ORIGINAL ARTICLE

CME

Scan With Me: A Train-the-Trainer Program to Upskill MRI Personnel in Low- and Middle-Income Countries

Abdul Nashirudeen Mumuni, PhD[a], Katerina Eyre, PhD[b], Cristian Montalba, BSc[c], Aduluwa Harrison, MSc[d], Surendra Maharjan, PhD[e], Francis Botwe, BSc[f], Marina Fernandez Garcia, MSc[g], Abderrazek Zeraii, PhD[h], Matthias G. Friedrich, MD, FESC, FACC[b,i], Abiodun Fatade, MBBS[j], Ntobeko A. B. Ntusi, MBChB, FCP(SA), DPhil, MD[k,l], Tchoyoson Lim, MBBS, FRCR, MMed Diagnostic Radiology[m], Ria Garg, MD[n], Muhammad Umair, MD[o], Hammed A. Ninalowo, MD[p], Sola Adeleke, MBBS, PhD, MRCP(UK)[q], Chinedum Anosike, MBBS[r,s], Farouk Dako, MD, MPH[t,u], Udunna C. Anazodo, PhD[d,k]

Credits awarded for this enduring activity are designated "CME" by the American Board of Radiology (ABR) and qualify toward fulfilling requirements for Maintenance of Certification (MOC) Part II: Lifelong Learning and Self-assessment. To access the CME activity visit https://cortex.acr.org/Presenters/CaseScript/CaseView?Info=vHYdCQwzTx2UWTNHfC78%2f2eW5Etrg85nEdrR0v3GinU%253d. CME credit for this article expires July 31, 2025. All CME articles can be found on JACR.org by navigating to CME on the dropdown menu.

[a]Department of Medical Imaging, University for Development Studies, Tamale, Ghana.
[b]Courtois CMR Research Group at the Research Institute of the McGill University Health Center, Montreal, Quebec, Canada.
[c]Biomedical Imaging Center, Pontificia Universidad Católica de Chile, Santiago, Chile.
[d]Montreal Neurological Institute, McGill University, Montreal, Quebec, Canada.
[e]Department of Radiology and Imaging Sciences, Indiana University School of Medicine, Indianapolis, Indiana.
[f]Clinical Imaging Sciences Centre, University of Sussex, Brighton, United Kingdom.
[g]Institute for Molecular Imaging and Instrumentation, Universitat Politenica de Valencia, Valencia, Spain.
[h]Biophysics Department, Higher Institute of Medical Technologies of Tunis, Tunis, Tunisia.
[i]Departments of Cardiology and Diagnostic Radiology, McGill University Health Center, Montreal, Quebec, Canada.
[j]Crestview Radiology Ltd., Lagos, Nigeria.
[k]Department of Medicine, University of Cape Town, Cape Town, South Africa.
[l]South African Medical Research Council Extramural Unit on Intersection of Noncommunicable Diseases and Infectious Diseases, Cape Town, South Africa.
[m]National Neuroscience Institute, Singapore, Singapore.
[n]Department of Internal Medicine, Geisinger Wyoming Valley Hospital, Wilkes-Barre, Pennsylvania.
[o]Johns Hopkins School of Medicine, Baltimore, Maryland.
[p]IRDOCNIGERIA, Lagos, Nigeria.
[q]Department of Oncology, Guy's & St. Thomas' Hospital, London, United Kingdom.
[r]Accuread Radiology Nigeria, Lagos, Nigeria.
[s]Warrington and Halton Hospitals National Health Service Foundation Trust, Warrington, United Kingdom.
[t]RAD-AID International, Chevy Chase, Maryland.
[u]Perelman School of Medicine, University of Pennsylvania, Philadelphia, Pennsylvania.
Corresponding author and reprints: Udunna C. Anazodo, PhD, Montreal Neurological Institute, McGill University, 3801 University Street, Montreal, QC H3A 2B, Canada; e-mail: udunna.anazodo@mcgill.ca.

This project was partially supported by the Natural Sciences and Engineering Research Council of Canada (NSERC), Healthy Brains and Healthy Lives (HBHL) through the support from Canada First Research Excellence Fund (CFREF) and by the McGill University Doctoral Internship Program and Graduate Mobility Award. The authors state they have no conflict of interest related to the material discussed in this article. The pilot SWiM Program was in collaboration with the Courtois CMR Reserach Group, McGill University Health Centre (MUHC), Siemens Healthineers Erlangen, Germany, Circle Cardiovascular Imaging, Accuread Radiology Nigeria Ltd, EuraCare Multispecialist Hospital, Nigeria, Crestview Radiology Ltd, Nigeria, Canon Medical USA, John Hopskins Medical School, USA, and Siemens Healthcare Limited South Africa. The authors are grateful to the faculty of the pilot program for their valuable contribution of course materials and training resources, especially to Guy Poloni and Gaia Banks of Siemens Healthineeers, Burno Triaire and Chia-Ying Liu of Cannon Medical Systems, Yoko Kato, Ela Chamera, and Bharath Venkatesh of John Hopkins Medical School, Anne Hui Sze Kwong of Circle Cardivovascular Imaging, Patricia Solomons of Siemens Healthcare Proprietary, South Africa, Nerissa Naidoo of Advance Imaging South Africa, Katia Menacho Medina of Barts Hearts Centre, St Batholomew's Hospital, UK and Nirmal Parsad Neupane of Shahid Gangalal National Heart Centre, Nepal. The authors thank the learners for their participation and evaluation of the first SWiM program. All authors are non-partner/non-partnership track/employee.

1546-1440/24/$36.00 ■ https://doi.org/10.1016/j.jacr.2024.04.026

Abstract

Purpose: Access to MRI in low- and middle-income countries (LMICs) remains among the poorest in the world. The lack of skilled MRI personnel exacerbates access gaps, reinforcing long-standing health disparities. The Scan With Me (SWiM) program aims to sustainably create a network of highly skilled MRI technologists in LMICs who will facilitate the transfer of MRI knowledge and skills to their peers and contribute to the implementation of highly valuable imaging protocols for effective clinical and research use.

Methods: The program introduces a case-based curriculum designed using a novel train-the-trainer approach, integrated with peer-collaborative learning to upskill practicing MRI technologists in LMICs. The 6-week curriculum uses the teach-try-use approach, which combines self-paced didactic lectures covering the basics of MR image acquisition (teach) with hands-on expert-guided scanning experience (try) and the implementation of protocols tailored to provide the best possible images on their infrastructures (use). Each program includes research translation skills training using an established advanced MRI technique relevant to LMICs. A pilot program focused on cardiac MRI (CMR) was conducted to assess the program's curriculum, delivery, and evaluation methods.

Results: Forty-three MRI technologists from 16 LMICs participated in the pilot CMR program and, over the course of the training, implemented optimized CMR protocols that reduced acquisition times while improving image quality. The training resources and scanner-specific standardized protocols are published openly for public use in an online repository. In general, at the end of the program, learners reported considerable improvements in CMR knowledge and skills. All respondents to the program evaluation survey agreed to recommend the program to their colleagues, while 87% indicated interest in returning to help train others.

Conclusions: The SWiM program is the first master class in MRI acquisition for practicing imaging technologists in LMICs. The program holds the potential to help reduce disparities in MRI expertise and access. The support of the MRI community, imaging societies, and funding agencies will increase its reach and further its impact in democratizing MRI.

