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RESEARCH ARTICLE

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A framework for advancing sustainable magnetic resonance imaging access in Africa

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Abstract

Magnetic resonance imaging (MRI) technology has profoundly transformed current healthcare systems globally, owing to advances in hardware and software research innovations. Despite these advances, MRI remains largely inaccessible to clinicians, patients, and researchers in low-resource areas, such as Africa. The rapidly growing burden of noncommunicable diseases in Africa underscores the importance of improving access to MRI equipment as well as training and research opportunities on the continent. The Consortium for Advancement of MRI Education and Research in Africa (CAMERA) is a network of African biomedical imaging experts and global partners, implementing novel strategies to advance MRI access and research in Africa. Upon its inception in 2019, CAMERA sets out to identify challenges to MRI usage and provide a framework for addressing MRI needs in the region. To this end, CAMERA conducted a needs assessment survey (NAS) and a series of symposia at international MRI society meetings over a 2-year period. The 68-question NAS was distributed to MRI users in Africa and was completed by 157 clinicians and scientists from across Sub-Saharan Africa (SSA). On average, the number of MRI scanners per million people remained at less than one, of which 39% were obsolete low-field systems but still in use to meet daily clinical needs. The feasibility of coupling stable

Abbreviations: CAMERA, Consortium for Advancement of MRI Education and Research in Africa; CME, continuing education; CMNN, communicable, maternal, neonatal, and nutritional; DALYs, disability-adjusted life-years; ESMRMB, European Society of Magnetic Resonance in Medicine and Biology; IAEA, International Atomic Energy Agency; ISMRM, International Society of Magnetic Resonance in Medicine; IT, information technology; MeSH, medical subject headings; MRI, magnetic resonance imaging; NAS, Needs Assessment Survey; NCDs, non-communicable diseases; OEMs, original equipment manufacturers; PACS, picture archiving system; pmp, per million people; SSA, Sub-Saharan Africa; WHO, World Health Organization.

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energy supplies from various sources has contributed to the growing number of higher-field (1.5 T) MRI scanners in the region. However, these systems are under-utilized, with only 8% of facilities reporting clinical scans of 15 or more patients per day, per scanner. The most frequently reported MRI scans were neurological and musculoskeletal. The CAMERA NAS combined with the World Health Organization and International Atomic Energy Agency data provides the most up-to-date data on MRI density in Africa and offers a unique insight into Africa's MRI needs. Reported gaps in training, maintenance, and research capacity indicate ongoing challenges in providing sustainable high-value MRI access in SSA. Findings from the NAS and focused discussions at international MRI society meetings provided the basis for the framework presented here for advancing MRI capacity in SSA. While these findings pertain to SSA, the framework provides a model for advancing imaging needs in other low-resource settings.

KEYWORDS

Africa, capacity building, global radiology, magnetic resonance imaging (MRI), MRI Access, MRI scanner density, needs assessment survey

1 | INTRODUCTION

The use of magnetic resonance imaging (MRI) as standard of care has grown significantly since its inception in the 1970s. This rapid growth is due in large part to the versatility of MRI in the management of noncommunicable diseases (NCDs). Despite a thriving overall trend in the proliferation of MRI in regions with limited resources, such as Africa, MRI availability and use are restricted by high acquisition and maintenance costs; limited access to the infrastructure; lack of expertise required to run and maintain the equipment; and other region-specific factors.[1,2] In 2016, there were only 84 MRI units serving West Africa's population of more than 370 million, with more than two-thirds of these units located in Nigeria.[2] In 2017, the Africa Region had 0.7 MRI scanners per million people (pmp)—the lowest density among six regions defined by the World Health Organization (WHO)—followed by 1.1 in the South-East Asian Region, 2.8 in the Eastern Mediterranean Region, 4.1 in the Americas, 5.4 in the Asia Western Pacific Region, and 11.6 in the Eurasian Region.[3] Given the centrality of MRI in the management of NCDs, increased availability and utilization of MRI services are critical to improving healthcare access and quality in Africa, in particular in Sub-Saharan Africa (SSA), where availability and access to MRI are even more restricted than in the rest of the continent.

Although NCDs are often associated with high-income countries, their burden in SSA is significant and growing due to the aging population, the drastically changing environment (e.g., air pollution),[4,5] increased urbanization,[6] and changing behavioral trends such as tobacco use, sedentary lifestyles, excess alcohol intake, and unhealthy diets.[7] From 1990 to 2017, while the disability-adjusted life-years (DALYs) due to NCDs decreased in high-income countries, in SSA, by contrast, the DALYs increased from 90.6 to 151.3 million, corresponding to an increase in the proportion of DALYs due to NCDs from 18.6% to 29.8%.[7,8] Although historically disease burden in SSA has been largely driven by communicable, maternal, neonatal, and nutritional (CMNN) diseases, the age-standardized DALY rate due to NCDs in 2017 was similar to that for CMNN diseases (21,757 per 100,000 population vs. 26,491).[8] Among NCDs, the leading causes of disability in SSA are cardiovascular diseases (22.9 million DALYs), neoplasms (16.9 million), mental disorders (13.6 million), and digestive diseases (12.6 million).[8] As NCD-related disabilities continue to increase in the region, it is critical to address barriers to NCD management in order to achieve the global target of reducing premature mortality from NCDs by one-third by 2030.[9]

Increasingly, the use of MRI has expanded to take on an integral role in the management of NCDs, including the management of cardiovascular disease, which, as mentioned above, is the leading cause of disability in SSA. While cardiovascular disease has decreased globally over recent decades,[10] its incidence is steadily increasing in SSA.[11,12] By enabling accurate assessment of cardiac morphology, function, flow, perfusion, acute tissue injury, and fibrosis, MRI can help determine disease etiology and risk, thus facilitating effective management of heart failure and other cardiomyopathies,[13] even at low magnetic field strengths.[14]

MRI is the recommended standard of care in the diagnosis and treatment of neurological diseases, including, but not limited to, seizures,[15] strokes,[16,17] and dementia.[18] MRI can help determine seizureetiology in epilepsy management,[15] visualize, and quantify tissue perfusion, vascular flow, and treatment response in acute and subsequent phases of stroke.[16] Recent evidence in stroke imaging suggests that the incidence and prevalence of stroke in Africa has grown to two to three times the number of cases observed in Western Europe and the United States.[19] The cerebrovascular implications of systemic disorders such as sickle cell disease with a high prevalence rate in SSA make neuroimaging particularly important in the region.[20] Beyond NCDs, MRI can play a paramount role in the management of infectious diseases, such as HIV and malaria.[21–23]

Furthermore, in the context of a growing global cancer burden, access to imaging services can avert millions of cancer deaths annually worldwide.[3] MRI is a core component of cancer management in high-income countries as it enables early and accurate diagnosis of cancer, thereby facilitating the treatment of neoplasms at a stage when they are more likely to be treatable. MRI is also used for assessing response to cancer therapy, thus aiding physicians in making effective and economical treatment decisions.[24] Of note, MRI can reduce healthcare costs by preventing unnecessary procedures or tests.[3] While the direct benefits of MRI on cancer survival are difficult to quantify due to the complexity of cancer management, in places such as Europe, cancer survival directly correlates with the number of MRI units per capita, supporting the view that MRI benefits cancer management.[25]

In a study published in *Lancet Oncology*, researchers estimated that a scale-up of imaging modalities (ultrasound, X-ray, computerized tomography [CT], MRI, positron emission tomography [PET], and single photon emission CT [SPECT]) in 2020–2030 would avert 207,800 deaths in Africa, comprising 3% of total cancer deaths in the region and resulting in 4.64 million life-years saved.[3] Beyond humanitarian benefit, a scale-up of imaging modalities is also projected to yield significant economical returns. With an estimated cost of US$0.46 billion, a scale-up of imaging modalities in Africa from 2020 to 2030 is projected to result in productivity gains of $27.38 billion, with a net benefit of $26.93 billion.[3] In other words, there is an estimated return of $59.97 per $1 of investment.

