Medical imaging and nuclear medicine: a *Lancet Oncology* Commission

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The diagnosis and treatment of patients with cancer requires access to imaging to ensure accurate management decisions and optimal outcomes. Our global assessment of imaging and nuclear medicine resources identified substantial shortages in equipment and workforce, particularly in low-income and middle-income countries (LMICs). A microsimulation model of 11 cancers showed that the scale-up of imaging would avert 3·2% (2·46 million) of all 76·0 million deaths caused by the modelled cancers worldwide between 2020 and 2030, saving 54·92 million life-years. A comprehensive scale-up of imaging, treatment, and care quality would avert 9·55 million (12·5%) of all cancer deaths caused by the modelled cancers worldwide, saving 232·30 million life-years. Scale-up of imaging would cost US$6·84 billion in 2020–30 but yield lifetime productivity gains of $1·23 trillion worldwide, a net return of $179·19 per $1 invested. Combining the 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. With the use of a conservative approach regarding human capital, the scale-up of imaging alone would provide a net benefit of $209·46 billion and net return of $31·61 per $1 invested. With comprehensive scale-up, the worldwide net benefit using the human capital approach is $340·42 billion and the return per dollar invested is $2·46. These improved health and economic outcomes hold true across all geographical regions. We propose actions and investments that would enhance access to imaging equipment, workforce capacity, digital technology, radiopharmaceuticals, and research and training programmes in LMICs, to produce massive health and economic benefits and reduce the burden of cancer globally.

Introduction

The global cancer burden is increasing at an alarming rate. From 2012 to 2018, the estimated number of new cancer cases worldwide grew by more than 28%, from 14·1 to 18·1 million, and the estimated number of cancer deaths rose by approximately 17%, from 8·2 to 9·6 million.[1,2] By 2030, the number of new cancer cases worldwide is expected to reach 22·2 million and cancer deaths to reach 13·2 million.[3,4] These statistics are all the more concerning because approximately 80% of disability-adjusted life-years are lost to cancer in low-income and middle-income countries (LMICs), where only approximately 5% of the global funding for cancer control and care are applied.[3,5]

In 2015, *The Lancet Oncology* published the results of two Commissions that assessed the gaps in access to cancer surgery and radiotherapy, and proposed actions to address the growing burden of cancer in LMICs.[6,7] The Commission reports provided specific recommendations for increasing access to these treatment modalities, and showed that doing so could prevent avoidable human suffering and reduce preventable deaths, and at the same time also provide substantial economic benefits. Both reports noted that cancer care is a multidisciplinary endeavour and that the effective use of surgery and radiotherapy requires, among other resources, medical imaging.

In high-income countries, imaging plays an essential role in the management of almost all cancer types. This medical technique is used throughout the care continuum, from detection, diagnosis, and staging, to treatment planning (especially in radiation oncology), the assessment of treatment response, and in long-term follow-up. Moreover, interventional radiology, which relies on imaging, is increasingly integral to cancer diagnostics and treatment. Although the direct effect of imaging on overall survival is difficult to quantify because of the complexity of cancer biology and cancer care, and with there being a paucity of data on the subject, many studies have shown that the appropriate use of imaging for indications such as cancer staging or the assessment of treatment response can improve management decisions and reduce the costs of cancer care (eg, by obviating the need for other tests or invasive diagnostic procedures, indicating the need for neoadjuvant therapy, improving surgical or radiotherapy planning, preventing unnecessary surgery, and discontinuing ineffective treatments).[8–16]

Despite the ubiquity of imaging in modern cancer care in high-income countries, the importance of imaging in oncology is frequently overlooked in efforts aimed at improving cancer care in LMICs. Many LMICs have severe shortages of imaging and nuclear medicine equipment and personnel. Data on the amount of imaging equipment available in LMICs have not been gathered systematically. There are scant data on the numbers and distribution of health professionals involved in providing imaging services—including radiologists and nuclear medicine physicians, imaging radiographers and technologists, medical physicists, and radiochemists, among others. There are few reliable studies that quantify the number and combination of different types of health professionals needed to operate, optimally use, and maintain imaging equipment.[17] Furthermore, even in high-income countries with ready access to imaging services, there is little appreciation for the importance of specialised training and expertise to the optimal interpretation and reporting of cancer

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imaging.[17] Without data on these crucial elements, it is not possible to appropriately plan the introduction and scale-up of cancer services whose effectiveness depends on effective and efficient imaging and nuclear medicine services.

At the suggestion and with the help of the International Atomic Energy Agency (IAEA), *The Lancet Oncology* Commission on Medical Imaging and Nuclear Medicine was established in 2018, with the charge of examining global access to imaging and nuclear medicine for cancer care. This endeavour was also charged with analysing the barriers to access to imaging for cancer care, providing new evidence to show the benefits of imaging in improving cancer care and cancer survival, and providing recommendations on how best to introduce and scale up imaging services to expand access to imaging and nuclear medicine services in LMICs. To produce this Commission, the health benefits of cancer imaging were analysed on a global level, with the use of data from high-income countries and LMICs. The financial return on investment in cancer imaging was also investigated. Finally, given the vast imbalances in cancer burden and cancer control resources between LMICs and high-income countries, recommendations for scaling up cancer imaging resources were produced, with a specific focus on LMICs.

This Commission is organised into eight sections. Section 1 discusses the evolving role of cancer imaging in LMICs and the main challenges that resource-poor countries should consider when tailoring the adoption and use of imaging and nuclear medicine services to the continuum of cancer care resources available to them. Section 2 expands on the barriers to increasing access to cancer imaging in LMICs, presenting new data on the global availability of imaging technologies and human resources and identifying specific gaps that need to be addressed. Section 3 presents an analysis of the costs, benefits, and returns on investment that could be achieved by investing in the global scale-up of imaging technologies and human resource capabilities, alone or in tandem with the improved availability of treatment modalities, quality of care, or both. Section 4 discusses financing for a global scale-up of imaging diagnostics. Section 5 discusses the important issue of ensuring radiation protection and safety for patients, workers, and the public, as well as quality systems when scaling up imaging and nuclear medicine capabilities globally. Section 6 provides an overview of innovations in digital science technologies and novel analytical tools, such as artificial intelligence and machine learning, which will transform the availability of and access to imaging diagnostics and aid decision making. Section 7 outlines the crucial importance of teaching, training, and research, to ensuring the adequate capabilities and quality of imaging sites and staff in LMICs. Section 8, the conclusion, discusses the success factors necessary to enabling the global expansion of access to imaging for cancer, and calls for action toward this goal.

Section 1: the evolving role of cancer imaging in LMICs—opportunities and obstacles

As already described, the global cancer burden is increasing rapidly—particularly in LMICs, where funding for cancer care is scarce and the capacity to manage this rising burden is low.[18,19] As a result, huge inequities exist between countries in their access to effective services for cancer care. In addition to intercountry inequities, large inequities also exist within countries, with lower amounts of access for those with a lower income and lower education compared with those with a higher income and higher education. Such intracountry inequities persist both in wealthy nations such as the USA and in LMICs, where any available highly trained personnel and advanced health-care infrastructure—including imaging equipment—might be confined largely to private practices.[17,20,21] These inequities in access to cancer services are reflected in inequities in health outcomes. Although worldwide the overall survival rates for cancer are improving, the improvement is much less evident in LMICs.[17–19] Even though the incidence of cancer in LMICs is lower than that in high-income countries, cancer-related mortality rates are significantly higher in LMICs, especially in people aged younger than 65 years. These circumstances are at least partly due to delays in diagnosis (affected by poor access to imaging and other diagnostic tools), inadequate access to optimal local and systemic treatments, and greater numbers of infection-associated cancers in LMICs.[22,23]

It is important to recognise that cancer care is a continuum and requires parallel investments in imaging and other diagnostics, as well as in treatments. The socioeconomic benefits of investments in improvements to cancer surgery[7] and radiotherapy[6] infrastructure have been shown, and cancer imaging is required for diagnosis, staging, and effective treatment with either surgery or radiotherapy. For example, patients undergoing radiotherapy require imaging for treatment planning, and quantitative imaging affects radiotherapy outcomes and survival.[24–26] Similarly, preoperative imaging bolsters the safety, appropriateness, quality, and effectiveness of cancer surgery. Furthermore, the use of imaging to guide biopsies and minimally invasive interventions (eg, image-guided placement of central venous catheters for the administration of medicines, or image-guided tumour ablations) is associated with improved quality, decreased morbidity, and enhanced affordability of these procedures[27–31] Moreover, the absence of staging information from imaging can lead to the inadequate or inappropriate use of medical therapies, surgery, or radiotherapy, and consequently increase morbidity and mortality. Selection of the most appropriate antineoplastic regimen for patients with cancer often relies upon imaging results.[32]

Use of cancer imaging and its benefits: a review of the literature

Although imaging plays pivotal roles in cancer care, because of the complexity of the care process, the direct effects of imaging on patient outcomes have historically been difficult to quantify. Nevertheless, we reviewed the (albeit scarce) published peer-reviewed literature and reports aimed at quantifying, on a large scale, the use of imaging, and its benefits, for patients with cancer. One study from Canada, based on a survey of centres providing imaging services, examined the amount of use of and the reasons for imaging; the study found that approximately 23·1% of CT examinations, 80·2% of PET-CT examinations, and 20·8% of MRI examinations were done for cancer indications.[33] However, the survey relied on subjective assessments of the distribution of indications rather than a direct analysis of administrative data, and the response rate regarding this issue was low.[33] Although CT scans are used to image a broad spectrum of conditions, a report for the UK National Health Service suggests that approximately 95% of the CT scanners in the UK National Health Service are used for cancer staging in addition to their use for non-cancer indications, though it does not provide details into the proportion of CT examinations done for oncological purposes.[34,35] A study of imaging studies in the USA that used data from the Centers for Medicare & Medicaid Services found that 9·5% of all advanced imaging studies (ie, CT, MRI, and PET studies) were done in patients with cancer.[35]

Imaging tests are included in oncology clinical practice guidelines by every major professional group, as well as the US National Comprehensive Cancer Network and the UK National Institute for Health and Care Excellence; and evidence-based studies being used for the justification of reimbursement decisions for imaging examinations in patients with cancer show the effect of such imaging studies in clinical practice. Data from large prospective examinations have shown how imaging can assist in management decisions; for example, the US National Oncologic PET Registry has collected data for more than 300 000 patients since 2006, and has shown that the use of PET leads to substantial changes in the clinical management of 30% of patients across various cancer types.[36,37] Our literature review did not find any relevant large-scale studies from LMICs.

Strengthening cancer care in LMICs: the need for a systems approach

Cancer control and care is complex and requires multidisciplinary teams for a successful delivery. The pathway encompasses prevention, screening, diagnostics (including imaging, pathology, and laboratory services), treatments (including surgery, radiotherapy, and systemic therapies), survivorship, palliative care, and end-of-life care. A good cancer programme would ideally include services to support all these areas at the appropriate times during the patient's journey. Optimal cancer control also relies on access to vaccines for common infections that can lead to cancer (eg, human papillomavirus and hepatitis). Additionally, the successful delivery of cancer care requires the coordination of the overall health system, including public and private health care facilities. Education of the public is necessary to promote cancer awareness and encourage them to seek care. Furthermore, the families and careers of those affected by cancer also require support. Although each of these needs demands focused attention, the process of cancer control should be viewed holistically and as consisting of a dynamic, interlinked, and interdependent chain of activities, where weak links might cause a breakdown in the system of care, and in which the links should be aligned with each other to provide value.

The shortage of a well-trained health workforce and the poor availability of health technologies in LMICs require the adoption of suitable approaches to diagnostics, including disease staging and management during treatment, which differ from those used in high-income countries. Cancer control and care in LMICs will be improved by the adoption of novel approaches to the management of the disease, implemented by way of the progressive expansion of human resources, health technologies, and health care services for prevention, diagnosis, treatment, and palliative care. For example, in LMICs, women with locally advanced breast cancer might undergo a staging work-up for metastatic disease, which includes a chest x-ray and liver ultrasonography, but not CT, single photon emission computed tomography (SPECT), or PET-CT, which would typically be used in high-income countries. Although an adapted approach in LMICs will miss metastatic disease in some patients whose disease might have been detected with more advanced technologies, this systematic approach will nonetheless benefit many patients. If the initiation of the evaluation and treatment of patients was delayed until more advanced imaging (and potential treatment options) were available, it would mean that in the interval, which might be many years, patients would go without any treatment at all.

Matching the imaging technologies with the treatments available in LMICs is crucial. This optimisation process should be done in a systematic and evidence-informed way for a multitude of cancer types, considering diagnostics (including pathology and imaging), surgery, systemic therapy, and radiotherapy. The specifics for each of the imaging and treatment modalities used will differ for each cancer. Investment in cancer detection and control should also take into account the complexity of the health-care system and ensure equitable patient access.[22] Furthermore, over time, technology improvements and evidence-based cost–benefit assessments of imaging and treatment modalities will result in changes in imaging recommendations for different cancers, depending on the stage of presentation. Moreover, changes in the patterns of cancer incidence and presentation that are likely to

result from economic development, because of factors such as environmental exposures, lifestyle changes, and ageing populations, as well as greater access to affordable screening and diagnostic services, will require the further adaptation of cancer services.[38,39]

When decisions are being made about which imaging modalities to adopt, it is also necessary to consider the overall resources available in a country to purchase, install, operate, maintain, and—when needed—repair the imaging equipment. In practice, governments allocate a proportion of their budgets to health, which is then apportioned to different areas of need, including for maternal and child health, communicable diseases, non-communicable diseases, and injuries.[23] Some of the funds are typically allocated to cancer control and care for capital expenditures (for infrastructural needs, including clinical space and capital outlays for radiology and nuclear medicine equipment, pathology laboratories, and operating rooms with necessary equipment) and operational expenditures for the salaries of health-care providers (eg, physicians, nurses, technologists, pharmacists, and community health workers, as well as trained oncology providers and appropriately trained staff in radiation units who are needed to safely and effectively operate them, including, for example, physicists and dosimetrists). Appropriate medicines (including chemotherapy and biological therapies), technologies (eg, for radiotherapy), and diagnostics (including imaging and pathology) should be available to balance diagnostic capabilities with subsequent treatment options. The proportion of the funds allocated to cancer care will vary across and within countries depending on priorities and the different levels of services available. For example, urban centres might have a higher level of care and more resources available than rural settings.[17] In each setting, however, all aspects of care resources should be coordinated and appropriated to ensure effective and efficient budgeting.

When allocating scarce resources, the management challenges posed by the constraints of imaging capacity should also be considered. For instance, in some settings, only one or two CT scanners might serve large populations, not just patients with cancer but also those with other conditions (eg, trauma or infection); consequently, wait times for scanning might be long, reducing the availability of CT scans for patients with cancer. For example, if a patient with diffuse large B-cell lymphoma with extensive mediastinal involvement has to wait 6 weeks for an initial staging CT, clinicians might need to begin treatment without the aid of the CT, which might then not be done at all. In this context, knowledge of the appropriate number of imaging units required per million people in a population to effectively manage cancer diagnosis and treatment is necessary to allow resource planning at a country level. More data on the use of imaging and equipment in high-income countries and LMICs would clearly assist with identifying gaps and facilitate the development of strategic recommendations for the expansion and use of cancer imaging at a global level.

The need for the maintenance of imaging equipment should also be taken into account when planning and budgeting for improvements in cancer imaging services. For example, in settings where there might be only one or two CT scanners, having one scanner out of service for an extended period of time will have a substantial clinical effect, but equipment vendors might not have in-country service personnel, and it can be months before technicians can attend to machines at some sites. The cost of repairs and maintenance can be especially expensive in LMICs, leading to delays in service and prolonged down-time of equipment. Many LMICs have facilities with non-functioning imaging equipment (along with non-functioning pathology processors, linear accelerators, etc). Unstable power grids that lead to regular interruptions in the supply of electricity, among other factors, compound this issue. Loss of electrical power and power surges are common in many locations in LMICs, in both urban and rural regions.

A further challenge in LMICs is the absence of a reliable supply chain for imaging diagnostics, such as contrast agents and radiopharmaceuticals. Gaps in the availability of crucial reagents are frequent and affect the functional status of the imaging modalities that depend on them. Quality management systems are essential to ensure imaging is done in a safe and effective manner. In addition to imaging equipment, the availability of a workforce appropriately trained to do imaging studies is a notable challenge in providing timely and equitable access to imaging for cancer. At present, in some LMICs, clinicians might be able to get their patients scanned in a timely manner, but a paucity of radiologists might delay scan reporting to a degree that affects patient care.

To help address the multitude of challenges faced by LMICs in relation to cancer imaging, comprehensive, global mapping of medical imaging and nuclear medicine resources is needed to identify existing gaps and inform strategies to mitigate them. In addition, given the contextual differences in cancer burden and funding availability across LMICs, as well as technical and human resource capacity, to enable strategic planning for optimal cancer care in LMICs, there is a need for evidence on how investments in the expansion of imaging could yield clear improvements in patient outcomes in different countries and health systems. These gaps and needs are addressed in more detail, and by the provision and analysis of new data, in the next two sections of this report.

Section 2: overcoming barriers to access and mapping gaps in imaging and nuclear medicine resources to facilitate a progressive expansion of cancer care

Greater guidance is needed to progressively expand access in LMICs to cost-effective, affordable technologies,

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which include diagnostic imaging and nuclear medicine, required to address the rising burden of cancer in these countries.

Applying this framework to the contemporary example of radiotherapy, *The Lancet Oncology* Commission on expanding global access to radiotherapy[6] showed that the cost of upscaling radiotherapy from 2015 to 2035 across all LMICs is matched by "compelling evidence that investment in radiotherapy not only enables treatment of large numbers of cancer cases to save lives, but also brings positive economic benefits." Similarly, *The Lancet Oncology* Commission on sustainable care for children with cancer has shown substantial health and economic benefits of scaling up high-quality cancer services and treatment for childhood cancers.[40] The study estimated net benefits of US$2 trillion, with an average investment of $30 billion each year in LMICs over a 30-year period (2020–50). Both Commissions were able to show a clear investment case, with estimated returns of up to $6 for radiotherapy and $3 for childhood cancers for every dollar invested.

Just a few decades ago, the possibility of extending the benefits of technologies such as radiotherapy to those without access was deemed unachievable. Since then, many LMICs have made notable progress in primary care, enabling them to begin integrating such technologies into their health-care systems. For example, the WHO Global Action Plan for the prevention and control of non-communicable diseases 2013–20 includes radiotherapy for cervical cancer and colorectal cancer.[41] Improvements in economic evaluation methods, applied as part of health technology assessment programmes, have enabled more effective and transparent priority setting by heath care systems and paved the way for the inclusion of new health technologies in Universal Health Coverage (UHC).[42]

In the gradual development of cancer imaging capacity in LMICs, modalities including ultrasound, conventional x-ray, CT, and mammography should be given priority because of their role in the initial assessment of patients, as well as their effect on patient management throughout the disease course.[43] In view of the complex nature of cancer management for some patient groups, the type of imaging equipment that should be installed and operational at health-care facilities should be based primarily on established, prioritised recommendations by WHO.[44] Our Commission's composite recommendations for new imaging technologies are intended to complement and support these (table 1).[44] Our aim is to promote the effective and efficient delivery of multidisciplinary cancer care, with resources implemented and progressively provided in a strategic manner. This approach might be challenging in LMICs with less funding for health care, but this framework bolsters the capacity of countries to develop facilities in an informed, contemporary, and sustainable manner.