Key Words: Cardiac MRI, medical education, peer learning, radiography, low- and middle-income countries, SWiM

J Am Coll Radiol 2024;21:1222-1234.

INTRODUCTION

The burden of noncommunicable diseases (NCDs) such as cancer, cardiovascular disease, and dementia continues to rise, with NCDs among the leading causes of death worldwide [1]. In 2015, the United Nations established a global target through its Sustainable Development Goals to reduce premature deaths due to NCDs by a third by 2030, through prevention and treatment. One path toward achieving this goal is to improve global capacity for timely and routine diagnostic imaging for detection of population-specific disease traits to enable tailored prevention and treatment strategies. These improvements must target regions with the largest and growing NCD burden, which are primarily in low- and middle-income countries (LMICs) [2]. MRI is routinely used for clinical diagnosis and management of NCDs, as well as in research to characterize disease etiology for drug discoveries. Although the rapid translation of MRI research continues to improve the prognosis of patients with NCDs, the majority of the world's population does not have access to standard MRI services [3], which exacerbates disparities in mortality and morbidity rates [1]. Africa, for example, a region with one of the largest burdens of chronic diseases [1], has the worst access to MRI [4]. With 3 times the population of the United States, it has 30 times fewer MRI scanners and, worse, 100 times fewer radiologists and imaging physicists [3,5]. This disparity is reinforced by its poor capacity for MRI; 40% of scanners are obsolete low-field (<1.0-T) systems, and standard-of-care (1.5-T) systems are severely underused, with suboptimal imaging protocols for clinical care and research translation [4]. The majority of imaging facilities are in private practices [4,6] that are disconnected from academic centers; as such, a substantial portion of personnel are excluded from continuing medical education activities, global outreach training opportunities, or research translation efforts including clinical trials. The limited imaging capacity to conduct deep population phenotyping bars the inclusion of Africa in prevention and treatment discoveries [7]. Thus, to ensure that we all can benefit from current and emerging imaging technologies to address the growing burden of NCDs, we must work together to increase MRI capacity in Africa and LMICs.

Various approaches have been proposed to improve MRI capacity [5], including MRI education to supplement the lack of postgraduate training [8], novel low-field MRI systems to improve availability and replace obsolete systems [9,10], (AI) solutions for fast scanning, image enhancement, and rapid analysis and interpretation

[9,11]. These approaches often focus on radiologists and do not include the MRI technologists who are tasked with providing high-quality MR images for clinical and research use. Moreover, current training interventions are usually brief, with limited measurable impact to transform the clinical and imaging landscape in LMICs. The increasing role of AI in radiology and its application to global health also create new inequities in LMICs, particularly in sub-Saharan Africa, where access to high-quality data for AI development and validation is equally limited [11]. Therefore, strategies aimed at closing these disparities should include lifelong learning opportunities for LMIC technologists, with an emphasis on building the critical capacity to adequately use their infrastructure to provide effective and accessible clinical and research services, even within their unique resource constraints. These interventions should upskill them to a comparable level of expertise as their counterparts in other parts of the world for equitable access to diagnostic imaging.

Here, we present an initiative to train MRI technologists in LMICs who can train their peers to acquire high-quality MR images that meet international best practices. The Scan With Me (SWiM) program is a free train-the-trainer capacity-building initiative of the Consortium for Advancement of MRI Education and Research in Africa (CAMERA) [4]. This is the first training of its kind that targets practicing MRI technologists in Africa, Latin America, and Asia and implements on-site and virtual training techniques under a structured curriculum that spans the full length of MRI practice from patient care to image analysis, including advanced techniques for research translation. To evaluate the proposed pedagogic approach and curriculum, a pilot program was conducted using cardiac MRI (CMR) to establish the train-the-trainer model and determine its impact in advancing practical MRI skills in resource-limited settings. CMR was chosen as the pilot because of the relatively high burden of cardiovascular disease in LMICs [12] and the limited cardiac diagnostic imaging capacity in these regions, coupled with the general lack of CMR training opportunities for technologists. The overall goal of the SWiM program is to train a collaborative network of LMIC experts to optimize their imaging infrastructure and use this to obtain rich datasets that will inform clinical care and drive the development of relevant imaging tools to advance prevention and treatment discoveries.

METHODS

The pedagogy, curriculum, and delivery of the SWiM program were developed using a conceptual framework informed by a comprehensive MRI needs assessment study [4] conducted by CAMERA. The CAMERA framework, described in detail by Anazodo et al [4], provides a path toward increasing MRI capacity by leveraging strategic global partnerships with imaging societies, industry partners, and global health advocates to train and mentor the critical mass of MRI experts in LMICs who will work together to implement relevant MRI innovations. This framework, along with the needs assessment study findings on training needs and gaps, shaped the program's objectives:

1. Upscale and advance the MRI knowledge of technologists practicing in resource-limited settings.
2. Build standard skills in MRI techniques to accelerate the competence of technologists.
3. Implement standard MRI protocols and best practices adapted for optimal image acquisition in resource-limited settings.
4. Train and retrain imaging experts who will sustainably advance the practice of MRI in LMICs.
5. Enable imaging research capacity through a collaborative culture and a network of imaging experts in LMICs.
6. Link vendor resources and partnership with local clinics.
7. Create a collaborative user and expertise network to support local needs.
8. Create a network of sites with standardized protocols and advanced MRI capability.

The SWiM Pedagogy

The SWiM program curriculum is based on RAD-AID's teach-try-use model, designed for informatics (PACS) implementation in LMICs [13] and CAMERA's peer-collaborative learning and blended-learning methods, introduced here (Fig. 1). Together, this curriculum provides rapid acquisition of MRI competencies in resource-constrained settings and the ability to track and measure competencies for a nonaccredited program. The program targets highly motivated private and academic imaging facilities across LMICs and provides free hands-on training to their practicing radiography personnel while linking the facilities together for robust cross- and intraregional collaborations. The learners are selected through an assessment process (ie, readiness application) designed to evaluate candidates' work environments and skill levels, to achieve a balance in career stage, gender, and geographic location and to tailor training to local needs.

Each SWiM program focuses on one real-world application and takes learners through three blocks in which they systematically gain competencies as a diverse team of small groups. The small groups facilitate peer learning and networking to encourage a deeper culture of teamwork and collaboration, especially given that most of the MRI systems in these regions are obsolete systems or clinical systems

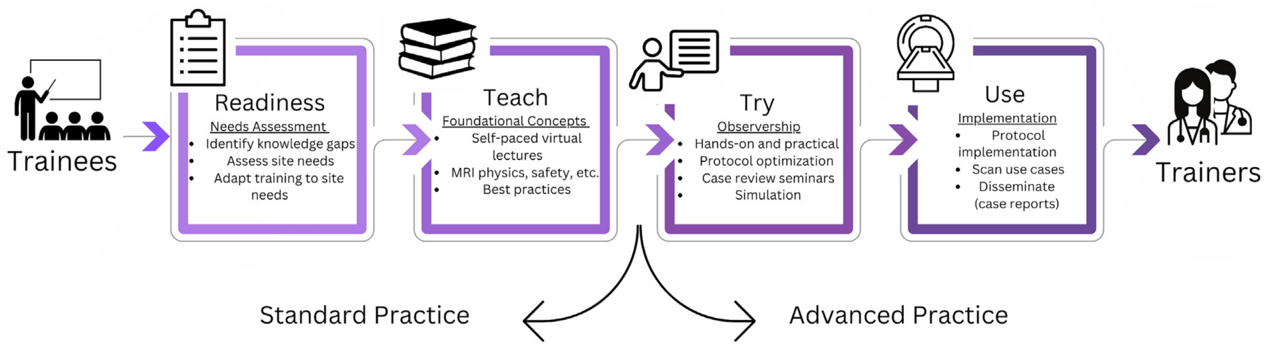

Fig. 1. The Scan With Me program train-the-trainer approach.

designed specifically for resource-constrained settings but often with limited application training. Networking is integrated throughout the training blocks by weekly scheduled team exercises for peer-based knowledge acquisition, assessments, and team bonding activities.

