A paradigm shift in point-of-care imaging in low-income and middle-income countries

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Summary

The concept of primary healthcare is now regarded as crucial for enhancing access to healthcare services in low-income and middle-income countries (LMICs). Technological advancements that have made many medical imaging devices smaller, lighter, portable and more affordable, and infrastructure advancements in power supply, Internet connectivity, and artificial intelligence, are all increasing the feasibility of POCI (point-of care imaging) in LMICs. Although providing imaging services at the same time as the clinic visit represents a paradigm shift in the way imaging care is typically provided in high-income countries where patients are typically directed to dedicated imaging centres, a POCI model is often the only way to provide timely access to imaging care for many patients in LIMCs. To address the growing burden of non-communicable diseases such as cancer and heart disease, bringing advanced imaging tools to the POCI will be necessary. Strategies tailored to the countries' specific needs, including training, safety and quality, will be of the utmost importance.

Keywords: Low-income and middle-income countries; Imaging; Point of care; Primary care; Portable imaging equipments

Introduction

Support for the concept of primary healthcare (PHC)[1–3] is now regarded as crucial for enhancing access to healthcare services in low-income and middle-income countries (LMICs); PHC is a cornerstone of a sustainable health system for universal health coverage (UHC) and health-related Sustainable Development Goals (SDG).[4] Primary care (PC) delivery is an essential component of the PHC system, promoting first-contact, ongoing, thorough, and coordinated patient-focused care. Effective PC includes delivery of a range of point-of-care services, providing medical services to patients where they are, instead of moving patients from remote locations to a different site for services. Since PC has been traditionally developed primarily to deliver "clinical" services, availability of point-of-care *in-vitro* and *in-vivo* diagnostics has often not been specifically included in models. We believe imaging deserves specific attention in the development of strategies for UHC and SDG. Making radiographic screening for communicable diseases such as tuberculosis (TB) available at the point of care is critical to immediately determining which patients need treatment. Furthermore, early diagnosis is key in lowering the morbidity and mortality from non-communicable diseases (NCD) such as heart disease and cancer, which require early diagnosis. Technological advances in all imaging modalities including plain X-ray, ultrasound (US), computed tomography (CT), nuclear medicine (NM) and magnetic resonance imaging (MRI) have resulted in these modalities being central to routine clinical practice worldwide. Even though the use of X-rays and ultrasound may address 70%–80% of illnesses, it is estimated that 3.2 billion people in LMICs lack access to even basic imaging.[5] Thanks to recent technological advancements that have made medical imaging devices smaller, lighter, more portable, and more affordable, the possibility to use imaging at the point of care has undergone a significant transformation. Additionally, advancements in power supply, improving global internet access, and breakthroughs in artificial intelligence (AI) have the potential to increase imaging implementation and operation. In a recent article,[6] we discussed increasing access to imaging in LMICs, and we believe point-of-care imaging (POCI) will be an important part of this strategy, worthy of specific analysis, particularly in the context of the current WHO policy[1,2] highlighting the importance of PC. In this article, we define POCI, compare it with point-of-care testing (POCT), and explore POCI's implementation requirements in national health plans with a PC focus. Furthermore, we

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want to raise awareness of the growing potential for imaging to impact the morbidity and mortality in LMICs, not only from communicable diseases but also from NCDs, so that key decision-makers will prioritise imaging in their strategies for improving health in LMICs.

Definitions and standards for point-of-care imaging

Unlike POCT, which is defined by an ISO International Standard,[7] the definition of POCI is still a work in progress. Like POCT, POCI could be defined as an imaging test carried out at or close to the point of care, at the time and place of care delivery. This may include diagnostic and screening procedures. We believe ultrasound and radiography already fit this definition, and MRI will soon be possible at the point of care. Providing imaging services at the same time as the clinic visit would represent a paradigm shift in the way care is typically provided in high-income countries (HICs) to patients referred to dedicated imaging centres. This is usually not a problem for HICs, since the imaging centres are usually located close to the clinics and patients, although POCI development could also benefit patients in some circumstances in HICs. However, since most imaging facilities in LMICs are geographically remote from the patients, a strategy that brings imaging to the point of care at the PC clinic would be much more impactful in LMICs than in the HICs.

Sonography: small hand-held ultrasound (SHUS) are game changers for LMICs

Point-of-care ultrasound (POCUS), which has been in use in HICs for a decade, is a targeted examination performed at the bedside by the patient's PC provider to answer a specific clinical question This contrasts with the traditional, more comprehensive ultrasound (US) examination that is typically performed by skilled medical personnel at a hospital or dedicated imaging facility. It is recognised that the skills necessary to perform POCUS examinations can be acquired quickly by PC providers to rapidly answer some limited and specific questions, favourably impacting patient treatment and outcomes.[8] SHUS are already widely used, and can provide high-quality US images at low cost. SHUS can be Internet-connected and embedded with AI software for assistance in image acquisition, initial interpretation, or remote transmission for review by imaging experts. Several LMICs currently using SHUS devices have shown a positive impact on clinical care for more than 60% of their patients,[9,10] and although there is still little research on how the local workforce is using SHUS in LMICs, wider dissemination is anticipated. The timeliness of POCUS will be particularly useful in pediatric and obstetrical care. Considering the encouraging experiences in Uganda and Tanzania,[11] a coordinated strategy for widespread dissemination of POCUS in LMICs based on local needs infrastructure, personnel, and workforce training requirements is needed[8] and should specifically include a strategy for using POCUS in the care of pregnant women and children.

