



Original Article

Access to the World Health Organization-recommended essential diagnostics for invasive fungal infections in critical care and cancer patients in Africa: A diagnostic survey



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ABSTRACT

Background: Invasive fungal infections (IFIs) contribute to significant morbidity and mortality among patients with haemato-oncological conditions, seriously ill hospitalised patients and those in intensive care (ICU). We surveyed for the World Health Organization-recommended essential diagnostic tests for IFIs in these risk groups in Africa.

Methods: The Global Action For Fungal Infections (GAFFI) evaluated the different levels of access to both diagnostics for IFIs for populations in Africa, with the aim of building a comparative dataset and a publicly available interactive map. Data was collected through a validated questionnaire administered to a country leader in relevant topics (i.e., HIV, laboratory coordination) and/or Ministry of Health representatives and followed up with 2 rounds of validation by video calls, and later confirmation by email of findings.

Results: Initial data was collected from 48 African countries covering 99.65 % of the population. Conventional diagnostics such as blood cultures, direct microscopy and histopathology were often used for diagnosis of IFIs in more than half of the facilities. Bronchoscopy was rarely done or not done in 20 countries (population 649 million). In over 40 African countries (population > 850 million), *Aspergillus* antigen testing was never performed in either the public or private sectors. Computed tomography (CT) imaging is routinely used in 27 (56 %) of countries in the public sector and 21 (44 %) in the private sector. However, magnetic resonance imaging remains relatively uncommon in most African countries.

Conclusions: There are critical gaps in the availability of essential diagnostics for IFIs in Africa, particularly *Aspergillus* antigen testing and modern medical imaging modalities. Early diagnosis and commencement of targeted therapy of IFIs are critical for optimal outcomes from complex cancer therapies.

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Introduction

Globally, over 1.5 million annual cases of invasive fungal infections (IFIs) due to opportunistic fungal pathogens such *Aspergillus* species, *Candida* species, *Cryptococcus* species, and *Pneumocystis* species are estimated to occur particularly in immunocompromised patients [1]. The growing number of immunocompromised haemato-oncological and transplant population, as well as immunocompetent patients requiring intensive care unit (ICU) admission are the main drivers of the steady increase in the frequency of IFIs in the past few decades [2].

Africa contributes up to 5.7 % (about 1.1 million cases) of new cancer cases and 7.1 % (700,000 cases) of deaths due to cancers globally [3]. Over 30,000 new cases of leukaemia, 50,000 lymphoma and over 4000 multiple myeloma cases, nearly 46,000 cases of lung cancer, along with over 100,000 intra-abdominal cases many requiring major surgery were anticipated in 2020 [4]. Therefore, cancer is an emerging public health concern in Africa. In addition, ICU care is picking up in Africa especially during the coronavirus disease – 2019 (COVID-19) pandemic [5]. As with severe COVID-19, severe influenza carries a high frequency of IFI, notably invasive aspergillosis [6]. Mortality rates in the ICU remains unacceptably high. Sepsis is a common cause of death both in the ICU and in patients with cancers [7]. However, data on the aetiology, morbidity, mortality, and healthcare costs attributable to fungal pathogens remains scarce in most African countries, mainly lack of human resource in mycology, and essential diagnostic procedures and tests [8–10].

In 2018, the World Health Organization (WHO) published a list of essential In Vitro Diagnostics (IVDs), including a group of general laboratory tests that can be used for routine patient care as well as IVDs designed for the detection, diagnosis and monitoring of WHO key disease areas [11]. The essential diagnostic list (EDL) is an essential component to advance universal health coverage, address health emergencies, and promote healthier populations [11]. Essential fungal diagnostics such as microscopy, histopathology, cultures and cryptococcal antigen tests were included in the 1st Edition [11] and *Histoplasma* antigen test, *Pneumocystis* PCR and *Aspergillus* antibody and antigen tests were added in the subsequent editions [11]. Performance of these tests has recently been reviewed [12].

Global Action For Fungal Infections (GAFFI) is an international foundation based in Switzerland and UK which aims to identify and publicise gaps in diagnostics and treatments for fungal disease [13], as a first step in enabling universal access. As part of this effort, GAFFI sought to evaluate the different levels of access to both diagnostics and treatments for fungal infections for populations across the world, with the aim of building a comparative dataset and a publicly available interactive map.

