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Review

How to improve access to medical imaging in low- and middle-income countries ?

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A B S T R A C T

Imaging has become key in the care pathway of communicable and non-communicable diseases. Yet, there are major shortages of imaging equipment and workforce in low- and middle-income countries (LMICs). The International Society of Radiology outlines a plan to upscale the role of imaging in the global health agenda and proposes a holistic approach for LMICs. A generic model for organising imaging services in LMICs via regional Centres of Reference is presented. The need to better exploit IT and the potential of artificial intelligence for imaging, also in the LMIC setting, is highlighted.
To implement the proposed plan, involvement of professional and international organisations is considered crucial. The establishment of an International Commission on Medical Imaging under the umbrella of international organisations is suggested and collaboration with other diagnostic disciplines is encouraged to raise awareness of the importance to upscale diagnostics at large and to foster its integration into the care pathway globally.

1. Introduction

Imaging in the medical context refers to different technologies using ionising (plain x-rays, computed tomography, nuclear medicine) and non-ionising radiation (ultrasound, magnetic resonance imaging) to diagnose, monitor, or treat medical conditions. Imaging is an integral part of healthcare, however, a recent study [1] highlighted a huge shortage of imaging equipment in low- and middle-income countries (LMICs.) For example, there is less than 1 CT scanner per million inhabitants in LMICs compared to almost 40 scanners per million inhabitants in high- income countries (HICs). The gap is even wider for MRI and nuclear medicine equipment. This shortage of equipment is accompanied by a huge workforce shortage affecting radiologists, radiographers and medical physicists (1.9 vs. 97.9 radiologists per million inhabitants in low and high-income countries respectively) [1].

Access to imaging services is crucial for the diagnosis and treatment of non-communicable diseases (NCDs) which are growing in LMICs and also of many communicable diseases (e.g., tuberculosis [2], Covid-19[3]). The lack of access makes it unlikely that the sustainable development goals (SDGs), including the universal health coverage concept (UHC), will be achieved by 2030/2035 unless current circumstances change. Primary prevention of diseases and risk reduction are advocated as most effective for disease control in LMICs [4]. However, imaging is essential to ensure timely diagnosis and appropriate treatment of diseases and it would be unethical not to transfer the benefits that state-of-the-art imaging provides in developed countries, to LMICs. We therefore strongly believe that improvement initiatives are needed to ensure better access and utilisation of imaging in LMICs.

This paper aims to analyse the essential and growing role of imaging services in healthcare, to propose potential solutions and initiatives to overcome the barriers and gaps which are preventing the sustainable implementation of these services in LMICs.

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2. The growing role of imaging

Imaging is crucial to the management of various diseases and is a major factor in ensuring the continuum of care in the definition of the UHC concept, ranging from primary prevention, timely detection and diagnosis to treatment and post-therapy rehabilitation or palliative care. Imaging strongly contributes to establishing accurate and timely diagnosis, informs and guides treatment decisions and contributes to improving treatment outcomes. Imaging is used for accurate planning of radiotherapy procedures as well as for real-time visualisation of different image-guided interventions and is essential in tumour sampling for pathology work-up. Following the concept of value-based healthcare, a novel healthcare delivery model, a multi-society statement was recently published to elucidate the value that radiology provides to patients and healthcare [5]. Appropriate imaging is very important, especially in LMICs where health-care resources are scarce [6].

The European Society of Radiology is undertaking a project with IAEA aimed at disseminating the ESR iGuide, ESR's imaging referral guidelines embedded in clinical decision support [7], in order to improve the appropriate use of imaging in Africa.

2.1. Communicable diseases

Imaging is crucial for diagnosis and management of patients with tuberculosis [8], HIV [9] related conditions and COVID-19 infection. During the ongoing COVID-19 pandemic, chest imaging is used in diagnostic workup and clinical management of patients in addition to laboratory parameters and clinical findings [3], and WHO recently emphasized the role of imaging assisted by artificial intelligence (AI) for tuberculosis screening [2,10].

2.2. Noncommunicable diseases

Imaging is an essential tool in clinical practice and in cancer research, with a major impact on actual cancer diagnosis and treatment [1]. Imaging has been used for decades for breast cancer screening [11] and may also be useful for lung cancer screening [12]. Advanced imaging techniques and image-guided biopsies provide information about tumour type, extent, aggressiveness, prognosis, and enable evaluation of tumour response to treatment. In the past decade, innovative technology has afforded remarkable advances in image-guided interventional oncological procedures and image-guided radiotherapy [1].

Different imaging modalities are used to diagnose and monitor a range of cardiovascular disorders: echocardiography is a modality of first choice in many patients with a suspected cardiac condition; vascular ultrasound is widely used for diagnosis and treatment evaluation in patients with peripheral and visceral blood vessel pathology; CT is an accurate diagnostic tool for the assessment of coronary artery disease; cardiac MRI is an advanced imaging modality for the identification of specific heart conditions [13]. Diagnostic and therapeutic imaging has transformed the management of coronary artery disease [14].

Several studies have demonstrated the importance of imaging in establishing prompt and accurate diagnosis and in guiding the proper treatment of many life-threatening emergency conditions including cardiovascular, abdominal [15] and gastrointestinal, neurological, musculoskeletal, obstetrical, genitourinary [16] and pulmonary conditions [17] in all age groups, as well as in trauma [18,19]. Imaging is an integral and crucial part in stroke diagnosis and image-guided endovascular treatment, and AI has a role to determine the presence and extent of involvement of brain parenchyma [20,21].

