate their catastrophic impact.

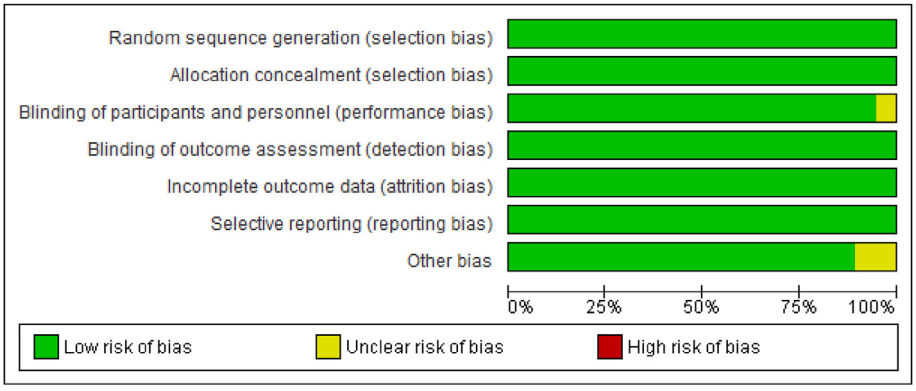

Fig. 2. Summary of analysis of risk of bias of included studies.

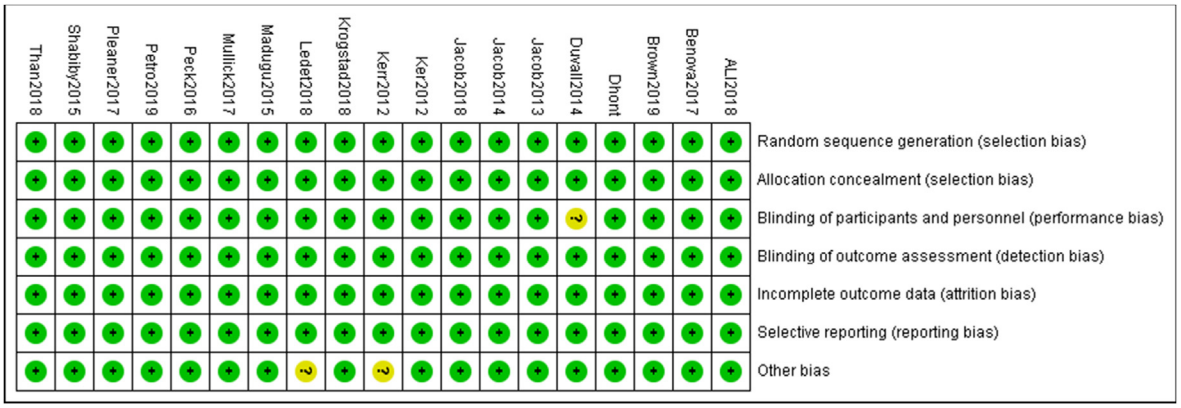

Fig. 3. Analysis of risk-of-bias of individual included studies.