The curriculum is tailored to accommodate the technologists' learning preferences [4], the typical work schedules of LMIC technologists, and the various time zones of the learners. A 60-hour course was developed and split into three 20-hour blocks, following the teach-try-use strategy (Fig. 1).

Teach: Two-Week Self-Paced Virtual Foundation Lectures (20 Hours). Self-paced didactic lectures were curated from reading materials and video lectures on fundamentals of medical image acquisition and analysis for the specific application (eg, CMR). This includes a physics primer; the basics of image acquisition, processing, and analysis; and the basics of patient care (including safety considerations) relevant to the use case or application. The concept of an advanced clinical-ready MRI technique, and to which the potential to provide high-value care in resource-constrained settings is apparent, is also introduced. This block is designed to comprehensively teach concepts on the topic over 16 hours supported by 3-hour weekend tutorials and 1-hour scheduled networking sessions. Weekly team assignments are given to elicit collaborative work and knowledge sharing, while assessing progress in knowledge acquisition. The assignments are reviewed at the tutorial to ensure that all learners understand the materials.

Try: Two-Week Hybrid Image-athon Observership (20 Hours). The foundation block is followed by hands-on live scanning and analysis skills training (observership) and replication (try) on simulators. Here, the learners work alongside experienced MRI technologists and applications experts from vendor partners to explore best practices and apply the knowledge gained from the first block by actively acquiring and analyzing high-quality images. The learners observe live demos of optimal scanning on similar infrastructure and design scan parameters on simulators to systematically learn how to tailor protocols for their relevant clinical needs. Demonstrations and hands-on trials of image analysis on established software are also provided. The live scans and software demos are offered virtually from vendor sites or selected learner training sites. The observership is balanced with a 10-hour case-based seminar series, delivered daily as 1-hour lectures by a faculty of clinical and technical content experts. The lectures are designed to provide a 30-min didactic overview and a 30-min case-series discussion and question-and-answer session. A 6-hour weekend peer coaching observation and feedback tutorial is used as a peer-learning conference [14] to track progress and further hone skills. The goal is to provide a simulated learning environment of best practices that blend virtual and on-site learning. A capstone team project of simulated cases is used to trial scan protocol optimization and best practices on patient care, acquisition, and analysis, to prepare learners for application on their scanners. This includes a description of MRI screening procedures and a clinical case report, structured following guidelines for publishing case reports [15].

Use: Two-Week Hybrid Practicum (20 Hours). In the final block, the learners are guided through weekly exercises and practical implementation training sessions to adapt scan parameters and protocols and use these to scan two to six volunteers at their local facilities. This block is split into a 16-hour scheduled networking session for collaborative implementation of imaging protocols and a 4-hour peer-learning weekend conference and tutorial. A second capstone team project is used to guide the application of best practices at local sites, where learners on each team work collectively to adapt scan parameters to their site and present one site's work at the final peer-learning conference. The adapted scanner-specific parameters, protocols, and MRI safety procedures from all sites are openly shared among learners and made available, where permitted, to the public. The images acquired are retained for teaching purposes and not made publicly available.

The SWiM Delivery Approach

Each learner selected for the SWiM program is trained as a member of a team and assigned a team before the start of the teach block. Because of time-zone limitations, the learners are placed in regional teams but regrouped during the practicum (try) phase on the basis of the make of their scanners (GE, Siemens, Philips, Canon, etc). This facilitates protocol implementation on common platforms.

The teams are organized into small groups of 7 to 10 learners with a leadership structure designed to overcome challenges associated with peer-learning group dynamics [14]. Each team is assigned a team supervisor and an elected team captain (ie, peer-learning leader [14]). The team supervisor is an experienced MRI technologist on the SWiM faculty, who codeveloped the training materials, coordinates tutorials, and provides logistical support and guidance to the team. The team captain is a learner who is delegated to coordinate the team's activities (including assignment submissions), report issues, and provide feedback to the supervisor. Each team manages its WhatsApp page independently with oversight from the supervisor. This encourages networking and collaborative learning in an informal and peer-to-peer fashion [16].

All course materials, from the foundational reading and video lectures to observership and practicum seminars and live demos, are delivered through a hybrid academic conference management platform (Fourwaves; https://fourwaves.com). The platform was adapted to host the program's web page and provide features for application processing, curriculum information, frequently asked questions, code of conduct, and the training schedule (https://event.fourwaves.com/swim). The Fourwaves live app was used for all live sessions by embedding a Zoom meeting link for each session. Recorded lectures and past seminars were integrated through YouTube for on-demand viewing when missed or for course reviews. The live app also features an intuitive live chat with an activity feed and networking rooms for group or one-on-one conversations. At the end of each SWiM program, all materials and permissible adapted scanner-specific protocols are publicly available on a repository (https://github.com/CAMERA-MRI/SwiM).

The SWiM Learning Assessment and Program Evaluation

Learners' assessments are composed of weekly assignments, capstone projects, and peer-learning conference presentations. Attendance to gauge active engagement in seminars and weekend tutorials and conferences was closely monitored. The involvement of learners during weekly networking meetings or team exercises is evaluated by team supervisors to recognize outstanding performers and provide feedback to those who require coaching. To incentivize active participation and outcomes that can be individualized, a program recognition in the form of a certificate and special mention at the final peer-learning conference and on social media channels is provided to learners.

The quality of the program curriculum, depth, delivery, and approach are evaluated by the learners using five-point Likert-type scale pre- and posttraining surveys administered at the start and end of the program, respectively. The impact of the program is measured through the number of learners, diversity and geographic coverage, program evaluation results, and competency of learners to obtain high-quality images from their limited infrastructure.

The Pilot CMR SWiM Program

The first SWiM program ran from August 22 to October 7, 2023. Candidates were selected according to the eligibility criteria, which included current employment as an MR technologist, availability of all essential CMR equipment at their clinic, CMR workload, and an effort to achieve balanced representation in terms of gender, career stage, and geographic location among the admitted applicants. The program was advertised via various platforms, including on X (formerly known as Twitter), LinkedIn, and WhatsApp, and through targeted regional professional mailing lists. The application was open from August 4 to 14, 2023.