3. Barriers

Several reasons may explain the insufficient use of imaging in LMICs despite its worldwide use in HICs.

3.1. Lack of investment plans and prioritisation

Investment plans and related resources for the purchase of imaging equipment are often lacking in LMICs. Moreover, investment in imaging is often not given priority in healthcare planning, as it is capital- and labour-intensive.

3.2. Equipment costs, maintenance and safety

Expensive and sophisticated imaging equipment is not adapted for use in LMIC settings, in particular in the case of rural and semi-rural areas. It requires a stable electricity supply which is often missing, even in urban areas, and must be installed in specific buildings which require air conditioning and a special design for radiation protection purposes. Regular maintenance is essential, failure is not uncommon, and repairs are often delayed because they are carried out by specialised companies that usually cover a large geographical area. In addition, there are comprehensive radiation protection requirements (usually based on the IAEA International Basic Safety Standards [22]), which requires a national support and organisation and availability of dedicated experts, like medical physicists. More robust regulation applies to nuclear medicine for the handling of non-sealed sources. This shows that imaging is more than just installing medical equipment: it is a complex ecosystem of which healthcare decision-makers are only aware of to a limited extent. This might explain why equipment donations to LMICs are often unsuccessful, because the complexity of this ecosystem is not considered.

Costs of purchasing equipment are high, however long-term maintenance and running costs represent a significant part of the overall costs and need to be calculated in advance when planning imaging centre functioning.

Equipment prices are not publicly available on websites of professional organisations of imaging equipment vendors like COCIR or DITTA. The range of prices can be elucidated from commercial websites (e.g. [23]), although the variability is huge in terms of considerable differences in technical levels of equipment. Also, maintenance and running costs are hard to assess because of the large variability specific to the local situation. Ultrasound machines are much cheaper, in general ten times less when compared to CT/MRI, and their maintenance is simple compared to CT and MR scanners. Portable hand-held ultrasounds are particularly cheap and are well suited to improve imaging access in remote LMIC settings.

3.3. Operation of imaging equipment

A properly trained workforce is needed to operate radiology equipment, including radiologists, radiographers and medical physicists who undergo structured training. Ultrasound training in LMICs is often adjusted to local circumstances and is far less comprehensive compared to HICs. Due to its price, easy maintenance and high practical yield, ultrasound is the most used imaging modality in LMICs, and a pragmatic approach with shortened education of the scarce workforce is understandable and needed to disseminate its utilisation.

Significant differences in income between private and public sectors contribute to worsening the workforce shortage in the public sector. Brain drain, to either outside the public sector or even outside the country, is a major challenge for LMICs [24].

4. Solutions to overcome the barriers

Implementation of imaging in LMICs is very challenging and needs to be adapted to the local setting. We believe that the concept of three levels of care is appropriate and could be applied. In the following section, we propose solutions to the barriers identified in the previous section.

4.1. Technical solutions

Current imaging technology developments largely focus on digitalisation with standards for image archiving and transmission that allow sharing and mining of images and reports, including teleradiology interpretation services. This offers the possibility to develop networks as a pillar of imaging organisation in LMICS. In addition, teleradiology may be used to develop comprehensive imaging systems based on network solutions between the different levels of care, which will contribute to compensate for workforce shortages.

Modern, portable battery-operated ultrasound systems provide good quality imaging at the point of care and can be used to solve many clinical questions.

AI already has the potential to improve the workflow in radiology, and in the future might help in interpretation by automated detection of abnormalities in chest, brain and other body regions, which might have considerable impact in LMICs [25]. Some vendors already use AI installed in the equipment, and many AI software solutions are open source. Also, free access to AI solutions for high-priority diseases, such as tuberculosis [26,27], should be promoted. We expect that with future development, refinement and validation, AI solutions will have a considerable impact on imaging in LMICs.

4.2. Regulatory solutions

Regulation supports the safe use of imaging for both patients and staff. International organisations have produced regulatory guidance, like the International Basic Safety Standards [22] and the European Basic Safety Standards Directive [28], which may help LMICs to introduce quality and safety in imaging through regulatory measures (see Table 1). However, even when quality and safety regulation is in place, clinical imaging practice differs significantly across and within countries [30,31]. Quality assurance schemes are recommended to monitor implementation of regulatory requirements, e.g. through clinical audit [32,33]. Teleradiology services also require a quality and safety framework and quality controls [34].

Table 1
Essential actions to improve quality and safety of imaging using ionising radiation, based on the principles of optimisation and justification.

1.	Adapt and adopt a regulatory framework to support the implementation of existing basic safety standards [22,28] and standards for imaging using MRI [29]
2.	Bridge the gap between radiation regulatory competent authorities and health policy authorities in order to convince healthcare decision makers to consider imaging safety and quality requirements in global healthcare policy, taking the IAEA-WHO Bonn Call for Action [65] as a reference
3.	Implement the ALARA ("as low as reasonably achievable") principle in imaging, which means delivering the lowest possible dose necessary to acquire adequate diagnostic images
4.	Implement Clinical Decision Support (CDS) systems to make imaging referral guidelines available and usable at the point of care in order to decrease inappropriate examinations
5.	Develop access to non-ionising radiation (NIR) imaging modalities (MRI, ultrasound), especially for children and pregnant women
6.	Develop an occupational exposure policy for medical application of ionising and non-ionising radiation

4.3. Organisational opportunities

We propose a holistic concept of imaging organisation in LMICs, based on the three levels of care, with the so-called Centres of reference (COR) being at its core. Given the prospect of achieving global access to good quality internet and cloud-based solutions in the near future [35], we consider digitalisation an essential element of the COR concept, with the possibility to develop a fully networked organisation of imaging. Education of the workforce is an essential part of the COR concept.