The barriers restricting access to imaging and nuclear medicine for cancer in LMICs, many of which were mentioned earlier, include: (1) not enough equipment, (2) insufficient human resources, (3) inadequate government funding for cancer care and health systems in general, (4) few reliable data about the availability of equipment and skilled human resources needed for imaging, (5) a paucity of studies that quantify patient imaging needs (for both cancer and non-cancer indications), (6) the absence of evidence-based guidance on investments in imaging required to achieve optimal patient management, (7) inadequate and insufficient programmes for training personnel for cancer imaging, (8) the dearth of a procurement process that is evidence-based and step-wise, to enable the selection of the most appropriate equipment (including appropriate technical specifications and requirements for the maintenance and repair for the amount of services and training available), (9) insufficient expertise in architectural planning for medical imaging and nuclear medicine (including radiation safety), (10) inadequate systems for appropriate patient referral and follow-up, (11) insufficient requisite clinical resources (eg, laboratories, resources for pathology, and supplies of consumables such as syringes, personal protective equipment, biopsy devices, catheters, contrast media, local anaesthetic, and other medicines, such as radiopharmaceuticals), and (12) poor provision of safe waste disposal (including biohazards and radiopharmaceuticals).[45] The barriers for the implementation of imaging equipment at appropriate levels of access, as well as in the provision of adequate workforce, training, and education, are similar across LMICs, although differences will always exist between countries.

Furthermore, the compatibility of equipment with local realities, such as the availability and reliability of electricity and clean water, optimal lighting in image

	Imaging modality
WHO Health Care Level 1 (primary health care)	Level 1 does not have adequate equipment or facilities to undertake cancer care; it might have a triage role to the next level up
WHO Health Care Level 2 (secondary health care)	Radiography with fluoroscopy Doppler ultrasonography Mammography Angiography CT Radionuclide scintigraphy, including SPECT–CT
WHO Health Care Level 3 (tertiary health care)	Magnetic resonance imaging Positron emission tomography–CT Theranostics

The Commission recommendation comes from a consensus development process that involved discussion at *Lancet Oncology* Commission meetings, where input from imaging experts into this topic was obtained. The differences in the recommendations for each WHO Health Care Level[44] for imaging equipment are as follows: (1) this Commission suggests explicitly that Health Care Level 1 should not be where cancer care should be done, because the full range of imaging equipment available at this level (including CT scans as a minimum) is not adequate for appropriate diagnosis and staging, and probably cannot provide the medical expertise or services required for complete cancer care; (2) this Commission recommends the inclusion of SPECT–CT (rather than SPECT alone) in Health Care Level 2, because the use of these modalities is now standard at this level; and (3) this Commission recommends the inclusion of theranostics in Health Care Level 3, as this procedure replaces radioimmunoscintigraphy. SPECT=single photon emission CT.

Table 1: **Imaging technologies recommended by this Commission for cancer care facilities, adapted for WHO Health Care Levels[44]**

Panel 1: Data collection for IMAGINE

The International Atomic Energy Agency (IAEA) medical imaging and nuclear medicine (IMAGINE) global resources database[51] was launched in 2019, and is being continuously updated. A total of 1857 datapoints in the profiles of 211 countries, territories, and principalities have been collected, with the dominant sources depicted in figure 1.

Primary sources for the IMAGINE database were as follows:

- The IAEA (from IAEA staff and experts; reports of national, regional, and interregional meetings; fact-finding missions; countries' authorities and counterparts to IAEA projects) and UN partner organisations and agencies such as WHO, WHO regional offices, the International Agency for Research on Cancer, the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the UN Development Programme, the World Bank, and the ministries of health of some countries, Eurostat, and the Organisation for Economic Cooperation and Development (OECD)
- National, regional, and global professional organisations and societies for medical imaging and nuclear medicine, such as the Arab Society of Nuclear Medicine; the Asia Oceania Federation of Nuclear Medicine and Biology; the Asociación Latinoamericana de Sociedades de Biología y Medicina Nuclear; the European Trade Association representing the medical imaging radiotherapy, health information and communication technologies, and electromedical industries (COCIR); the European Association of Nuclear Medicine; the European Society of Radiology; Global Diagnostic Imaging; the Healthcare Information Technology and Radiation Therapy Trade Organisation; the International Organisation for Medical Physics; the International Society of Radiographers and Radiation Technologists; the International Society of Radiology; RAD-AID International; the Society of Nuclear Medicine and Molecular Imaging; and the World Federation of Nuclear Medicine and Biology
- A comprehensive review of published studies and reports on medical imaging and nuclear medicine resources in different countries, particularly from WHO, UNSCEAR, OECD, and Eurostat
- A survey of individual experts to address gaps in data, including ministry of health representatives and radiation authority experts in countries who work with the IAEA and agreed to share data on equipment and human resources for their respective countries

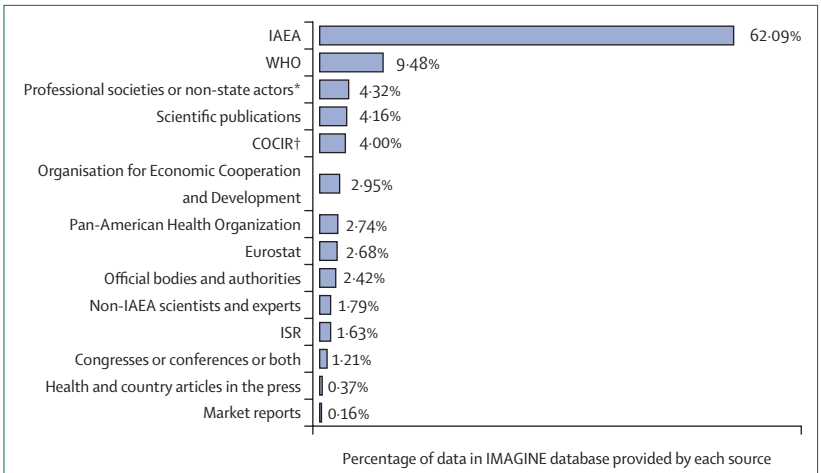

Figure 1: **Major data sources for the IMAGINE database**
IAEA=International Atomic Energy Agency. IMAGINE=IAEA medical imaging and nuclear medicine global resources database. ISR=International Society of Radiology. *COCIR and ISR have been considered separately from the professional societies or non-state actors category, because each association independently contributed more than 1% of all data in IMAGINE. †COCIR is the European trade association of medical imaging, radiotherapy, health information technology, and electromedical industries.

interpretation and procedural areas, sustainable infrastructure (including temperature control, or equipment that functions durably without it), and digital linkages to patient information, are issues that need to be overcome to ensure access to effective and reliable cancer imaging services.[46,47] To safeguard sustainability, it is also essential to guarantee adequate maintenance coverage, including service contracts, warranties, the availability of spare parts, and an understanding of anticipated software updates.

Furthermore, relevant patient-centred processes should include an assessment of patient satisfaction, adequate communication pathways (including patient access to telephone services), and available transportation to facilities for the entire target population. Additionally, health campaigns and community engagement can increase awareness of the target patient population regarding cancer care, including the role of medical imaging.

Another essential requirement is to ensure the availability not just of affordable imaging, but also of affordable treatment after a cancer is diagnosed. In some LMICs, current and projected estimates of patient resources (including the national UHC strategy) are necessary, taking into consideration financial toxicity for individuals marginalised by the overall cost of cancer care.[48–50]

Identifying the global gaps in the availability of imaging diagnostics and human resources

To address the data gaps identified as part of *The Lancet Oncology* Commission on Medical Imaging and Nuclear Medicine, we collected new data to comprehensively analyse and map the availability of medical imaging and nuclear medicine resources globally. The survey and analysis were led by the IAEA. The data were used to construct a new database, the IAEA medical imaging and nuclear medicine (IMAGINE) global resources database.[51] The sources of data for the IMAGINE database are included in panel 1 and summarised in figure 1; sources for, and access to, the database are also discussed further in the appendix (p 1).[51] IMAGINE data were stratified into high-income, upper-middle-income, lower-middle-income, and low-income countries, according to World Bank country income classifications.[6]

Data on the amount of available CT, PET, mammography, MRI, and SPECT equipment at a country level and by the income stratification of countries are shown in figures 2–6, and more detailed interactive information is available on the IAEA IMAGINE database website.[51] Information about the numbers of x-ray and ultrasound equipment per country could not be accurately assessed because of the absence of available data from the broad range of health-care facilities, including small health clinics, where this equipment can be installed.

The survey results display a substantial difference in the numbers of scanners per million people in the

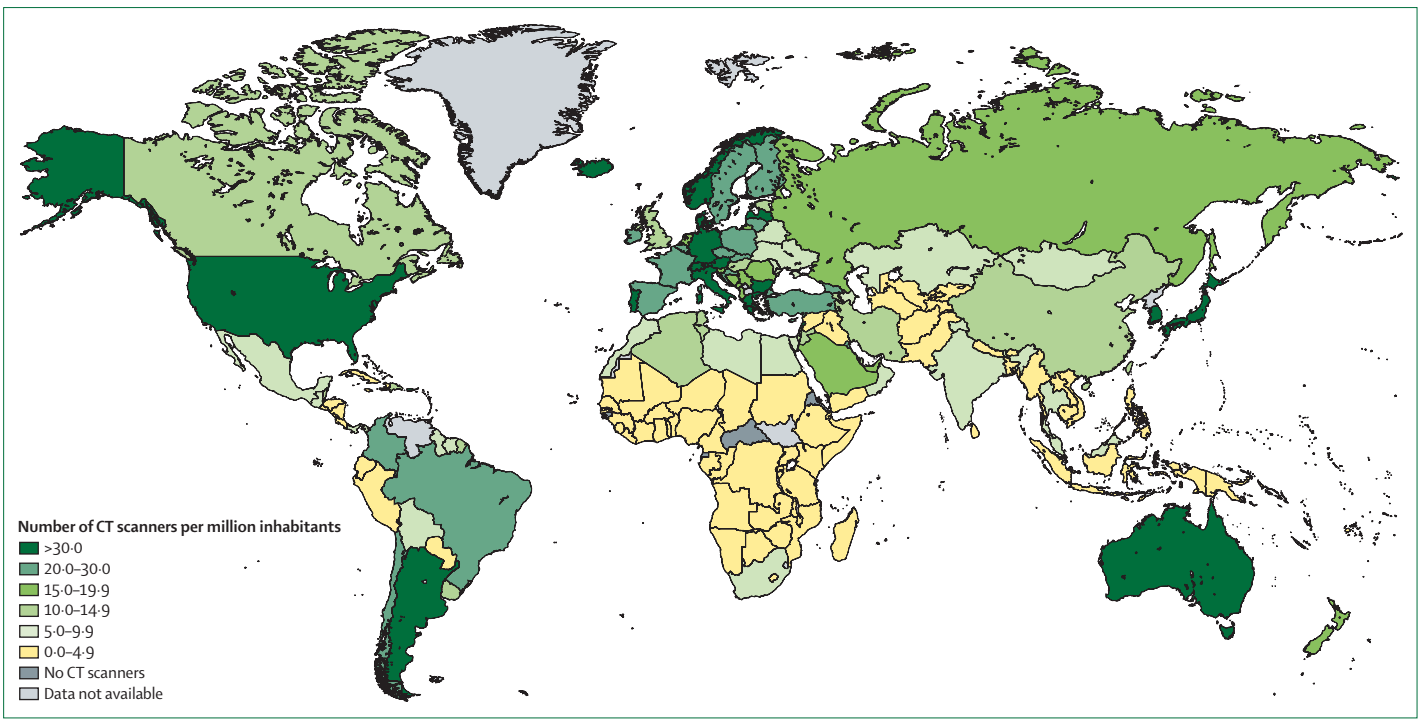

Figure 2: **Estimates of the number of CT scanners per million inhabitants**
Data are from the International Atomic Energy Agency medical imaging and nuclear medicine global resources database (IMAGINE). The map was produced by the International Atomic Energy Agency (Vienna, Austria) and is included here with permission.

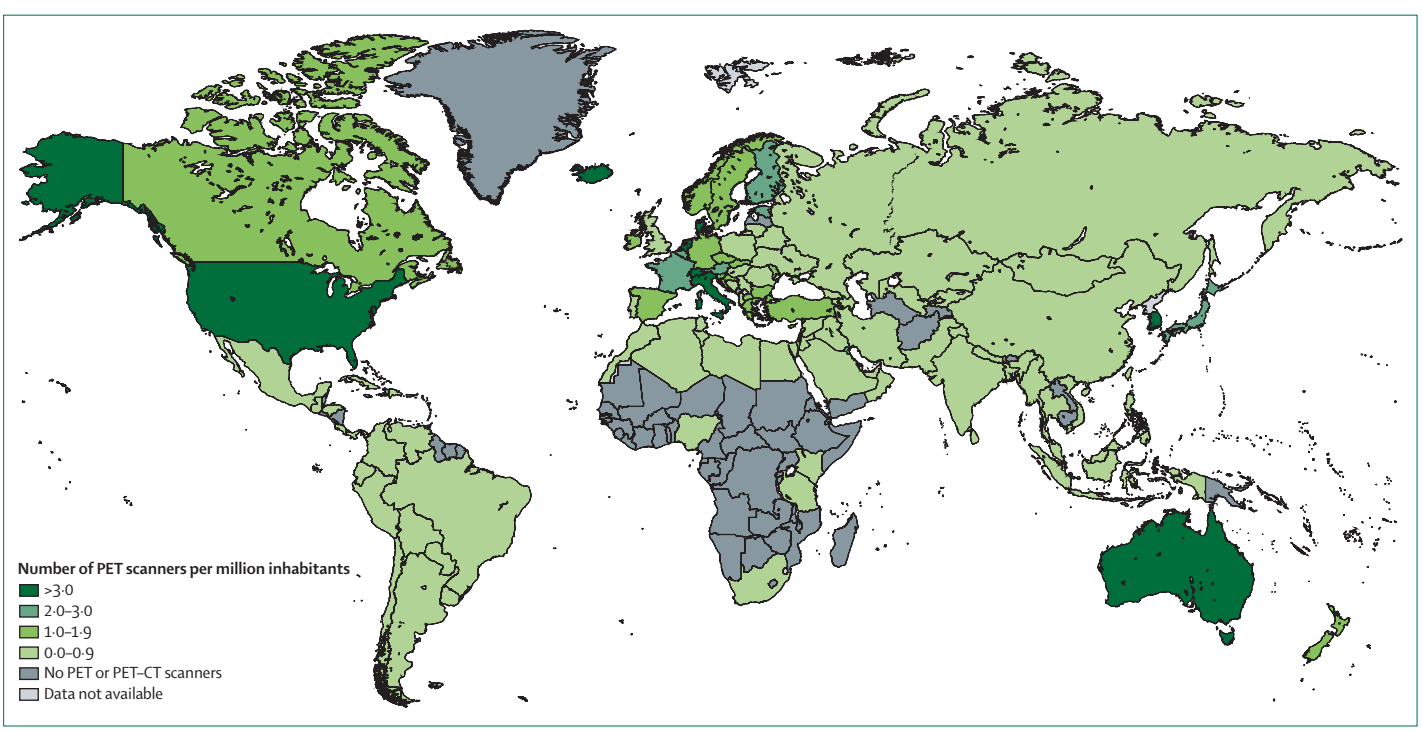

Figure 3: **Estimates of the number of PET scanners per million inhabitants**
Data are from the International Atomic Energy Agency medical imaging and nuclear medicine global resources database (IMAGINE). The map was produced by the International Atomic Energy Agency (Vienna, Austria) and is included here with permission.

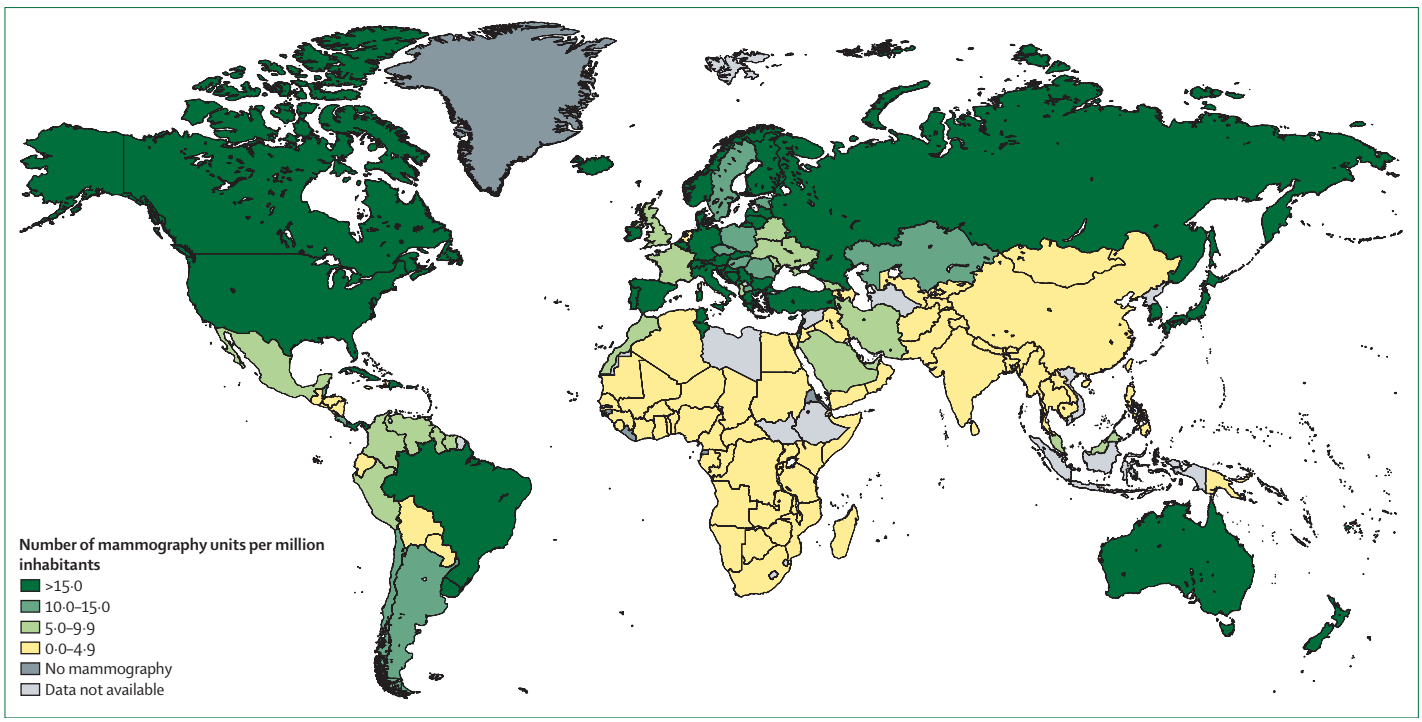

Figure 4: **Estimates of the number of mammography units per million inhabitants**
Data are from the International Atomic Energy Agency medical imaging and nuclear medicine global resources database (IMAGINE). The map was produced by the International Atomic Energy Agency (Vienna, Austria) and is included here with permission.