In this study, we report findings of the GAFFI diagnostic access survey of the WHO recommended essential diagnostic tests for IFIs in Africa. This study sheds light on the significant gaps in access to essential diagnostic tests for IFIs in Africa, particularly among critical care and cancer patients. Addressing these gaps is crucial for improving public health mycology in Africa and enabling timely diagnosis and appropriate treatment of fungal infections, which can significantly impact patient outcomes and reduce morbidity and mortality rates.

Methods

Questionnaire development and structure

A questionnaire was developed to country contacts, including GAFFI Ambassadors. The original questionnaire was iterated after a pilot phase and consisted of seven separate sections. Part 1 covered the respondent (s), including their role, facility and whether their

Table 1
Diagnostic tests and procedures surveyed and reported here.

Clinical procedures	Radiology	Mycology tests
Bronchoscopy	Chest X-ray CT scan MRI scan Radiologist reporting	Direct microscopy (e.g., urine, BAL)* Blood culture* Histopathology* Fungal culture* <i>Aspergillus</i> antigen test* <i>Pneumocystis</i> PCR test*

* On the EDL (WHO Model List of Essential In Vitro Diagnostics)

country had a BSL-3 laboratory. Part 2 covered the WHO-recommended list of essential fungal diagnostics (Table 1). Availability of diagnostics was classified by use in five different facilities (not used, private sector, specialist/university hospitals, district or local referral hospitals and community services) and regularity of use. Frequency of testing was classified as ‘never’ done, ‘rarely’ done, ‘occasional’ which covered infrequent clinical requests as well as inability of patients or caregivers to pay (if charged for) or a combination and ‘often’ indicating a good and regular diagnostic service. Some qualitative information on barriers to testing was also collected in open fields. We obtained general information of who paid for diagnostics in each country as follows: charity/foundation, insurance, government, or patient (or family). Part 3 concerned CD4 counts (reported separately). Part 4 of the questionnaire covered essential clinical procedures and radiology using the same tabular structure as Part 2. Part 5 asked for approximate costs of some diagnostics and procedures. Finally, there were two free-prose sections: part 6, which asked for any additional fungal diagnostics used in the respondent’s country; and part 7 for any other comments.

The survey was conducted in six phases: 1) questionnaire development, piloting with iterative improvements, 2) questionnaire completion by in country respondents, 3) questionnaire review and data analysis by GAFFI team and then video conference call with respondent (s), 4) external validation from public or private sources, 5) country validation via video conference call with country leaders in relevant topics (i.e., HIV/AIDS, laboratory coordination) and/or Ministry of Health representatives, where possible and 6) further validation and input with regional multi-country online meetings with Africa CDC.

Questionnaire completion in country

African countries with populations of at least 1 million people were contacted. A snowball sampling approach was used to disseminate the questionnaire starting with GAFFI Ambassadors and existing networks of contacts. All questionnaires were disseminated, completed, and collected online. Respondents were encouraged to contact and include colleagues in topic areas where they did not have first-hand knowledge of diagnostics (i.e., radiology, or spirometry). In some countries, few or no medical or laboratory professionals were willing to complete the questionnaire (usually because of their professional position or lack of knowledge). To ensure more thorough coverage, additional responses were sought from other centres in larger countries.

Questionnaire clarification and external validation

After receipt of a completed questionnaire, at least one online meeting was organised to provide clarification, as well as qualitative data and narrative. Translators were used during the meetings, when necessary. In some cases, the questionnaire was completed during this meeting. Companies with point of care diagnostic assays were also contacted to check for regular sales in countries reporting regular use of a given test. Publications from individual countries were checked for alignment of reported diagnostic use and questionnaire answers.

Data compilation and display and country summaries

Data was compiled and visualised using QGIS software and Natural Earth vectors [14] to design maps showing each diagnostic's coverage across the continent. One-page profiles were also created for each country, summarising the data collected alongside basic information about the country, demographic data, key health indicators relevant to fungal disease and its health system. This information included country-specific data on: cancer (Globocan); GDP (IMF); total health expenditure (World Bank); domestic health expenditure (WHO); area, population and age structure (CIA World Factbook) [15].