5. Centres of reference (COR)

The concept of Centres of reference has been adopted by several institutions for different health purposes [36,37,38,39] but has not been applied to imaging as far as we know. The COR, corresponding to tertiary care centres (level 3) and similar to the comprehensive tertiary centre of excellence described for oncology [1], is proposed to organise imaging services in LMICs. CORs are more than a concentration of equipment and comprise all aspects of the imaging ecosystem: regional networking, training capacities, high level of equipment and workforce. Imaging equipment requires a specific building for safe use, regulatory guidance (IAEA BSS [22]) in order to ensure quality and safety for patients and staff and a funding plan which guarantees long-term sustainability.

The setup, operation, and sustainable maintenance of CORs is capital- and labour-intensive. Thus, the selection of CORs should be made following a high-level evaluation and decision process, considering the support from international organisations as well as their developed criteria, such as the IAEA Quality Improvement Quality Assurance Audit for Diagnostic Radiology (QUAADRIL) [32] as well as criteria for establishment of Designated Regional Centres under Africa Regional Cooperative Agreement for Research, Development and Training related to Nuclear Science and Technology [40].

5.1. Setup of COR

Equipment: Running a hospital-based imaging service should involve advanced diagnostic and interventional radiology functionality, including several units such as neuro imaging, chest and abdominal imaging, oncologic imaging, musculoskeletal imaging, breast imaging, paediatric imaging, cardiovascular imaging and interventional radiology. CORs should have high-end ultrasound scanners, digital radiography, fluoroscopy and mammography units, multidetector-row CTs of higher class, at least a 1.5T MRI scanner equipped with advanced software and all coils, as well as digital subtraction angiography equipment. Ideally, nuclear medicine equipment, including SPECT and PET, should also be included. Nuclear medicine increases the complexity of operations and strongly depends on the supply of radiotracers but is crucial in managing oncological diseases [1]. MRI is crucial when neurological and musculoskeletal disorders have to be investigated, while stroke management could rely on CT when MRI access is not available [41]. To attain the level of high-income countries in terms of equipment, we would need to invest an additional 11.4 CTs per million and 5.2 MRIs per million inhabitants in LMICs, according to the Imagine database and World Bank data [42].

5.2. Workforce education and training

CORs should have sufficient numbers of clinically qualified general and subspecialised radiologists, nuclear medicine physicians, radiographers and medical physicists with adequate expertise, as well as some IT professionals, with clear definition of each profession's responsibilities. CORs should from their inception employ properly trained staff but should also serve as strong centres for regional theoretical education and practical training of the workforce. A COR should have a strong educational unit providing education and training in specific areas of imaging, which is locally accredited for that purpose. To achieve these challenging goals, cooperation with institutions in HICs and NGOs should be sought. Radiological, nuclear medicine, radiographer and medical physicists professional societies [43,44,45,46,47] offer education and training programmes, which are available on-line, mostly for free, and could help to develop structured education of workforce in LMICs through visiting professorships, online education etc. A minimum of four years of residency after graduating in medicine would be required before the first radiologists and nuclear medicine physicians are fully trained, while radiographers could be trained in the period of two to four years after secondary school and medical physicists in about four years after an undergraduate degree. Bringing sub-Saharan LMICs to an intermediate stage in terms of workforce comparable to upper-middle-income countries would require the training of 64.9 and 2.6 more people per million population respectively for radiologists and nuclear medicine physicians, according to the IMAGINE database [48] and World Bank data [49].

5.3. Regional management of imaging

CORs as tertiary centres should also manage and monitor the provision of imaging in the relevant region or country (see Fig. 1). A two-level organisation is proposed: level one targeting primary care, and level two targeting secondary care. Specific attention needs to be paid to rural and semi-rural areas that are often without hospital infrastructure [50,51] and with limited power supply, requiring an innovative approach based on new equipment solutions, artificial intelligence and teleradiology.

Equipment policy for primary and secondary levels of care should be based on careful analysis and experience of the local workforce, with a predominant use of portable ultrasound and portable X-ray devices, available at the point of care for primary care in clinical and emergency scenarios [50,51], while level two could be equipped with an X-ray and a CT unit (fixed or mobile). It is to be noted that battery-operated equipment cannot serve as a substitute for the high-end imaging equipment in tertiary centres (CORs) but is a reasonable solution for non-urban regions where infrastructure is missing. Teleradiology solutions for the general support of image interpretation should be established for the entire system.

In primary care, imaging could be delivered by the existing workforce on the condition that they undergo relevant education and training and follow continuous training thereafter [50]. However, a specifically trained workforce should be provided for the secondary care level. Education of workforce at both levels by the CORs needs to be structured and methods and content carefully designed to ensure good clinical practice and achieve benefit for patients. Further research is needed for the development of the training scheme for level 1 and level 2 staff, as are field studies on the quality of imaging services on the ground in order to develop practice improvement measures including decision guidance when to transfer patients to CORs.

5.4. Quality management

Benefits and results of COR implementation at the national level should be evaluated by the local healthcare authority system assessment metrics, and CORs should be incorporated in local healthcare planning. A framework of quality and safety should be implemented based on the IAEA International Basic Safety Standards [22]. Internal clinical audits should also be performed, focused on the most important aspects of the workflow, like justification, and the support of relevant international organisations [32] or professional societies [33,7] could be sought for its implementation. Efficiency of equipment use should be integrated in the management policy; implementation of key performance indicators (KPIs) should be developed [52,53] and adapted to the local setting. Audit and KPIs should help to monitor the overall organisation, including the primary and secondary levels which would be under the responsibility of the COR. Strong IT support should be provided for the management tasks.