Despite the obvious and urgent need to invest in medical imaging in SSA, a gap in knowledge and access to high value MRI services in the region persists. The aim of this study is to address this gap by: (1) providing an assessment of access to high value MRI services in SSA using findings from the needs assessment survey (NAS) developed and performed by the Consortium for Advancement of MRI Education and Research in Africa (CAMERA); (2) describing the needs for MRI development in the region from recent discussions about the current state of MRI in SSA from the CAMERA symposia at the International Society of Magnetic Resonance in Medicine (ISMRM) and European Society of Magnetic Resonance in Medicine and Biology (ESMRMB); and (3) presenting a framework informed by the NAS and symposia for addressing the need for MRI access and development in the SSA.

2 | METHODS

CAMERA is a network of African experts, global partners, and ISMRM/ESMRMB members implementing innovative approaches that are advancing MRI access in Africa through training and research capacity building. In May 2020, CAMERA initiated a NAS study that was designed as described below.

2.1 | Needs assessment survey

The NAS was designed to identify MRI needs unique to Africa based on a pilot field survey of seven MRI facilities in Nigeria and the RAD-AID Radiology-Readiness Survey.[26] A French and an English version of the CAMERA NAS were created using Google Forms and distributed via email and WhatsApp messaging to radiologists, radiographers, and radiology organizations in Africa through the CAMERA member network. The participating radiology organizations were the Association of Radiologists in Nigeria (ARIN), Radiographers Registration Board of Nigeria (RRBN), Société de Radiologie d'Afrique Noire Francophone (SRANF), Federation of African Medical Physics Organizations (FAMPO), and the Pan African Congress of Radiology and Imaging (PACORI).

The NAS form consisted of 68 questions divided into nine components aiming to capture key needs along four central priorities/targets: (1) availability and access; (2) personnel training and education; (3) research translation; and (4) sustainable technology (Table 1). The first eight components consisted of close-ended questions to provide insight on: (1) facility information; (2) scanner description; (3) maintenance; (4) usage and indications; (5) facility infrastructure; (6) personnel training and education; (7) health economics; and (8) research capacity. Optional short answer open-ended questions were included at the end of the survey to allow responders to provide additional context to MRI needs as well as suggestions for potential solutions.

To meet one of CAMERA's mission of strengthening MRI networks within Africa, participants were asked to opt-in to be notified and included in networking efforts by providing their center and primary contact information. This optional input is only accessible to The CAMERA Environmental Scan Task Force, as disclosed on the survey, and is not reported in this study. The English and French versions of the CAMERA NAS can be obtained via an email request to the corresponding author.

To assess the MRI density in the region, the NAS data were supplemented with data on the total number of MRI scanners per country from the WHO 2010–2014 Global Health Observatory data repository[27] and the International Atomic Energy Agency (IAEA) IMAGINE Database.[28] Both databases were accessed in August 2020, with the most recent IMAGINE data information retained for data analysis. Population density was obtained from World Bank estimates. The MRI density for each African country was calculated as the number of MRI machines per million inhabitants.

TABLE 1 CAMERA NAS structure

Challenge priority/target	NAS component
1. Availability and access a. Density (number of MRI scanners or personnel/facility) b. Location (public/private/teaching - rural vs. urban) c. Field strength (low/high) d. Utility - indications, how well the system is utilized	Facility information Scanner description Usage and indications
2. Personnel training a. Capacity to utilize (image acquisition) – acquire good images and run the system well (radiographer) b. Capacity to utilize (image interpretation) – diagnose and provide outcomes (radiologist) c. Access to CME and workshops	Personnel training and education
3. Research translation a. Capacity to drive MRI innovations to solve local health care needs b. Capacity for use of MRI in clinical trials and large population studies c. Relevant imaging technology development (hardware and software) d. Networking and access to research networks	Facility information Facility infrastructure Scanner description Research capacity
4. Sustainability a. Maintenance and servicing access and frequency b. Life cycle of MRI scanner c. Power supply infrastructure d. Funding to sustain the MRI facility and scanner	Facility infrastructure Scanner description Maintenance Health economics

Abbreviations: CAMERA, Consortium for Advancement of MRI Education & Research in Africa; CME, continuing medical education; MRI, magnetic resonance imaging; NAS, needs assessment survey.

To further explore research capacity across the region, the total number of MRI papers published from 2018 to 2020 were tabulated from the Journal Citation Reports Journal Profile page. Ten journals, listed in the Radiology, Nuclear Medicine & Medical Imaging and the Spectroscopy, Physics, Atomic & Molecular categories of the Journal Citation Reports, and whose scope falls predominantly within MRI research, were included.[29] To gain a better understanding of the research performance in the region, data from all regions of the world captured for each journal were included in this analysis and classified based on The World Bank Country Income Groups.[29] To further characterize the scope and research interest within Africa, a systematic search of original MRI research articles from January 2000 to December 2020 was conducted in PubMed using Medical Subject Headings (MeSH) and keyword search terms. The PubMed search was categorized by the top three research interest topics expressed in the NAS responses (brain, cardiovascular, hardware and pulse sequence) and a collection of other topics (such as oncology, pediatrics, and musculoskeletal disorders). Case reports, editorials, and reviews were excluded from searches. Duplicate and irrelevant publications, articles without an author affiliation from an African institution, and research studies not conducted in Africa were manually removed from the search results.

2.2 | CAMERA societies meetings: Agenda

Between 2020 and 2021, CAMERA held three symposia at ESMRMB and ISMRM annual meetings. The goal was to highlight Africa's complex and unique MRI needs and outline opportunities for breakthrough increase to MRI access and research in the continent. These symposia expanded on concepts central to the four priorities captured in the NAS: availability and access, personnel training and education, research translation, and sustainable technology, as well as the needs and opportunities from non-Anglophone and non-Francophone African countries.

Briefly, the meetings were organized through proposal submissions to the ESMRMB congress planning committee and the ISMRM virtual meeting approval process. Speakers and moderators were sourced from the network of MRI users and experts working in the region. All meetings were held virtually using the standard Zoom video conferencing platform, except for the symposium at the 2021 ESMRMB congress, which was facilitated by Conventus Congress Management & Marketing GmBH (Jena, Germany). The 2020 ESMRMB Congress symposium and the 2021 ISMRM Virtual Meeting were free to attend, while the 2021 ESMRMB Congress symposium was limited to attendees who registered to attend the entire congress. The symposia featured 2–5 talks ranging from 20–30 min per speaker, followed by a 1-h panel discussion to draw more inputs from the attendees (Table 2).

TABLE 2 Agenda for the CAMERA symposia

	Topic title	Speaker name and affiliation
ESMRMB 2020 Congress, 1 October 2020		
1	Doing much with little: benefits and challenges of low-field MRI in Africa	Godwin Ogoble, MD, University College Hospital, University of Ibadan, Nigeria
2	Expanding the imaging enterprise and implementation of artificial intelligence in Africa	Farouk Dako, MD, Perelman School of Medicine, University of Pennsylvania
3	Installation of an MRI system in Mozambique – implementation, difficulties, and impact	Mario Forjaz Secca, PhD, Central Hospital of Maputo, Maputo, Mozambique
ISMRM Virtual Meeting: ISMRM Spotlights Africa, 25 February 2021		
1	MRI in practice in Africa	Abiodun Fatade, MBBS, Crestview Radiology, Lagos, Nigeria
2	Diagnosing cardiac disease using MRI in SSA: battling cardiac disease in a perfect storm	Ntobeko Ntusi, MBChB, Department of Medicine, University of Cape Town, South Africa
3	Breast MRI in Africa: current status and challenges of implementation in screening, diagnosis, staging, and follow-up	Nagla Abdel Razek, MD, Department of Radiology, Cairo University, Egypt
4	The role of machine learning in MRI in low- and middle-income countries	Daniel Alexander, PhD, University College London, UK
5	Developing techniques for low-field MRI applications in SSA	Johnes Obungoloch, PhD, Mbarara University of Science and Technology, Uganda
ESMRMB 2021 Congress, 8 October 2021		
1	Reimagining accessible MRI education in Africa: Physics + Medicine YouTube	Abayomi Opadele, MSc, Hokkaido University, Japan
2	MRI in clinical practice in Africa – A radiographer's perspective	Harrison Aduluwa, BSc, MPH, Euracare Multi-Specialist Hospital, Nigeria

Abbreviations: CAMERA, Consortium for Advancement of MRI Education & Research in Africa; ESMRMB, European Society of Magnetic Resonance in Medicine and Biology; ISMRM, International Society of Magnetic Resonance in Medicine; MRI, magnetic resonance imaging; SSA, Sub-Saharan Africa.