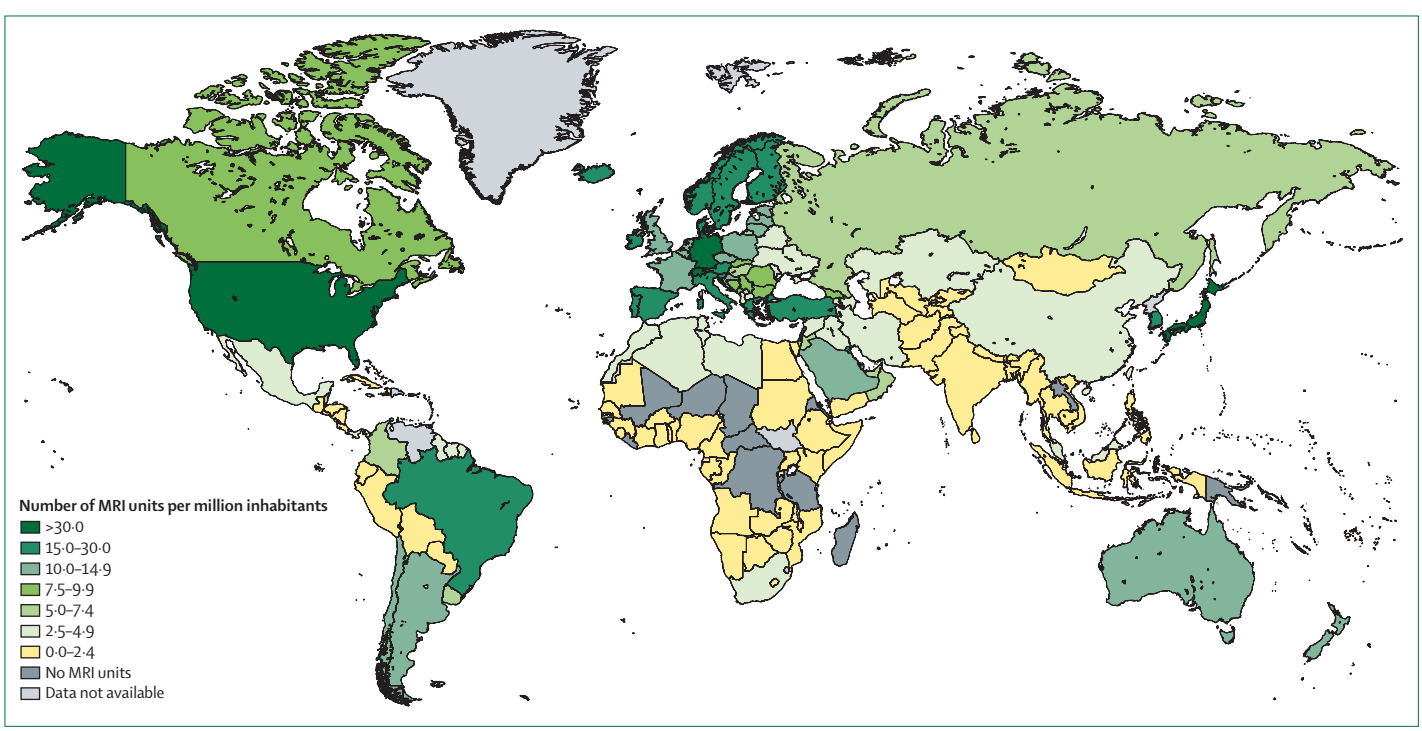

Figure 5: **Estimates of the number of MRI units per million inhabitants**
Data are from the International Atomic Energy Agency medical imaging and nuclear medicine global resources database (IMAGINE). The map was produced by the International Atomic Energy Agency (Vienna, Austria) and is included here with permission.

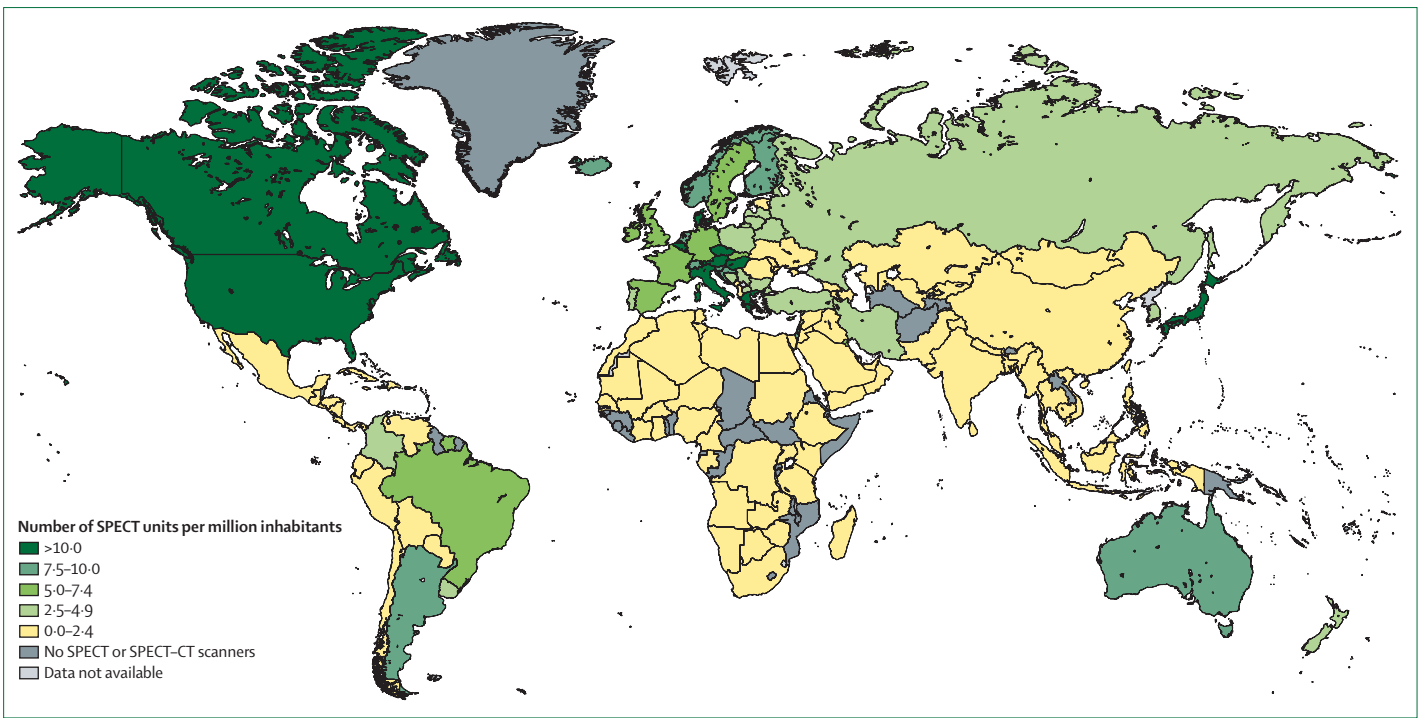

Figure 6: **Estimates of the number of SPECT units per million inhabitants**
Data are from the International Atomic Energy Agency medical imaging and nuclear medicine global resources database (IMAGINE). The map was produced by the International Atomic Energy Agency (Vienna, Austria) and is included here with permission. SPECT=single photon emission CT.

population between high-income countries and LMICs (table 2).[51] For example, the mean number of people served by one CT scanner in high-income countries is 25 000; in upper-middle-income countries, 79 000; in lower-middle-income countries, 227 000; and in low-income countries, 1 694 000.[51] Although no formal recommendations for numbers of scanners per million population exist, the information obtained from the IMAGINE database (table 2) can be used to obtain estimates of the amount of installed imaging equipment to provide a range by different country income groups, enabling the projection of requirements in different settings. Additionally, evidence-based tools such as a health technology assessment can enable nations to rationally set their own benchmarks. One relevant example of a country using a health technology assessment is the Framework for the Development of PET Services in England.[52] Nations might adopt and adapt such pre-existing templates from other nations to set benchmarks for themselves, in support of rational, achievable planning.

As with the availability and coverage of imaging equipment, little information exists at a global level about the numbers of radiologists and nuclear medicine physicians in different countries. The IMAGINE database revealed susbantial differences in the numbers of trained radiologists and nuclear medicine physicians between countries (figures 7, 8), with substantially fewer trained professionals in low-income countries than in upper-middle-income and high-income countries (table 3).[51] Although in some countries nuclear medicine scans are read by radiologists, the survey data suggest that the use of nuclear medicine scans is less in countries where lower access to radiopharmaceuticals and trained

	CT	MRI	SPECT	PET
High-income countries				
Range	6·3–42·3	0·0–34·3	0·0–20·5	0·0–4·3
Mean (SD)	38·8 (16·0)	27·3 (10·4)	18·2 (7·5)	3·6 (3·4)
Median (IQR)	20·5 (14·4–32·7)	12·6 (8·5–19·2)	5·4 (2·4–9·7)	1·2 (0·6–2·5)
Upper-middle-income countries				
Range	0·0–29·8	0·0–16·0	0·0–5·2	0·0–0·7
Mean (SD)	12·1 (10·1)	5·4 (4·8)	1·6 (1·8)	0·3 (0·5)
Median (IQR)	7·8 (4·8–16·2)	3·4 (1·3–7·2)	0·9 (0·0–2·5)	0·2 (0·0–0·4)
Lower-middle-income countries				
Range	0·0–7·8	0·0–3·3	0·0–0·9	0·0–0·2
Mean (SD)	4·3 (3·2)	1·1 (1·2)	0·3 (0·3)	0·2 (0·3)
Median (IQR)	1·4 (0·9–3·9)	0·4 (0·1–1·4)	0·1 (0·0–0·4)	0·0 (0·0–0·1)
Low-income countries				
Range	0·0–1·1	0·0–0·3	0·0–0·1	0·0–0·0
Mean (SD)	0·7 (0·8)	0·2 (0·5)	0·1 (0·1)	0·0 (0·0)
Median (IQR)	0·4 (0·2–0·9)	0·1 (0·0–0·2)	0·0 (0·0–0·0)	0·0 (0·0–0·0)

The data source is the International Atomic Energy Agency medical imaging and nuclear medicine global resources (IMAGINE) database.[51] SPECT=single photon emission CT.

Table 2: **Number of different types of scanners per million inhabitants by country income group**

For the **IMAGINE global resources database** see https://humanhealth.iaea.org/HHW/DBStatistics/IMAGINE.html

See **Online** for appendix

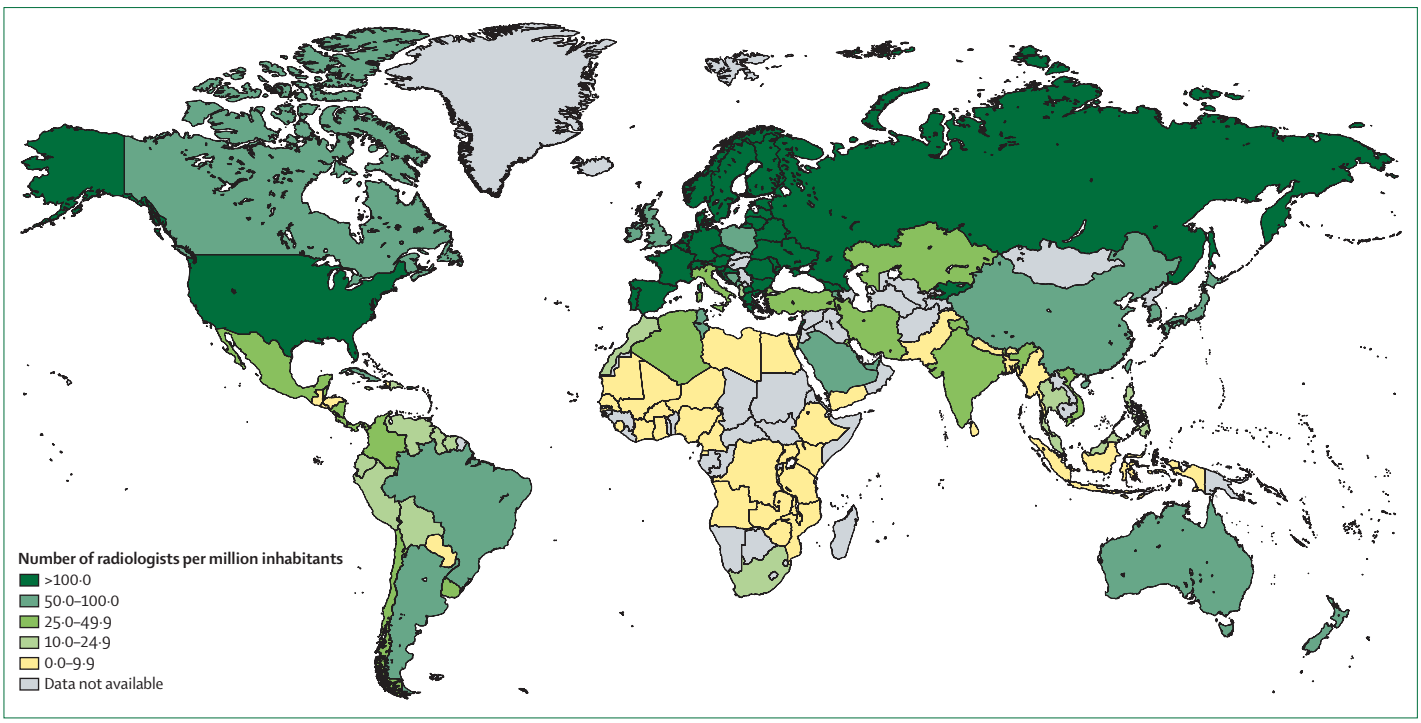

Figure 7: **Estimated number of radiologists per million inhabitants**
Data are from the International Atomic Energy Agency medical imaging and nuclear medicine global resources database (IMAGINE). The map was produced by the International Atomic Energy Agency (Vienna, Austria) and is included here with permission.

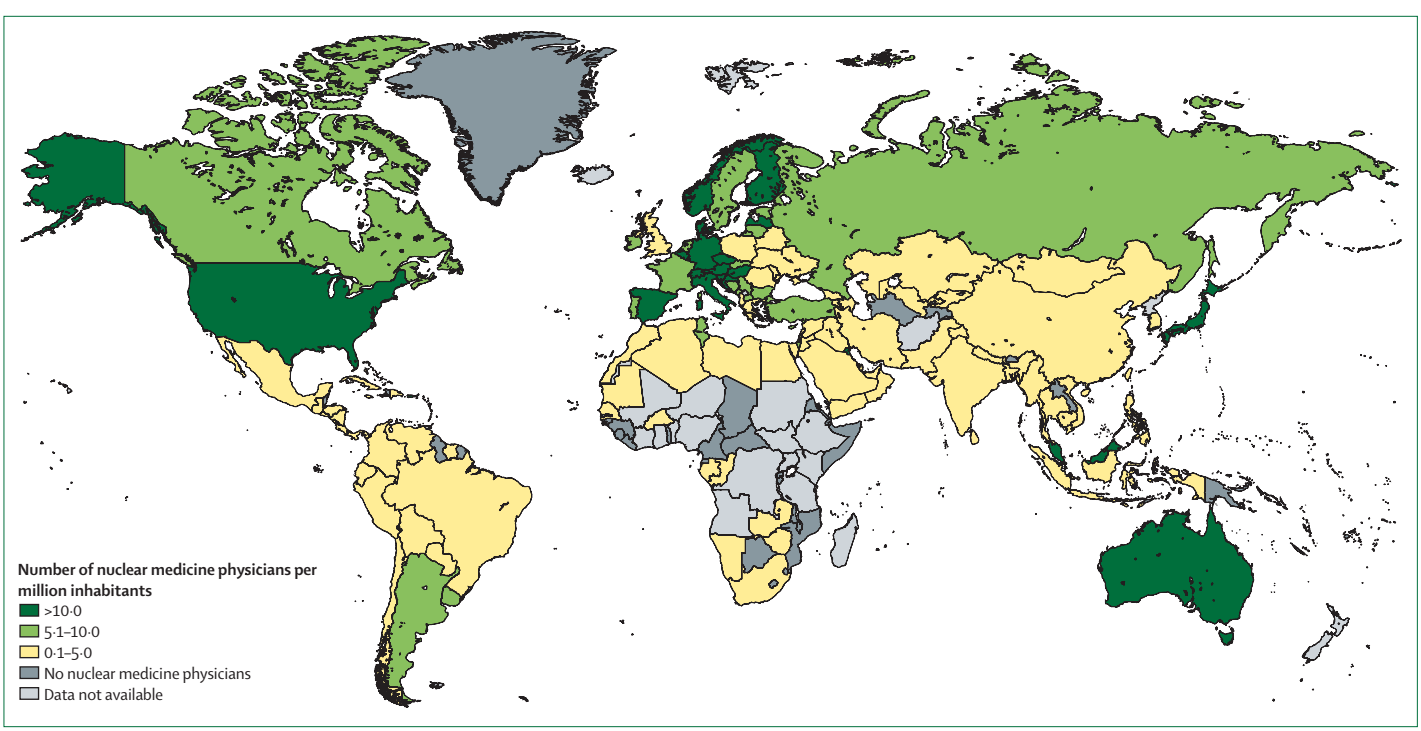

Figure 8: **Estimated number of nuclear medicine physicians per million inhabitants**
Data are from the International Atomic Energy Agency medical imaging and nuclear medicine global resources database (IMAGINE). The map was produced by the International Atomic Energy Agency (Vienna, Austria) and is included here with permission.

professionals are additional confounding factors in appropriate scan use.

Although imaging use data in patients with cancer in LMICs are scarce, the data from the IMAGINE database project suggest that in many LMICs, the availability of imaging for these patients is quite restricted. As such, the main effect of imaging in LMICs is likely to be on establishing accurate staging information to guide initial treatment decisions. As previously noted, the absence of such information can lead to the inadequate or inappropriate use of medicines, surgery, or radiotherapy, and increase morbidity and mortality.[53] In this context, the health outcome and economic case for improving access to imaging in LMICs for patients with cancer—as detailed in the following section—is of great practical relevance.

Section 3: costs versus health and economic benefits of scaling up diagnostic imaging for cancer—a case for investment

Section 2 of this report presents new data on the gaps in the availability of imaging modalities for cancer in LMICs. The expansion of cancer imaging capacity could help to improve the diagnosis, treatment, and care of patients with cancer worldwide. However, analysis of the IMAGINE database reveals not only a substantial shortage of imaging modalities, but also large variation among countries within and across country income groups. For example, in high-income countries, there is a two-times variation in the lower quartiles and upper quartiles in the availability of CT scanners, but a four-times difference for SPECT scanners. The variation in availability of all imaging modalities for upper-middle-income countries, lower-middle-income countries, and low-income countries is larger than that observed for high-income countries (table 2).

Research undertaken in conjunction with this Commission included modelling studies that estimated the potential effect of scaling up treatment (chemotherapy, surgery, radiotherapy, and targeted therapy) and imaging modalities (ultrasound, x-ray, CT, MRI, PET, and SPECT) on cancer survival. These studies estimated the net survival benefit of scaling up treatment and imaging, both individually and in combination, in 200 countries and territories, to that of the mean amount of high-income countries, for 11 cancer types (cancer of the oesophagus, stomach, colon, rectum, anus, liver, pancreas, lung, breast, cervix, and prostate).[54,55] We modelled all cancer sites for which comparable international classification of diseases for oncology 3 topography codes were available in both the GLOBOCAN[56] (to estimate incidence) and the CONCORD-3[18] (to estimate survival) studies. These cancers account for 60% of all global diagnosed cases of cancer.[55] These studies revealed substantial health benefits of scaling up imaging modalities in the management of cancer, in that they improved 5-year net survival. The studies showed that the simultaneous expansion of treatment, imaging modalities, and quality of care could improve 5-year net survival by more than ten times in low-income countries, from 3·8% (95% uncertainty interval [UI] 0·5–9·2) to 45·2% (40·2–52·1), and could more than double 5-year net survival in lower-middle-income countries, from 20·1% (7·2–31·7) to 47·1% (42·8–50·8). There was increased survival for all country income groups with scale-up, with traditional imaging modalities (ie, traditional treatment including surgery, radiotherapy, and chemotherapy; and traditional imaging including ultrasound and x-ray) estimated to provide the largest increase in low-income countries, and MRI and PET estimated to yield the largest increase in higher-income countries. The studies showed that investing in medical imaging would be necessary for substantial survival gains.[54,55]

	Nuclear medicine physicians	Radiologists
High-income countries		
Range	0·0–26·2	13·9–194·0
Mean (SD)	10·9 (10·5)	97·9 (56·2)
Median (IQR)	6·5 (1·8–11·8)	93·1 (51·3–129·3)
Upper-middle-income countries		
Range	0·0–6·5	1·5–118·0
Mean (SD)	2·7 (3·4)	66·8 (65·3)
Median (IQR)	1·5 (0·2–3·0)	30·6 (15·6–61·0)
Lower-middle-income countries		
Range	0·0–1·2	0·4–68·4
Mean (SD)	0·5 (0·9)	22·3 (36·4)
Median (IQR)	0·1 (0·0–0·6)	6·9 (3·0–30·9)
Low-income countries		
Range	0·0–0·1	0·1–3·9
Mean (SD)	0·1 (0·1)	1·9 (2·5)
Median (IQR)	0·0 (0·0–0·0)	1·1 (0·5–3·3)

The data source is the International Atomic Energy Agency medical imaging and nuclear medicine global resources database.[51]

Table 3: **Radiologists and nuclear medicine physicians per million population by country income group**

However, these studies did not estimate the cost of scale-up and the potential economic benefits. Therefore, to show the health and economic benefits and costs of the scale-up of imaging modalities worldwide and to ascertain whether a worldwide scale-up would generate positive and substantial rates of return on these investments, we developed and extended a modelling approach that was conceived initially for *The Lancet Oncology* Commission on expanding global access to radiotherapy and developed for *The Lancet Oncology* Commission on Sustainable Care for Children with Cancer.[40]

Briefly, we extended the microsimulation model of cancer survival for 11 cancer types in 200 countries and territories, described earlier,[55] to include a module on lifetime survival, treatment costs, and economic benefits. We used observed data from the CONCORD-3

study[18] to calibrate our microsimulation model and to estimate 5-year net survival for 200 countries. We provide a detailed description of the methods in the appendix (pp 2–7). We simulated the clinical course of each individual patient with cancer diagnosed between 2020 and 2030 over their lifetime until death (from any cause), accounting for net cancer survival and competing mortality risks based on country-specific lifetable projections with and without scale-up. In our model we did not estimate the effect of screening, but modelled cancer cases conditionally depending on diagnosis and stage.