In country validation

Collected data and country profiles were distributed to relevant local stakeholders and experts, with the purpose of verifying data and/or correcting inaccuracies. Online validation meetings were held with stakeholders including representatives of the Ministry of Health and the national laboratory service, as well as the initial questionnaire respondent(s). Individual country profiles were prepared and circulated to all respondents. Additional validation and sensitisation online meetings were held in October 2022, hosted by the Africa Centres for Disease Control (CDC) in multiple languages as appropriate for the region, preceded by sending each country the country profile. These meetings resulted in further refinement and validation of the results.

Results

Countries profile

We collected diagnostic capacity data for IFIs from 48 African countries between the first of October 2020 and the thirty-first of October 2022, covering 99.65 % of the African population. We were unable to collect any data from Lesotho. We excluded countries with small populations including Djibouti, São Tomé and Príncipe, Cabo Verde, Comoros, Seychelles, and Western Sahara. Several African territories of European countries, such as Ceuta (autonomous city of Spain) and Réunion (overseas region of France), were not included. Overall, the questionnaire was completed by respondents linked to 72 health facilities distributed in the surveyed countries, some responding only for their institution and surrounding area, others nationally. Multiple country respondents were from Nigeria, Democratic Republic of Congo (DRC), Egypt, Tanzania, Kenya, Zimbabwe, and Somalia. Follow up review was conducted with Africa CDC, by sharing single country profiles with each country and adjusting results with country feedback, as well as utilising external data for validation.

Direct microscope examination

Direct microscopic examination includes wet mount, potassium hydroxide (15–20 %), India ink preparation and other mycology staining techniques. It has a particularly important role in diagnosing fungal bronchitis, fungal keratitis, mucormycosis and superficial fungal infections. It is widely used to diagnose fungal infections in the majority of African countries, both in the public (27 countries) and private sectors (23 countries), with an estimated population of more than 800 million (Table 2). In nine African countries, including Algeria, Chad, Malawi, Mauritania, Morocco, Sudan, Tanzania, Tunisia, and Zambia, direct microscopic examination was occasionally performed in the private sector. In Ethiopia and Uganda, direct microscopy was rarely performed. In Eritrea, Guinea-Bissau, Sierra Leone, South Sudan, Equatorial Guinea and Angola direct microscopic examination was never performed to diagnose fungal

diseases in the public sector but was in Angola and South Sudan in the private sector.

Blood culture

Blood culture, for the aetiological diagnosis of sepsis and diagnosis of bacterial and fungal endocarditis and bloodstream infection, is often used in almost half of African countries in the public sector (Fig. 1) with an estimated population covered of 776 million. In the private sector, it was commonly used in 17 countries, namely Botswana, Cameroon, Central African Republic (CAR), Côte d'Ivoire, Egypt, Kenya, Liberia, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, South Africa, Tanzania, Zambia, and Zimbabwe (Table 1).

Ten African countries, namely Algeria, Cameroon, Equatorial Guinea, Malawi, Mali, Mauritania, Sudan, Tanzania, and Togo, with an estimated population of 259 million, rarely used blood culture to diagnose fungal infections in the public sector. In six countries - Malawi, Mali, Burkina Faso, Sierra Leone, Sudan and Tunisia blood culture is rarely used in the private sector. In seven countries Angola, Eritrea, Guinea-Bissau, Libya, Senegal, Sierra Leone, Somalia, and South Sudan blood culture is never performed in the public sector with an estimated population of 76 million (Table 2) (Fig. 1).

Aspergillus antigen test

The *Aspergillus* antigen test is regularly used in the public sector in only two African countries, Morocco and Tunisia, and occasionally in Niger and Chad and in the private sector only in Niger, Kenya, Burundi, Eswatini and South Africa (Fig. 2). In Tunisia it is performed often at 3 of the 7 mycology laboratories and occasionally in the others but also in very few private laboratories. In addition, *Aspergillus* antigen testing was rarely used in the public sector in six countries (Algeria, Burundi, Egypt, Kenya, Tanzania, and Tunisia) and in the private sector in five countries (Egypt, Ghana, Liberia, Tanzania, Tunisia, and Zambia) with a total population of 296 million. However, in the remaining African countries with an estimated population of over 1 billion, *Aspergillus* antigen testing was never performed in either the public or private sectors.