Radiography and mammography: digital imaging, portability, and AI will expand capabilities in LMICs

As compared to chemical-based analog film processing, the evolution of digital radiography detectors has revolutionised image storage, post-processing, transmission, rapid remote interpretation, and the use of AI solutions for radiography. These systems can fit in a backpack, require no permanent lead shielding, can be battery-operated, are compatible with AI-powered software solutions, and enable image transmission via the Internet. Image acquisition can often be done with fewer staff and fewer infrastructure requirements, which is important for LMICs with limited physical and human resources. AI software can facilitate proper patient positioning and provide preliminary immediate assessment of the presence or absence of a significant abnormality. As a result, these technological breakthroughs for digital radiography systems will allow significant expansion of diagnostic capacities in underserved areas and LMICs.[12,13] Though originally focused on TB screening, modern digital radiography systems can be applied to detection of other conditions including pneumonia, cardiac failure, trauma and other skeletal conditions, and like the POCUS model, PC providers will be able to use imaging to help answer specific clinical questions at the time they are seeing the patient. Additionally, breast cancer is currently a leading cause of morbidity and mortality in LMICs. Early detection is the best way to improve patient survival and therefore providing mammography and breast US services at the point of care is crucial in improving women's health in LMICs. The development of digital mammography and ultrasound systems connected to the Internet and enabled with robust AI software to assist positioning, quality assurance, and disease detection significantly improves the ability to provide breast imaging services at the point of care. Breast imaging should be addressed in all strategies for increasing access to imaging services in PC as the necessary equipment (although not hand-held) is generally relatively easy to move around and transfer. Implementation strategies for point-of-care radiography and mammography must include consideration of radiation safety for patients and healthcare workers. As the imaging workforce is expanded to include a broader array of healthcare providers who (unlike formally-trained radiological technologists and radiographers) have not been previously trained in

medical imaging, all individuals who use digital radiography must receive sufficient training in radiation protection, radiation safety, and image management techniques such as post-processing, image storage, use of CAD, and connection and image transmission to a remote centre.

Portable ultra-low field MRI can bring modern imaging to LMICs

MRI is a crucial tool for the diagnosis of important neurological conditions, which represent a growing burden of disease in LMICs. A new generation of small ultra-low field MRI systems, with design components fundamentally different from classical higher field strength MRI devices, offers the possibility of POC operation in LMICs where access to MRI is currently limited. As a less expensive and more portable alternative to traditional 1.5 T and 3 T systems, ultra-low-field MRI systems, operating at field strengths of 100 mT or less, are of low weight, lower cost, have a shielding-free design and battery-operated capabilities[14,15] making these devices amenable to the variety of installation parameters required in LMICs. At least one company has received regulatory clearance from the US Food and Drug Administration, and the Bill & Melinda Gates Foundation intends to install more than 45 of these units in Africa.[15] These systems have been tested with satisfactory results on patients with stroke, multiple sclerosis, and traumatic brain injuries.[16] The Consortium for Advancement of MRI Education and Research in Africa (CAMERA)[17] should be applauded for going beyond merely supplying the equipment, to also provide scientists, physicians, and medical technologists in LMICs the tools they need to locally design, operate, and build low-cost MRI systems. We believe this emerging portable MRI technology will play an important role in increasing access to imaging care in LMICs.

Other portable imaging equipment will also be important

Currently-available mobile CT scanners specifically designed for intensive care units may not be well suited for POCI in LMICs, due to overall cost, power consumption, available local infrastructure, workforce expertise, and inaccessibility in remote locations due to device size and weight. Carbon nanotube-based X-ray emitters will make CT scanners smaller, lighter, and more power-efficient and as such more suitable for deployment in LMICs. Initial results are promising but thus far inconclusive. However, increasing access to CT is critical for improving the detection and management of NCDs, and strategies for increasing access to imaging in LMICs should include strategies for improving access to CT.

While strategies to increase the availability of nuclear medicine in regional imaging referral centres[18] are