We estimated the economic benefits of improving cancer survival using the full income approach (also called the value-of-life-year approach). The full income approach recognises the intrinsic societal value of a life-year. We followed the methods used in *The Lancet* Commission on Global Health in 2035,[57] which estimated the willingness to pay for a 1-year increase in life expectancy in countries with different income levels and applied a value of 2·3 times the gross domestic product (GDP) per person per year in LMICs and 1·4 times the GDP in high-income countries.

For a sensitivity analysis, we used a more conservative human capital approach. With the human capital approach, the economic value of a life-year is based on the economic contribution of an individual and is valued at one times the GDP per person. We accrued productivity benefits only to individuals aged 18–64 years in the model when using the human capital approach to reflect typical working ages.

Because the human capital approach only values productivity and economic contribution and not the intrinsic value of health and an additional year of life, we used the full-income approach as our base case, which better reflects the value of an additional year to a society.

Cancer treatment costs were estimated with the use of a modelled relationship between costs and per person GDP based on empirical data obtained from a targeted literature review. More details on the model specifications and assumptions, estimations of costs, projected health, and economic benefits and restrictions with the data and model are available in a paper by Ward and colleagues[58] and in the appendix (pp 2–7).

Using the model, we estimated the global costs and benefits of four different packages of scale-up, in which we improved the availability of imaging or treatment modalities, or both, and quality of care to the mean value of high-income countries under different scenarios: (1) imaging only, a scenario in which all imaging modalities (ultrasound, x-ray, CT, MRI, PET, and SPECT) only are scaled up; (2) treatment only, in which all treatment modalities (chemotherapy, radiotherapy, surgery, and targeted therapy) only are scaled up; (3) treatment and quality of care, in which all treatment modalities and quality of care are scaled up; and (4) comprehensive, in which all imaging and treatment modalities and quality of care are scaled up. We compared the potential gains from scaling up all imaging modalities versus all treatment modalities. We also estimated the potential gains foregone from not including imaging as part of a comprehensive scale-up (ie, treatment and quality of care only *vs* comprehensive scenarios).

We include a variable for quality of care to control for health system and facility-level factors not explicitly included in the model, which cover health service capabilities that also affect cancer survival, such as adequate laboratory and pathology diagnostics, infection control, nursing standards, and coordination of care (appendix p 4).

We estimated the cancer deaths averted, life-years gained, cancer treatment costs, productivity gains, and lifetime return on investment for the cancer cases diagnosed in 2020–30, compared with a baseline scenario or status quo of no scale-up. We computed health and economic benefits, costs, and return on investment for the 200 countries and territories included, and for world regions. We discounted costs and benefits at 3% (a commonly used discount rate).[59] The detailed description of the data sources, methods, and the approach for the modelling are provided in other published papers.[55,58]

The results show that the comprehensive scenario, with a scale-up of all imaging modalities, treatment methods, and quality of care in 2020–30 would avert 9·55 million deaths worldwide, accounting for 12·5% of the projected total worldwide deaths of 76·00 million in this period and 232·30 million life-years saved. The scale-up of imaging alone would avert 2·46 million deaths, accounting for 3·2% of worldwide deaths and 54·92 million life-years saved (table 4).[58]

The vast majority of the deaths averted under a comprehensive scale-up scenario would be in Asia (5·28 million) accounting for 11·9% of projected cancer deaths in Asia in 2020–30 and 133·99 million life-years saved. In Asia, the scale-up of imaging alone would avert 1·42 million deaths, accounting for 3·2% of projected cancer deaths in Asia, and would result in 33·47 million life-years saved (table 4).[58]

Similarly, there would be major health gains in Africa where the comprehensive scale-up would avert 2·51 million cancer deaths amounting to 35·7% of total projected cancer deaths in Africa, and result in 61·27 million life-years saved. Scale-up of imaging alone would avert 207 800 cancer deaths (3·0% of the projected total cancer deaths in Africa) and result in 4·64 million life-years saved on this continent (table 4).[58]

Worldwide scale-up of imaging alone or in conjunction with treatment and improved quality of care produces substantial economic benefits and return on investments (table 5).[58]

Incremental costs in 2020–30 of scaling up imaging alone would be $6·84 billion, but this investment would result in productivity gains of $1·23 trillion and a net benefit of $1·22 trillion, yielding a return per dollar

	Deaths from cancer averted (95% uncertainty interval)		Projected life-years saved, millions (95% uncertainty interval)	
	Number	Proportion of total deaths	Undiscounted	Discounted (3% annually)
Global				
Imaging only	2 463 500 (1 154 900–4 073 900)	3·2% (1·6–5·3)	54·92 (25·15–91·40)	33·17 (15·18–54·93)
Treatment only	4 095 600 (1 632 300–7 093 400)	5·4% (2·2–9·1)	103·28 (40·37–184·19)	58·36 (22·71–102·73)
Treatment and quality of care	5 369 100 (2 894 300–8 032 800)	7·0% (3·9–10·3)	134·96 (72·84–208·11)	76·13 (40·94–116·06)
Comprehensive	9 549 500 (6 677 800–12 743 800)	12·5% (9·0–16·3)	232·30 (157·29–311·30)	133·71 (91·94–179·03)
Africa				
Imaging only	207 800 (78 700–579 100)	3·0% (1·1–8·3)	4·64 (1·65–13·76)	2·72 (0·99–7·89)
Treatment only	984 300 (299 900–1 926 700)	14·1% (4·3–26·9)	23·99 (7·11–47·13)	13·50 (4·06–26·43)
Treatment and quality of care	1 569 400 (925 500–2 211 400)	22·3% (14·1–30·5)	38·54 (22·47–54·77)	21·62 (12·63–30·37)
Comprehensive	2 508 100 (2 004 500–2 932 800)	35·7% (29·8–41·7)	61·27 (49·52–72·07)	34·58 (27·86–40·30)
Asia				
Imaging only	1 420 600 (381 700–2 784 800)	3·2% (0·9–6·3)	33·47 (9·16–67·14)	20·12 (5·43–39·85)
Treatment only	2 509 100 (399 600–4 813 600)	5·6% (0·9–10·4)	65·74 (10·72–124·31)	36·93 (6·09–69·93)
Treatment and quality of care	3 038 000 (822 900–5 402 900)	6·8% (1·9–11·7)	79·56 (21·62–142·02)	44·64 (12·03–79·77)
Comprehensive	5 282 200 (3 203 400–7 616 800)	11·9% (7·4–16·5)	133·99 (79·09–191·59)	76·88 (45·70–110·17)
Europe				
Imaging only	435 700 (158 600–769 700)	3·2% (1·1–5·6)	8·18 (2·97–14·76)	5·16 (1·90–9·13)
Treatment only	350 500 (91 800–709 800)	2·6% (0·7–5·2)	7·40 (1·98–14·62)	4·45 (1·22–8·81)
Treatment and quality of care	455 800 (116 800–971 100)	3·3% (0·9–7·0)	9·46 (2·41–19·98)	5·68 (1·44–11·98)
Comprehensive	982 400 (610 700–1 366 200)	7·2% (4·6–9·8)	19·38 (12·02–27·12)	11·95 (7·48–16·50)
Latin America and the Caribbean				
Imaging only	354 900 (26 900–633 700)	7·0% (0·6–12·6)	7·64 (0·55–14·04)	4·57 (0·33–8·36)
Treatment only	210 700 (28 600–610 400)	4·1% (0·6–12·1)	5·19 (0·77–15·17)	2·93 (0·41–8·50)
Treatment and quality of care	247 600 (53 400–728 300)	4·9% (1·1–13·8)	6·08 (1·36–17·04)	3·42 (0·75–9·77)
Comprehensive	665 000 (370 300–1 039 000)	13·1% (7·5–19·5)	15·13 (8·08–24·02)	8·84 (4·81–13·85)
North America				
Imaging only	29 700 (0–219 500)	0·5% (0·0–4·0)	0·67 (0·00–4·88)	0·40 (0·00–2·94)
Treatment only	15 300 (0–119 600)	0·3% (0·0–2·2)	0·35 (0·00–2·83)	0·20 (0·00–1·72)
Treatment and quality of care	21 100 (0–129 400)	0·4% (0·0–2·4)	0·47 (0·00–2·85)	0·27 (0·00–1·72)
Comprehensive	50 900 (0–235 800)	0·9% (0·0–4·3)	1·14 (0·00–5·27)	0·68 (0·00–3·15)
Oceania				
Imaging only	14 700 (700–53 900)	2·7% (0·1–9·7)	0·33 (0·01–1·23)	0·19 (0·01–0·72)
Treatment only	25 700 (800–73 300)	4·7% (0·2–12·3)	0·60 (0·02–1·70)	0·34 (0·01–0·98)
Treatment and quality of care	37 300 (3000–79 800)	6·8% (0·6–14·2)	0·86 (0·07–1·87)	0·49 (0·04–1·06)
Comprehensive	61 000 (22 800–95 800)	11·1% (4·4–17·1)	1·38 (0·50–2·27)	0·80 (0·30–1·30)

Estimates are from the global cancer survival microsimulation model.[58] The four different scenarios are: (1) imaging only, a scenario in which all imaging modalities (ultrasound, x-ray, CT, MRI, PET, and SPECT) only are scaled up; (2) treatment only, in which all treatment modalities (chemotherapy, radiotherapy, surgery, and targeted therapy) only are scaled up; (3) treatment and quality of care, in which all treatment modalities and quality of care are scaled up; and (4) comprehensive, in which all imaging and treatment modalities and quality of care are scaled up.

Table 4: **Potential health benefits for patients with cancer diagnosed between 2020 and 2030 under various scenarios of scale-up for the 11 modelled cancer types**

invested of $179·19. The large returns that could be achieved from investment are because the scale-up of most of the cancer imaging modalities is not costly. However, the absolute numbers of deaths averted with scaling up imaging alone would be modest compared with what could be achieved with the comprehensive scale-up scenario (table 4).

The estimated incremental cost of comprehensive scale-up globally would be $232·88 billion, amounting to a 6·9% increase in the current global cost of cancer treatment and care. However, the benefits of this scale-up would be substantial, with lifetime productivity gains of $2·89 trillion for the cancer cases diagnosed in 2020–30. This benefit would produce a net economic benefit of $2·66 trillion and a return on investment of $12·43 for every dollar invested. Scale-up of just treatment and quality of care without imaging would produce a notably lower net economic benefit of $1·16 trillion and a return

	Incremental cancer treatment costs (2020–30), US$ billion (95% uncertainty interval)		Lifetime return on investment: full income approach (95% uncertainty interval)		
	Difference	Percentage increase	Productivity gains, US$ billion	Net benefit, US$ billion	Return per US$ invested
Global					
Imaging only	6·84 (1·77 to 15·86)	0·2% (0·1 to 0·3)	1226·21 (540·05 to 2161·80)	1219·37 (535·47 to 2157·29)	179·19 (84·71 to 625·09)
Treatment only	50·72 (14·92 to 111·88)	1·5% (0·8 to 2·4)	1183·24 (504·90 to 2206·54)	1132·51 (489·13 to 2114·69)	23·33 (12·40 to 60·40)
Treatment and quality of care	225·50 (83·87 to 408·34)	6·7% (5·7 to 7·8)	1386·07 (726·42 to 2342·19)	1160·56 (484·04 to 2053·70)	6·15 (2·66 to 16·71)
Comprehensive	232·88 (85·92 to 421·97)	6·9% (6·0 to 8·0)	2894·41 (1794·55 to 4025·16)	2661·54 (1631·20 to 3775·64)	12·43 (6·47 to 33·23)
Africa					
Imaging only	0·46 (0·23 to 0·79)	1·9% (1·2 to 3·0)	27·38 (9·61 to 65·80)	26·93 (9·29 to 65·34)	59·97 (22·11 to 128·14)
Treatment only	6·85 (3·82 to 11·22)	29·4% (17·6 to 42·2)	120·97 (52·46 to 210·96)	114·12 (44·51 to 203·06)	17·67 (8·09 to 33·93)
Treatment and quality of care	11·14 (6·64 to 16·98)	47·8% (34·1 to 63·1)	164·86 (88·57 to 237·47)	153·72 (79·95 to 225·41)	14·80 (8·05 to 25·71)
Comprehensive	11·67 (7·01 to 17·70)	50·1% (36·2 to 66·4)	249·66 (187·61 to 303·31)	237·99 (177·71 to 291·80)	21·39 (14·15 to 34·34)
Asia					
Imaging only	3·42 (0·66 to 9·37)	0·4% (0·1 to 0·6)	713·38 (86·71 to 1616·35)	709·96 (86·03 to 1610·45)	208·70 (77·77 to 850·18)
Treatment only	24·58 (4·35 to 69·42)	2·7% (0·5 to 6·2)	679·76 (107·85 to 1681·10)	655·17 (103·01 to 1621·55)	27·65 (12·89 to 68·97)
Treatment and quality of care	37·98 (13·16 to 86·15)	4·4% (1·9 to 8·5)	772·73 (182·13 to 1686·61)	734·75 (164·77 to 1613·12)	20·35 (8·10 to 49·52)
Comprehensive	41·59 (14·76 to 91·25)	4·7% (2·3 to 8·9)	1653·82 (828·58 to 2458·01)	1612·22 (802·55 to 2410·54)	39·76 (17·99 to 101·74)
Europe					
Imaging only	1·95 (0·23 to 5·52)	0·2% (0·0 to 0·4)	281·15 (77·79 to 612·65)	279·20 (76·86 to 605·35)	144·32 (71·07 to 686·83)
Treatment only	14·73 (1·88 to 38·95)	1·2% (0·2 to 2·6)	257·18 (82·05 to 517·31)	242·45 (72·14 to 493·25)	17·46 (8·28 to 66·89)
Treatment and quality of care	171·39 (59·50 to 314·06)	14·5% (13·3 to 16·0)	301·80 (114·77 to 602·30)	130·41 (−119·56 to 444·47)	1·76 (0·49 to 6·02)
Comprehensive	173·59 (59·79 to 315·94)	14·7% (13·6 to 16·1)	618·57 (367·27 to 884·37)	444·98 (160·23 to 737·88)	3·56 (1·64 to 10·47)
Latin America and the Caribbean					
Imaging only	0·52 (0·03 to 1·31)	0·6% (0·0 to 1·1)	138·85 (8·89 to 259·83)	138·33 (8·85 to 259·06)	266·38 (109·69 to 1351·47)
Treatment only	2·21 (0·20 to 7·03)	2·9% (0·3 to 7·4)	79·99 (8·78 to 241·17)	77·79 (8·54 to 237·43)	36·28 (14·10 to 152·10)
Treatment and quality of care	2·56 (0·45 to 7·42)	3·4% (0·7 to 8·0)	87·66 (9·42 to 264·11)	85·10 (8·85 to 260·56)	34·27 (12·16 to 124·16)
Comprehensive	3·08 (0·61 to 8·04)	4·1% (1·3 to 8·7)	245·96 (123·82 to 403·20)	242·88 (122·20 to 397·69)	79·77 (30·36 to 384·86)
North America					
Imaging only	0·37 (0·00 to 3·26)	0·0% (0·0 to 0·2)	47·48 (0·00 to 348·01)	47·12 (0·00 to 345·16)	128·94 (64·85 to 361·54)
Treatment only	1·22 (0·00 to 11·54)	0·1% (0·0 to 0·8)	24·24 (0·00 to 202·14)	23·02 (0·00 to 181·52)	19·83 (7·95 to 72·25)
Treatment and quality of care	1·22 (0·00 to 11·54)	0·1% (0·0 to 0·8)	32·60 (0·00 to 202·14)	31·37 (0·00 to 190·39)	26·66 (8·18 to 1398·67)
Comprehensive	1·59 (0·00 to 11·58)	0·1% (0·0 to 0·8)	80·12 (0·00 to 373·7)	78·53 (0·00 to 371·43)	50·36 (8·42 to 984·28)
Oceania					
Imaging only	0·13 (0·00 to 0·59)	0·1% (0·0 to 0·6)	17·96 (0·13 to 77·95)	17·83 (0·13 to 77·42)	137·36 (24·94 to 338·03)
Treatment only	1·14 (0·02 to 4·59)	1·2% (0·0 to 4·4)	21·09 (0·12 to 86·53)	19·96 (0·11 to 83·31)	18·56 (5·28 to 51·96)
Treatment and quality of care	1·21 (0·09 to 4·68)	1·3% (0·1 to 4·5)	26·42 (0·67 to 93·98)	25·21 (0·57 to 91·45)	21·77 (5·70 to 191·78)
Comprehensive	1·35 (0·13 to 4·83)	1·4% (0·2 to 4·5)	46·29 (9·13 to 112·39)	44·95 (8·92 to 109·14)	34·41 (11·48 to 244·48)

All results discounted 3% annually. Estimates are from the global cancer survival microsimulation model.[58] The four different scenarios are: (1) imaging only, a scenario in which all imaging modalities (ultrasound, x-ray, CT, MRI, PET, and SPECT) only are scaled up; (2) treatment only, in which all treatment modalities (chemotherapy, radiotherapy, surgery, and targeted therapy) only are scaled up; (3) treatment and quality of care, in which all treatment modalities and quality of care are scaled up; and (4) comprehensive, in which all imaging and treatment modalities and quality of care are scaled up. GDP=gross domestic product.

Table 5: **Potential economic costs and benefits for patients with cancer diagnosed between 2020 and 2030 for 11 modelled cancer types**

on investment of $6·15, less than half of what would be achieved if imaging were included in the scale-up (table 5).[58] To provide a specific example, we compared our model estimates to the reported costs from Ethiopia using data from Ethiopia's national health accounts (see the case study in panel 2).[60,61]

The net economic benefits of a comprehensive scale-up would be substantial in all world regions (table 5).[58]

All regions worldwide would achieve substantial positive returns per dollar invested on investment in comprehensive scale-up or with the scale-up of imaging alone or in combination with treatment and quality of care (table 5). Lifetime returns on investment accrued to countries worldwide are shown in figure 9.