Bronchoscopy

Bronchoscopy is a skilled procedure usually undertaken by respiratory specialists and also in intensive care by ICU physicians. It is the standard procedure for diagnosing carcinoma of the lung and can be used to contribute to the diagnosis of many non-malignant lung disorders. It is of real value for diagnosing complex lung infection, including tracheobronchial infection, mycobacterial infection, *Pneumocystis* pneumonia, invasive aspergillosis and pulmonary mucormycosis. In ICU it is used to document fungal tracheobronchitis and collect samples for microscopy, culture, *Pneumocystis* PCR and *Aspergillus* antigen. The survey revealed the frequent use of bronchoscopy in 15 countries (Table 2) and occasionally in 13 countries in the public sector, and in 20 countries in the private sector. In contrast, there were 10 countries with no bronchoscopy service (Angola, Burkina Faso, Cameroon, Central African Republic, Equatorial Guinea, Guinea, Guinea-Bissau, Libya, Namibia and South Sudan). Twenty-one countries have no private bronchoscopy service.

Histopathology

Histopathology has a critical role in diagnosing mucormycosis, acute fungal rhinosinusitis and in skin samples taken for possible disseminated infection such as fusariosis and histoplasmosis. The finding of fungal structures in tissue provides definitive proof of invasive fungal disease and the nature of the histologic response. In

Table 2

Access to diagnostics relevant to rapid diagnosis of serious fungal disease in cancer and intensive care in 48 countries in Africa. In this table, Somalia includes Somaliland and Puntland.

	Countries surveyed (n = 50)		Population (public sector) n (%)
	Public sector n (%)	Private sector n (%)	
Frequency of direct microscopy of non-cutaneous samples			
Often	27 (56 %)	23 (48 %)	803 million (57 %)
Occasional	13 (27 %)	10 (21 %)	380 million (27 %)
Rare	2 (4 %)	2 (4 %)	160 million (11 %)
Never	6 (13 %)	13 (25 %)	64 million (5 %)
Frequency of blood culture			
Often	22 (46 %)	17 (26 %)	776 million (55 %)
Occasional	9 (19 %)	10 (21 %)	297 million (21 %)
Rarely	10 (21 %)	6 (13 %)	259 million (18 %)
Never	7 (15 %)	15 (31 %)	77 million (5 %)
Frequency of <i>Aspergillus</i> antigen			
Often	2 (4 %)	2 (4 %)	49 million (4 %)
Occasional	2 (4 %)	3 (6 %)	42 million (3 %)
Rare	5 (10 %)	6 (13 %)	284 million (20 %)
Never	39 (81 %)	37 (77 %)	1031 million (73 %)
Frequency of bronchoscopy			
Often	15 (31 %)	10 (21 %)	355 million (23 %)
Occasional	13 (17 %)	10 (21 %)	433 million (31 %)
Rare	10 (21 %)	7 (15 %)	519 million (37 %)
Never	10 (21 %)	21 (44 %)	130 million (9 %)
Frequency of histopathology			
Often	19 (40 %)	10 (21 %)	690 million (49 %)
Occasional	12 (25 %)	8 (17 %)	474 million (40 %)
Rare	8 (15 %)	5 (10 %)	176 million (8 %)
Never	9 (15 %)	27 (56 %)	56 million (3 %)
Frequency of CT scanning			
Often	27 (56 %)	21 (44 %)	590 million (42 %)
Occasional	11 (23 %)	12 (25 %)	553 million (39 %)
Rare	5 (10 %)	3 (6 %)	205 million (15 %)
Never	5 (10 %)	12 (25 %)	59 million (4 %)
Frequency of MRI scanning			
Often	15 (31 %)	21 (44 %)	454 million (32 %)
Occasional	10 (21 %)	6 (13 %)	391 million (28 %)
Rare	11 (23 %)	6 (13 %)	337 million (24 %)
Never	12 (25 %)	15 (31 %)	226 million (16 %)
Image reporting by radiologist			
Often	33 (69 %)	30 (63 %)	1071 million (76 %)
Occasional	7 (15 %)	3 (6 %)	229 million (16 %)
Rare	4 (8 %)	5 (10 %)	58 million (4 %)
Never	4 (8 %)	10 (21 %)	50 million (4 %)

19 African countries with an estimated population of 690 million, histopathology is commonly used to diagnose fungal infections in the public sector, and occasionally in another 15 countries. In Kenya, histopathology was commonly used in the private sector but occasionally in the public sector.