6. Upscaling and financing

Economically sustainable, well designed national plans are needed to establish or upscale imaging in LMICs, in addition to achieving prioritisation of health investments including imaging in national policy strategy [35]. In addition to equipment costs, broader investments in regional infrastructure are needed to ensure reliable power supply and secure internet access, essential components for modern imaging. Studies about imaging in oncology [1], as well as radiotherapy [54], pathology [55] and surgery [56] have shown a clear benefit of investing in infrastructure. On the one hand, the lack of comprehensive data on imaging needs, by type of disease, preclude the use of quantitative approaches like in radiotherapy, for instance [54]. Cancer is an exception, where there are registries. On the other hand, the benefit of a diagnostic test is often significantly more difficult to establish than for a therapeutic one.

Evidence demonstrating the health and economic benefits of scaling up imaging will likely facilitate investment in imaging equipment and related infrastructure. A Lancet Oncology Commission report recently demonstrated the substantial health and economic benefits of scaling up imaging and nuclear medicine access for health outcomes of cancer patients; a microsimulation model estimated that the scale-up of imaging would avert 3.2% (2.47 million) of all 76 million deaths caused by cancer worldwide between 2020 and 2030, saving 54.92 million life-years. Model estimates indicate that a combined scale-up of imaging, treatment, and quality of care would provide a net benefit of $2.66 trillion and a net return of $12.43 per $1 invested [1]. A global Task Force on Radiotherapy for Cancer Control achieved the same kind of findings a few years before, considering investments for infrastructure and beyond for the entire cancer treatment ecosystem [57].

One cannot apply the results of those studies to imaging at large directly, as this would require specific health economics modelling; however, the growing non-communicable disease burden (cancer, cardiovascular diseases, stroke, trauma) in HICs indicates that a

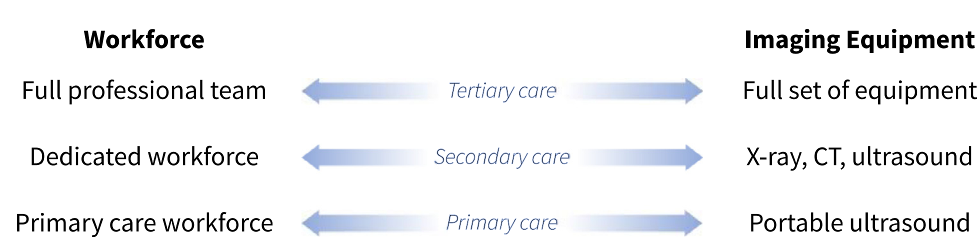

Fig. 1. The three levels of care and imaging.

similar outcome might be expected and underlines the importance of upscaling imaging in LMICs.

Rubin has shown that the costs of imaging should be related to the holistic approach of the radiology value chain [58]. If utilised properly by trained personnel, imaging equipment can be used for the management of a wide variety of clinical conditions in all organ systems.

Development of imaging policies in LMICs may take advantage of plans to control cancer, tuberculosis, pregnancy related conditions, and others, in which imaging should constitute an integral part.

Taking into account the complexities of the imaging ecosystem outlined above, we believe that a global plan for utilisation of imaging in LMICs is needed. The plan needs to consider economic factors and population health benefits of imaging and to raise awareness of these among national decision makers. Such a global plan requires engagement of multiple stakeholders, like the IAEA, the WHO, the World Bank and professional radiology societies to support procurement and purchasing, installation and maintenance of equipment, providing infrastructure (including stable power supply and internet access), training of workforce, and to evaluate impact on the local health care systems. Support of national and local authorities and detailed planning are thus essential to bring the benefits of modern imaging to local health-care systems.

7. Integration of imaging in strategic priorities of international organisations

Access to affordable, quality primary healthcare is the cornerstone of UHC. This concept has been used by WHO and the World Bank in particular. Improving access to imaging in LMICs is an integral part of this concept and should be integrated into the strategic priorities of international organisations for UHC definition, goal setting and implementation.

The WHO sustainable development goal 3 (UN SDG3 [59]) and disease control priorities (DCP3) [60,61] are orientated in many aspects on primary prevention of diseases, while our imaging plan is more transversal and focused on providing appropriate care to those who suffer diseases and are patients already. We consider that the concepts of primary prevention and infrastructure development for diagnosis and treatment of patients are fully complementary. Imaging is only indirectly represented in some of WHO's strategic priorities [62], including UN SDG3, which emphasise innovations of diagnostic and therapeutic health technologies and increasing resilience to environmental threats. We think the concept of UHC should be more specific as regards to imaging and include diagnostics (laboratory) and treatment tools (image-guided interventions and radiotherapy) for communicable and NCDs, which should form an integral part of essential benefit packages, particularly in LMICs [63]. Lancet commissions have paved the way for some policies (pathology [55], surgery [56], radiotherapy [54], imaging in oncology [1]), but a holistic approach for imaging is lacking so far.

The IT aspects of imaging and the future potential of AI deserve a more prominent focus in the WHO recommendations on digital interventions for health system strengthening [64].