The foundation, observership, and practicum materials were curated from existing open-access resources and through recruitment of highly qualified content experts. The content was progressively varied in skills complexity from standard CMR acquisition to emerging advanced applications such as non-contrast-enhanced techniques (4-D flow [17], oxygen-sensitive CMR [OS-CMR]) [18], rapid imaging approaches [19,20], quantitative CMR [21], and training in CMR case reporting [15]. The acquisition and analysis simulated learning environments were based on the Smart Simulator (Siemens Healthineers) and Circle Cardiovascular Imaging (cvi42) CMR software trial licenses. Two cases (apical cardiomyopathy and cardiac hydatid cyst) were simulated to match common LMIC cases [12] using references from the Society for Cardiovascular Magnetic Resonance case of the week library and provided for the observership capstone project. One of the cases included a scan contraindication (Swan-Ganz thermodilution catheter and electrodes with tip in the right lower lobe pulmonary artery) to assess overall

CMR knowledge, including safety. Each team was tasked to deliver CMR protocols for the simulated cases designed on the Smart Simulator, a general MRI safety screening form, two case-specific MRI safety screening forms, and two case reports with images and analysis obtained from the cvi42 software package. Collectively during the practicum, CMR protocols were tailored for different cardiac indications using a limited selection of available imaging sequences, while optimizing for balance between resolution, signal-to-noise ratio, and scan time for the local scanners and accessories (eg, 1.5-T MRI six-channel body coil). The practicum capstone project required submission of the collection of optimized CMR protocols implemented on their scanners.

Advanced CMR in the form of OS-CMR [18] was fully implemented on-site on a 1.5-T MRI scanner (Magnetom Essenza; Siemens Healthineers) equipped with a six-channel body coil at one of the learner sites (Euracare Multi-Specialist Hospital [EMH], Lagos, Nigeria) [22]. OS-CMR is a needle-free, nonpharmacologic technique for assessing coronary vascular dysfunction in ischemic and nonischemic cardiomyopathies including heart failure, using T2-weighted MRI and vasoactive breathing maneuvers (hyperventilation and hypercapnia) [18,23]; it is thus a promising highly accessible tool for CMR in resource-limited settings. The OS-CMR training included 4 hours of live scanning and software analysis demos from EMH. Six healthy volunteers were scanned for teaching purposes only, to assess the feasibility of a complete on-site implementation of standard tailored CMR protocols, the effectiveness of the optimization, and the application of the OS-CMR protocol. The OS-CMR protocol followed the established method described by Hillier et al [18] and included cine imaging (balanced steady-state free precession cine sequence) across three long-axis views and the short-axis stack [18], along with OS-CMR during vasoactive breathing maneuvers through two short-axis slices. Left ventricular ejection fraction was determined using the Simpson method [24], and breathing-induced myocardial oxygenation reserve was computed as previously described [18].

A follow-up CMR awareness webinar was provided to referring cardiologists invited from the learners' communities to enhance the use of CMR at the trained sites. The webinar, held on October 2, 2023, by Professor Matthias Friedrich, provided practical knowledge on the appropriate use of CMR and highlighted its utility in clinical care for typical conditions in the region.

RESULTS

A total of 104 candidates applied for the pilot program. Forty-three learners from 28 imaging facilities were selected across nine African, four Latin American, and three Asian countries on the basis of their scores on the assessment criteria (Fig. 2a). Thirty percent were women, 5% were interns, the majority worked on Philips (48%) and 1.5-T (81%) scanners, and most of the learners' facilities did not perform CMR (43%), although they have the hardware to do so (Fig. 2b). The selected learners were grouped into five teams, which consisted of three teams from Africa, one from Latin America, and one from Asia. Each team had appropriate gender and career stage diversity. The pilot program syllabus is outlined in Table 1, and course resources including training materials and optimized protocols are publicly available at the repository (https://github.com/CAMERA-MRI/SWiM). To compensate for the underrepresentation of Canon MRI scanners in the selected pilot cohort, known sites with Canon and CMR hardware were invited to participate in the Canon

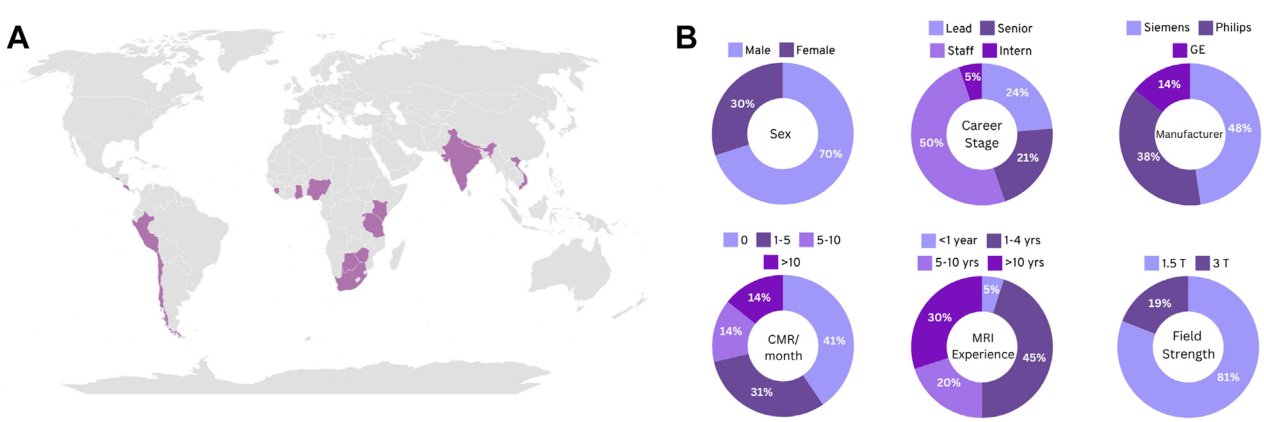

Fig. 2. The pilot program learners' demographics, showing the countries where they work (A) and proportions of the cohort (B) by sex, career stage (categorized as lead, senior, intern technologist, and staff member who is none of the three), MRI experience on the basis of number of years including educational training, the scanner manufacturer, field strength, and number of cardiac MRI scans per month at their facility. CMR = cardiac MRI.

Table 1. The pilot program syllabus and the faculty members who provided original training content