Histopathology is never performed in the public sector in 9 countries (Central Africa Republic, Equatorial Guinea, Eritrea, Guinea-Bissau, Liberia, Libya, Sierra Leone, Somalia, and South Sudan) and not in private sectors in 27 countries. In some countries, fungal stains are rarely, if ever, done. Some services are for fungal infection are almost exclusively focused on skin biopsy interpretation, including mycetoma.

Computerized tomography (CT) scan

Computed tomography (CT) scanning plays a critical role in identifying cancer in most organs, in defining its stage and in the diagnosis of some fungal infections. CT scans are often used to in 27 African countries in the public sector (590 people) and 21 African countries within private sectors (Fig. 3A). It is also used occasionally in the public sector for nearly 553 million people in 11 African countries (Botswana, Burundi, Cameroon, DRC, Gabon, Madagascar, Mali, Nigeria, Somalia, Sudan, and Tanzania). However, in five African countries, namely Angola, Equatorial Guinea, Guinea-Bissau, Sierra Leone, and South Sudan, with an estimated population of ~59

million people, CT scanning is not used in the public sector for diagnosis. In the private sector, CT scanning is unavailable in 12 African countries, namely Angola, Central African Republic, Republic of Congo, Eritrea, Gabon, Guinea, Guinea-Bissau, Libya, Mali, Rwanda, Senegal, and Uganda (Fig. 3A).

Magnetic resonance imaging (MRI) scan

Magnetic resonance imaging (MRI) is very useful for imaging the brain in immunocompromised patients, as well as bones, the spine, joints, and paranasal sinuses, with increasing indications for breast and cardiac problems. MRI is often used for diagnosis in 15 African countries (Algeria, Benin, Côte d'Ivoire, Egypt, Eritrea, Guinea, Kenya, Madagascar, Mauritius, Morocco, Mozambique, Senegal, South Africa, Tunisia, and Zambia) in public hospitals with an estimated population of 454 million. In most African countries (Algeria, Benin, Côte d'Ivoire, Democratic Republic of Congo, Egypt, Equatorial Guinea, Kenya, Liberia, Mauritius, Morocco, Mozambique, Niger, Somalia, Somaliland, South Africa, Sudan, Tanzania, Togo, Tunisia, Zambia, and Zimbabwe), MRI examination for the diagnosis of mycoses was used more frequently in the private sector than in the public sector (in 39 % versus 28 %). In eight countries (Gabon, Ghana, Liberia, Mauritania, Niger, Nigeria, Togo, and Uganda), MRI scan was occasionally used in the public sector in an estimated population of 288 million. It has also been used occasionally in the private sector