The COR model fits with UN SDG3: it covers equipment and sustainability of infrastructure, health workforce, education and training and regional organisation for imaging. The COR model also fits with the IAEA's commitments to quality and safety, audit and education in the area of medical use of radiation [65]. It is also in line with the IAEA activities to increase access to imaging in LMICs and to foster capacity building and related investments. The World Bank addresses imaging through its Industry Engagement Programme with the aim to improve procurement approaches [66].

However, we believe that awareness of the full clinical benefits of the use of imaging and its upscaling in LMICs needs to be strengthened among the various stakeholders in order to foster a prioritisation in investment plans, and we encourage the World Bank to support the call to action of this paper.

8. Limitations

The proposed COR concept is a generic model and does not consider the differences between and within countries and variability in prevalence of diseases. The COR model may therefore not be universally applicable and would need to be adapted to national and local settings while preserving its two major strengths: integrating imaging in the continuum of care through a networked regional organisation, and training capacity. The possibility of exploiting existing primary care resources when integrating imaging, needs to be clarified on a case-by-case basis but should remain a strategic goal.

9. Outstanding questions

The goals of this article face two levels of complexity: the one inherent to imaging in all its dimensions, the other coming from the global health aspect and the related need to have an integrated and multidisciplinary approach. Future research points might be: what would be the framework for implementation of an imaging plan, is it better to scale-up primary care imaging first vs tertiary care, how to monitor and devise metrics and benchmarks to evaluate the impact of implementing imaging in the LMICs health systems, how to ensure funding sustainability linked to the middle/long term local fiscal policies, what kind of support would be needed for the kick-off, how to strengthen the project by using IT and AI in supportive IT companies and finally how to promote an efficient imaging cost assessment method, adapted to the different settings. An additional research area might be to develop models for evaluating the impact of imaging deployment on global health indicators.

10. Conclusion and call to action: setting up an international commission on medical imaging

The clinical utility of imaging is clearly demonstrated in high-income countries and should be the basis of its deployment and upscaling in LMICs. The convergence between digitalisation of imaging and digitalisation of other areas of societal life presents an unprecedented situation, since digitalisation and recent technological developments are providing an opportunity for the deployment of imaging in LMICs at a wide scale and at more affordable costs than previously. Prerequisites are to carefully evaluate the needs of the population and to appropriately organise and fund imaging implementation on a local level, using the holistic approach that takes into account all complexities specific to LMICs and fosters collaboration with other medical specialties to strengthen the healthcare systems.

We recognise the collaborative global approach needed to improve imaging services in LMICs and therefore propose the setting-up of an International Commission on Medical Imaging (ICOMI) under the umbrella of WHO, IAEA and the World Bank, in which major NGOs in the field of imaging, such as the International Society of Radiology [67] and RAD-AID [68], would be involved, primarily in education and training, but potentially also in a convenor function. ICOMI's role would be to draft an imaging plan for LMICs, to propose relevant funding models based on the cost of equipment, education and training of staff, to initiate studies to assess the impact and benefit of imaging in health-care systems in LMICs, followed by the development of concrete implementation plans.

11. Search strategy and selection criteria

The content of this paper is based on a literature search via PubMed, Science Direct and Google Scholar, performed using search terms: "imaging", "LMICs", "imaging equipment", "portable equipment", "oncology", "radiotherapy", "pathology", "global health". MeSH terms were used where possible. The website of the International Society of Radiology (ISR), a non-governmental organisation related to WHO that the authors represent was also considered. Finally, grey literature, in particular the websites of IAEA, WHO, World Bank and Gates Foundation were searched. Data from 2000 to 2021 were considered.

Contributors

The concept was developed by GF with contributions to the methodology from BB, MK, DF, LD. GF and IB wrote the first draft of the manuscript with support from MH. GF, BB and MH lead the process of revision, with contributions from IB, MK, DF, LD, including critical feedback. GF and MH supervised the development of the manuscript. All authors approved the final version of the submitted manuscript.

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Declaration of Competing Interest

All authors declare no competing interests.