The estimated variation on the return on investment between countries is mainly because of differences in the availability of imaging modalities in different countries. Regional differences in these estimations are largely because of: (1) differences in the baseline availability of surgery, radiotherapy, and medicines and imaging

modalities; (2) differences in the quality of care; (3) differences in income levels in countries, which influences productivity estimates; and (4) the fact that the value placed on a life-year with the use of the full income approach varies by income group, where the value is 2·3-times the GDP per person per year in LMICs, and 1·4-times that the GDP per person in high-income countries. New data compiled by this Commission on coverage of imaging modalities by country and presented in this report (table 2) reveal substantial variation in the availability of imaging modalities between countries at different income levels.[51] The range of per person income between and without country income categories is substantial. The Gross National Income per person (calculated with the use of Atlas methods[62] and purchasing power parity) ranges from $280 to $1035 in low-income counties, from $1036 to $4045 in lower-middle income countries, from $4046 to $12 535 in upper-middle income countries, and from $12 536 to more than $100 000 in high-income countries.[63]

We present in the appendix (p 8) a sensitivity analysis (based on estimates of the global cancer survival microsimulation model)[58] of costs, productivity gains, net benefits, and return on investments that use the more conservative human capital approach. This sensitivity analysis shows a net benefit of $209·46 billion (95% UI $94·96–394·72) and a return per dollar invested of $31·61 (95% UI $15·09–110·14) for scaling up imaging alone. With comprehensive scale-up, the worldwide net benefit is $340·42 billion (95% UI $99·37–592·59) and the return per dollar invested is $2·46 (95% UI $1·29–6·52), because costs of comprehensive scale-up are much higher than scaling up imaging alone. There are substantial net benefits and returns to scaling up imaging in all world regions and, with the exception of Europe, considerable net benefits and return on investment with comprehensive scale-up (appendix p 8).

The modelling, with the use of either the full income or human capital approaches, shows notable health and economic benefits, with substantial returns on investments achieved when scaling up imaging diagnostics alone or as part of a comprehensive scale-up that involves the simultaneous scale-up of treatment and quality of care.

Modelling suggests synergistic benefits when all of these aspects are scaled up simultaneously. Therefore, the results are not additive. Scaling up imaging without scale-up in treatment is not likely to lead to major improvements in cancer survival, because treatment capacity is soon reached and additional cases will not be adequately treated. Similarly, scaling up quality of care without diagnostics or improving treatment availability will probably have little effect on cancer survival in LMICs, because many individuals will not be diagnosed, and even when they are diagnosed they will not receive the surgery, radiotherapy, or medicines that they need to treat their cancer. Hence, the results establish a compelling case for investing in the worldwide comprehensive scale-up of diagnostic imaging for cancer.

***Panel 2:* Incremental costs and benefits of comprehensive scale-up: Ethiopia case study**

As a specific example, we compare our model estimates to reported costs from Ethiopia, for which national health accounts data are available. According to the Ethiopian Ministry of Health, national health expenditures were $US3·10 billion for 2016–17 (around 4·2% of their gross domestic product), of which an estimated 1·8% ($55·8 million) was spent on patients with cancer.[60] Our model estimates that cancer treatment costs in Ethiopia for the baseline scenario (no scale-up) are $90·55 million (95% uncertainty interval [UI] 64·51–124·12) per year on average between 2020 and 2030, similar to the reported estimates after accounting for population growth (UN population projections estimate that the population of those aged older than 50 years in Ethiopia will grow by 40% between 2015 and 2025).[61]

We estimate that with a comprehensive scale-up, cancer treatment costs would rise to $171·17 million (95% UI 125·55–224·80), accounting for an additional $80·6 million (95% UI 54·3–110·0) of spending per year on average—a 90% increase in cancer costs. Although this estimate represents a large increase in cancer spending, it is a small proportion of total health expenditures, comprising approximately 2·8% of current total health expenditures. In return, we estimate that a comprehensive scale-up would yield large economic benefits over the lifetime of patients who have survived cancer, yielding an estimated return of $18·44 (95% UI 12·94–28·80) per dollar invested in Ethiopia.

Section 4: financing the global scale-up of diagnostics

New financing will be needed to scale-up the capacity for cancer imaging diagnostics to expand access to effective and affordable services in LMICs. But where will this new financing come from?

In most LMICs, the largest proportion of funding will probably come from domestic sources—namely, public financing (the government budget allocated to health) and complementary financing from the private sector. Additionally, there is the potential for funding from external private companies, Overseas Development Assistance, or development banks that provide loans or invest in health infrastructure projects; for example, banks that establish new diagnostic imaging facilities or upgrade existing ones. Examples of development banks include the World Bank Group, a conglomerate of five institutions, as well as the European Investment Bank, African Development Bank, InterAmerican Development Bank, Islamic Development Bank, and Asian Development Bank.

Donations can also come from or be facilitated by non-state actors or non-governmental organisations and UN organisations, such as WHO and the IAEA. For example, the IAEA allocated €5·74 million in 2019 for the support of nuclear medicine and diagnostic imaging, including the procurement of medical imaging equipment and the expansion of capacity. The beneficiaries of cooperation are member state LMICs (eg, Algeria).[64]

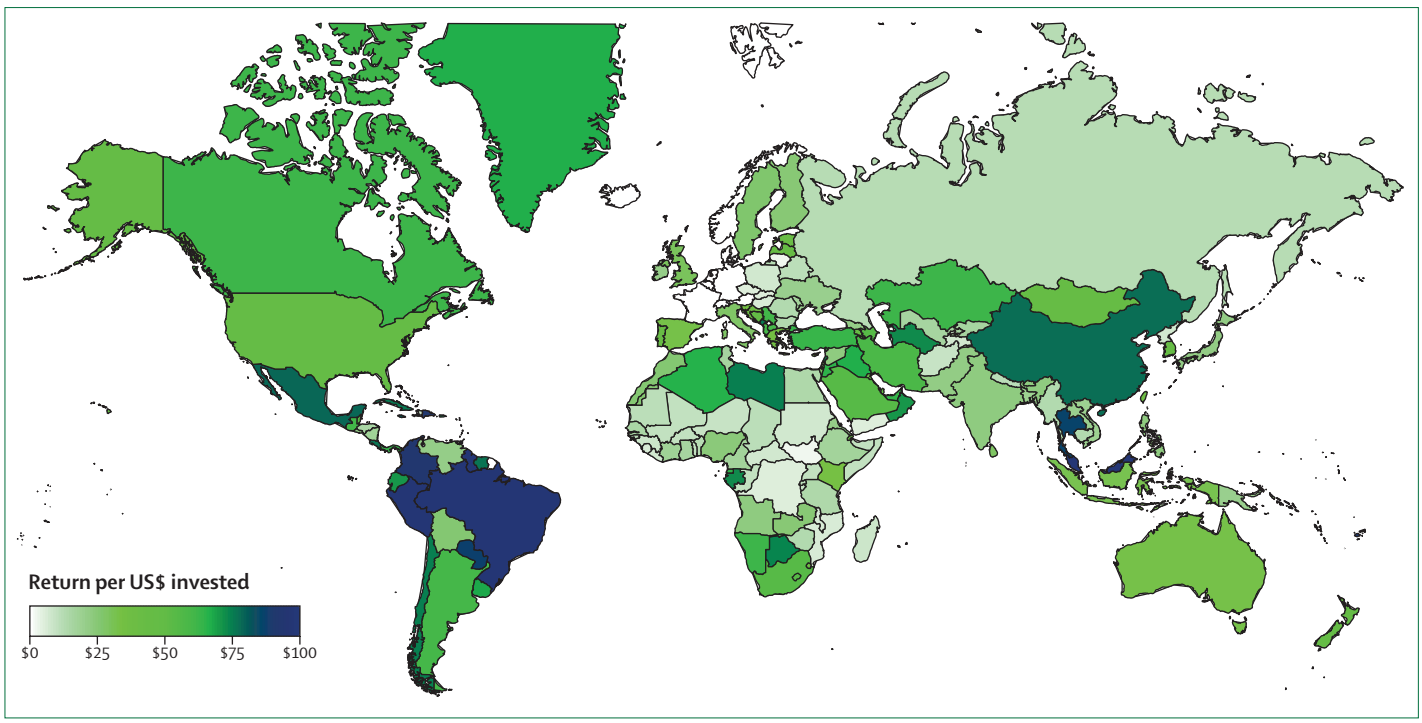

Figure 9: **Estimated lifetime return on investment (comprehensive scale-up of imaging, treatment, and quality of care) by country for 11 cancer types**
Comprehensive scale-up refers to scale-up of all imaging and treatment modalities and quality of care to the mean amount of that of high-income countries. Returns per US$ invested are estimated for patients diagnosed with cancer in 2020–30, compared with a baseline scenario of no scale-up. Estimates are presented in US$ in 2018 and discounted at 3% annually.

The amount of public financing for any sector is established by the so-called fiscal space available to the government, which is defined as "…the availability of budgetary room that allows a government to provide resources for a desired purpose without any prejudice to the sustainability of a government's financial position".[65] Fiscal space depends on the sources of finances, which can be from: (1) economic growth that creates favourable macroeconomic conditions for increased government revenues and budget, (2) the strengthening of tax administration, (3) the reprioritisation of health within the governments' budget, (4) borrowing from domestic and international sources or Overseas Development Assistance to invest in health, (5) more effective and efficient allocation of available health resources, and (6) innovative domestic and international financing.[66,67] In the following paragraphs, we describe the main sources of financing that could be used to expand fiscal space and summarise the potential magnitude of funds and the suitability of different funding sources for investing in the scale-up of imaging diagnostics and cancer care.

Improved economic growth

The International Monetary Fund projects positive economic growth in LMICs between 2020 and 2025.[68] Other estimates suggest that in 2015–40, the continued growth of GDP and higher government revenues could help to increase government spending on health per person by around 5·3% each year in upper-middle-income countries, 4·2% in middle-income countries, and 1·8% in low-income countries.[69] However, notably, these estimates are based on pre-COVID-19 economic variables. An investment case for imaging diagnostics is crucial to harness new funding for this area.

Generation of revenues by strengthening tax administration

In LMICs, government revenues from tax are low, being on average 15% of the GDP in low-income countries, 25% in lower-middle-income countries, 30% in upper-middle-income countries, and 40% in high-income countries.[70] Modelling studies estimate that an increase in tax revenue, where at least a third of newly raised revenues is allocated to health, could on average increase public expenditure on health in LMICs by 78% (95% CI 60–90%).[71]

Increased taxes on tobacco and alcohol are highly cost-effective public policies. Egypt, the Philippines, and Thailand have successfully introduced tobacco taxes to generate funding for the health sector.[72] A 20% and 50% price increase in tobacco prices could generate more than 50 years' worth of additional tax revenues globally, with a 20% price increase resulting in approximately $1987 billion (UI 1613–2297 billion) in additional tax revenues over 50 years, and a 50% price increase

generating $3625 billion (UI 2534–4599 billion) over 50 years; and in low-income countries, an average additional revenue of 0·17% of GDP each year in the 50% price increase scenario.[73]

Reprioritisation of health within government budgets

Evidence for the health and economic benefits of new health investments could be made use of to persuade governments to reprioritise their investments. Modelling estimates that budget reprioritisation could potentially increase the funds allocated to health in LMICs by 72% (95% CI 57–87%).[71]

Borrowing from domestic and international sources and Overseas Development Assistance

Concessional financing with low interest rates and generous grace periods for repayments could be mobilised from international development banks to invest in the expansion of diagnostics capacity. In 2017, the World Bank had 45 active projects for a total sum of US$470 million for medical equipment procurement.[74] In 2020, the African Development Bank approved an equity investment that will raise $100 million to fund health infrastructure projects in Africa.[75]

Investment in diagnostic imaging is particularly attractive for development banks, because these are infrastructure investments that can generate an income stream for the investors to service the loans over time and also provide an opportunity for public–private partnerships or private sector investments for the provision of public services that can be outsourced by governments. In addition to loans, guarantees provided by development banks can be used to encourage the mobilisation of private financing by mitigating investment risks in LMICs for projects to establish or develop facilities for imaging diagnostics.

Over the past 20 years, World Bank Group guarantees have mobilised more than US$42 billion in commercial capital and private investments.[76] The guarantees were structured as partial risk guarantees, partial credit guarantees, or policy-based guarantees.[77] Partial risk guarantees support private sector investment, including public–private partnerships. Partial credit guarantees enable commercial borrowing in support of public investment projects, and policy-based guarantees support commercial borrowing for budget financing or reform programmes. Guarantees offer several benefits to the borrowers. The reduced risk of default improves the country's ability to borrow for investment. Guarantees can reduce the cost of capital as a result of lower interest rates that the borrowing government must pay, because these rates are moderated by the guarantor's credit worthiness (the World Bank has an AAA rating). Guarantees also allow governments to share the risk of projects with the private sector. Such guarantees would be suited to investments in expanding the capacity for imaging diagnostics in LMICs.

More effective and efficient allocation of available health resources in health systems

With appropriate priority setting and the more efficient allocation and use of financial resources, governments in LMICs could generate a 26% (95% CI 21–31%) increase in public expenditure on health.[70] For example, governments in LMICs could undertake reviews of their health budgets to reduce the spending on interventions and programmes that are not cost-effective, and channel these resources to more cost-effective interventions. These governments could also improve the procurement of health products, by benchmarking the prices achieved or through the use of pooled procurement to secure a better value for these products.

Innovative financing

Funding mobilised from non-traditional sources is another potential source of financing for diagnostic imaging. Innovative financing mechanisms such as the Global Fund to Fight AIDS, Tuberculosis and Malaria, Gavi, and Unitaid[78,79] (which link different elements of the financing value chain—namely, resource mobilisation, pooling, channelling, resource allocation, and implementation) have channelled more than $55 billion to LMICs for the health sector.

Social or development impact bonds are promising innovative financing instruments that could be used to finance the expansion of diagnostics capability in LMICs. A social or development impact bond is created by a government agency (or external funder such as a development agency or a charitable foundation) that aims to achieve a desired social or health outcome.[80,81] The government agency or external funder engages an external organisation to achieve the outcome. A third-party investor provides upfront working capital to the external organisation as an at-risk investment. If the desired social outcome is accomplished, the government agency or external funder releases payment to the external organisation, on the basis of terms specified in an upfront contract, which repays its investors their principal, plus a return on the investment. If the outcome is not met, the government agency or external funder disburses no payment.

The potential new funding from multiple sources to expand fiscal space (table 6)[68–77,79–82] far exceeds the financing needed globally for the comprehensive scale-up of interventions for cancer care. With measurable performance indicators, the investment in population-based health can be a tool towards a nation's development, rather than a mere byproduct of it. Medical imaging is a cornerstone of the strengthening of health systems to address the disability-adjusted life-years lost to cancer, a burden that falls disproportionately (80%) on LMICs, even though these nations receive only approximately 5% of current global funding for cancer control.[3,5]

	Potential additional fiscal space that could be created	Feasibility of creating additional fiscal space	Suitability for funding the scale-up of imaging diagnostics for cancer
Improved economic growth	Substantial. Could help increase government spending on health per person each year by approximately 5·3% in upper-middle-income countries, 4·2% in middle-income countries, and 1·8% in low-income countries[69]	Feasible. LMICs are projected to have robust economic growth,[68] and despite the COVID-19 pandemic, many have returned to positive growth trajectories[82]	Would generate sustainable general revenue income for allocation to health
Generation of revenues by strengthening tax administration	Susbtantial. Allocating at least a third of newly raised revenues to health could on average increase public expenditure on health in LMICs by 78% (95% CI 60–90%)[71]	Feasible. Tax revenues in LMICs are only 15–30% of GDP compared with 40% in high-income countries, but would require stronger tax collection systems, which would take time to implement[70]	Additional revenues would need to be allocated to health; however, it is a sustainable funding source
Increased taxes on tobacco, alcohol, and sugary beverages	Substantial. In low-income countries, a 50% increase in tobacco prices could generate on average an additional revenue of 0·17% of GDP each year[73]	Feasible, but would require political will to fight opposition. Highly cost-effective[72]	Sustainable funding with additional health and economic benefits. Could be earmarked for health
Reprioritisation of health within the government budget	Substantial. In LMICs, governments could increase funds allocated to health by 72% (95% CI 57–87%)[71]	Less feasible. Would require strong political capital to achieve reprioritisation	Sustainable funding
Borrowing from domestic and international sources and Official Development Assistance	Substantial, but underused. Could be in the form of hybrid financing: a mix of loan and equity from public and private sectors	Feasible. Low interest rates make this an attractive option. Infrastructure loans are available from the World Bank and regional development banks. Export guarantees would substantially reduce borrowing costs[74–77]	This option would encourage public-private partnerships to reduce capital investment requirements for governments; and could provide a revenue stream to investors to offset costs
Innovative financing	Substantial, with a large potential	Feasible. Social or development impact bonds could be used to invest in scale-up.[79–81] Easily measurable results with investment in imaging diagnostics	This option would encourage public-private partnerships to reduce capital investment requirements for governments; and provides a revenue stream to investors to offset costs

The sources for this table was an analysis synthesis of evidence[68–77,79–81] and the International Monetary Fund 2020 report.[82] GDP=gross domestic product. LMICs=low-income and middle-income countries.

Table 6: **Potential funding sources for expanding fiscal space for health and investment in the scale-up of imaging diagnostics and cancer care in LMICs**

Section 5: radiation protection and safety and quality systems

The safe use of medical imaging in cancer care requires appropriate standards for radiation protection and safety with regard to patients, families, workers, and the public, irrespective of the level of economic development of a country. Responsibilities to ensure that appropriate standards are met, lie at the national, institutional, and individual levels. Whether the imaging modality makes use of ionising or non-ionising radiation, adequate safety infrastructure, education and training of staff, appropriate staffing amounts, and effective quality assurance systems are all essential.

Protecting patients and workers when ionising radiation is used in medicine

The latest figures published by the UN Scientific Committee on the Effects of Atomic Radiation[83] indicate that approximately 3·6 billion diagnostic radiology x-ray examinations and 33 million diagnostic nuclear medicine examinations are done each year worldwide. However, imaging frequency during cancer care is not explicitly considered in these figures.[83] Medical uses of ionising radiation (excluding therapeutic uses) constitute more than 98% of the world population's exposure to radiation from man-made sources. Between the global surveys for 1991–96 and 1997–2007, the total annual number of diagnostic medical examinations (both medical and dental) was estimated to have risen by 50%.[83] However, more recent national figures for the USA[84] suggest that the largest contributor to radiation doses, CT scanning, has stabilised in numbers. The second largest contributor, imaging with the use of nuclear medicine, has shown similar numbers per year in the last 5 years for SPECT-CT procedures, and continued to increase its contribution to radiation doses in PET-CT studies (mainly in patients with cancer) globally, in both high-income countries and LMICs.[85–87] In relation to occupational radiation exposure, according to the UN Scientific Committee on the Effects of Atomic Radiation,[83] worldwide, the estimated number of health-care workers involved in the medical uses of radiation is 7·4 million (estimated in 2008), which is considered to be increasing with time.