	Topic	Faculty
	Foundational Module—Week 1: Introduction to CMR	
1	Introduction to MRI Physics for CMR 1	
2	Introduction to MRI Physics for CMR 2	
3	Virtual CMR Scanning with Siemens Healthineers	Dr Gaia Banks and Stephanie Koch—Siemens Healthineers, Erlangen, Germany
4	Cardiac Anatomy and Physiology for CMR	
5	CMR Safety I, Artifacts, and Imaging With Devices and Pregnant Women	
6	Weekend Tutorial and Group Exercise: Introduction to CMR Assignment	
	Foundational Module—Week 2: Applications of CMR	
1	CMR Acquisition and Image processing Basics	
2	CMR imaging Techniques (Cine, LGE, and Perfusion Imaging)	
3	Quantitative CMR Imaging (Parametric Mapping): T1 Mapping, T2 Mapping, ECV Assessment, Image Post-Processing and Analysis	
4	CMR Normal Appearance And Pathologies	
5	Advanced CMR: O2-Sensitive CMR	
6	CMR for Radiography I—Introduction to CMR with Philips (French)	Dr Abderrazek Zeraii—Higher Institute of Medical Technologies of Tunis, Tunis, Tunisia
7	Weekend Tutorial and Group Exercise: Applications of CMR Assignment	
	Observership Module—Week 3	
1	CMR II for Radiography: CMR Acquisition, Protocols, and Planning (French)	Dr Abderrazek Zeraii—Higher Institute of Medical Technologies of Tunis, Tunis, Tunisia
2	CMR Flow and Myopathies	Dr Muhammad Umair—Johns Hopkins Hospital, Baltimore, Maryland
3	Myocardial Stress With CMR	Dr Matthias Friedrich MD—Division of Experimental Medicine, McGill University, Montreal, Canada
4	CMR Rapid Protocol: From Research to Practice	Dr Katia Menacho Medina—Barts Heart Centre, Saint Bartholomew's Hospital, London, UK
5	Circle cvi42 Demo	Anne Hui Sze Kwong—Circle Cardiovascular Imaging, Strasbourg, France/Calgary, AB, Canada
6	O2-Sensitive CMR Live Demo I—Scanning	Dr Katerina Eyre—Division of Experimental Medicine, McGill University, Montreal, Canada
7	Group Exercise: Develop an MRI Screening Form and Safety Policy	
	Observership Module—Week 4	
1	How to Write a Case Report	
2	Myocardial Fibrosis	Dr Olukayode (Solomon) Aremu—Cape Heart Institute, Department of Medicine, University of Cape Town, South Africa
3	Cardiac MRI in Evaluation of Postoperative TOF	Dr Nirmal Prasad Neupane—Shahid Gangalal National Heart Centre, Kathmandu, Nepal
4	CMR III for Radiography: Flow, Mapping & Vessel Imaging (French)	Dr Abderrazek Zeraii—Higher Institute of Medical Technologies of Tunis, Tunis, Tunisia
5	CMR Rapid Protocol: Applications in Cardiomyopathies	Dr Katia Menacho Medina—Barts Heart Centre, Saint Bartholomew's Hospital, London, UK

(continued)

Table 1. Continued

	Topic	Faculty
6	CMR Safety and Contraindications	Dr Ives Levesque—Gerald Bronfman Department of Oncology & Medical Physics Unit, McGill University, Montreal, Canada
7	O2-Sensitive CMR Demo II—Analysis	Dr Katerina Eyre—Division of Experimental Medicine, McGill University, Montreal, Canada
8	Capstone Project I CMR Case Study: MR Scan Simulator and Analysis on cvi42	
	Practicum Module—Week 5	
1	Circle cvi42 Live Demo: 4D Flow	Anne Hui Sze Kwong—Circle Cardiovascular Imaging, Strasbourg, France/Calgary, AB, Canada
2	Capstone Project II: CMR Protocol and Parameter Optimization	
	Practicum Module—Week 6	
1	Canon Medical Live Demo	Dr Chia-Ying Liu, Ela Chamera, Dr Yoko Kato, Dr Bharath Ambale Venkatesh, Dr Chikara Noda, Joao Lima—Canon Medical Systems and John Hopkins School of Medicine, Baltimore, Maryland
2	CMR Artifacts	Nerissa Naidoo—Advanced Imaging, Durban, South Africa
3	Siemens South Africa CMR Safety Practicum	Patricia Solomons—Siemens Healthcare Proprietary Limited, Cape Town, South Africa
4	Capstone Project II: Case Report and Capstone Presentation	

Note: CMR = cardiac MRI; ECV = extracellular volume; LGE = late gadolinium enhancement; TOF = tetralogy of Fallot.

lectures, making it four additional sites and 13 attendees for this single course. On the basis of the knowledge gained from the training, each team prescribed appropriate CMR protocols for the simulated cases, simulated standardized protocols to generate high-quality CMR images for the cases, and presented case reports on each condition for the observership capstone project. Seven site- and scanner-specific protocols collectively created on Siemens [5] and GE [2] systems were made publicly available on the repository. Figure 3 illustrates examples of the tailored standard CMR protocols from one leaner's site (EMH) optimized to enhance the value of CMR. Within the volunteer group scanned at EMH, all images were of good, fully diagnostic quality (Fig. 4), and the left ventricular ejection fractions on OS-CMR were within the normal range of values compared with the usual data obtained at McGill University [25]. Incorporating the OS-CMR protocol with vasoactive breathing maneuvers added an average of 10.4 ± 3.3 min to the total scan time and required no additional hardware or sequence licenses.

The program evaluation survey results are summarized in Figure 5, and the posttraining survey was completed by 53.5% of the learners (23 of 43). All areas evaluated showed noticeable increases in positive responses from the start to the end of the program, indicating an overall improvement in learners' confidence in the topics covered and the skills acquired. The largest improvements were in understanding of artifact detection and removal, the utility of T1 and T2 mapping, and their proficiency in performing pharmacologic stress scans (Fig. 5). The posttraining survey included questions about learners' satisfaction with the training and open-ended feedback for improvement for future SWiM programs. All 23 posttraining survey respondents agreed to recommend SWiM to their colleagues, and 20 of the 23 indicated their willingness to participate in the next program as trainers. In general, the positive feedback underscored the value of the course, appreciation of the course content, resources, and delivery, and networking opportunities. Four instances of the learners' feedback on what they liked best about the program are transcribed as follows, unedited:

- *The best part of the course was the meetings, and the inclusion of software such as CVI, as well as the skill in processing live images during the meetings.*
- *Very practical in approach with countless access to learning resources simplified to suit my learning capacity.*
- *SWiM was not only educational, it gave us a platform to discover our potential to become research MRI*