3 | RESULTS

3.1 | Outcome of the CAMERA needs assessment survey

The NAS was conducted from May to October 2020. A total of 172 responses were received from the following 12 SSA countries: Cameroon, Gabon, Gambia, Ghana, Kenya, Malawi, Niger, Nigeria, Somalia, South Africa, Tanzania, and Uganda. Out of all responses, 15 were discarded as duplicate entries by multiple individuals from the same institution. Results from the 157 CAMERA NAS responses are summarized in Figures 1–3. Results for each of the NAS survey entries—Availability and access, Training and education, Research translation, and Technology sustainability—are provided below.

3.2 | Availability and access

The combined data from CAMERA NAS, WHO,[27] and IAEA[28] databases showed that MRI scanner density in Africa was on average 0.8 scanners pmp (Figure 1A). Density data were unavailable for five of the 54 countries. Of the 49 countries that reported density data, 11 countries reported zero MRI scanners, a list that included highly populated countries such as the Democratic Republic of Congo with ∼95 million inhabitants, Niger with ∼26 million, and Mali with ∼21 million (Table S1). By contrast, Romania, with a population similar to that of Mali, and one of the countries with the lowest gross national income in Europe, has 7–10 MRI pmp.[28]

Of the 157 NAS responses, 45% (70) reported not having an MRI scanner in their center. Of all the imaging departments/centers with MRI, 56.6% were public, including government-funded academic healthcare centers (7.54%) and regional/tertiary and community hospitals (13.3%). The others (43.4%) were private practices, which included only two public-private partnerships.

In total, 110 MRI scanners were reported across the 87 centers, with 83 scanners reported as functioning at the time of the survey. Four of the 110 scanners were 3 T, 58 were 1.5 T, one was 1 T, and 41 were less than 1 T. Three participants reported the total number of MRI scanners at their center but did not provide the field strength. The distribution of MRI by field strength is shown in Figure 1B. Three centers, one in Nigeria, one in Tanzania, and one in South Africa, all affiliated with public universities, reported working with 3- and 1.5-T scanners at their center, with two of the four 3-T scanners in the South African center. The single 1-T scanner reported was in a National Hospital in Nigeria. Out of the 42 respondents who reported working with low-field (≤ 1-T) MRI in regular clinical practice, 35 worked in public/government centers. Notably,

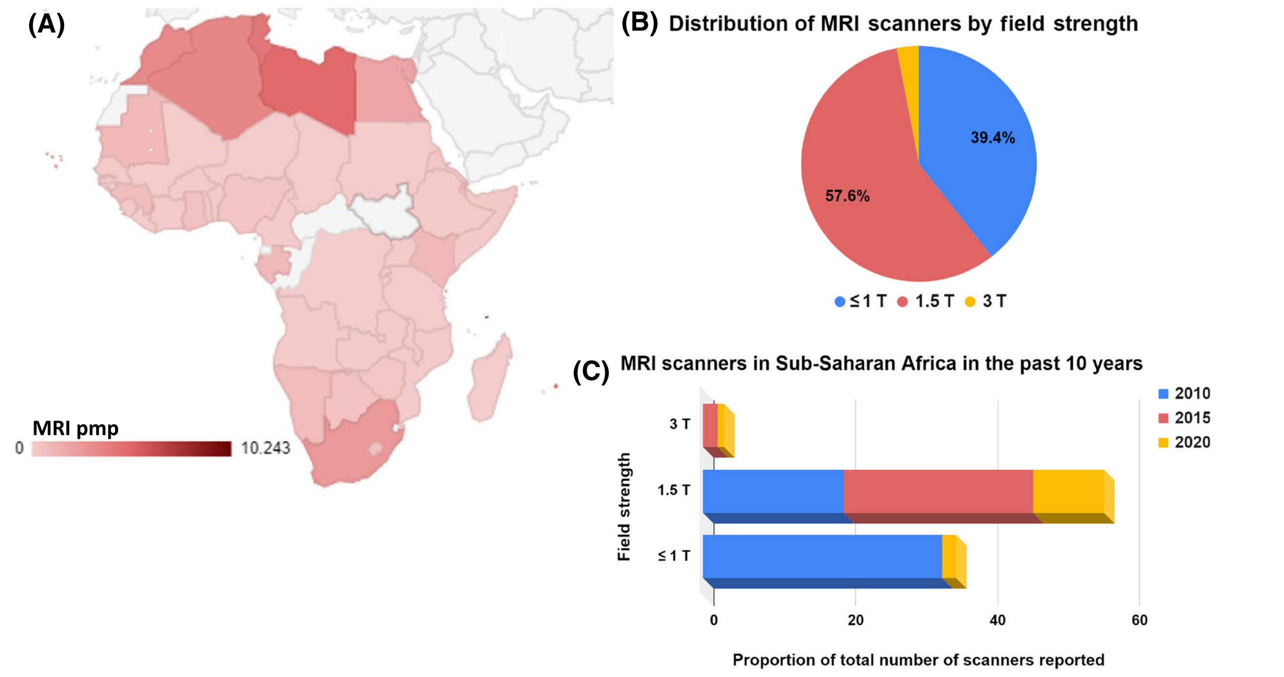

FIGURE 1 MRI density and proportion of scanners by field strength. (A) Density of MRI across Africa demonstrating the number of scanners pmp for each country with data (colored). (B) Distribution of MRI scanners in Sub-Saharan Africa by field strength show that a considerable proportion of reporting centers use low-field (≤ 1-T) scanners; (C) However, there is a growing number of high-field (1.5- and 3-T) scanners in the region but also ongoing procurement of low-field MRI. MRI, magnetic resonance imaging; pmp, per million people