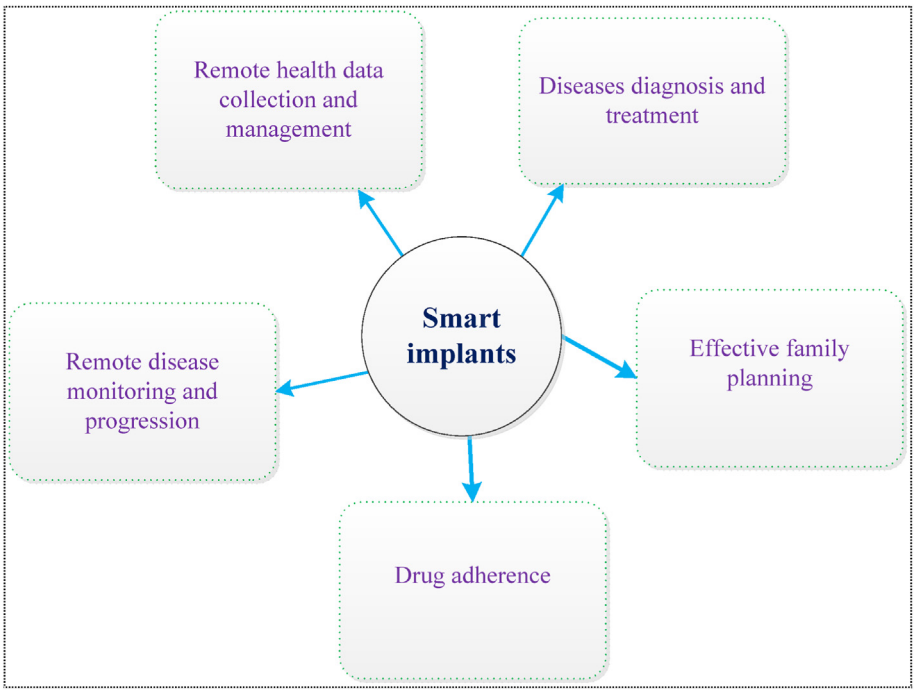

Fig. 4. Opportunities of smart implants in healthcare services in SSA.

3.7. Treatment of diseases

Smart implants have been utilised in the treatment and prevention of diseases. For example, osteoarthritis is a joint disease caused by the gradual disintegration of cartilage, a cushiony structure that prevents bones at joints from physical contact [55]. This disease is most prevalent in the elderly which consequently lead to restricted mobility and pain. Although stem cell technology has provided renewed hope in the treatment of osteoarthritis through the manipulation of stem cells to form progenitor chondrocytes [56,57], conventional medicine is primarily concerned with osteoarthritis management rather than treatment [58–60]. However, orthopaedic implants have been used to replace damaged joints such as the knee and elbow joints [61].

4. Potential barriers and challenges associated with smart implants in SSA

The potential use of smart implants is promising as evidenced by the rising utilization of contraceptive implants, substantially, and equitably, in many sub-Saharan African countries, across almost all sociodemographic categories. However, the adoption of smart implants has some barriers and hindrances in SSA health systems. These challenges include poor technological infrastructure, cultural barriers, legal and health policy issues, lack of manufacturing manpower, potential resistance by regulatory authorities and users, lack of political will and funding, data privacy and security concerns, and lack of medical expertise. Further challenges that hamper the adoption of smart implants in daily clinical practice include hardware footprint and the high commercial cost of sensing, processing, powering and communication [44]. Despite the advancement of sensor technology over the past decades, technical challenges need to be addressed before smart implants can become an integral part of daily clinical practice [34]. Given the continuous improvements in sensor technology, next-generation smart implants will be smaller, simpler, more robust and inexpensive, requiring minimal to no modification to current implant designs [34]. With the rapid advancement of sensor technology, the widespread adoption of smart implants in healthcare is not far away.

A study conducted by Kwete et al. [62] in the Democratic Republic of Congo highlighted lack of political will, political instability, weak transportation infrastructure, inadequate human and financial resources to properly train and supervise health care providers, lack of equipment, the deterioration of physical infrastructure as factors that affected the distribution of donor funding and contraceptive implants. The cost (price and consultation fees) of contraceptive implants has been a prohibitive barrier, especially in less privileged families in SSA. A study by Sinai et al. [63] noted that the conservative nature of some Africans and their cultural and religious conventions that discourage the insertion of foreign objects into the human body deter the use of contraceptive implants in Nigeria. In the Democratic Republic of Congo, Kwete et al. [62] also noted that women with contraceptive implants are likely to have fewer children, and, therefore, their husbands are free to marry additional women.

One of the challenges to smart implants development in SSA is the lack of active investment and funding in new scientific innovations early in their infancy [64]. This can be attested to by the little investment in stem cell technology in SSA [65] despite its importance in tackling diseases in Africa. Therefore, investing in smart implants require huge capital investment and collaborations with technological companies is required in many SSA countries. Creating awareness about smart implants and training of healthcare professionals (insertion and implant removals) can tremendously improve implants uptake [66]. Other challenges to the use of smart implants are tissue inflammation or infection, possible implant dislocation, and possibilities of drug delivery failure [67].