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Supplementary materials

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References

[1] Hricak H, Abdel-Wahab M, Atun R, Mikhail Lette M, Paez D, Brink J, et al. Medical imaging and nuclear medicine: a lancet oncology commission. Lancet Oncol 2021 Mar 3. doi: 10.1016/S1470-2045(20)30751-8.
[2] World Health Organization. (2020). Rapid communication on systematic screening for tuberculosis. Available from: https://www.who.int/publications/i/item/rapid-communication-on-the-systematic-screening-for-tuberculosis (accessed 10 December 2020)
[3] World Health Organization. Use of chest imaging in COVID-19: a rapid advice guide: web annex A: imaging for COVID-19: a rapid review. World Health Organization; 2020 https://apps.who.int/iris/handle/10665/332326 (accessed 2 December 2020).
[4] Gelband H., Jha P., Sankaranarayanan R., et al., editors. Cancer: disease Control Priorities, Third Edition (Volume 3). Washington (DC): the International Bank for Reconstruction and Development /The World Bank; 2015 Nov 1. [Table,]. Available from: https://www.ncbi.nlm.nih.gov/books/NBK343628/table/fm3.utable1/ doi: 10.1596/978-1-4648-0349-9
[5] Brady AP, et al. Radiology in the era of value-based healthcare. A multisociety expert statement from the ACR, CAR, ESR, IS3R, RANZCR and RSNA. Insights 2020;11:136. doi: 10.1186/s13244-020-00941-z.
[6] Brownlee S, Chalkidou K, Doust J, Elshaug AG, Glasziou P, Heath I, et al. Evidence for overuse of medical services around the world. Lancet 2017;390(10090):156–68.
[7] European Society of Radiology (ESR). Methodology for ESR iGuide content. Insights Imaging 2019;10(1):32. Mar 13PMID: 30868370; PMCID: PMC6419665. doi: 10.1186/s13244-019-0720-z.
[8] Nachiappan A, Rahbar K, Shi X, Guy E, Barbosa Jr E, Shroff G, Ocazionez D, Schlesinger A, Katz S, Hammer M. Pulmonary tuberculosis: role of radiology in diagnosis and management. RadioGraphics 2017;37:52–72. doi: 10.1148/rg.2017160032.
[9] C M, Al-Jahdali HH, Irion KL, Al Ghanem S, Gouda A, Khan AN. Imaging lung manifestations of HIV/AIDS. Ann Thorac Med 2010;5(4):201–16 OctPMID: 20981180; PMCID: PMC2954374. doi: 10.4103/1817-1737.69106.
[10] World Health Organization. WHO consolidated guidelines on tuberculosis: systematic screening for tuberculosis. Available from: https://apps.who.int/iris/bitstream/handle/10665/340255/9789240022676-eng.pdf [Accessed 1st June 2021]
[11] Schünemann HJ, Lerda D, Quinn C, Follmann M, Alonso-Coello P, Rossi PG, Lebeau A, Nyström L, Broeders M, Ioannidou-Mouzaka L, Duffy SW, Borisch B, Fitzpatrick P, Hofvind S, Castells X, Giordano L, Canelo-Aybar C, Warman S, Mansel R, Sardanelli F, Parmelli E, Gräwingholt A, Saz-Parkinson Z. European Commission Initiative on Breast Cancer (ECIBC) contributor group. breast cancer screening and diagnosis: a synopsis of the european breast guidelines. Ann Intern Med 2020;172(1):46–56 Jan 7Epub 2019 Nov 26. PMID: 31766052. doi: 10.7326/M19-2125.
[12] de Koning HJ, van der Aalst CM, de Jong PA, Scholten ET, Nackaerts K, Heuvelmans MA, Lammers JJ, Weenink C, Yousaf-Khan U, Horeweg N, van 't Westeinde S, Prokop M, Mali WP, Mohamed Hoesein FAA, van Ooijen PMA, Aerts JGJV, den Bakker MA, Thunnissen E, Verschakelen J, Vliegenthart R, Walter JE, Ten Haaf K, Groen HJM, Oudkerk M. Reduced lung-cancer mortality with volume CT screening in a randomized trial. N Engl J Med 2020 Feb 6;382(6):503–13 Epub 2020 Jan 29. PMID: 31995683. doi: 10.1056/NEJMoa1911793.
[13] The ESC textbook of cardiovascular imaging (2 edn), Edited by Jose Luis Zamorano, Jeroen Bax, Juhani Knuuti, Udo Sechtem, Patrizio Lancellotti, and Luigi Badano, Publisher:
[14] Saraste A, Barbato E, Capodanno D, Edvardsen T, Prescott E, Achenbach S, Bax JJ, Wijns W, Knuuti J. Imaging in ESC clinical guidelines: chronic coronary syndromes. Eur Heart J Cardiovasc Imaging 2019;20(11):1187–97 Nov 1PMID: 31642920. doi: 10.1093/ehjci/jez219.
[15] Wise SW, Labuski MR, Kasales CJ, Blebea JS, Meilstrup JW, Holley GP, LaRusso SA, Holliman J, Ruggiero FM, Mauger D. Comparative assessment of CT and sonographic techniques for appendiceal imaging. AJR Am J Roentgenol 2001;176 (4):933–41 AprPMID: 11264081. doi: 10.2214/ajr.176.4.1760933.