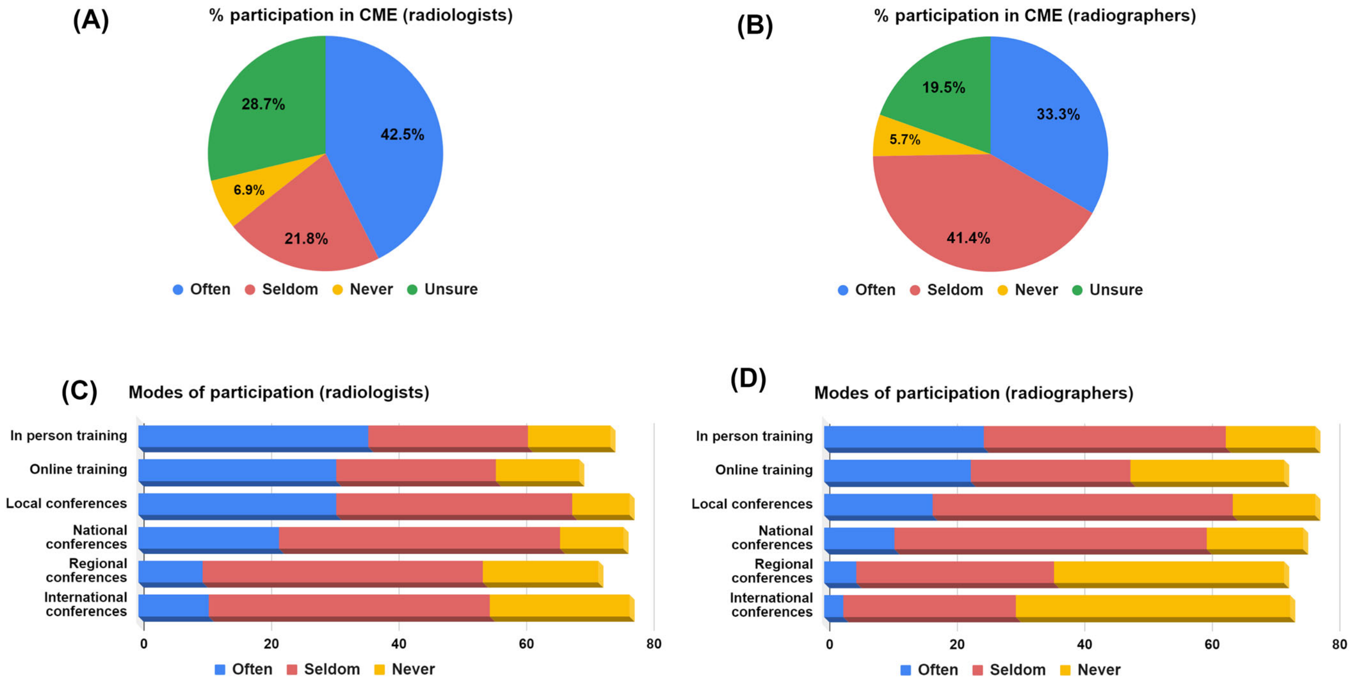

FIGURE 2 MRI training and education access in SSA. (A and B) Proportion (%) of CAMERA NAS respondents (n = 87) who have participated in MRI meetings, workshops, or conferences in the past 5 years frequently (2–3 times per year), seldom (once per year), or never over this period using (C and D) Various modes of participation (online or in-person) and at various levels of participation, locally (within their institution), nationally (within their country), regionally (within Africa), or internationally (abroad). CAMERA, Consortium for Advancement of MRI Education & Research in Africa; CME, continuing medical education; MRI, magnetic resonance imaging; NAS, needs assessment survey; SSA, Sub-Saharan Africa

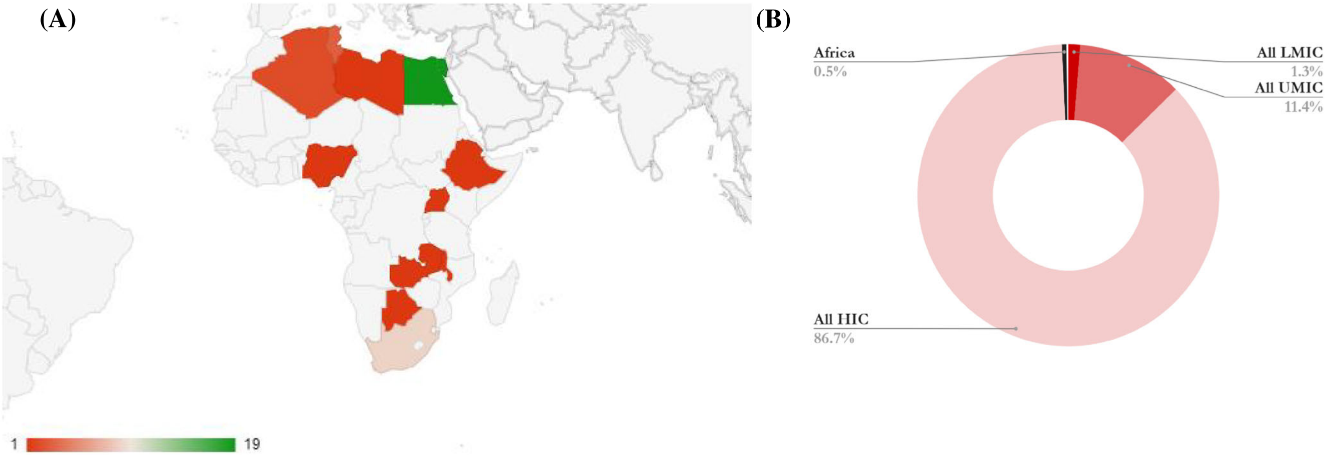

FIGURE 3 Research output. Total number of MRI publications in MRI exclusive journals from 2018 to 2020 for each country with data (colored). (A) All SSA countries with data minus South Africa (nine) produced just a single publication each. (B) Africa as a whole produced ~0.5% of the total MRI publications over this period in the 10 journals. HIC, high-income countries; LMIC, low- to middle-income countries; MRI, magnetic resonance imaging; SSA, Sub-Saharan Africa; UMIC, upper middle-income countries

about 81% of the low-field systems were reported as having exceeded their obsolescence period (Figure 1B). However, a steady growth in the number of high-field scanners, primarily 1.5 T, was also reported (Figure 1B).

3.3 | Personnel training and education

All centers with an MRI reported having at least one radiologist and one radiographer on the staff. The distribution of staff by discipline is shown in Table S2. However, 65% (57/87) of respondents reported not having a staff MRI physicist.

Figure 2 shows the proportion of radiologists and radiographers who regularly attend continuing medical education (CME) MRI events, their levels of participation (local/national/regional/international), and the common mode of participation/attendance (online/in-person). All 69 respondents who completed the section of the survey on interest in attending MRI workshops said their staff would benefit from attending local/national/regional MRI workshops. Out of 69 respondents, 63 responded "yes" or provided further elaboration to the question related to perceived training opportunity challenge, while only four indicated no perceived challenge to training. Training cost, limited time off to attend training, and lack of available training courses/workshops/opportunities were commonly expressed as barriers to continuing education. Provided below are a few examples of the respondents' unedited replies to training opportunity challenges:

> *Given the challenges faced in my locality, there is increased in number of patient. Revolving technological advancement needs continuous training to meet the needs of the community I'm serving and impact the knowledge into my students in the University. Thank you.*
> *We have very few radiographers and the absence of one will increase TAT, cost and lack of sponsorship and total apathy to personnel development by management.*
> *We are motivated if we are not limited by costs of training.*
> *Training in English is a problem.*

3.4 | Research translation capacity

Of the 87 MRI centers who completed the NAS, 52 (60%) lead or participate in research using MRI, yet only 63 (72%) have a research ethics board. Brain imaging applications, neuroscience, and musculoskeletal imaging applications were the most indicated areas of MRI interest (Figure S1).

Five of the 10 MRI journals profiled on the Journal Citation Reports Journal Profile page were official publications of MRI societies, with 2020 impact factors ranging from 2.31 to 5.36. In total, 83 countries published 8131 MRI-related papers from 2018 to 2020. Of these, 11 countries were from Africa and seven from SSA. The total numbers of MRI publications from the region were 40 (Africa) and 17 (SSA), representing

0.5% and 0.2%, respectively, of the total MRI publications in the most recent 3 years (Figure 3, Table S3). By contrast, upper middle-income regions such as Brazil, China, Turkey, and Iran had a combined 57 times more MRI publications compared with SSA, while high-income countries such as Canada, Chile, Germany, England, South Korea, and the USA published a combined 86.7% of the total MRI publications over the same period, representing 433 times the number of papers from SSA (Figure 3B, Figure S2A, and Table S3). In SSA, Nigeria, Uganda, and South Africa were the only countries that published a total of four MRI research studies in the ISMRM (*JMRI*), ESMRMB (*MAGMA*), and Society of Cardiovascular Magnetic Resonance (*SCMR*) journals.

A total of 3295 MRI research publications were retrieved from PubMed searches. Of these, 879 original research studies spanning 2 decades were identified from 12 countries across Africa, after removal of duplicates, unrelated studies, case reports, reviews, studies not conducted in Africa, and those without researchers from African institutions (Figure S2B). Brain was the primary research interest in nearly all countries, followed by a collection of other topics that were largely focused on oncology, pediatrics, and musculoskeletal imaging. Egypt, South Africa, Tunisia, and Nigeria were the only countries to produce 20 or more publications over this 20-year period (Figure S2B).

3.5 | Sustainable technology

In terms of utility, about 48% of centers perform clinical scans on five or less patients/scanner/day and only 8% scan 15 or more patients/scanner/day (Figure 4A). The top three reported clinical indications were brain, spine, and musculoskeletal disorders (Figure S3). The average reported cost of an MRI examination was US$200. Payment for MRI services at the facilities were overwhelmingly from private or out-of-pocket sources (37% sole source or 89% as one of the sources of payment) compared with partial or full public funding including national insurance schemes (3.4% sole source or 35.6% as one of payment sources) or private insurance (0% sole source or 37.93% as one of payment sources), as shown in Figure S4.