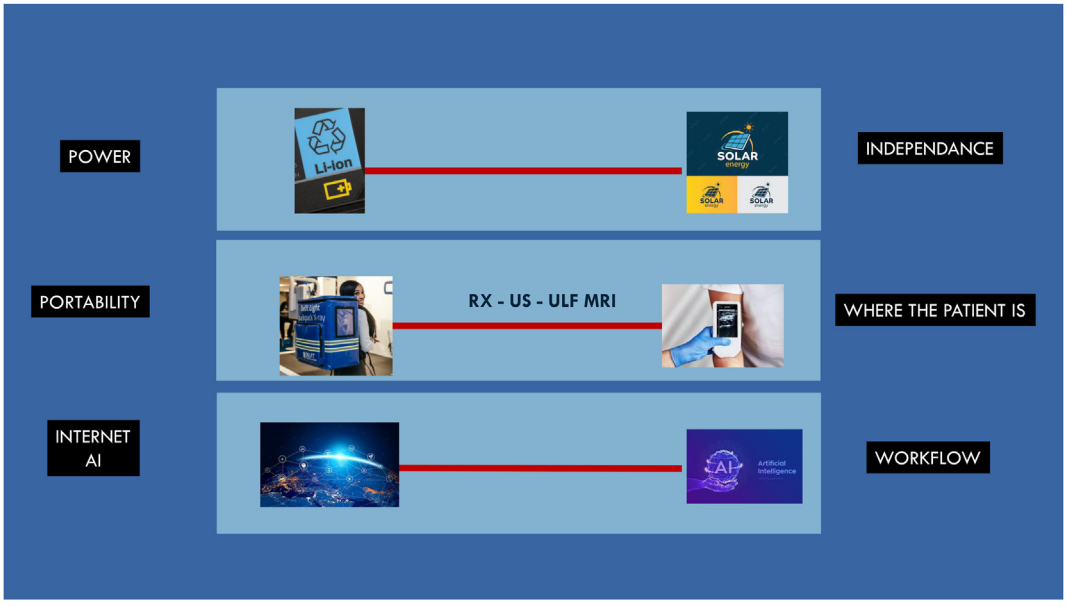

Fig. 1: A new imaging environment allowing POCI in LMIC. The interaction of three factors produces a new environment. The improvements in power supply, which rely on batteries and solar panels, are represented by the upper box. The middle box represents the portability of the technology that makes POCI possible (ULF MRI: ultra-low field MRI, US: ultrasonic imaging). For the workflow of the images, the lower box refers to the pair of Internet access and AI: automatic positioning and protocoling, automatic image analysis, and second opinion. Images source (free access): Upper-box; Left image: image by freeimageslive.co.uk - freebie.photography, Right: Image by Freepik.com. Middle-box; Left: https://stoptb.org/, Right: https://www.vendra-medical.com/. Lower-box; Left and right: Image by Freepik.com.

advocated, opportunities for providing nuclear medicine at the point of care in LMICs are limited due to the necessary infrastructure, regulation and transportation issues (including shelf life of the radiotracers used for imaging).

Finally, dental imaging is increasingly portable and also aligns with the WHO's oral health objective. Therefore, we believe dental imaging should also be considered as part of the POCI strategy.[19]

Regulatory issues are important and should be addressed

The foundation of the WHO's approach to healthcare systems in LMICs continues to be the continuum of care. International standards like DICOM have made it possible for those who perform imaging to interact technically and simply; therefore networking should be developed in order to connect primary care with reference centres and enable the provision of second opinions. Additionally, growing access to the Internet in LMICs makes regional and global interconnectivity for imaging care possible, and provides a framework for the use of AI and provision of specialized medical care in remote regions in LMICs. However, this interconnectivity is not without risk. To protect the privacy of patients and regional communities, health systems are often heavily regulated; such regulations, especially those dealing with patient data privacy and data sharing, may slow digital technology adoption. Since digital equipment may be relatively easy to operate, there is a risk of unauthorised and unskilled usage, especially where human resources are scarce. Thoughtful modifications to the regulatory environment may be necessary in certain areas to allow the benefits of POCI to be realised.

Outstanding questions

As a result of recent technology advancements in all major imaging modalities and beyond, POCI is an innovative approach for expanding access to medical imaging in LMICs (Fig. 1). While continued advances in POCI using radiography and US will meet many current imaging needs in LMICs, more advanced imaging will be necessary to ensure an impact on the growing burden of NCDs. POCI using advanced imaging tools such as MRI is on the horizon and inevitable advances in POCI must be considered within the overall framework for UHC in the context of SDG. Given the diversity of infrastructure and workforce in LMICs, plans must be customised for each country to account for variations, and nations should create a national diagnostic strategy that is most appropriate for their situation. POCT and POCI should have a resource-pooling strategy[4] within a cohesive plan that considers synergies in developing an integrated PC workforce. While bringing basic imaging services to remote populations in LMICs is an important way to improve imaging access, a POCI strategy does not negate the need for a plan to develop reference centres equipped with cutting-edge technology. These dually-aligned strategies are complementary means to provide imaging networks that ensure a continuum of services across the three levels (primary, secondary and tertiary) of imaging care.[6] Therefore, we believe that POCI should be considered an essential package in the context of achieving UHC and PC.[20]

Search strategy and selection criteria

References for this article were identified through searches of PubMed with the search terms "LMICs," "imaging equipment" and "portable", "MRI" and "portable"," point-of-care" and "imaging", "POCUS" from 2000 until, April 2023. Articles were also identified through searches of the authors' own files. Only papers published in English were reviewed. The final reference list was generated on the basis of originality and relevance to the broad scope of this article.

Contributors

Guy Frija: writing the first draft, incorporating co-authors input, orchestrating the revision process.

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Declaration of interests

We declare no competing interests.

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