5. Policy recommendations for the adoption of smart implants in SSA

Recommendations highlight the need for SSA countries to develop strategies that will strengthen current implant services, including the provision of improved training of healthcare professionals, sensitisation of communities about smart implants and their potential benefits, increase of community engagement, and improved systems for programmatic monitoring and evaluation. These strategies should be part of legal,

regulatory and policy recommendations. Therefore, this study presents recommendations as follows: (i) legal, regulatory and policy recommendations, (ii) technological recommendations, (iii) financial recommendations, (iv) organizational recommendations, and (v) recommendations for existing cultural barriers.

5.1. Legal, regulatory and policy recommendations

The health sector is critical and requires proper, sound, and adequate regulations to protect patients while enabling the provision of essential health services efficiently and effectively [64]. With the rise in the usage of smart implants in other continents, policymakers must consider establishing relevant policies, legislations, and ethical standards to govern the usage of smart implants in SSA's healthcare settings. However, such regulations must not be prohibitive but must strike a balance between providing a legal framework that protects patients from unscrupulous practices while benefitting from and promoting the ethical use of such technologies.

5.2. Technological recommendations

The healthcare domain is a sensitive one that calls for technologies to ensure data privacy and confidentiality. To that end, we recommend the encryption of patient data that might be communicated between the smart implants and software applications interfaced with them. Moreover, we recommend that all smart implants must be rigorously tested and validated to rectify design errors and manufacturing problems before the implants are distributed for public use. This helps minimize design error effects which may have detrimental effects on patients.

5.3. Financial recommendations

Despite the benefits of implants (contraceptive implants and others) in SSA, the adoption of smart implants is still comparatively low. One of the inherent challenges in the health sector in SSA is the lack of funding [68], which stalls progress towards the adoption and use of smart implants. We, therefore, recommend that authorities and health players work hand-in-glove to provide adequate funding to promote the development of smart implants locally. This can be achieved through public-private partnerships [69], as well as, the removal of import duties on smart implants and associated technologies and building of self-sustained models for establishing manufacturing of smart implants locally.

5.4. Organizational recommendations

Through public-private partnerships, many organisations can develop capacity building and development strategies and probably manufacture smart implants locally. Such affiliations can present tremendous opportunities to alleviate such as lack of medical infrastructure and facilities [70–72] and develop prescribed health solutions without or with minimal consultation of patients. We, therefore, recommend a proactive approach to smart implant technology and create awareness using various digital platforms. This can assist implants users to understand and be aware of the side effects of smart implants [73].

5.5. Recommendations for existing cultural barriers

Africans are well known for different cultural practices and diverse religious beliefs. Cultural practices should be taken into consideration if smart implants are to be included in the healthcare services provision. is to take off successfully in sub-Saharan Africa. Therefore, the ethical and moral issues that are attributed to this technology must be addressed. Different African countries hold differing views regarding the sanctity of the human body. Therefore, since smart implant technology involves the physical insertion of inanimate objects into the human body, which may violet some cultural practices. We, therefore, recommend inclusive participation of communities and involvement of users in the development process of smart implants.

6. Conclusion

Smart implants present great opportunities to move towards personalized and precision medical healthcare. Such transformative shift requires strategies and policies that will strengthen current implant services in order to realise the benefits of smart implants, including patient data mining and management, disease diagnosis and treatment, remote disease monitoring and progression, drug adherence and effective family planning methods. This can greatly improve health care delivery, especially in SSA where a large populace experiences healthcare disparities and inadequacies. Despite the potential benefits of smart implants in SSA, their adoption can encounter barriers and challenges. These challenges include poor infrastructure, cultural barriers, legal and health policy issues, lack of manufacturing manpower, potential resistance by regulatory authorities and users, lack of political will and funding, data privacy and security concerns, and lack of medical expertise. Further challenges that hamper the adoption of smart implants in daily clinical practice include hardware footprint and the high commercial cost of sensing, processing, powering and communication. However, there is a need for SSA countries to develop strategies that will strengthen current implant services to stimulate the manufacturing of smart implants. This can be achieved through funding, public-private partnerships, training of healthcare professionals, sensitizing communities, increasing community engagement and most importantly the development of strategies and policies that will regulate the use of smart implants in healthcare settings.

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Disclaimer

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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