Of the 87 MRI facilities, 81 have access to a service engineer (Figure 4), as a staff/faculty member (5/81), third party (61/81), both (5/81), or through other means (5/81). The reported frequency of scanner maintenance/service from 81 respondents was 13% (11/81) for monthly, 34.5%

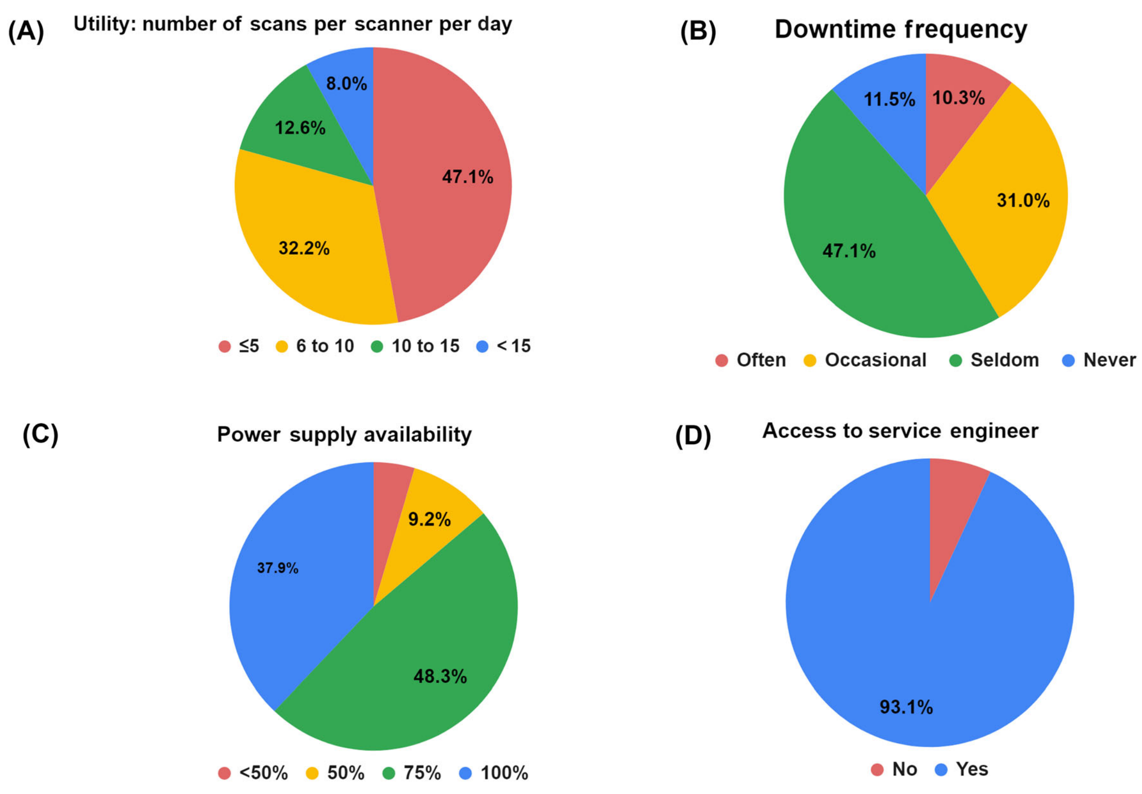

FIGURE 4 Sustaining high-value MRI in SSA. The proportion (%) of CAMERA NAS respondents (n = 87) who have at least one MRI scanner reported (A) The number of scans per scanner per day, (B) Their downtime frequency (as never/none, occasional [1–3 times per month], often [1–2 times per week], or seldom [< 1 times in a 6-month span]), (C) How often they have a steady power supply, and (D) If they have access to regular service and maintenance support. CAMERA, Consortium for Advancement of MRI Education & Research in Africa; MRI, magnetic resonance imaging; NAS, needs assessment survey; SSA, Sub-Saharan Africa

(28/81) for 2–3 times per year, 11% (9/81) for annually, and 40.74% (33/81) for never. Downtime frequency and power supply availability reported by the 87 centers with MRI are shown in Figure 4. Up to 86% of facilities reported access to constant power supply (≥ 75% of 24 h/7 days/week), 41.4% reported downtime frequency of at least 1–2 times/week (often) or 1–3 times per month (occasional) (Figure 4B,C), 94% (82/87) reported access to a backup power supply, 83% (82/87) reported access to a picture archiving system at their center, and 29% (25/87) use teleradiology (reading and interpretation at another facility).

Table S4 and Figure S5 summarize the short answer responses to NAS questions of challenges faced by the facilities that (1) impair their day-to-day operation of their MRI program, (2) affect their ability to conduct or participate in MRI-related research, and (3) stem from limited personnel capacity. Suggested solutions to address these challenges are also summarized.

3.6 | Outcome of the CAMERA symposia at the MRI societies meetings

A total of approximately 120, 100, and 21 individuals attended the 2020 ESMRMB symposium, 2021 ISMRM virtual meeting, and 2021 ESMRMB symposium, respectively. The low attendance for the 2021 ESMRMB symposium was due to the relatively high registration cost (90 euros). On average, 30% of attendees were resident in Africa.

Highlights of discussions from the three symposia are outlined in Table S5. The discussions expanded on the issues of availability and access, personnel training and education, research translation, and sustainable technology. For each issue, challenges and opportunities for CAMERA and the MRI community were identified and discussed (Table S5). Major barriers that contribute to the ongoing low use of MRI in Africa were recognized as either infrastructural or institutional, both involving issues of availability and access, challenges in education and training, lack of research environment, high operational cost, and limited specialized expertise needed to sustain MRI technology (Figure 5). These challenges, along with recommended solutions, are briefly summarized below.

3.7 | Challenges in availability and access to MRI

3.7.1 | Acquisition costs

African countries are required to outsource MRI equipment as medical devices because they are rarely produced on the continent. As a result, the MRI equipment can be more expensive in Africa than in the West and other regions with locally sourced medical equipment. The lackluster medical manufacturing market coupled with the general lack of country- or region-specific and dedicated device regulation[30] not only hinders access to medical technology, but also denies Africa the technical expertise and skills development necessary for a sustainable healthcare industry.

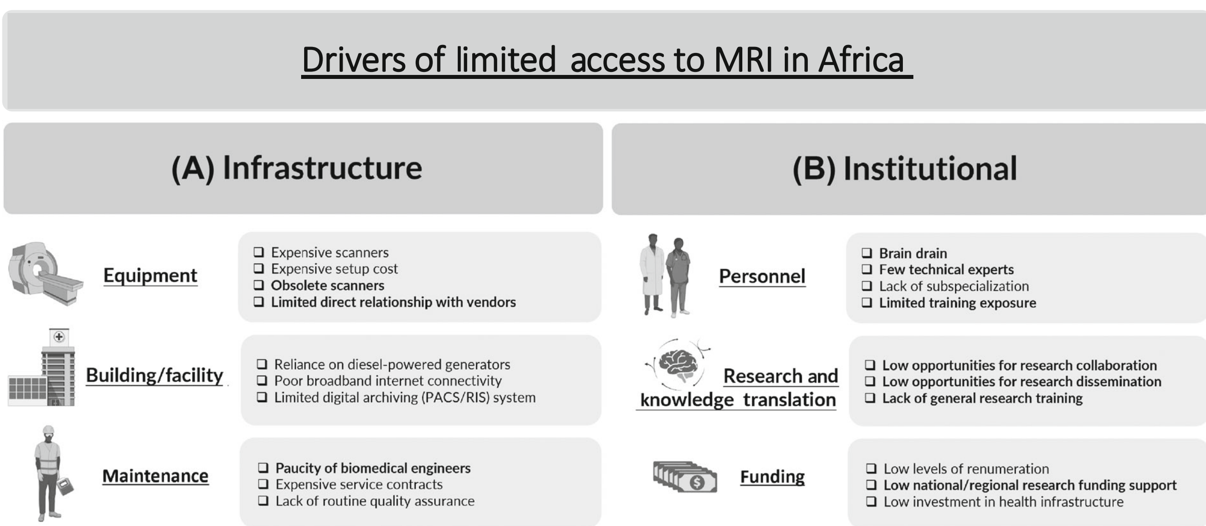

FIGURE 5 Barriers to high value MRI in Africa. MRI, magnetic resonance imaging; PACS, picture archiving system; RIS, radiology information system

3.7.2 | Limited access to financial capital to support investment in MRI equipment

Because of poor health insurance coverage in the region, healthcare providers in SSA cannot generate adequate returns to justify investment in high-cost MRI equipment. Furthermore, healthcare providers have limited options for funding: financial companies are not healthcare friendly as medical equipment often cannot generate quick returns, while banks do not have existing lending schemes for medical devices. Small- and medium-scale healthcare providers are particularly disadvantaged in accessing loans because of their lack of banking history and limited collateral.