For the use of ionising radiation in medicine, radiation protection for patients and workers needs to be approached systematically.[88] In the past century, remarkable progress has been made in understanding the health effects of radiation. There is a need to increase awareness among the medical community about the amount of radiation received by patients in imaging procedures.[89] However,

there is an absence of qualified support for medical physics, in particular in diagnostic radiology and nuclear medicine theranostics, in LMICs.[90] This shortfall poses notable risks for patients and health-care workers because radiation safety, quality systems, and maintenance are insufficiently guaranteed. Furthermore, in many LMICs, the medical radiation devices and their use are not sufficiently governed by appropriate governmental, legal, and regulatory frameworks for safety. The rapid evolution of technology for imaging involving radiation exposure poses challenges for maintaining the safety of patients and health-care workers, because this maintenance requires the education and training of health professionals and regulatory staff; moreover, the rapid evolution of this technology makes it challenging to keep regulations up to date. Regulation of the use of ionising radiation in medicine differs between countries globally.[91]

The radiation exposure of patients for diagnosis, intervention, or therapy differs from other uses of radiation in that it is done for the direct benefit of the individual, who also incurs the radiation risk and other risks of the procedure.[92] The guidelines that justify the use of a procedure should be developed by health authorities together with professional bodies and should be reviewed regularly to ensure that radiological procedures that are no longer justified are removed from guidelines and medical practice.[93] The optimisation of radiation protection in imaging means that the amount of protection and safety should be the best possible under the prevailing circumstances, and should be implemented in all scenarios. Notably, this pertains not only to radiation doses that are excessive for the given imaging being done but also to doses that are too low to generate images of a suitable diagnostic quality for accurate interpretation. This trade-off between radiation exposure and a suitable diagnostic quality is a challenging issue in cancer care, because repeated exposure to radiation over short and long intervals is common. Dose limits apply to occupational exposure and public exposure arising from medical uses of ionising radiation, but not to the exposure of patients. For some areas of medical uses of ionising radiation, such as image-guided interventional procedures, good radiation protection practice for staff must be followed to not exceed occupational dose limits.[93]

Responsibilities at a national level

For the safe operation of facilities and use of radiation sources, a country must have appropriate governmental, legal, and regulatory frameworks for safety.[94] The government establishes laws and adopts policies relating to safety as well as the responsibilities and functions of different governmental bodies involved in safety. The important responsibilities of a government include the establishment of an independent regulatory body with the necessary legal authority, competence, and resources to oversee radiation safety for the public and radiation workers. In the health sector, according to international safety standards,[95] it is the responsibility of the government to ensure that a country's diagnostic reference levels, an optimisation tool for diagnostic imaging, are established through consultation between the relevant health authorities, professional bodies, and the regulatory agencies. The regulatory agency has different means of ensuring compliance, such as the authorisation and inspection of facilities and activities, and enforcement of regulatory requirements.[94] At a national level, other organisations have an important role for the safety of patients, workers, and the public, such as health authorities, professional bodies, technical standards associations, regulatory agencies involved in the approval of medical devices, and agencies involved in health technology assessments.[95] Many countries do not have adequate infrastructure for radiation safety. For LMICs and other countries that might need to strengthen this infrastructure at a national level, the IAEA has published guidance on overcoming this challenge, including on national policy, regulatory framework, and technical infrastructure.[96]

Responsibilities at the facility and individual levels

Hospitals and other health-care institutions that do radiological and nuclear medicine imaging procedures should have appropriate equipment (with planned replacement cycles), maintenance and quality systems, and enough staffing to do studies in an optimal manner. Health professionals working in such facilities should have appropriate training and qualifications in clinical practice and adhere to relevant radiation safety standards. The optimisation of radiation protection is inadequate in facilities in many countries and can be improved with the use of simple and inexpensive techniques.[97]

Clinical imaging guidelines and appropriate use criteria are the imaging referral guidelines developed by international expert groups that facilitate the choice of the best imaging test for a clinical scenario, and help to strengthen the justification of exposure to radiation in imaging procedures.[98] Justified procedures, by definition, bring individual patients more benefit than risk. This means that the proposed overall increase of imaging with the use of ionising radiation will bring the global population more benefit than risk, as long as a generic justification of the radiological procedure has been done by the health authority in conjunction with appropriate professional bodies, and the justification of the medical exposure for the individual patient has been done by means of consultation between the radiological medical practitioner and the referring medical practitioner. Improving the appropriate use of imaging is important for the radiation protection of patients and for overall patient care. According to the international basic safety standards developed by the IAEA,[95] relevant national or international referral guidelines should be taken into account when justifying

the medical exposure of an individual patient in a radiological or nuclear medicine procedure. These guidelines are produced, maintained, and disseminated by many international organisations,[99–104] are for the use of referring physicians, radiologists, and nuclear medicine physicians, and are important for the radiation protection of patients. However, it should be noted that knowledge in cancer care, especially for new therapeutic drugs, is evolving rapidly, which makes it challenging to keep guidelines up to date.

Quality systems

The provision of safe, high-quality imaging services depends on the control of several variables, including infrastructure, staffing, regulatory environment, quality control of instruments, compliance with national regulations for patients' and workers' safety, and for the conduct of imaging studies according to appropriate clinical need. This framework requires the identification of quality policies and objectives, and the production of a documented system with clearly defined processes, procedures, and responsibilities. Such a system is usually referred to as a quality management system, and its purpose is to help direct activities to meet patient and regulatory requirements and to continually improve the effectiveness and efficiency of the imaging service. Typically, a quality management system also provides a platform to identify areas for improvement. The IAEA has developed quality management audit methods for nuclear medicine (QUANUM)[105,106] and radiology (QUAADRIL),[107] which facilitate the adoption of quality policies in medical imaging departments. The programmes cover all aspects of medical imaging, including management, radiation regulations and safety, radiation protection of patients, quality control of instruments, operations and services, diagnostic clinical services, and radiopharmacy. The European Society of Radiology has also published guidance on clinical audits.[108]

Radiopharmaceuticals and targeted therapy

Radiopharmaceuticals are radiolabelled compounds that, once administered to the patient, are incorporated into cells or tissues to provide diagnostic information or to trigger a therapeutic effect. These unique molecular tools, which are indispensable for the practice of nuclear medicine, need to be prepared shortly before being administered to patients, because of the short physical half-life of the radionuclides used. Most radiopharmaceuticals that are used for diagnostic and therapeutic purposes are dosed in subpharmacological quantities of ligand attached to radioisotope, such as ^{18}F-fluorodeoxyglucose for PET imaging or ^{131}I-metaiodobenzylguanidine for imaging and therapy of neuroblastoma, thereby avoiding clinically relevant drug-related side-effects. According to the international pharmacopoeia, radiopharmaceuticals are defined as medicinal formulations and, therefore, they should be produced in facilities that have appropriate quality management systems in place. Radiopharmaceuticals can be produced by a licensed commercial organisation, or alternatively by hospital-based facilities that comply with appropriate domestic or international standards.[109–111] Testing of the final product and radiation safety are essential in ensuring safe and appropriate use.

Access to, and availability of, radiopharmaceuticals are a major factor in the provision of nuclear medicine procedures that are clinically necessary. Barriers to accessing radiopharmaceuticals include an absence of coordinated supply (especially in LMICs), transportation issues, inadequate facility infrastructure, and little appropriate staff training and availability. The provision of essential nuclear medicine procedures for patients with cancer therefore requires a health system and regulatory framework that facilitates access to radiopharmaceuticals, as well as the infrastructure and trained staff needed to do these procedures.[110] In this context, the local production of radiopharmaceuticals for immediate injection should not necessarily require facilities that meet Current Good Manufacturing Practice standards in full, but the radiopharmaceuticals should undergo appropriate quality control before administration.[110]

With regard to the radiation protection of patients and workers, the safety of the public and of family members should also be considered.[112] Many nuclear medicine procedures are done on an outpatient basis and the exposure to the public and patients' families after a procedure needs to be considered.[31] The mitigation of this risk includes educating the patient on how to reduce the risk of public and family exposure to the ionising radiation from the radiopharmaceuticals that have been administered to the patient for the diagnostic test or for radionuclide therapy.[113]

Protecting patients and health-care workers when using MRI

In contrast to imaging procedures with ionising radiation, there are few comprehensive data in the field of MRI. The number of workers involved in MRI worldwide is unknown, although the safety of health-care workers involved with MRI is an important area of consideration. In particular, for some types of MRI procedures, the occupational exposure of health professionals to the magnetic fields can be substantive, and requires considerable protective measures, especially in the case of high and very high magnetic fields. Workers' protection has been comprehensively addressed in the directive 2013/35/EU of the European Parliament[114] on the health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields) and is also mentioned in some national and professional guidelines.[115]

MRI safety is mostly dominated by the interaction of implanted devices with the different magnetic fields used

to make the images. Therefore, it is of utmost importance to have a policy to assess the safety of medical implants and devices before MRI (eg, cardiac pacemakers, vascular clips in the brain, neurostimulators, cochlear implants, medication patches, and delivery pumps); access to an updated list of device magnetic compatibility is necessary. Guidelines for the safety of patients undergoing MRI procedures are necessary at an institutional and national level, with some countries developing standards that can be used by LMICs.[115]

MRI protocols should be integrated within clinical sites that use this imaging method. Furthermore, safety culture developed in the field of ionising radiation should be expanded to the use of MRI, even if the health effects of ionising radiation and MRI are fundamentally different.

Radiation regulatory bodies do not always consider MRI and, in general, the safety of MRI is mostly a concern of labour organisations in the general context of medical and non-medical magnetic fields. The establishment of a legal and regulatory framework for magnetic fields would be helpful, provided medical applications are considered separately from non-medical use. The involvement of professional medical bodies in this endeavour is considered essential. The potential benefits of such a framework for LMICs would be substantial, and ensure patient and worker safety in MRI facilities.

Safety processes are fundamental in the daily life of MRI facilities, and mostly involve the screening of patients for implanted devices and avoiding the missile effects of ferromagnetic objects in the MRI scanner room, which can harm both patients and staff members. The use of quality management systems should be increased and incentivised.

Specific attention should be paid to pregnant women. Although no harmful fetal effects of MRI on pregnant workers are known, some national authorities recommend avoiding any magnetic exposure during pregnancy. Staff at MRI facilities should be educated and incentivised to develop a safety-oriented culture, based on published guidelines, so that near-miss events are shared and used for process improvement.[116]

Section 6: the potential of advances in digital sciences and device engineering for improving cancer care in LMICs

Unprecedented advances in computing, data science, information technology, and engineering in the last decade are affecting all aspects of health care, including radiology and nuclear medicine.[117,118] For example, in cancer imaging specifically, artificial intelligence (AI) and its subfields, machine learning and natural language processing, have been used to assist in clinical diagnosis and outcome prediction in various ways, including tumour detection and characterisation, and for the identification of cohorts of patients who require vigilant monitoring.[119–123] Novel analytical techniques based on AI are also being implemented to tackle unmet needs in patient workflow and logistics. Furthermore, the growth of wireless technologies (mobile phones and other wireless devices that acquire and transmit data) is opening new possibilities for innovation in health-care delivery. Indeed, according to WHO, mobile health, which might be defined as the application of mobile phones or other wireless devices for medical or public health purposes, could potentially transform health service delivery around the world.[124] Advances in digital sciences promise to reduce the cost and improve the deployment of cancer imaging in both high-income countries and LMICs.

Although digital technologies are gradually replacing existing established structures in high-income countries, LMICs with less developed digital infrastructures are in a unique position to implement digital technologies from the start, and therefore possibly at a faster pace. For example, in some LMICs, mobile phone systems have already superseded communication with traditional landlines for health telecommunications[124] and mobile health is already used for cancer screening.[125] Mobile teleradiology, in particular, is a branch of mobile health that makes use of mobile phone technology to provide specialist expertise in image interpretation. Mobile teleradiology refers not only to radiology and nuclear medicine specialists providing services remotely, but also to communication with the patient via telemedicine visits—a strategy that has been used in high-income countries and has expanded markedly during the COVID-19 crisis. In LMICs, the dissemination of technology for telemedicine (including teleradiology) would not only help with the COVID-19 crisis and future pandemics, but would also help more generally to provide country-wide care, lessening the need for travel to medical centres. Hospital stakeholders in LMICs need to overcome many hurdles, because they first need to assess information technology infrastructure, internet access, and the electricity supply to establish appropriate regional goals that leverage technologies that are easily accessible, affordable, and user-friendly, and at the same time guarantee patient privacy. According to a 2016 WHO survey, only 28% of lower-middle-income countries and 30% of low-income countries had legislation for the protection of eHealth data, as opposed to more than 80% of high-income countries.[126] Nevertheless, progress is being made, at least in some eHealth areas: the implementation of e-learning, for example, has already enhanced access to self-learning modules and video conferences in many LMICs.[127]

In this section is a discussion of various digital technologies that hold particular promise for advancing cancer imaging in LMICs, now or in the future. It should be noted that the infrastructure required to implement many of these technologies includes electronic medical record (EMR) systems. Although EMR systems are widely used in high-income countries, their distribution in LMICs is less pervasive. Additionally, although more than 50% of upper-middle-income and high-income

Panel 3: Use of ultrasound in low-income settings

In the past two decades, the widespread adoption of smartphone technology has facilitated the near-ubiquitous availability of powerful computation and high-resolution displays in such devices. Ultrasound manufacturers have leveraged the availability of these technologies to create a new class of low-cost mobile health (mHealth) portable devices (ie, ultrasound probes) that connect directly to consumer electronic devices (smartphones). New ultrasound transducer technologies that mitigate the frequency limitations of piezoelectric crystals permit a single transducer to be used for several clinical applications.[131] In combination, these technologies have vastly increased the availability of medical ultrasound at the same time as reducing its cost. Medical ultrasound is routinely available in low-income and middle-income countries (LMICs), where its central use is for oncological diagnosis and monitoring in the female pelvis, thyroid, liver, breast, peritoneal cavity, and kidneys, and is commonly also used for biopsy and tumour ablation guidance. For example, mHealth devices are facilitating a competency-based training programme that enables Nigerian radiologists to do breast biopsies guided by ultrasonography, which are the standard of care in high-income countries and are recommended by the Breast Health Global Initiative for many LMICs.[132] This project was started in Nigeria in 2020, because it is the most populous country in Africa, with the highest rate of breast cancer mortality.[133] Furthermore, the Nigerian Government is committed to cancer control, with more than 350 available radiologists nationwide, a number similar to that found in other African countries. This work was done with the African Research Group for Oncology (ARGO), a National Cancer Institute-recognised cancer consortium that aims to improve outcomes for patients with cancer in Nigeria. In 2017, none of the ARGO radiologists were able to do an ultrasonography-guided breast biopsy because they had not been trained for it.

The project's first step was a multidisciplinary assessment of the needs of local stakeholders, which identified a need for and favourability towards an mHealth-based ultrasonography-guided biopsy training programme in Nigeria.[132,133] The local stakeholders included surgeons, radiologists, and pathologists, because the proposed change in practice was feasible only with multidisciplinary support. The training programme approach was competency-based and included instructor-led and e-learning modules, as well as simulation-based training. This approach enabled independent learning and provided users wtih access to newly developed artificial intelligence applications, which helped in the successful training and clinical implementation of ultrasonography-guided biopsies. The training programme is self-propagating and the assessment metrics are being validated.

countries have adopted national electronic health record systems that are based on EMRs, adoption rates in lower-middle-income and low-income countries are much lower, at 35% for lower-middle-income countries and 15% for low-income countries.[126] However, open-source EMR platforms have been used in dozens of countries in Africa, Asia, and Latin America,[128] and as the implementation of eHealth solutions in LMICs is a key factor in improving health outcomes, novel approaches for providing low-cost, easily accessible electronic health records are a major focus of governments, international bodies (eg, WHO), and industry.[126,129,130]

Imaging technology and image acquisition: mobile and low-cost imaging equipment

The acquisition of high-quality digital image data is a prerequisite for accurate diagnosis with any of the imaging technologies used in the management of patients with cancer. In many LMICs, hospital systems continue to function in the analogue world, with digital image data often only available in private practices. However, where hospital systems in LMICs are able to invest in high-quality digital image data, then connectivity between imaging sites can assist with technical queries and enhance the quality of acquired image data.[124] The imaging systems must be installed according to protocols that meet the standard of care in high-income countries and local health-care professionals, including technologists, nurses, and pharmacists, must be adequately trained in using these systems.

The availability of any imaging devices in LMICs is often restricted by cost; hence, innovative technologies have been used to create next-generation scanners that are less expensive to purchase and operate and have mobile capabilities. The development of these technologies has required collaboration between industry and academia, and has immediate relevance for their implementation in LMICs. The average hospital-grade ultrasound unit can cost more than a hospital's annual capital budget and often serves as the primary diagnostic imaging modality in many LMICs. The more than 65-times disparity factor between high-income and low-income countries in the number of CT installations, as indicated by the IAEA IMAGINE data and mentioned earlier,[51] is therefore unsurprising. A relevant factor in this context might be that most (>90%) high-income countries rely chiefly on the public funding of eHealth programmes, whereas in the majority of low-income and lower-middle-income countries (70%), donor funding is the dominant source of support.[126] This difference in commitment by governments might affect middle-term and long-term strategic goals and investment decisions by stakeholders. This infrastructural deficit also greatly restricts the use of available scanners for image-guided procedures, which is one reason why many LMICs continue to rely on blind (non-image guided) or surgical biopsies for cancer diagnosis. New, innovative, low-cost solutions, such as handheld mobile health ultrasound devices that are used at the point-of-care, now offer a safe, simple, and sustainable solution toward building capacity for cancer control in LMICs. For example, new ultrasound transducer technologies mitigating the frequency limitations of piezoelectric crystals[131] permit a single low-cost, portable transducer to be used for multiple clinical applications (panel 3).[132,133]

Advances in the design of x-ray sources, detectors, and reconstruction algorithms have made possible the potential for motion-free, completely solid-state CT scanners.[134] Compared with standard CT scanners, these scanners promise to be less expensive, and easier to transport, assemble, and service, owing to the elimination of moving parts in the CT gantry, which will be ideal for use in LMICs. Specialised MRI systems that have been developed that use permanent magnets instead of superconducting or resistive electromagnets

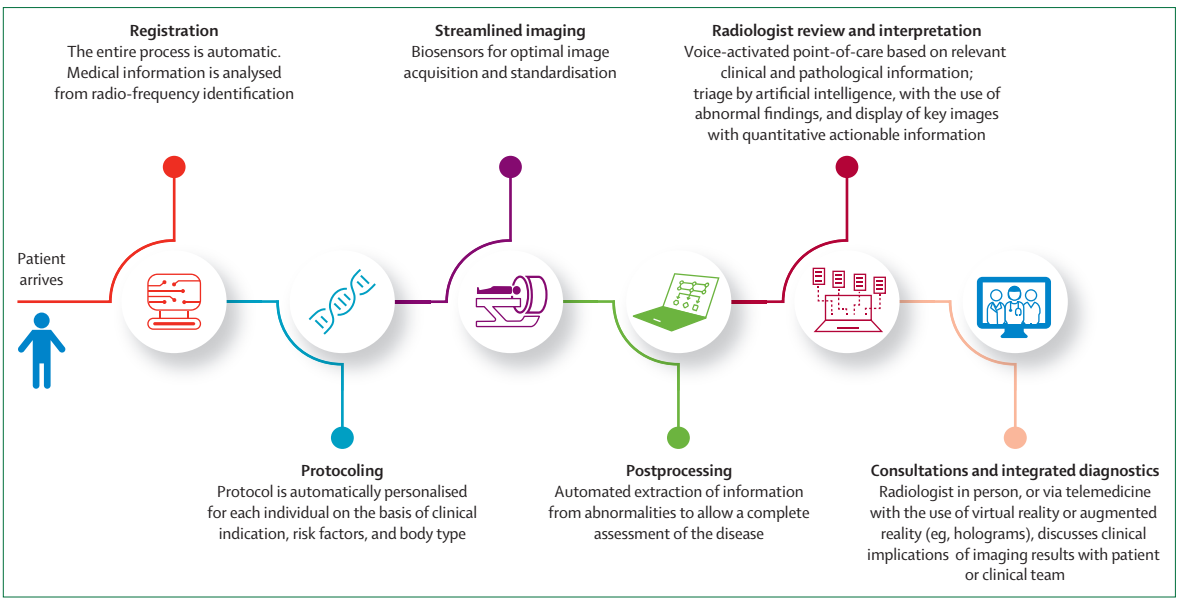

Figure 10: **Artificial intelligence-driven workflow for imaging in patients with cancer**
An illustration of a streamlined, artificial intelligence-driven imaging workflow, in which digital technologies enable the automation, standardisation, and optimisation of every step, from patient registration to imaging acquisition and interpretation.

will enable low-cost, portable, and point-of-care MRI scans.[135] Although the resulting field strength (<0·3T) is lower than that of standard 1·5T MRI scanners, advances in hardware design and reconstruction algorithms have made the use of low-field MRI scanners possible, particularly for niche applications such as brain imaging.[136] Such scanners promise to be lightweight, low cost, and portable, enabling them to be deployed more readily than standard MRI scanners in LMICs. Similarly, other technological advances include PET systems with scalable ring configurations, which reduce costs while maintaining diagnostic capabilities.[137] LMICs looking to invest in these new technologies need to be informed about the type of regional support that is available, and partnerships between manufacturers, governments, and private providers in LMICs will be required to ensure that equipment can be maintained and operational for routine patient access and avoid scenarios where longer downtime might occur. New AI-based approaches will reduce—or in some cases eliminate—the need for in-person equipment services, will monitor quality and safety, and will also allow more information to be extracted from imaging examinations, because digital imaging data could be analysed not just qualitatively but also quantitatively. AI-based approaches for optimising imaging include the use of biosensors (eg, for MRI and PET scanners) that automatically adjust for patient bodyweight and anatomy, optimise coil positions, and analyse heartbeat and breathing rhythm to correct for body motion.[138] Furthermore, AI-based image reconstruction algorithms are fast and can suppress noise and artifacts and produce higher-quality images, as shown in CT,[139] MRI,[140] and PET.[141] Because quantitative imaging features are affected by the vendor-specific settings and image acquisition protocols, AI-based approaches for standardised image analysis are currently being investigated.[142] With MRI as an example, figure 10 presents a vision of a streamlined, AI-driven workflow, in which digital technologies enable the automation, standardisation, and optimisation of every step, from patient registration to imaging acquisition and interpretation.