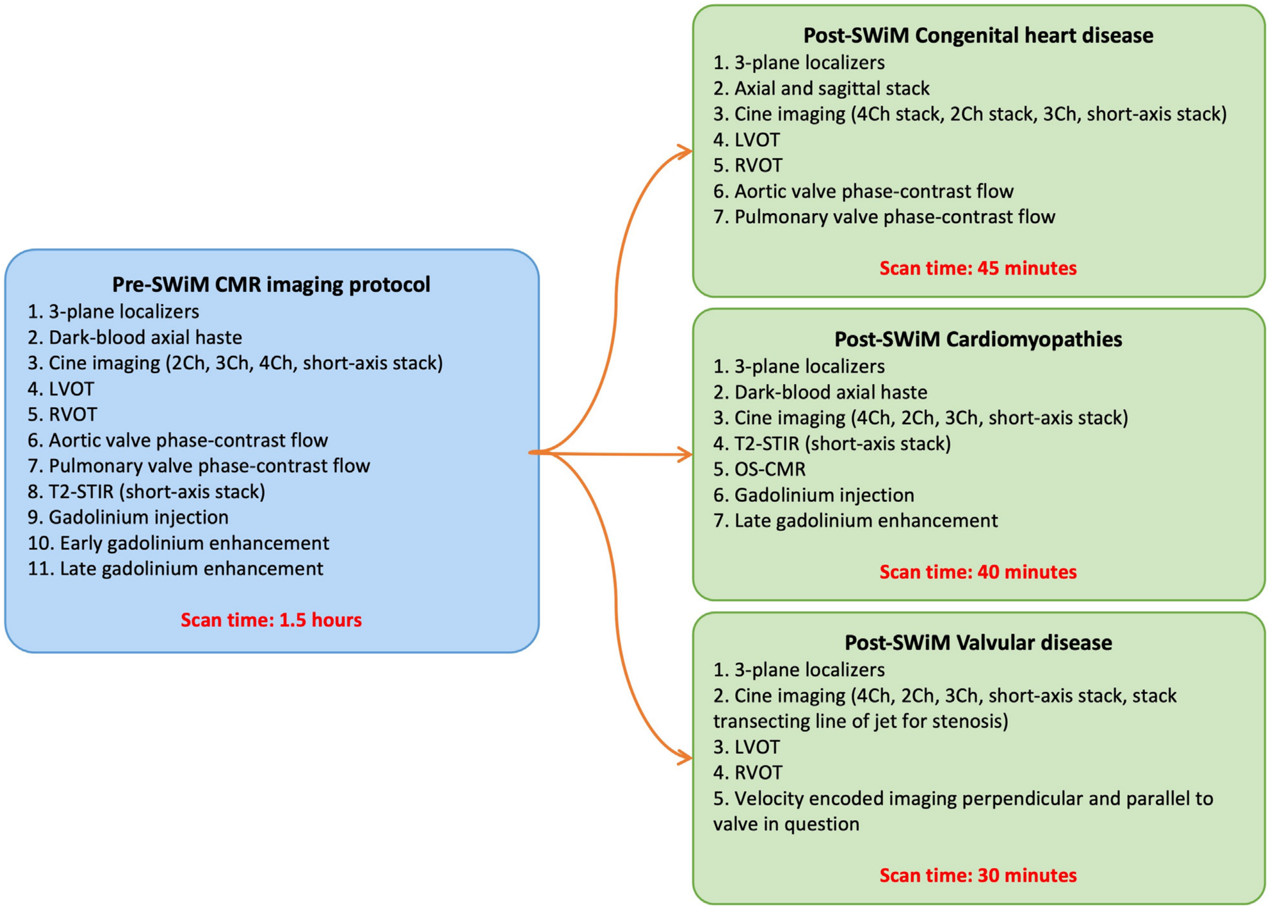

Fig. 3. Example of the tailored standard protocols implemented for different clinical indications at a learner's site (Euracare Multi-Specialist Hospital) in Lagos, Nigeria. These cardiac MRI (CMR) protocols encompass the imaging needs required for clinical pathologies prevalent in low- and middle-income countries [12]. They are separated into broad categories but may be altered on the basis of specific patient needs. The goal was to reduce the imaging time to improve workflow and capacity while providing high value from the images obtained. Ch = chamber; LVOT = left ventricular outflow tract; OS-CMR = oxygen-sensitive cardiac MRI; RVOT = right ventricular outflow tract; STIR = short-tau inversion recovery.

radiographers. We were able to connect with radiographers from different backgrounds and that was an amazing opportunity and learning experience.

- *I like the fact that SWiM pushed me out of my comfort zone to do more and read more. I started learning CMR couple of months before SWiM but I've always struggled with it and would always need guidance during each exam, but halfway through SWiM program, I completed my first CMR unaided. Thank you SWiM.*

The feedback on improvements for future programs stressed the time-zone difficulties in attending live events and the technical difficulties using the MRI simulator, especially for teams in Africa, where the cloud-based simulator servers are not accessible from their geographic locations. A total of 130 clinicians registered to attend the CMR awareness webinar, with 86 in attendance, including from countries outside of the training sites (eg, Gambia, Algeria).

DISCUSSION

The SWiM program is a competency-based training opportunity focused on upskilling practicing MRI technologists in LMICs. The program used a novel train-the-trainer approach integrated with blended and peer-collaborative learning delivery. The pilot program demonstrated the feasibility of the curriculum to train a team of LMIC technologists who worked together as a unit to grow their skills and are ready to collectively train others. Best practice protocols were successfully introduced at local MRI facilities during the pilot program including full on-site implementation and validation of an advanced CMR protocol for clinical and research translation.

CMR was carefully chosen as the first application to close gaps in care. Although experienced cardiologists are available in most health care settings in LMICs, they have limited access to cardiac imaging methods for management of cardiac conditions [11]. For example, Lagos, Nigeria, the

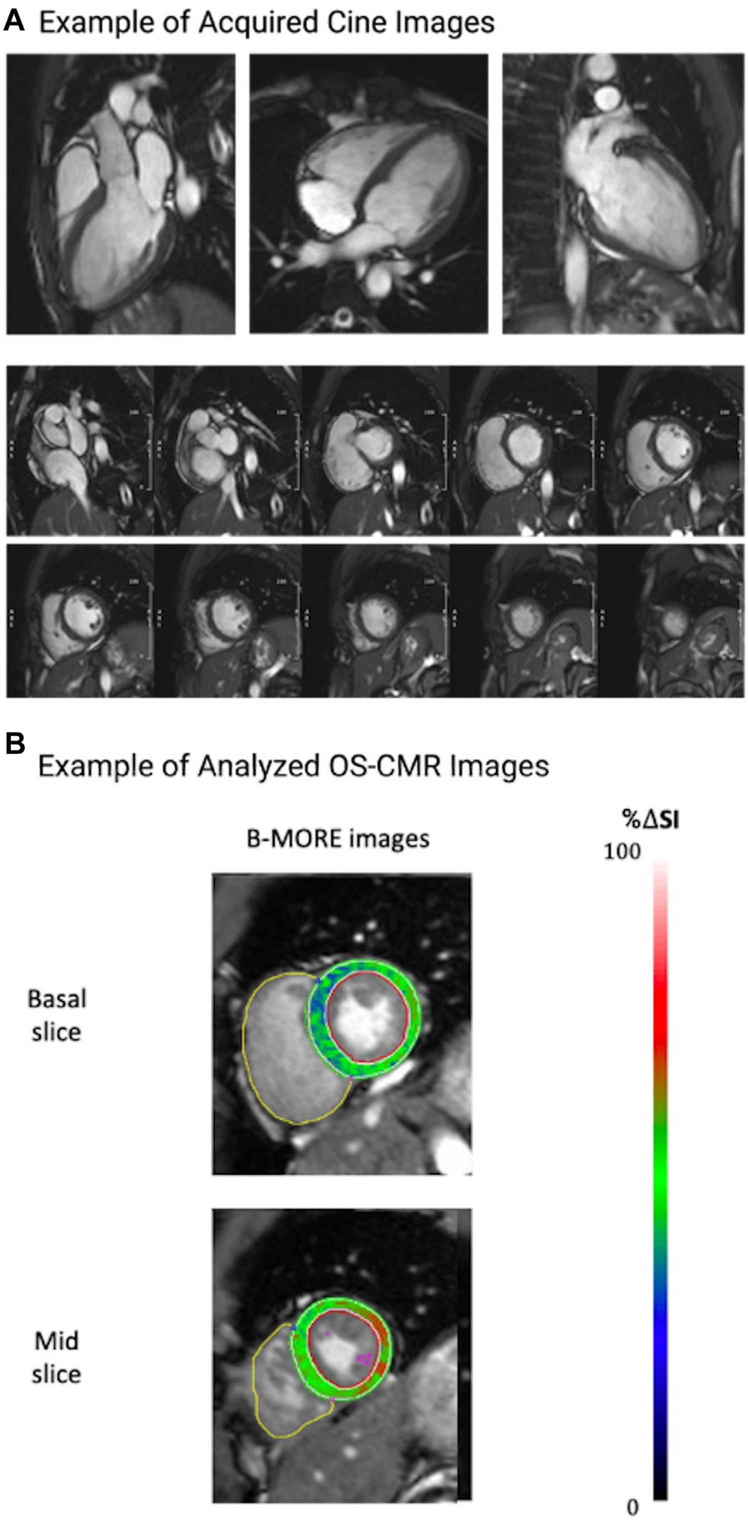

Fig. 4. Example of representative cine images from a healthy volunteer. Images were acquired using the balanced steady-state free precession sequence with a six-channel coil surface and a body coil. The three-, four-, and two-chamber and short-axis stack views are shown in the end-diastolic phase (A). An example of analyzed oxygen-sensitive cardiac MRI (OS-CMR) maps at the basal and midventricular short-axis level in the same volunteer is shown (B). The overlayed color bar displays the percentage signal intensity (SI) change between the SI of the myocardium at the end of the breath hold and at beginning of the breath hold, representing the breathing-induced myocardial oxygen-reserved (B-MORE) contrast. In healthy volunteers, a positive percentage SI change is expected in B-MORE and was achieved, whereas in patients no change in SI is expected.