3.8 | Challenges in sustainable technology

3.8.1 | Scarcity of human capital to run, utilize, and maintain MRI technology

The limited experience of radiographers, radiologists, and biomedical engineers contributes to the general low throughput. Poor maintenance often renders MRI systems unusable far in advance of the expected product lifetime. In Uganda, US$1.3 million worth of medical equipment was found to be nonfunctional across 17 medical facilities within 2 years of donation. In some cases, the equipment had never even been installed. Because a significant portion of medical devices in SSA is donated, recipient facilities often have limited decision-making power in what equipment they receive, which can result in a mismatch between a donor's agenda and a facility's needs. Recipient facilities invariably lack resources and expertise to appropriately maintain and utilize the donated equipment. Furthermore, Africa's brain drain exacerbates the shortage of medical professionals and strips the region of its best human resources.[31,32]

3.8.2 | Poor electricity and technology infrastructure impedes effective MRI technology utilization

Limited access to stable electricity infrastructure prevents utilization of high-field MRI systems that require cryogens. Additionally, electricity from the power grid is often delivered with fluctuating voltages and thus may damage expensive equipment.[33] The poor penetration of the internet, computers, and other technology presents challenges in healthcare management, including accessing and storing patient information, imaging files, and referrals.[34]

3.9 | Proposed solutions

3.9.1 | Create vendor-financing programs

Original equipment manufacturers (OEMs) and equipment vendors can create vendor-financing programs to facilitate healthcare providers in obtaining loans for medical equipment. In 2019, GE Healthcare and the Medical Credit Fund entered into a partnership to improve access to medical equipment in Kenya.[35] Under this partnership, small- and medium-scale private healthcare providers can borrow up to US$100,000 with a 24-month repayment program to purchase GE Healthcare-manufactured medical equipment.[35] Similar partnerships in other countries in SSA can enable small- and medium-scale healthcare providers to secure loans to purchase MRI systems. These partnerships will become readily feasible if gaps in national medical device regulation and standards are closed, thus presenting a unique opportunity to develop a region or continent-wide regulation that aligns with international standards such as the European CE Mark. This regional effort fits well with the WHO recommendations for harmonization of regulations among national bodies to promote standards within the industry, particularly safety standards.[30]

3.9.2 | Invest in low-field MRI as a cost-effective and adaptable alternative to high-field MRI

Low-field MRI systems are significantly cheaper than high-field systems, and not only do they have the potential to address most clinical needs in SSA, they also has manifold advantages over high-field MRI.[14,16,36] Furthermore, low-field equipment requires less technical expertise to run and maintain. It is important to note that low-field equipment is significantly less heavy and easier to transport than high-field systems, thus reducing transportation costs and the challenges associated with setting up the equipment. Because low-field systems are more robust and can better handle fluctuations in electricity, they are better suited to low-resource settings in SSA where power outages can occur frequently.[37] Despite breakthrough technological advancements in low-field MRI, the image quality is relatively low when compared with those from high-field MRI. However, mounting evidence suggests that low-field MR image quality can approach that of high-field MRI, especially for core clinical applications.[37–39]

3.9.3 | Establish skills development and training programs for MRI personnel

OEMs, ISMRM. and MRI networks such as CAMERA should regularly host curriculum-based skills development and training programs for radiologists, radiographers, and biomedical engineers in SSA.[40,41] These programs can produce a more skilled local workforce for medical facilities to rely on for the running and maintenance of MRI systems. Furthermore, an increased number of medical professionals can help to offset the effects of Africa's brain drain. Dr. Naglaa Abdel Razek, who now runs a breast MRI program in Egypt after partaking in a European Society of Breast Imaging (EUSOBI) training program, is a prime example of how investing in human resources can generate remarkable returns for local populations. Another striking example is installation of new Siemens Healtineers magnets by Mr. Alausa Olakunle, a local third-party biomedical engineer, who, in 2015, received skills training on the Siemens platform at Cary, USA, to enable installation of OEM magnets across Africa, including recent installation of a 3-T MRI scanner at the Ruby Medical Center in Kampala, Uganda, and the first 0.55-T MRI scanner (MAGNETOM Free. Max, Siemens Healthineers, Erlangen, Germany) in Africa, at Hospital Geral De Cabinda, in Cabinda, Angola.

3.9.4 | Apply machine learning technology to enhance healthcare services and delivery

One of the ways to boost the quality of the low-field MR images is the use of artificial intelligence (AI) approaches such as Image Quality Transfer,[38] which propagates information from expensive high-quality images acquired at high-field to the inexpensive, low-quality images, such as those acquired with low-field.[39] Beyond image enhancement, AI technology can enhance healthcare delivery by enabling faster diagnoses as well as facilitating patient referrals. Alhough the role of AI technology continues to grow in the medical field, there is a lack of data diversity, especially from low- and middle-income countries.[42] Countries in SSA need to develop legal and regulatory frameworks to support data science research that may pave the way for precision medicine and other medical advances.

3.9.5 | Digitize radiology and adopt enterprise imaging to improve data management

Digitizing radiology is a critical step for medical facilities as it enables teleradiology services, interinstitutional image exchange, robust storage of imaging data, as well as cost and time savings for patients. Furthermore, digitizing radiology is essential to the adoption of enterprise imaging, which involves integrating all healthcare data into one system that can be accessed using a universal viewer.[34] Instead of storing patient information and imaging files in disparate departmental systems, with enterprise imaging, all data are stored in a central database. The benefits of enterprise imaging include improved patient safety, a reduction in redundant tests, and remote access to imaging on mobile devices.[34]

3.9.6 | Advocate for increased public and private investment in medical imaging research

Locally sourced medical equipment and consumables will provide significant cost reductions for both the healthcare provider and the patient. Increased production of medical research in SSA will facilitate knowledge transfer of the best clinical practices in low-resource settings. More importantly, local manufacturing of MRI technology such as the low-field brain MRI system developed at Mbarara University of Science and Technology, Uganda, led by Dr. Johnes Obungoloch in collaboration with global partners,[43] addresses procurement and sustainability challenges.

3.9.7 | Couple energy sources to provide stable electricity solutions for healthcare providers

In the absence of stable electrical power infrastructure, healthcare facilities can couple up different energy sources to provide a reliable source of electricity for MRI equipment and other medical devices. For example, Crestview Radiology Limited, a busy private clinic in Nigeria with a 1.5-T MRI (20–25 MRI scans/day) and one CT (10–15 scans/day), developed a local solution to stable uninterrupted power supply by coupling the electricity provided from the National Grid and alternative power sources to support full operation of its imaging devices (Figure 6, Figure S6). To ensure that stable power is supplied to imaging scanners, the clinic connects its imaging equipment to the power supply via automated voltage regulators/uninterruptible power supply (UPS) systems, while maintaining two backup power diesel generators. Most of the time, the backup generators serve as the main source of power, running at alternate times with one serving as a backup to the other. To ensure proper operation and to minimize the downtime, the clinic has information technology personnel who regularly monitor the performance of the generators and the automatic voltage regulators/UPS systems.

FIGURE 6 Energy solutions for steady power supply in SSA medical imaging facilities. Images of the local energy solution at Crestview Radiology Limited in Lagos, Nigeria, for steady power supply for operation of the MRI equipment and other imaging devices. MRI, magnetic resonance imaging; SSA, Sub-Saharan Africa; UPS, uninterruptible power supply

3.10 | The CAMERA framework

CAMERA was established in 2019 as an ad hoc working group of the ESMRMB in direct recognition of the challenges outlined above. Since then, CAMERA has formalized its goals and strategic plan via a NAS and consultations with several investigators and academic stakeholders through the ISMRM and ESMRMB engagements.

3.10.1 | Vision

To make MRI accessible to provide high value care in Africa and to advance innovation geared towards solving the relevant healthcare needs of the continent.