Patient registration and protocoling: improvement of patient safety with radio-frequency technology

Radio-frequency identification (RFID) technology has been commercially available in one form or another since the 1970s, but it has only recently been introduced into health care. RFID is a wireless system of communication, whereby tags containing patient data transmit that data through radio waves, which can be picked up or read by stationary or portable devices.[143] Many health-care device manufacturers are incorporating RFID technology into their workflow solutions. Similarly to the way contactless payment services that have become standard in the consumer economy allow efficient, convenient, and safe financial transactions, contactless patient identification and registration by means of RFID is expected to improve the workflow, patient safety, and patient experience.[144] Prerequisites for the use of RFIDs are a compatible Hospital Information System and EMR system. A key advantage to the use of RFIDs and accessible EMRs is the improvement of patient safety through the prevention of human error,[145] including the failure to recognise a predisposition to a contrast media reaction, the need for premedication, or the presence of an implantable medical

device that precludes a patient from undergoing high-field MRI examinations. Another advantage is that, with the help of RFID technology, amendments to national or global safety guidelines can be implemented automatically after approval by a central health-care authority, thereby enabling the application of safety standards that are uniform throughout a country. An additional important benefit of modern digital technology is the potential of AI to manage, predict, and reduce patient exposure to ionising radiation and thus further contribute to improved patient safety.[146]

Further advantages can be found in the use of RFIDs and EMR information to directly guide image acquisition to tailor imaging protocols to a particular type of cancer or clinical question, without the need for manual interaction by a radiologist or a nuclear medicine physician, such as directing imaging protocols for specific body areas. This approach enables the country-wide standardisation of imaging protocols that adhere to the latest versions of published expert guidelines, and ensures that state-of-the-art imaging can be done in areas and at institutions that do not have relevant specialists. Finally, the use of RFIDs might reduce physical interaction between patients and health-care personnel, depending on the imaging test being done—a benefit that is particularly valuable during the COVID-19 pandemic, with its obligatory physical distancing rules. Notably, implementation of this type of technology is facilitated by a supporting legal framework, which is often missing in most LMICs. As the 2016 WHO survey shows, policies or legislation to address patient safety and quality of care are only in place in 10–20% of low-income and lower middle-income countries, compared with almost 80% in high-income countries.[126]

Image analysis and interpretation: AI and machine learning to bring tertiary care image interpretation to community hospitals in LMICs

State-of-the-art diagnostic image analysis and interpretation require digital imaging, lossless compression, and transfer with the use of picture archiving and communication system technology. Moreover, advanced workstations and screens are needed to view radiology and nuclear medicine images, which most facilities in LMICs do not have[147] (often, a laptop serves as the diagnostic workstation and the radiology report is handwritten and placed in the patient's paper chart). Additionally, the availability of an EMR system is highly desirable for the effective management of imaging data, but again, most LMICs do not have this system either. Access to an open-source picture archiving and communication system that is integrated with an open EMR would provide crucial information for clinical decision making and possibly help to reduce costs. Advanced AI-based image analysis and interpretation are among the most extensively investigated topics in radiology and nuclear medicine, as well as computer science, with the main goals being automation, improved accuracy, and decision support.[148–153]

Computer-aided detection systems have been applied in different cancer types and organs or tissues, most extensively for lung nodules and breast cancer.[122,123,150,153–156] Although commercial solutions have been available for several years, widespread clinical implementation is still pending. This situation is likely to change as positive and negative predictive values improve with the amount of model complexity and generalisability, as offered by novel AI-driven approaches that use mathematical patterns extracted from imaging data—the so-called radiomic features. Because the application of deep learning algorithms to cranial CT has been shown to allow for the expert-level identification of findings that require urgent attention (eg, haemorrhage and fractures),[157,158] machine learning algorithms could be used for the triage of patients with cancer. For instance, machine learning algorithms could be applied in lung cancer and breast cancer screening programmes in high-risk populations, or in the follow-up of patients with cancer undergoing surveillance after complete remission. In LMICs, such an approach could help to address the gaps in expertise and availability in rural, difficult-to-access areas where few trained radiologists are available to provide care,[128,159] as well as in situations where radiologists are overwhelmed by the volumes of images they are required to interpret.[147] The same applies to ultrasound, which, for example, is used extensively in LMICs to stage cervical cancer.[160] The high operator dependence of ultrasound makes the absence of sufficiently trained experts even more detrimental, so that deep learning algorithms, such as those which have been used to interpret thyroid, breast, and abdominal ultrasonographies,[153,161,162] are expected to have a substantial effect. For example, AI could be used as a second reader to confirm accuracy or serve as a reference standard. This application of AI could have immediate applicability in LMICs where there are few radiologists and ultrasounds are often done by technicians and nurses.[147]

Decision support represents another application of computer-assisted image analysis, although this is still experimental and therefore not yet in clinical use.[163] On the basis of radiomic data, diagnostic confidence could be improved for the interpretation of equivocal lesions that are difficult to characterise by human visual perception. For instance, studies have suggested that radiomics can help to differentiate CNS lymphoma and atypical glioblastoma multiforme on PET[164] and MRI,[165] or different types of gastric malignancies on CT.[166] Notably, radiomic features can be extracted not only after the selection of a lesion by the radiologist, but also fully automatically by AI algorithms such as the convolutional neural network U-Net, which segments lesions without the need for human interaction.[167] This use of AI, however, requires powerful computing infrastructure, with especially powerful graphics processing units. In

view of the reported association between molecular tumour phenotypes and radiomic features, these features could possibly have a role as surrogate markers in LMICs where genomic and molecular biomarkers are not readily available and accessible.[168–170] The use of radiomics to predict tumour phenotype is also an area of ongoing research, and further validation will be required before it becomes part of the standard of care.

Integrated reporting and the promise of integrated diagnostics

An important goal in cancer imaging is the efficient production of integrated imaging reports, in which all pertinent imaging and other patient data are accounted for and combined. This process can be enhanced by AI. For example, the use of natural language processing for qualitative content extraction from routine clinical reports could provide radiologists and nuclear medicine physicians with relevant clinical information that can be readily used during image interpretation.[120,149] The automated extraction of quantitative metrics (eg, PET standardised uptake values) and derivation of changes over time could also enhance and accelerate image interpretation. Radiologists and nuclear medicine physicians might then integrate all of this information into final reports to better assist referring clinicians with regards to patient management decisions.[171]

There is an unmet need to condense the wealth of medical diagnostic data produced during routine patient tests into a form that retains and emphasises all clinically relevant information. Efforts to develop this novel, holistic approach, termed integrated diagnostics, strive to provide a digital framework for combining imaging, pathology, laboratory, genomic, and other diagnostic and clinical data to give clinicians easy access to aggregated information. A prerequisite for integrated diagnostics is the collection and aggregation of digitally structured big data[118]—for example, through the use of electronic health records. In practice, the first step in applying integrated diagnostics to an individual patient would be the extraction of all the relevant types of clinical and diagnostic data from that patient in digitised form. The second step would be the visualisation and integrated display of the data on a single dashboard. The final step would be the use of computational data analytics to integrate the patient's data in light of insights drawn from big data, and offer precise predictive and prognostic information on which to base clinical decisions and patient counselling. One of the substantial hurdles to the implementation of this vision of integrated diagnostics, even at elite institutions in high-income countries, is the need to be able to mine clinical notes digitally—a process for which natural language processing will be a key tool. However, with natural language processing technology quickly evolving, and with the growing need to streamline information resulting from the rapid increase in the complexity and volume of patient data, integrated diagnostics is the best hope for ensuring consistently personalised, evidence-based cancer management and optimised patient outcomes.

Section 7: research and training

Research is essential to the formation of practices and policies in cancer care; in fact, integrating research and teaching into clinical practice ultimately leads to improved care and better patient outcomes.[172] Hence, research should also be considered as essential to elevating practice standards and driving training and education in any institution. Although available resources, socioeconomic issues, and health systems in high-income countries differ vastly to those in LMICs, the integration of research into clinical practice is no less important. The creation and support of LMIC-based research groups is a precondition for setting research priorities that address local situations, developing evidence-based practices uniquely suited to LMICs, and adapting evidence developed in high-income countries to an LMIC context. Research requires data, and the acquisition of prospective, complete, and accurate data is a challenge in many settings. The provision of cancer care, including the associated imaging services, in LMICs, should be continually assessed to establish patient outcomes and gaps in care. Many of these gaps could relate to imaging, either poor availability or suboptimal quality, but continual prospective data collection can help to design interventions to overcome these challenges. This data collection can be viewed as part of the spectrum of implementation research, and is crucial in these settings.

Evidence-based research

Clinical trials are essential to the evolution and development of cancer treatment. Trials are increasingly being done for novel radionuclide therapy, interventional radiology, and diagnostic imaging studies, and these imaging approaches also serve to evaluate treatment response and disease progression as study endpoints for treatment efficacy and decision making.[173–176] For cancer trials of solid tumours (phase 3 trials especially), conventional CT size measurements by Response Evaluation Criteria In Solid Tumours (RECIST) are used in the vast majority of evaluations, although different criteria might be used for modern technologies, including hybrid PET (eg, PET Response Criteria in Solid Tumours, and Deauville criteria) in some trials.[177] Clinical trials can be extended to LMICs to evaluate LMIC-specific pathologies or to do multicentre, multinational trials. An innovative approach could also be to pool data from several individual trials, including sites in LMICs, as has been proposed for data obtained from trials in patients with COVID-19.[178] High-income countries are working on major training programmes, for example in nuclear medicine, to establish cooperative trial networks and site validation processes.[179] Such programmes, extending from high-income countries to LMICs, advance the goal of population-based evidence for new indications and

data registries, which is essential for health technology assessments.

The introduction of new health-care technology, including imaging, should be evidence based, and systematic evaluation of its effect and cost-effectiveness should inform policies related to technology in health care.[179] Health technology assessments can be initiated in high-income countries and adapted for submission to LMICs with the use of local country health systems and cost information. Evidence-based assessments of new imaging (and radionuclide therapy) indications arising from high-income countries could arguably be made available for regulatory approval and funding in LMICs to avoid duplicating trials or health technology assessments in multiple countries. Additionally, policies that have been successful in high-income countries should be evaluated in the context of LMICs and subject to relevant science and research. Different approaches for the integration of imaging into cancer care might well be needed, particularly in the context of low-resource settings.

Global health research

LMICs carry the highest burden of cancer globally.[41] However, most of the world's research funding originates in and is distributed to high-income countries, both for adult and childhood cancers.[5,180,181] This situation influences the development of new imaging technologies, radiopharmaceutical innovation, and analytic approaches (eg, AI), which require essential infrastructure and expertise to generate and implement novel approaches to imaging. Global health research fosters collaboration between high-income countries and LMICs and provides opportunities to address global health disparities, accelerating the development of therapeutics and building research capacity in LMICs. The overarching goal is to foster independence and promote professional development in LMICs to sustainably develop resources and capacity, expand access to cancer imaging, and provide affordable and high-quality cancer care. In addition, global research initiatives provide an opportunity to not only assess resource-sparing approaches, but also to implement new techniques in LMICs in a real-world research setting that is controlled to allow for an in-depth and unbiased assessment of these techniques. Several grant funding bodies have dedicated funds to global health research; for example, the National Institutes of Health offer international research training grants that support research training programmes that develop and strengthen the scientific leadership and expertise needed for research in LMICs. Global research from patterns of care studies to randomised phase 3 trials are funded and done through the IAEA coordinated research programme.[182] The programme facilitates research collaboration between high-income countries and LMICs in medical disciplines that use radiation (eg, nuclear medicine, radiology, radiotherapy, and medical physics) and supports the development of quality-assured clinical research in LMICs. Furthermore, the programme allows for cross-specialty research collaborations (panel 4; figure 11).[184] Other grant funding bodies include the Medical Research Council (UK), The Bill and Melinda Gates Foundation (USA), and the Wellcome Trust (UK).

Research, education, and training

The establishment of a research culture in imaging departments is essential, and requires institutional commitment, dedicated leadership, and exemplary role models; these aspects are highly relevant in both high-income countries and LMICs. Research should be integrated into training programmes. Research structures within LMICs should include a well-organised policy framework that facilitates research, and the provision of appropriate infrastructure for research. The provision of protected research time, although challenging in a busy clinical practice environment, should be prioritised in LMICs, where time constraints represent a substantial barrier to research activities. A special priority should be placed on implementation research, which is essential to translate research from high-income countries to clinical practice in LMICs. Currently, the research infrastructure in many LMICs is either weak or non-existent. There is frequently little or no in-country expertise in clinical and implementation science research, and although increasing funding sources are encouraging, personnel should be hired and dedicated to cancer research to begin the process. Continuing reviews and quality assurance and audit programmes should be integrated into the routine activity of imaging departments. These endeavours can form an important research activity that is often underemphasised and might include assessing the accuracy and consistency of reports, quality and safety studies, workflow, and unique practices to improve the quality of imaging services and cancer care in general.

Education and training activities in LMICs can extend from country-based programmes to overseas attachments, distance learning, online didactic lectures, and workshops. With the support of digital technologies, the transmission of images for training in image interpretation can also be facilitated in LMICs, and this might be combined with practical training in local facilities in a blended learning approach. For example, tele-ultrasound training by real-time image interpretation and guidance from experts from afar has been shown to be feasible and of value in training and patient management in the LMIC setting.[185] Many international professional imaging societies have organised outreach programmes to LMICs for this purpose, including the Society of Nuclear Medicine and Molecular imaging, the European Association of Nuclear Medicine, the Radiological Society of North America, the European Society of Radiology, and the World Federation of

Panel 4: **Research and training support for low-income and middle-income countries (LMICs)**

To improve outcomes for patients with cancer, LMICs should support the development of workforces suited to contemporary practice in imaging and nuclear medicine. Many meaningful initiatives by governments and professional organisations around the world have been implemented, with the most comprehensive global coordination of such programmes undertaken by the International Atomic Energy Agency (IAEA) since 1987. A primary mission of the IAEA is to promote and support research on the practical applications of atomic energy and related techniques for peaceful purposes worldwide, including in health care, with a particular focus on LMIC member states. The challenges of doing such work in LMICs include insufficient resources (human and infrastructural), an absence of training in clinical research, and underestimation of participant countries' own capabilities to support projects. Through the IAEA Coordinated Research Activities platform, pertinent activities and plans to strengthen health systems are initiated, supported, and coordinated between LMICs and high-income countries. Through well-designed, multicentre, international research protocols, participants are supported in their work to develop and contribute to local research and autonomously implement quality improvements.

So far, approximately 100 coordinated research projects (CRPs) in the field of nuclear medicine and diagnostic imaging have been initiated, with more than 1000 research institutions participating. These collaborative strategies aim to engage LMICs in well-designed, international, multicentre clinical trials, to address the most relevant scientific questions, including those that are specific to LMICs, and to improve daily clinical practice. In nuclear medicine and diagnostic imaging, projects range from workforce training for advanced imaging modalities, to scaling up the local applications of advanced imaging modalities, such as PET, to addressing specific types of cancer prevalent in LMICs. The worldwide distribution of countries active in the IAEA's CRPs devoted to addressing health conditions is illustrated in figure 11.

CRPs also support the optimal supervision of research by postgraduate students in LMICs. For example, a doctoral CRP in advances in medical imaging techniques linked PhD students on a medical physics course from LMICs with faculty supervisors from degree-conferring institutions in high-income countries. Students were selected from LMICs across the globe, including Bangladesh, Bulgaria, Mexico, Montenegro, Morocco, and Thailand, and worked with faculty from institutions in Australia, Belgium, Italy, the UK, and the USA. The related core research projects assessed the effectiveness, applications, quality, optimisation, and safe use of advanced imaging techniques. The students learned how to do advanced clinical research and implement practice and quality improvement strategies. The research measurably enhanced local and national training programmes and improved the clinical practice of advanced imaging in radiology and nuclear medicine in the researchers' home countries.

Another CRP aimed to improve the clinical applications of PET–CT in LMICs. This project included an international study on the use of PET–CT for stage III non-small-cell lung cancer radiotherapy planning (the IAEA-PERTAIN study) that involved more than 350 patients in LMICs including Brazil, Estonia, India, Jordan, Pakistan, Turkey, Uruguay, and Vietnam.[183] Following rigorous and comprehensive training from hands-on courses, webinars, and participant feedback, knowledge and skills were successfully transferred to study sites for the delineation of radiotherapy target volumes, and a study on the effect of PET–CT in radiotherapy planning on 2-year survival rates was done. Additional outcomes included the development of guidelines for PET–CT in image acquisition and target volume delineation, the adoption of new protocols, and changes in clinical practice. Instrumental to the success of CRPs was the accreditation of ^{18}F-fluorodeoxyglucose-PET–CT studies by means of quality control and quality assurance measures by the European Association of Nuclear Medicine Research. This accreditation was provided through the collaboration of the European Association of Nuclear Medicine with imaging facilities in the target countries. Local trainers were trained, and their experience and expertise were subsequently disseminated through seminars and conferences. This CRP also fostered multidisciplinary training and skill development on contouring with the use of PET–CT for radiation oncologists and medical imaging specialists alike. Successful CRP examples such as this one are amenable to being applied in other LMICs and tailored to their local contexts. Future programmes will address areas of unmet need, including updates on the use of diagnostic imaging in LMICs, the application of digital connectivity and artificial intelligence, and theranostic techniques.

Paediatric Imaging, among others, who also provide online education on their websites. Furthermore, international organisations, including WHO and the IAEA, regularly reach out to LMICs to provide training and education in radiation safety and skillsets required for establishing imaging facilities. These activities are essential to ensuring that radiologists, nuclear medicine physicians, and other imaging professionals gain practical education and training, and enhance the quality of imaging studies done in LMICs.