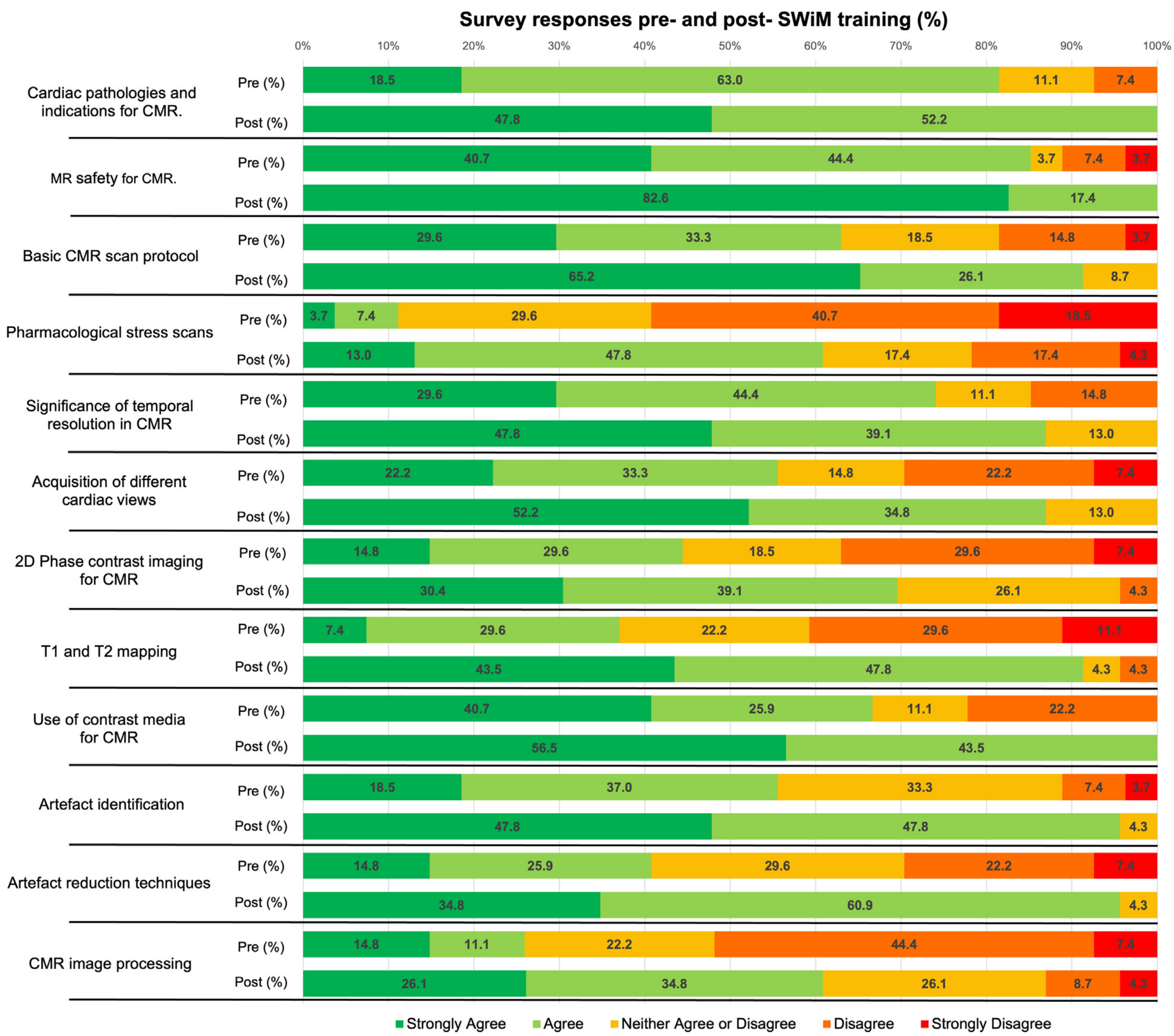

Fig. 5. Learners' responses to the pre- and postprogram evaluation surveys. The responses to questions about cardiac MRI (CMR) knowledge or experience were based on a five-point Likert-type scale ("strongly agree," "agree," "neither agree or disagree," "disagree," and "strongly disagree"). SWiM = Scan With Me.

most densely populated region in Africa with 15 million inhabitants, has one nuclear imaging facility (PET in a private oncology center) and five 1.5-T MRI scanners across the main city, but routine CMR is performed only at EMH. Before SWiM, EMH had one CMR protocol for all indications. Through SWiM, it now offers tailored protocols to meet specific imaging requirements for conditions commonly referred to the center. The combination of the unique MRI safety needs for CMR, the use of pharmacologic stress during scanning, and the translation of promising MRI research techniques such as OS-CMR also made CMR an ideal application for testing the SWiM curriculum. The full implementation and validation of OS-CMR on six volunteers demonstrated the program's ability to train technologists who can obtain high-quality images and effectively execute a breathing-enhanced CMR protocol. The OS-CMR images produced values within the normal range observed at other institutions [25]. Thus, enabling follow-up observational studies to further validate the use of this non-contrast-enhanced technique in offering unique insights into tissue oxygenation and endothelial dysfunction in vascular-impaired pathologies in LMICs [18,23].

The Program's Impact

As demonstrated at EMH and other sites (see protocols in the program repository), the immediate improvement in scan time, image quality, and technical skills will translate to increased access to CMR in LMICs. The awareness campaigns included at the end of the program for referring physicians could increase interest in MRI and drive up demand for appropriate use in the LMICs, including in research studies. More CMR awareness webinars will be conducted in 2024, while the CMR interpretation training program for radiologists is in development. The combination of dedicated MRI technologist training, followed by awareness campaigns for referring physicians and focused radiologist training will increase local MRI expertise, including in the use of advanced techniques for local unique cases. This will expand the use of MRI and provide novel insights. The inclusion of research translation training for promising techniques such as OS-CMR and standardization of optimized scanning protocol will enable inclusion of LMICs in research studies, particularly in clinical trials.

Areas of Improvement

The pilot program included relatively little content in French during the observerships through three seminars from a Philips application specialist and in Spanish in the form of weekend tutorials by one of the program coordinators. This limited the full participation of Francophone and Hispanophone learners in LMICs, although one site in Latin America provided its optimized protocols in Spanish (see repository). Plans are under way to recruit more French- and Spanish-speaking content experts to translate course materials and assignments and provide new lecture content for future programs. Six weeks may not be enough to transfer pivotal knowledge needed for expertise on a topic, but as the pilot demonstrated, it may be suitable for upskilling personnel, provided the appropriately skilled learners are identified. Additional time may be required for topics for which there are little to no prior basic skills.