3.10.2 | Mission

1. **C**reate enabling clinical and research MRI environments
2. **A**dvance MRI education – train and retain
3. **M**aintain, expand, and strengthen MRI networks within Africa
4. **E**mpower African researchers towards need-specific innovation
5. **R**ealize lasting partnerships with academia, industry, and relevant organizations
6. **A**dvocate for diversity and inclusion in MRI

3.10.3 | Structure

The structure of CAMERA is outlined in Figure S7. The governance structure provides strategic direction for the day-to-day activities of CAMERA, ensuring that effective oversight and adequate representation of African MRI clinicians and scientists are balanced with global partners and stakeholder engagements. Five task forces are being established to address the specific MRI needs identified in this study.

3.10.4 | Strategy and approach

We understand that in SSA, training builds on access to technology, and research excellence depends on high-capacity personnel and sustainability is required for Africa to thrive in relevant MRI research translation and clinical application. In this regard, to increase high value MRI use in Africa, CAMERA will focus activities on four core pillars (Figure 7):

1. Advocacy:

a. Raise awareness of the role of MRI in management of Africa's unique healthcare needs through webinars and symposia.
b. Facilitate partnerships and collaboration between MRI OEMs, distributors, and users in the region to enhance procurement, effective use, and maintenance of scanners.
c. Advocate for funding support for MRI research including from nontraditional sources (e.g., the recent award from the Chan Zuckerberg Initiative).

2. Effective training and mentorship:

a. Use a train-the-trainer approach with tiered learning competency to upskill and mentor an interdisciplinary group of emerging influential MRI experts in targeted areas (i.e., brain imaging and low-field MRI) that will lead to: (i) high value acquisition and workflow (i.e., protocol optimization, pulse sequence programming, MRI safety, hardware development, and enterprise imaging); (ii) high image quality (i.e., image processing and analysis and imaging informatics); (iii) high value diagnostics (i.e., a case-based learning approach); and (iv) improved research translation capacity (i.e., grant writing, publication, research ethics, data management).

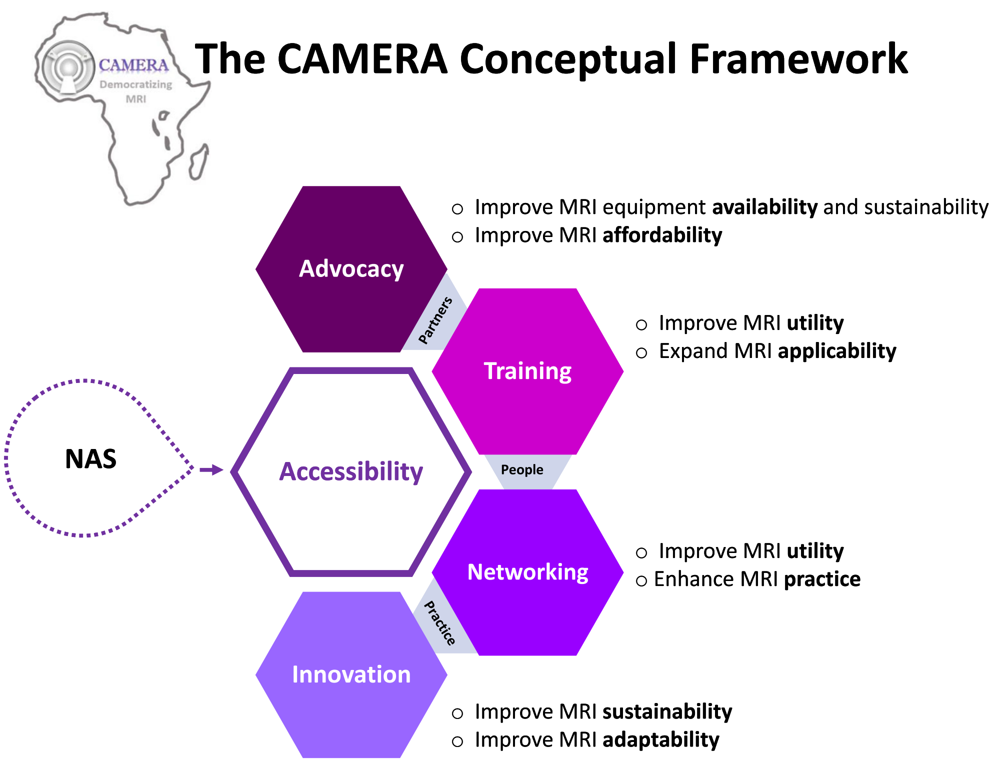

FIGURE 7 The CAMERA conceptual framework for advancing MRI access in Africa. The CAMERA conceptual framework integrates four core pillars of activities (advocacy, training, networking, and translational research innovation) to address Africa's multifaceted MRI accessibility challenges and transform healthcare across Africa. The framework is informed by a NAS and a series of focused meetings where accessibility gaps were identified. This framework outlines an approach for working with partners to advocate for affordable MRI technology, which will provide enabling environments for qualified people to use best practices to drive and democratize MRI across Africa. CAMERA, Consortium for Advancement of MRI Education & Research in Africa; MRI, magnetic resonance imaging; NAS, needs assessment survey

b. Use a decentralized training approach to enable wide replicability, particularly to non-Anglophone regions. Novel training modes and tools such as the use of social media (e.g., Abayomi Opadele's Physics + Medicine YouTube series), podcasting, and Twitter will be employed to asynchronously provide educational opportunities.
c. Train in place by bringing experts to train-the-trainer at their local setting using the local infrastructure to improve capacity. This train-in-place approach supported by optimal network will retain trained experts and minimize human capital flight.

3. Networking:

a. Provide access to regular crossregional meetings to foster regional collaboration, support local isolated groups, and expand the use of MRI in, for example, cardiac application, learning from regional leaders such as Professors Ntobeko Ntusi and Ernesta Meintjes at University of Cape Town, South Africa.
b. Provide access to global MRI collaboration through establishment of the African Chapter of the ISMRM as well as partnerships with other international imaging societies (ESMRMB, SCMR, and MICCAI, etc.)
c. Develop a platform for MRI resources and user forums to share best practices, especially given that most of the scanners in SSA, including the 1.5- and 3-T systems, are reconfigured versions and SSA users do not have direct connection to OEMs.

4. Translational MRI technology innovations:

a. Develop, support, and implement relevant MRI innovations that will facilitate sustainable MRI technology through: (i) AI-enabled retooling of existing MRI scanners; (ii) clinical application of contrast-free imaging techniques to provide no-cost solutions to consumables, such as the use of arterial spin labeling; and (iii) ease-of-use or graphical-user-interface open-sourced image processing and analysis pipelines.

4 | DISCUSSION

We examined the availability and use of MRI in Africa, focusing on the Sub-Saharan region to provide a novel framework to address MRI needs. Over a 2-year period, we identified threats to access, use, and development of MRI in the region from a NAS and a series of focused discussions at ISMRM and ESMRMB. We observed a promising increase in high-field MRI despite challenges due to limited power supply, suboptimal physical infrastructure, and lack of knowledgeable MRI personnel. A significant proportion of the high-field MRI scanners were in small- to medium-sized private centers, often unaffiliated with academic institutions and driven by a business model. Despite the general limited access to biomedical engineers to provide regular MRI equipment maintenance, a substantial proportion of low-field MRI scanners were still in clinical use past their obsolescence period. The prohibitive cost of MRI services contributes significantly to lack of access, underutilization, and challenges to sustainability of MRI in SSA. At an average cost of US$200 for an MRI examination and an average monthly salary of roughly US$470 purchasing power parity,[44] the average African in SSA cannot afford an MRI scan. These challenges notwithstanding, we discerned a zeal in the region to receive relevant training, research support, and access to collaborate and partner with the global MRI community to enable local experts and users address the MRI needs in Africa, particularly SSA.