[16] Brisbane W, Bailey MR, Sorensen MD. An overview of kidney stone imaging techniques. Nat Rev Urol 2016;13(11):654–62. doi: 10.1038/nrurol.2016.154.
[17] Sin D, McLennan G, Rengier F, Haddadin I, Heresi GA, Bartholomew JR, Fink MA, Thompson D, Partovi S. Acute pulmonary embolism multimodality imaging prior to endovascular therapy. Int J Cardiovasc Imaging 2021;37(1):343–58 JanEpub 2020 Aug 30. PMID: 32862293; PMCID: PMC7456521. doi: 10.1007/s10554-020-01980-9.
[18] Vela JH, Wertz CI, Onstott KL, Wertz JR. Trauma Imaging: a Literature Review. Radiol Technol 2017 Jan; 88(3):263–76 PMID: 28298577.
[19] Heiken JP, Katz DS, Menu Y. Emergency radiology of the abdomen and pelvis: imaging of the non-traumatic and traumatic acute abdomen. In: Hodler J, Kubik-Huch R, von Schulthess G, editors. Diseases of the abdomen and pelvis 2018–2021. Cham: IDKD Springer Series. Springer; 2018. doi: 10.1007/978-3-319-75019-4_13.
[20] Murray NM, Unberath M, Hager GD, Hui FK. Artificial intelligence to diagnose ischemic stroke and identify large vessel occlusions: a systematic review. J Neurointerv Surg 2020 Feb;12(2):156–64 Epub 2019 Oct 8. doi: 10.1136/neurintsurg-2019-015135.
[21] van der Zijden T, Mondelaers A, Yperzeele L, Voormolen M, Parizel PM. Current concepts in imaging and endovascular treatment of acute ischemic stroke: implications for the clinician. Insights Imaging 2019 Jun 13;10(1):64. PMID: 31197499; PMCID: PMC6565797. doi: 10.1186/s13244-019-0744-4.
[22] International Atomic Energy Agency (IAEA): Radiation protection and safety of radiation sources: international basic safety standards: https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1578_web-57265295.pdf (accessed 2 December 2020)
[23] Medical Price. *Medical Price website.* Available from: https://www.medicalpriceonline.com/[*Accessed* 1*st June* 2021]
[24] El Saghir NS, Anderson BO, Gralow J, et al. Impact of merit-based immigration policies on brain drain from low- and middle-income countries. JCO Glob Oncol 2020;6:185–9. doi: 10.1200/JGO.19.00266.
[25] Mollura DJ, Culp MP, Pollack E, Battino G, Scheel JR, Mango VL, Elahi A, Schweitzer A, Dako F. Artificial intelligence in low- and middle-income countries: innovating global health radiology. Radiology 2020;00:1–8. doi: 10.1148/radiol.2020201434.
[26] Qin Z.Z., Sander M.S., Rai B., Titahong C.N., Sudrungrot S., Laah S.N., Adhikari L.M., Carter E.J., Puri L., Codlin A.J., Creswell J. Using artificial intelligence to read chest radiographs for tuberculosis detection: a multi-site evaluation of the diagnostic accuracy of three deep learning systems. Sci Rep 2019 Oct 18;9(1):15000. doi: 10.1038/s41598-019-51503-3. PMID: 31628424; PMCID: PMC6802077.
[27] Jha, Yogesh & Kik, Sandra & Ruhwald, Morten. (2021). Digital chest radiography and Computer-Aided Detection (CAD) solutions for tuberculosis diagnostics, technology landscape analysis. 10.13140/RG.2.2.29862.86087.
[28] The Council of the European Union. Council Directive 2013/59/EURATOM of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation. Off J Eur Union 2014(13):1–73.
[29] Directive 2013/35/EU of the European Parliament and of the Council of 26 June 2013 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields) http://data.europa.eu/eli/dir/2013/35/oj (accessed 2 December 2020)
[30] Directorate-general for energy (European Commission), medical radiation exposure of the European population, 2014; https://ec.europa.eu/energy/sites/ener/files/documents/RP180.pdf (accessed 2 December 2020)
[31] Directorate-general for energy (European Commission) European study on clinical diagnostic reference levels for X-ray medical imaging, 2021. https://op.europa.eu/en/publication-detail/-/publication/a78331f7-7199-11eb-9ac9-01aa75ed71a1 (Accessed 1st June 2021)
[32] International atomic energy agency, Comprehensive clinical audits of diagnostic radiology practices: a tool for quality improvement, human health Series No. 4, IAEA, Vienna (2010).