Section 8: scaling up capacity for sustainable access to cancer imaging diagnostics—a call to action

This Commission has identified several important challenges hindering access to effective services for cancer imaging diagnostics, especially in LMICs; these challenges include inadequate investment in imaging equipment, a low workforce capacity, an absence of digital technology including electronic clinical data, poor access to radiopharmaceuticals, and a deficiency in

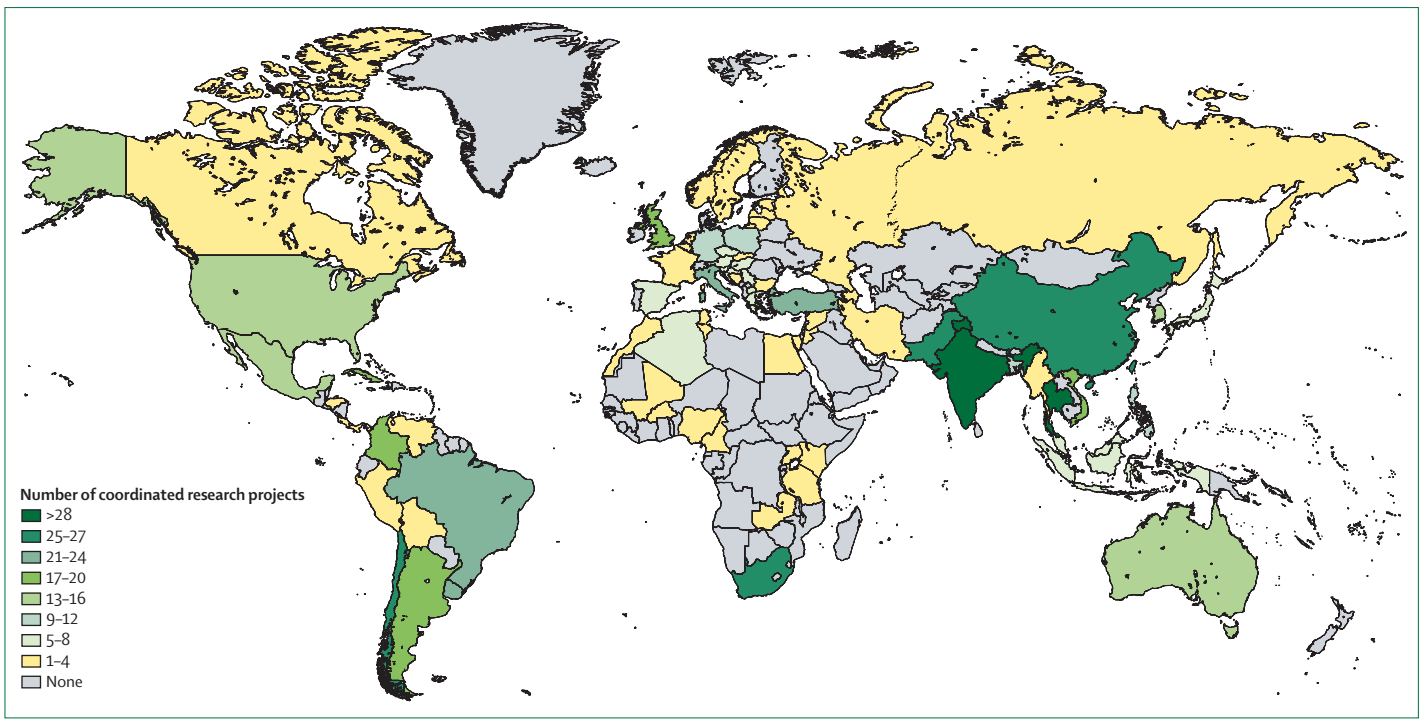

Figure 11: **Active International Atomic Energy Agency coordinated research projects in human health**
The map was produced by the International Atomic Energy Agency (Vienna, Austria) and is included here with permission.

research and training. We have also presented new and compelling evidence on the substantial health and economic benefits of scaling up cancer imaging diagnostics in LMICs, where they are most needed and where the widest inequities exist in access to effective cancer services and in cancer outcomes. These benefits will be greatest with a comprehensive approach to scale-up, where the scale-up of diagnostic capacity is aligned with treatment capacity and where there is a simultaneous improvement in quality of care.

In this section, we examine crucial success factors for scaling up, the roles that key stakeholders could play in the scale-up process, and targets that will help to translate aims into actions and accomplish the vision of an effective and equitable scale-up of cancer imaging diagnostics in LMICs.

Crucial success factors for scaling up cancer imaging diagnostics

The challenges and opportunities in the global fight against cancer and crucial success factors for an effective response with comprehensive scale-up have been outlined in earlier studies.[6,40,186]

The first crucial success factor is strong and visible leadership, at both a global and country level. International development agencies, global leaders, and governments with commensurate funding should firmly commit to scaling up imaging diagnostics capabilities. Additionally, the inclusion of medical imaging and nuclear medicine metrics in global health statistics and country progress monitoring is essential.

The second crucial success factor relates to the development of a compelling case for investing in the scale-up of cancer imaging diagnostics. The results of this Commission show that such investments can yield substantial health and economic benefits. Now that clear evidence of an investment case exists, a straightforward narrative should communicate the benefits of investment for individuals, households, and countries, and the potential opportunities provided by imaging diagnostics for patients with cancer worldwide.

The third crucial success factor relates to alignment. Activities aimed at the scale-up of services for cancer imaging diagnostics align with global efforts to achieve Sustainable Development Goals. In particular, the health-related Sustainable Development Goal 3, "Ensure healthy lives and promote well-being for all at all ages," has set the achievement of UHC by 2030 as the target.[187] Global efforts to scale-up cancer imaging diagnostics should be fully aligned and integrated with actions aimed at achieving UHC. The alignment of the expansion of imaging diagnostics with UHC will require a comprehensive approach to scale-up, where the scale-up of diagnostic capacity is aligned with a scale-up in treatment capacity. This alignment will optimise the use of available resources in countries, help to strengthen health systems, ensure a more strategic approach to the provision of diagnostic

Panel 5: An inclusive global coalition to scale up capabilities for diagnostic cancer imaging in low-income and middle-income countries

An inclusive coalition of partnerships and networks is essential for the development of an effective global-level and country-level response to the scale-up of cancer imaging diagnostics. All actors involved in the scale-up—such as governments, civil society, affected individuals, health professionals, professional associations, researchers, funders, international agencies, the private sector, and innovators—bring capabilities that can be harnessed to create synergies in the scale-up process.

Governments

Governments can use the evidence generated by this Commission to convene relevant stakeholders and coordinate investments in diagnostic imaging services for patients with cancer as part of the efforts aimed at the expansion of universal health coverage (UHC). Governments are needed to provide leadership and make political and fiscal decisions to invest in health systems that generate health and economic returns for their citizens and economies.

International agencies

International agencies, such as WHO, can be integral in the incorporation of cost-effective imaging diagnostics into essential diagnostics lists, in that these agencies support their inclusion as part of benefits packages for UHC. The WHO Best Buys list for non-communicable diseases[188] and the WHO priority medical devices list[43] include diagnostic imaging, and imaging is also included in a WHO publication on providing cancer care for all.[189] WHO provides leadership in the establishment of guidelines and policies on human health, including for cancer, and in the implementation of programmes aimed at improving access to essential diagnostics and treatment to reduce the burden of disease globally, particularly in LMICs.

Global and regional development banks have a crucial role in working with governments and the private sector to develop innovative financing solutions (see section 3) to enable the expansion of cancer imaging diagnostics in LMICs.

The International Atomic Energy Agency (IAEA), an independent, intergovernmental, and technology-based, organisation within the UN family, is an important stakeholder in the scale-up of cancer imaging diagnostics in LMICs. As the focal point for nuclear cooperation worldwide, the IAEA works to promote the safe, secure, and peaceful use of nuclear technologies, including diagnostic imaging and nuclear medicine. This agency provides a wide range of support, which encompasses the provision of equipment, education, and training; quality and safety of clinical practice through guidance documents; equipment calibration; and support of clinical and health economics research. Working with WHO and its International Agency for Research on Cancer, the IAEA has undertaken fact-finding missions and imPACT reviews[190] in more than 100 countries to assess their cancer control, from national registries to palliation, including diagnostic imaging. In addition, IAEA quality assurance methods such as Quality Management Audits in Nuclear Medicine Practices (QUANUM; for nuclear medicine) and Quality Assurance Audit for Diagnostic Radiology Improvement and Learning (QUAADRIL; for radiology) have been instrumental in supporting quality programmes in many countries, including LMICs.[105]

Civil society

Civil society involvement is crucial for bringing a voice to those affected by cancer, building awareness at the global and national levels, and mobilising support for concerted action. Civil society has an important role in articulating health rights, and influencing global actors and country-level policies to help to include cancer imaging diagnostics as an integral part of UHC expansion. The Union for International Cancer Control, which has brought together more than 1000 non-governmental organisations involved in cancer, is well positioned to strengthen civil society and help to mobilise global leaders through the World Cancer Summit and the World Cancer Declaration.

Professional associations

Professional associations are important for establishing professional standards, developing capacity, expanding access to high-quality health-care services for patients with cancer, and for the appropriate use of imaging technologies (eg, the American College of Radiology, the American Society of Clinical Oncology, the American Society for Radiation Oncology, the European Society for Medical Oncology, the Radiological Society of North America, the European Society of Radiology, the International Society of Radiology, the International Society for Strategic Studies in Radiology, the European Society for Radiotherapy and Oncology, the Society of Nuclear Medicine & Molecular Imaging, the European Association of Nuclear Medicine, the Asia Oceania Federation of Nuclear Medicine and Biology, and the World Federation of Nuclear Medicine and Biology). These groups could effectively contribute to and accelerate the scale-up of the capacity for imaging diagnostics and access to effective imaging services in LMICs by working with international and country-level partners to expand human resource capacity through education and training, by providing clinical guidelines adapted to the LMIC setting for the optimal use of imaging resources, and by establishing or strengthening regional collaborations in research, development, and innovation.

Philanthropic organisations

In LMICs, philanthropic organisations have been key in mobilising donations and public funding to establish academic cancer centres that provide high-quality services to some populations. Many of these centres have twinning arrangements with cancer centres in high-income countries and provide an opportunity to integrate operations with publicly funded elements of health systems to establish integrated cancer networks. Such integration will help to create synergies to optimise the exapansion of access to care for patients with cancer. A good example is the International Cancer Research Centre in Kyebi, Ghana, which is being constructed by the Eugène Gasana Jr Foundation. This state-of-the-art children's

(Continues on next page)

For **details on the Union for International Cancer Control** see https://www.uicc.org

For **details on the IAEA** see https://www.iaea.org

For **details on the International Agency for Research on Cancer** see https://www.iarc.fr

(Panel 5 continued from previous page)

cancer research centre will be aligned with the University of Ghana Medical Centre, and the medical programme will be designed in cooperation with Memorial Sloan Kettering Cancer Center in the USA. The facility is intended to serve as a centre of excellence in cancer care for the continent of Africa.

The private sector

In LMICs, the private for-profit sector has created substantial capacity for cancer imaging diagnostics, but generally only for those who can afford to pay for the services. The private sector can use this experience to work with governments, international agencies, and philanthropic organisations to develop innovative financing and service delivery models to scale-up imaging diagnostics and expand access to effective services.

However, the private for-profit sector for health-care providers is not well regulated in many LMICs, and there are few data on the quality of services provided or the outcomes achieved. The private sector is also a major funder of research and development, and innovation for diagnostics, medicines, and health technologies for the management of cancer, but much of this effort is similarly targeted for high-income countries. Novel collaborations of public–private institutions, universities, philanthropic organisations, and international development agencies could help to harness the private sector's capability to develop affordable imaging diagnostics solutions for cancer in LMICs.

services for cancer, and help with the sustainability of the scale-up.

The fourth crucial success factor is the creation of inclusive coalitions of partnerships and networks to drive the scale-up of cancer imaging diagnostics (panel 5).[43,105,188–190] Such coalitions should involve, among others, civil society, individuals affected by cancer, professional associations, health professionals, researchers, funders, international agencies, the private sector, and innovators.

Wide-ranging initiatives have emerged over the years to expand the capacity for cancer care in LMICs by improving clinical knowledge, increasing the amount and quality of cancer care, and establishing research activities. These initiatives have been underpinned by collaborations involving multiple stakeholders from LMICs and high-income countries, typically through academic institutions that have established twinning arrangements (ie, partnerships). For example, St Jude Children's Research Hospital in the USA, a pioneer of this model, has established close collaborative relationships with two dozen partner sites in more than 15 countries, including Brazil, China, Guatemala, Haiti, Jordan, Morocco, and the Philippines.[191] To be successful, such collaborations should involve a two-way transfer of expertise, advice, knowledge, and skills, and be characterised by mutual respect between the local stakeholders and the international partners.[192] However, although beneficial to those institutions involved in the collaborations and patients accessing the institutions involved in these collaborations, many such initiatives have been small-scale projects; as such, they have not always produced noticeable differences in the access to cancer services for a large numbers of citizens in LMICs, or made cancer outcomes more equitable at a population level.

The implementation of multidisciplinary teams including oncologists, surgeons, radiologists, nuclear medicine physicians, and pathologists is necessary to ensure the provision of high-quality care for patients with cancer. The establishment of collaborative networks in LMICs that bring together experts in cancer imaging diagnostics with oncologists and other health professionals to ensure quality standards and the appropriate use of medical imaging and nuclear medicine in clinical care is a key driver of improved outcomes of patients with cancer.

At present, no clear, overarching global strategy for scaling up cancer imaging diagnostics exists in many LMICs, and efforts are often fragmented as a result. A multistakeholder coalition should develop a global strategy for scaling up imaging diagnostics to ensure alignment with and the coordination of the many short-term initiatives and pilot projects, which do not sustainably address the shortcomings in access to effective cancer imaging diagnostics.

The fifth crucial success factor is investment in research, development, and innovation to develop novel technological solutions and service delivery models that can rapidly address any shortages in human resources, infrastructure, affordable diagnostics, care models, and financing. For example, these initiatives could involve the expansion of the use of new, less expensive scanner technologies through the wider application of digital connectivity solutions that can enable radiologists in-country or internationally to interpret scans remotely, and through the use of virtual digital learning platforms to train and support health professionals. Investment in research, development, and innovation will also enable the better application of evidence-based solutions, best practices, and transfer of knowledge. The application of these innovative approaches can provide opportunities for the rapid and more affordable scale-up of the capacity for imaging diagnostics and digital health solutions in LMICs.

The sixth crucial success factor is the mobilisation and better use of existing resources by optimising the use of the existing health workforce, equipment, and infrastructure assets in countries through networks or collaboratives for cancer imaging diagnostics. These networks or collaboratives could be operationally aligned with cancer networks and include public, private, and

Panel 6: **Major actions and targets**

Action 1: incorporate imaging diagnostics into essential benefits packages when expanding universal health coverage (UHC) in low-income and middle-income countries (LMICs)
Cancer imaging diagnostics should be incorporated into national essential benefits packages for diagnostics when expanding UHC, with explicit targets for the scale-up of capacity in health systems to expand the coverage of effective services.

Target
By 2030, as part of the efforts to expand UHC, at least 80% of LMICs should incorporate appropriate cancer imaging diagnostics in their essential benefits packages to expand access to effective services.

Action 2: incorporate costed actions into national cancer control plans to scale-up cancer imaging diagnostics
Predictable financing is essential for the scale-up of cancer imaging diagnostics and to sustain these services. LMICs should develop national cancer plans that are fully costed that establish how sustainable cancer care could be progressively developed and funded.

Target
By 2030, 60% of LMICs should have national cancer control plans that specify actions for the scale-up of cancer imaging diagnostics, with the necessary fiscal space for funding this expansion.

Action 3: expand access to effective services for imaging diagnostics by scaling up the current capacity of human resources and imaging equipment
The ability of LMICs to improve health outcomes for patients with cancer depends on their ability to expand the availability of imaging equipment and a suitable trained workforce to an amount that provides appropriate access for these patients. The quantity of imaging equipment and human resources per million people in the population varies substantially in countries of similar and different income groups. The difference in the average and median amounts of imaging equipment and human resources per million people in the population ranges from three-times to ten-times between low-income and lower-middle-income countries, between lower-middle-income countries and upper-middle-income countries, and between upper-middle-income countries and high-income countries (see sections 2 and 3).

Target
By 2040, at least 50% of low-income, lower-middle-income, and upper-middle-income countries should expand the capacity of human resources and availability of imaging equipment to reach or exceed the median amounts per million people in the population of that currently achieved in countries of the next income group up, adjusted for cancer incidence.

Action 4: ensure the provision of optimal access to effective imaging diagnostics by establishing collaboratives for cancer imaging diagnostics
Countries should work with stakeholder coalitions to create national and regional collaboratives focused on cancer imaging diagnostics, or to expand them where they already exist, to better use available capacity for providing packages of effective cancer services. These collaborations could be enabled through virtual digital linkages.

Target
By 2030, establish collaborative networks of imaging diagnostics in 50% of LMICs to expand the coverage of effective imaging diagnostics services for cancer.

Action 5: invest in education and training to expand human resources
The establishment of a trained workforce of radiologists, nuclear medicine physicians, radiographers and technologists, nurses, physicists, and radiochemists is essential to ensure that safe and effective imaging and nuclear medicine services can be provided and that quality systems provide accurate and reliable information for cancer care. Digital solutions and virtual platforms that facilitate the development of workforce planning and training could enable the rapid scale-up of training in LMICs.

Target
By 2030, 80% of LMICs should establish plans for workforce development and for the use of digital platforms for workforce training.

Action 6: invest in training, research, development, and innovation to develop affordable cancer imaging diagnostics in LMICs
Research funding related to cancer imaging diagnostics in LMICs is small, fragmented, and largely inaccessible to researchers outside high-income countries. The absence of affordable solutions for imaging diagnostics hinders the achievement of improved health outcomes for patients with cancer. Investments are needed in research and innovation in LMICs to ensure the better use of available interventions and create affordable and accessible imaging solutions and new care delivery models for patients with cancer appropriate for LMICs.

Target
By 2025, a US$100 million innovation fund for cancer imaging diagnostics should be established to improve the coordination of funding for education, training, research and development, and innovation in LMICs, with a target of mobilising and investing thereafter at least $25 million per year.

philanthropic institutions. The development of such networks or collaboratives requires careful planning at both the national and subnational level to ensure appropriate investment to address capacity gaps. Planning could be augmented with the strategic purchasing of imaging diagnostic services by national authorities to produce economies of scale and the equitable allocation of available funds.

The findings of this Commission show the substantial health and economic benefits of the successful scale-up of the capacity for cancer imaging diagnostics in LMICs and high-income countries. These benefits will be the greatest with a comprehensive approach to scale-up, where the scale-up of diagnostic capacity is aligned with treatment capacity. The pathway to scale-up and the speed of the expansion of imaging diagnostics for cancer in each country will necessarily vary, given that the political will, infrastructure, the availability of radiotherapy, surgery, medical treatment, imaging modalities, human resources, and financing will be different in each country. However, there are a set of actions that each country could take to enable scale-up.

We propose six main actions, with targets, to achieve the important goal of equitable access to imaging diagnostics worldwide (panel 6).

Conclusion

Compelling evidence exists for the substantial health benefits of scaling up medical imaging and access to nuclear medicine for patients with cancer. Improvements in science have enabled rapid developments in affordable imaging technologies and solutions, and flexible, low-cost digital platforms for virtual training. Science and technology are not the barriers to a worldwide equitable scale-up of effective cancer imaging diagnostics; rather, achieving equitable scale-up is a matter of vision and will. Successful scale-up will result from effective political leadership, active participation from all major stakeholders, and the alignment of country-level and global efforts to expand access to medical imaging and nuclear medicine, leading to better outcomes for patients with cancer worldwide.

Contributors

RA, HH, MA-W, and AMS were co-leaders of the Commission and co-developed and co-wrote the study design with input from co-authors. MML, DP, and MA-W co-conceived the commission and co-led the International Atomic Energy Agency Secretariat, which convened the commission. HH wrote section 1 with MA-W, MH, AMS, GM, MML, DP, and LNS. MML wrote section 2, with DP, MA-W, HH, and AMS. MML and DP accessed and verified the data in the IMAGINE database. RA wrote sections 3 and 4. RA also conceived the modelling approach for sections 3 and 4. RA and ZJW led the modelling and analysis for section 3, with input from AMS and HH. ZJW collated the data and built the model. OH wrote section 5, with contributions from GF, MH, JSL, DP, and AMS. JAB co-wrote section 6 with HH, MH, LD-B, and AMS. P-LK wrote section 7 with AMS, JSL, MML, WJGO, and DP. RA wrote section 8 with input from HH, AMS, MML, and MA-W. RA, HH, and AMS revised all sections of the report. All authors contributed and approved the final version of the submitted manuscript.

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