4.1 | The state of MRI imaging in SSA

MRI in Africa has been evolving over the last decade, although progress has been very slow and disproportionate in meeting the needs of the 1.5 billion people on the continent, and insufficient in competing adequately with global imaging trends. Africa, a continent with the largest global burden of chronic diseases and where premature deaths from NCDs, including heart disease and cancer, will surpass deaths from infectious diseases in 10 years,[45] has the worst access to MRI technology.[28] The USA, with a population similar to West Africa, has 37 times more MRI scanners than the entire region of West Africa.[2,28]

The CAMERA NAS revealed that a considerable portion (40%) of MRI scanners in SSA are low-field, that is, less than 1 T field strength, and 80% are still in use well past their obsolescence. These low-field units have limited resolution and poor signal-to-noise ratio compared with 1.5- and 3-T scanners standard in clinical practice and research, but can be retooled to produce high-value images using machine learning.[46] Although the number of high-field scanners is steadily increasing in SSA (Figure 1), the severe shortage in skilled MRI personnel has exacerbated the lack of access to MRI and its advancement in the region to meet local needs.

MRI is grossly underutilized in SSA as our NAS indicated, with 47% of the sites performing clinical imaging on ~five patients/scanner/day and only 8% imaging 15 or more patients per/scanner/day. An average MRI facility in the Global North scans 20–23 patients/scanner/day and is able to do so because it has highly skilled MRI technologists, optimized MRI imaging protocols, access to MRI physicists and engineers, and highly specialized radiologists.[47] Around 65% of imaging facilities in SSA do not have access to an MRI physicist. This is quite troubling given that most available scanners provide low-quality images. There are approximately two radiologists pmp in SSA compared with 116 pmp in Europe and North America.[28] These radiologists are nonsubspecialized, work longer hours, face challenges of frequent machine breakdowns and low supply of consumables (e.g., contrast agents), and have to contend with suboptimal infrastructure to care for a population with unique medical conditions.[47] To raise the capacity of MRI in SSA to provide high value care comparable with the Global North, a minimum of 72,000 radiologists,[48] 22,000 radiographers,[49] 2400 medical physicists,[50] and 800 biomedical engineers[51] need to be trained across the region over the next 8 years.

For preclinical research, essential in drug discoveries, virtually none of these scanners have been used for preclinical research. In fact, a PubMed search revealed no publication from Africa where MRI was used for preclinical imaging. This is no surprise given that a large majority of preclinical research performed globally are on ≥3T MRI scanners. However, with novel imaging protocols and large animal models, African scientists supported by skills training can develop preclinical MRI research capacity on lower field strength scanners.

4.2 | Key challenges to the advancement of MRI in SSA

The challenges in Africa are enormous and there is a critical need to build the necessary infrastructures, acquire adequate equipment, attract and retain qualified professionals, develop relevant educational training programs, and have a political will that will generate policies for effective and accessible healthcare within budgetary constraints. Given the growth of technological advances in imaging with the application of data science and artificial intelligence, without any robust intervention, Africa's disparities will worsen. The strategic solutions in Africa must be tailored to the unique socioeconomic fabric, culture, and heterogeneous nature of the region. There is a huge temptation to dump ideas and innovations from developed nations on Africa. Even although this may appear simpler and faster, by and large the results over the years have been dismal at best. The solutions must come from within, through educational empowerment and capacity development.

Infrastructural problems such as a lack of proper laboratories and unserviceable, obsolete equipment for research has hampered medical research in Africa, in general. This is even more acute for highly advanced and relatively expensive MRI scanners, which after 10 years are no longer deemed state-of-the art and receive no support from manufacturers and software developers.[47] For the growing fleet of newly acquired high-field scanners in SSA, this raises another area of concern as the majority will reach their end-of-life cycle by 2025. Lack of proper facilities cannot be understated, as almost all the scanners in SSA are not equipped with research licenses to unlock advanced research imaging sequences readily available in academic centers in other regions. Besides the principal challenge of skilled manpower, another key barrier to the advancement of MRI in SSA is the isolation of emerging local MRI experts. There are no formal networks within Africa to bring together African MRI experts and users to exchange ideas, pool resources, and develop relevant imaging solutions to address local needs. Although 72% of respondents to the CAMERA NAS participate in MRI research, an overwhelming majority are not able to engage or share their work with other MRI scientists nationally, regionally, or internationally (Figure 2). As of 2019, less than 1% of attendees to the ISMRM, the largest scientific society for development and application of MRI in biomedicine, come from Africa.[52] This is well reflected in MRI research output (publications) from Africa, which comprise less than 1% of the global output. Moreover, major contributions from SSA come from either collaborative work with scientists from the "West" or institutions with a large presence of scientists from the "West" (e.g., The ENIGMA publications).

While the problems are vast and multidimensional, we aim to address four crucial challenges: access and availability, personnel training and education, research capacity, and sustainable technology, using a four-pronged approach within our framework (Figure 7), to create what Teng-Leong Chew[53] aptly denotes as "an unbroken chain of resources and expertise" that will enable Africa to use MRI to realize its healthcare needs.

4.3 | Anticipated impact

MRI is a versatile imaging tool for investigating structural, functional, and molecular changes in vivo. Improving training and research collaboration in SSA will advance the use of MRI technology in the region to find relevant solutions to imaging needs, especially in the absence of "luxury suite" imaging (e.g., PET, magnetoencephalography [MEG], and high-density electroencephalography [EEG]).[3,28] For instance, epilepsy disproportionately impacts SSA (10-fold higher incidence compared with high-income countries),[54] and up to 30% of epilepsy patients require surgery to resect brain lesions to alleviate seizures. Anatomical brain MRI performed as standard of care to localize the lesion for surgery appears normal in one-third of these patients and luxury suite imaging using PET or MEG and high-density EEG are functionally used to localize lesion(s).[54] In SSA, these luxury technologies are extremely scarce: there are three PET scanners and no MEG in the entire region (minus South Africa).[28] Functional MRI techniques (perfusion, diffusion spectroscopy) can functionally identify epileptic lesions,[54] but none of these are routinely used in clinics in the Global North and, as such, there are no standard image acquisition, processing, or interpretation guidelines. Current research data reporting these techniques focus largely on 3-T MRI studies using higher brain acquisition coils. By (1) training MRI radiographers to master acquisition of these advanced techniques and adapt parameters from research to their lower-field strength systems, (2) training MRI physicists to analyze images from their lower quality scanners leveraging on machine learning, (3) training biomedical engineers and physicists to build brain coils compatible with reconfigured and legacy systems to increase the spatial resolution, and (4) upskilling radiologists to read these novel MRI techniques, epilepsy surgical patients in SSA may expect to have similar outcomes to their peers in the rest of the world. Until then, these African patients—approximately 303,000 each year[55]—will continue to suffer tractable epilepsy without any access to successful treatment. Similar remarks can be made for cancer, stroke, and cardiac imaging, as well as research studies, particularly in dementia and mental health, where functional and molecular imaging biomarkers are highly sought after but underdeveloped in MRI scanners typically available in SSA.

5 | CONCLUSION

With nearly one-fifth of the world's population, Africa has the least access to MRI machines. Our NAS combined with WHO and IAEA data provide the most up-to-date data on MRI density in Africa, although several high-field systems have been installed since October 2020 (when the last survey responses were captured). Although a considerable number of NAS responses came from West Africa, the findings along with the focused symposia provide a unique insight into Africa's MRI needs. Although it appears that more high-field systems are being used in the region, reported gaps in training, maintenance, and research capacity indicate ongoing challenges in providing sustainable high value MRI access in SSA. As we lay out our roadmap for achieving access to high value MRI in SSA and establish task forces to accomplish our mission, we invite the global MRI community to partner with us and our African colleagues in effecting transformative access to MRI. CAMERA can be reached through our website, https://www.cameramriafrica.org/, by direct email at info.camera.mri@gmail.com, and on social media at Twitter, @CAMERAAfrica.

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AUTHOR CONTRIBUTIONS

Udunna C. Anazodo conceptualized and developed the outline of the manuscript. Udunna C. Anazodo, Jinggang J. Ng, Boaz Ehiogu, Iris Asllani, and Farouk Dako conducted background work, analyzed the NAS, and wrote the first draft. Udunna C. Anazodo designed the NAS along with editorial contributions from the CAMERA Environmental Scan Task Force (Edward Chege Nganga, Godwin Ogbole, Farouk Dako, Henk-Jan Mutsaerts, Mario Forjaz Secca, and Johnes Obungoloch) Mamadou Diop translated the NAS to a French version. All authors provided valuable input, reviewed, and approved the final version of the manuscript.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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