[33] European Society of Radiology (ESR). The ESR Audit Tool (Esperanto): genesis, contents and pilot. Insights Imaging 2018;9:899–903. doi: 10.1007/s13244-018-0651-0.
[34] European Society of Radiology (ESR). ESR white paper on teleradiology: an update from the teleradiology subgroup. Insights Imaging 2014;4:1–6.
[35] Mollura D.J., Matthew Lungren M.P. Radiology in global health: strategies, implementation, and applications. https://doi.org/10.1007/978-1-4614-0604-4
[36] World Bank. Building centers of excellence in Africa to address regional development challenges, 2020. Available from: https://www.worldbank.org/en/results/2020/10/14/building-centers-of-excellence-in-africa-to-address-regional-development-challenges [Accessed 1st June 2021]
[37] The international federation of red cross and red crescent societies. *Reference Centres.* Available from: https://media.ifrc.org/ifrc/reference-centres [Accessed 1st June 2021]
[38] Africa centres for disease control and prevention. *Africa CDC website.* Available from: https://africacdc.org [Accessed 1st June 2021]
[39] Institut Pasteur. *Les CNR* Available from: https://www.pasteur.fr/fr/sante-publique/CNR/les-cnr [Accessed 1st June 2021]
[40] International Atomic Energy Agency. The Text of the African Regional Co-operative Agreement for Research, Development and Training Related to Nuclear Science and Technology (AFRA). Available from: https://www.iaea.org/the-text-of-the-african-regional-co-operative-agreement-for-research-development-and-training-related-to-nuclear-science-and-technology-afra [Accessed 1st June 2021]
[41] Muir KW, Buchan A, von Kummer R, Rother J, Baron JC. Imaging of acute stroke. Lancet Neurol 2006 Sep;5(9):755–68 PMID: 16914404.). doi: 10.1016/S1474-4422(06)70545-2.
[42] (ref loci) (https://data.worldbank.org/indicator/SP.POP.TOTL?locations=ZG)
[43] Radiological society of north America. RSNA website. Available from: https://www.rsna.org/[*Accessed* 1*st June* 2021]
[44] European Society of Radiology. ESR website. Available from: https://www.myesr.org/[*Accessed* 1*st June* 2021]
[45] The European association of nuclear medicine. EANM website. Available from: https://www.eanm.org/[*Accessed* 1*st June* 2021]
[46] International organization for medical physics. IOMP. Available from: https://www.iomp.org/[*Accessed* 1*st June* 2021]
[47] International society of radiographers and radiological technologists. ISRRT website. Available from: https://www.isrrt.org/[*Accessed* 1*st June*]
[48] IMAGINE - IAEA medical imaging and nuclear medicine global resources database. Published online Oct 2019. https://humanhealth.iaea.org/HHW/DBStatistics/IMAGINE.html (accessed 20 January 2020)
[49] World Bank. *World Bank Indicator.*Available from: https://data.worldbank.org/indicator/SP.POP.TOTL?locations=ZG [*Accessed* 1*st June* 2021]
[50] Kawooya MG. Training for rural radiology and imaging in sub-saharan Africa: addressing the mismatch between services and population. J Clin Imaging Sci 2012;2:37. Epub 2012 Jun 29. PMID: 22919551; PMCID: PMC3424787. doi: 10.4103/2156-7514.97747.
[51] Find 2021, Digital chest radiography and computer-aided detection (CAD) solutions for tuberculosis diagnostics: technology landscape analysis. Available from: https://www.finddx.org/wp-content/uploads/2021/04/FIND-CXR-CAD-solutions-for-TB-diagnosis-7Apr2021-2pg-spread.pdf [Accessed 1st June 2021]
[52] Sarwar A, Boland G, Monks A, Kruskal JB. Metrics for radiologists in the era of value-based health care delivery. Radiographics 2015;35(3):866–76 May-JunEpub 2015 Apr 3. PMID: 25839737. doi: 10.1148/rg.2015140221.
[53] European Society of Radiology (ESR). Performance indicators for radiation protection management: suggestions from the European society of radiology. Insights Imaging 2020;11(1):134. Dec 9PMID: 33296040; PMCID: PMC7726050. doi: 10.1186/s13244-020-00923-1.
[54] Atun R, Jaffray DA, Barton MB, Bray F, Baumann M, Vikram B, Hanna TP, Knaul FM, Lievens Y, Lui TY, Milosevic M, O'Sullivan B, Rodin DL, Rosenblatt E, Van Dyk J, Yap ML, Zubizarreta E, Gospodarowicz M. Expanding global access to radiotherapy. Lancet Oncol 2015;16(10):1153–86 SepPMID: 26419354. doi: 10.1016/S1470-2045(15)00222-3.
[55] Sayed S, Cherniak W, Lawler M, Tan SY, El Sadr W, Wolf N, Silkensen S, Brand N, Looi LM, Pai SA, Wilson ML, Milner D, Flanigan J, Fleming KA. Improving pathology and laboratory medicine in low-income and middle-income countries: roadmap to solutions. Lancet 2018 May 12;391(10133):1939–52 Epub 2018 Mar 15. PMID: 29550027. doi: 10.1016/S0140-6736(18)30459-8.
[56] Meara JG, Leather AJ, Hagander L, Alkire BC, Alonso N, Ameh EA, Bickler SW, Conteh L, Dare AJ, Davies J, Mérisier ED, El-Halabi S, Farmer PE, Gawande A, Gillies R, Greenberg SL, Grimes CE, Gruen RL, Ismail EA, Kamara TB, Lavy C, Lundeg G, Mkandawire NC, Raykar NP, Riesel JN, Rodas E, Rose J, Roy N, Shrime MG, Sullivan R, Verguet S, Watters D, Weiser TG, Wilson IH, Yamey G, Yip W. Global surgery 2030: evidence and solutions for achieving health, welfare, and economic development. Lancet 2015 Aug 8;386(9993):569–624 Epub 2015 Apr 26. PMID: 25924834. doi: 10.1016/S0140-6736(15)60160-X.
[57] Jaffray DA, Knaul FM, Atun R, Adams C, Barton MB, Baumann M, Lievens Y, Lui TY, Rodin DL, Rosenblatt E, Torode J, Van Dyk J, Vikram B, Gospodarowicz M. Global task force on radiotherapy for cancer control. Lancet Oncol 2015;16(10):1144–6 SepPMID: 26419349. doi: 10.1016/S1470-2045(15)00285-5.
[58] Rubin (ref: costing in radiology and health care: rationale, relativity, rudiments, and realities radiology: volume 282: number 2—February 2017)
[59] United Nations. Sustainable development goals. Available from: https://sdgs.un.org/goals/goal3 [Accessed 1st June 2021]
[60] Disease control priorities network. Disease control priorities 3 website. Available from: http://dcp-3.org/[*Accessed* 1*st June* 2021]</bib>
[61] Jamison DT, Gelband H, Horton S. Disease control priorities: improving health and reducing poverty. Washington, DC: World Bank; 2018.
[62] World Health Organization. WHO report on cancer: setting priorities, investing wisely and providing care for all, World Health Organization; 2020 https://apps.who.int/iris/handle/10665/330745 [Accessed 10 December 2020].
[63] Grossi RM. The importance of medical imaging and nuclear medicine in universal health coverage. Lancet Oncol 2021;22(4):423–4 AprEpub 2021 Mar 4. PMID: 33676608. doi: 10.1016/S1470-2045(21)00092-9.
[64] World Health Organisation. WHO guideline: recommendations on digital interventions for health system strengthening. Available from: https://apps.who.int/iris/bitstream/handle/10665/311941/9789241550505-eng.pdf?ua=1 [Accessed 2 December 2020]
[65] IAEA, WHO. Bonn Call for Action: Joint position statement by the IAEA and WHO. Available from: https://www.who.int/ionizing_radiation/medical_radiation_exposure/BonnCallforAction2014.pdf?ua=1 Accessed950
[66] World bank: medical diagnostic imaging (MDI) equipment .understanding how to procure medical diagnostic imaging equipment https://pubdocs.worldbank.org/en/258511553620191211/Procurement-Guidance-MDI-Equipment-Buyers.pdf
[67] The international society of radiology. *International society of radiology website.* Available from: https://www.isradiology.org/[*Accessed* 1*st June* 2021]
[68] RAD-AID. RAD-AID website. Available from: https://rad-aid.org/[*Accessed* 2 *December* 2020]