Next Steps

The key strength of the SWiM program is in its adaptability for any MRI application and its delivery to technologists across different career stages. Lessons learned will be applied to the development of future programs, which will be progressively scaled up to cover a wider geographic area and with the help of returning learners as trainers, train, and mentor more technologists. The 2024 program will focus on brain imaging, and the curriculum is being designed in collaboration with the Open Source Initiative for Perfusion Imaging (OSIPI) Education Task Force education task force, a special interest group of the International Society for Magnetic Resonance in Medicine. The OSIPI Education Task Force will provide foundational materials for perfusion imaging, including needle-free advanced techniques such as arterial spin labeling. Efforts are under way at CAMERA to provide lifelong learning opportunities such as mentorship and regular webinars. The SWiM program aims to be one of the flagship training initiatives of CAMERA and over the years will build competencies for other MRI applications, including musculoskeletal, breast MRI, and pediatric imaging, among others. The SWiM program team looks forward to collaborating with international imaging organizations, MRI technology companies, funding agencies, and individuals interested in working together to increase MRI capacity around the world.

CONCLUSIONS

This master class in MRI acquisition represents the first initiative of its kind, focused on enhancing the skill sets of MRI technologists in resource-constrained settings. This effort contributes to enhancing MRI accessibility and driving innovation targeted at addressing the health care needs of LMICs. Ultimately this competency-based training program contributes to the broader global health objective of making diagnostic imaging accessible to all.

TAKE-HOME POINTS

- The lack of skilled MRI technologists in LMICs contributes significantly to the long-standing poor access and low capacity for MRI in these regions.
- The SWiM program fills the gap in MRI radiography postgraduate training with an emphasis on upskilling practicing technologists in resource-constrained settings.
- The SWiM program combines a novel train-the-trainer and peer-collaborative learning approach delivered in a blended manner, with considerations for educational needs, skills gaps, the work environment in resource-limited settings, and time-zone differences to provide a comprehensive practical curriculum.
- Each program is focused on a given clinical application, with the pilot program in 2023 upskilling technologists in standard and advanced CMR, including the implementation of tailored CMR protocols for clinical cases and imaging infrastructures in LMICs.

REFERENCES

1. GBD 2019 Diseases and Injuries Collaborators. Global burden of 369 diseases and injuries in 204 countries and territories, 1990-2019: a systematic analysis for the Global Burden of Disease Study 2019. Lancet 2020;396:1204-22.
2. Ezzati M, Pearson-Stuttard J, Bennett JE, Mathers CD. Acting on non-communicable diseases in low- and middle-income tropical countries. Nature 2018;559:507-16.

3. Hricak H, Abdel-Wahab M, Atun R, et al. Medical imaging and nuclear medicine: a Lancet Oncology Commission. Lancet Oncol 2021;22:e136-72.
4. Anazodo UC, Ng JJ, Ehiogu B, et al. A framework for advancing sustainable magnetic resonance imaging access in Africa. NMR Biomed 2023;36:1-19.
5. Frija G, Blažić I, Frush DP, et al. How to improve access to medical imaging in low- and middle-income countries? eClinicalMedicine 2021;38:101034.
6. Hasford F, Mumuni AN, Trauernicht C, et al. A review of MRI studies in Africa with special focus on quantitative MRI: historical development, current status and the role of medical physicists. Phys Med 2022;103:46-58.
7. Poirier SE, Suskin NG, Khaw AV, Thiessen JD, Shoemaker JK, Anazodo UC. Probing evidence of cerebral white matter microstructural disruptions in ischemic heart disease before and following cardiac rehabilitation: a diffusion tensor MR imaging study. J Magn Reson Imaging 2023;59:2137-49.
8. Laage Gaupp FM, Solomon N, Rukundo I, et al. Tanzania IR Initiative: training the first generation of interventional radiologists. J Vasc Interv Radiol 2019;30:2036-40.
9. Webb A, Obungoloch J. Five steps to make MRI scanners more affordable to the world. Nature 2023;615:391-3.
10. Qin C, Murali S, Lee E, et al. Sustainable low-field cardiovascular magnetic resonance in changing healthcare systems. Eur Heart J 2022;23:e246-60.
11. Anazodo UC, Adewole M, Dako F. AI for population and global health in radiology. Radiol Artif Intell 2022;4:e220107.
12. Lakshmanan S, Mbanze I. A comparison of cardiovascular imaging practices in Africa, North America, and Europe: two faces of the same coin. Eur Heart J Imaging Meth Pract 2023;1: qyad005.
13. Elahi A, Dako F, Zember J, et al. Overcoming challenges for successful PACS installation in low-resource regions: our experience in Nigeria. J Digit Imaging 2020;33:996-1001.
14. Chetlen AL, Petscavage-Thomas J, Cherian RA, et al. Collaborative learning in radiology: from peer review to peer learning and peer coaching. Acad Radiol 2020;27:1261-7.
15. Julia G. How to write your first clinical case report. JACC Case Rep 2022;4:1456-8.
16. Mani K, Shah K, Kadom N, Seidenwurm D, Nemeth AJ. Peer learning in neuroradiology: not as easy as it sounds. AJNR Am J Neuroradiol 2023;44:1109-15.
17. Markl M, Frydrychowicz A, Kozerke S, Hope M, Wieben O. 4D flow MRI. J Magn Reson Imaging 2012;36:1015-36.
18. Hillier E, Covone J, Friedrich MG. Oxygenation-sensitive cardiac MRI with vasoactive breathing maneuvers for the non-invasive assessment of coronary microvascular dysfunction. J Vis Exp 2022;186.
19. Raman SV, Markl M, Patel AR, et al. 30-minute CMR for common clinical indications: a Society for Cardiovascular Magnetic Resonance white paper. J Cardiovasc Magn Reson 2022;24:13.
20. Menacho KD, Ramirez S, Perez A, et al. Improving cardiovascular magnetic resonance access in low- and middle-income countries for cardiomyopathy assessment: rapid cardiovascular magnetic resonance. Eur Heart J 2022;43:2496-507.
21. Sharrack N, Chiribiri A, Schwitter J, Plein S. How to do quantitative myocardial perfusion cardiovascular magnetic resonance. Eur Heart J Cardiovasc Imaging 2022;23:315-8.
22. Eyre K, Aduluwa H, Hillier,et E, et al. ECMR 4-04 - Scan with me (SWiM): Implementing oxygen-sensitive cardiovascular magnetic resonance imaging in Lagos, Nigeria. J Cardiovasc Magn Res 2024;26:100096.
23. Hillier E, Friedrich MG. The potential of oxygenation-sensitive CMR in heart failure. Curr Heart Fail Rep 2021;18:304-14.
24. ISAS. Multiomics: a systems biology approach for cardiovascular research. Available at: https://www.isas.de/en/research/research-projects/multiomics-a-systems-biology-approach-for-cardiovascular-research. Accessed May 24, 2024.
25. Hillier E, Covone J, Fischer K, Chen HY, Hafyane T, Friedrich MG. Microvascular dysfunction as a possible link between heart failure and cognitive dysfunction. Circ Heart Fail 2023;16:e010117.