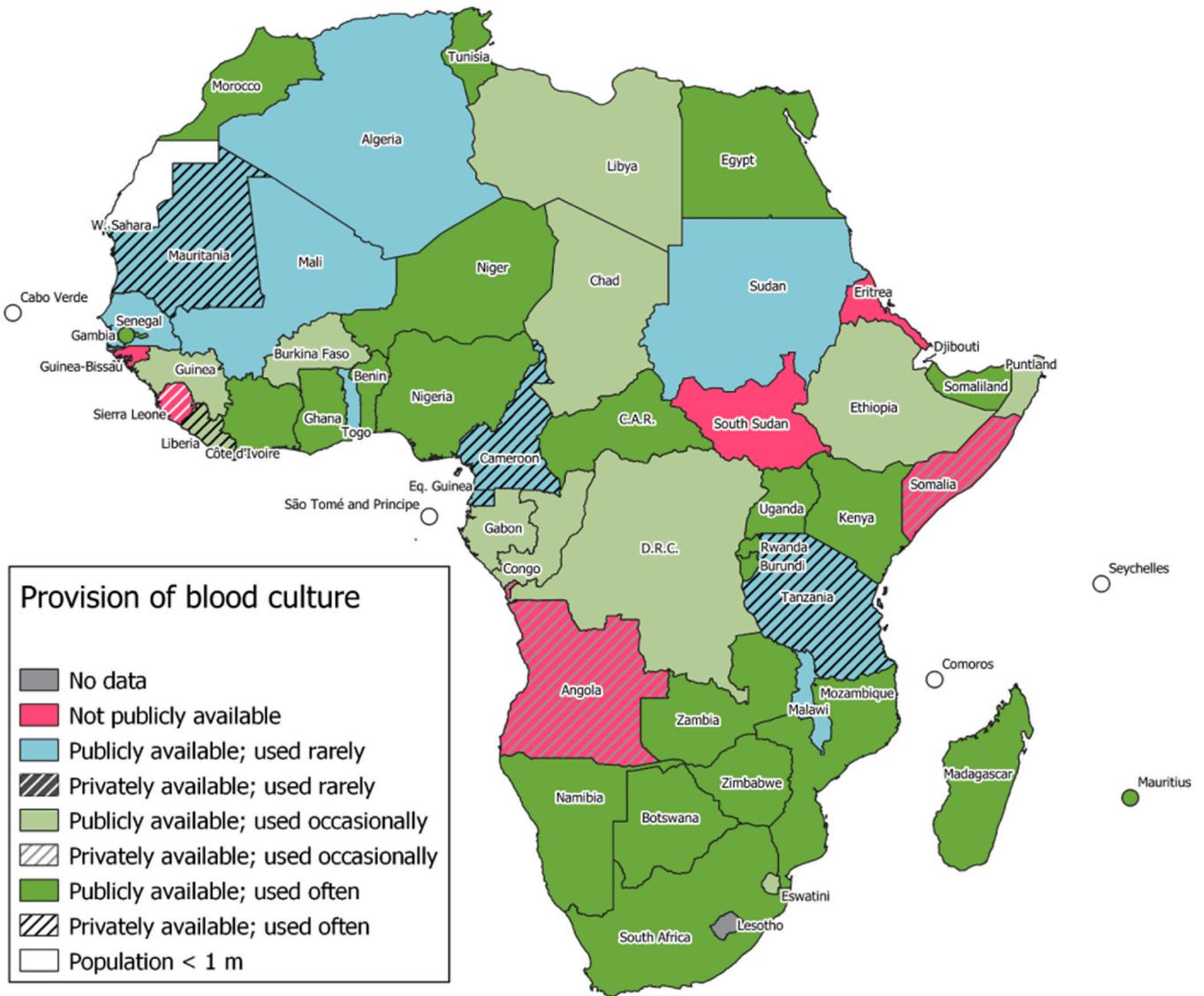


Fig. 1. Provision of blood culture by frequency in the public and private sectors in each surveyed country in Africa. Unless indicated by stripes, private provision was not in a better category than public provision.

in six countries, namely Botswana, Eswatini, Ghana, Mauritania, Namibia, and Puntland. In countries such as Botswana, Burundi, Cameroon, Chad, Congo Republic, Ethiopia, Gambia, Malawi, Mali, and Sudan Tanzania, MRI scanning was rarely used in the public sector. However, in 16 African countries (Angola, Burkina Faso, Democratic Republic of Congo, Equatorial Guinea, Eswatini, Guinea-Bissau, Libya, Namibia, Puntland, Rwanda, Sierra Leone, Somalia, Somaliland, South Sudan, and Zimbabwe) with estimated 201 million populations, MRI scan has never been used to diagnose fungal diseases in the public sector.

Radiological reporting

Overall, 33 countries have regular reporting by radiologists for chest X-rays and CT scans covering about 1, billion people and another 7 countries have some radiology reporting (229 million population). In Angola, Equatorial Guinea, Guinea-Bissau and South Sudan, there appear to be no radiologists working in the public sector and very few in Burundi, Cameroon, and Rwanda, although reports are written in the private sector in all these countries except Angola and Guinea Bissau (Fig. 3B).

Discussion

In this diagnostic capability survey across over 70 public and private health facilities across 48 African countries with additional input from ministries of health, we found that conventional diagnostics such as blood cultures, histopathology, and direct microscopies are routinely performed in over 50% of the study sites. However, access to *Aspergillus* antigen tests and medical imaging modalities such as CT and MRI remains relatively uncommon in most African countries. This survey focused on diagnostics for the evaluation of IFIs in complex hospitalised patients, who are immunocompromised (without advanced HIV disease), undergoing cancer treatments, after major surgery and those admitted in ICU. The frequency of these types of medical care is hugely variable across the African continent, partly related to economics and partly related to availability of appropriately skilled healthcare personnel and equipment. A major component of successful care for such patients is handling the infectious consequences such as IFIs that frequently occur in these patients. Dual or sequential infections are common – for example invasive aspergillosis complicating severe influenza or the coronavirus disease – 2019 (COVID-19) [16], candidemia frequently following bacteremia and bacterial co-infection

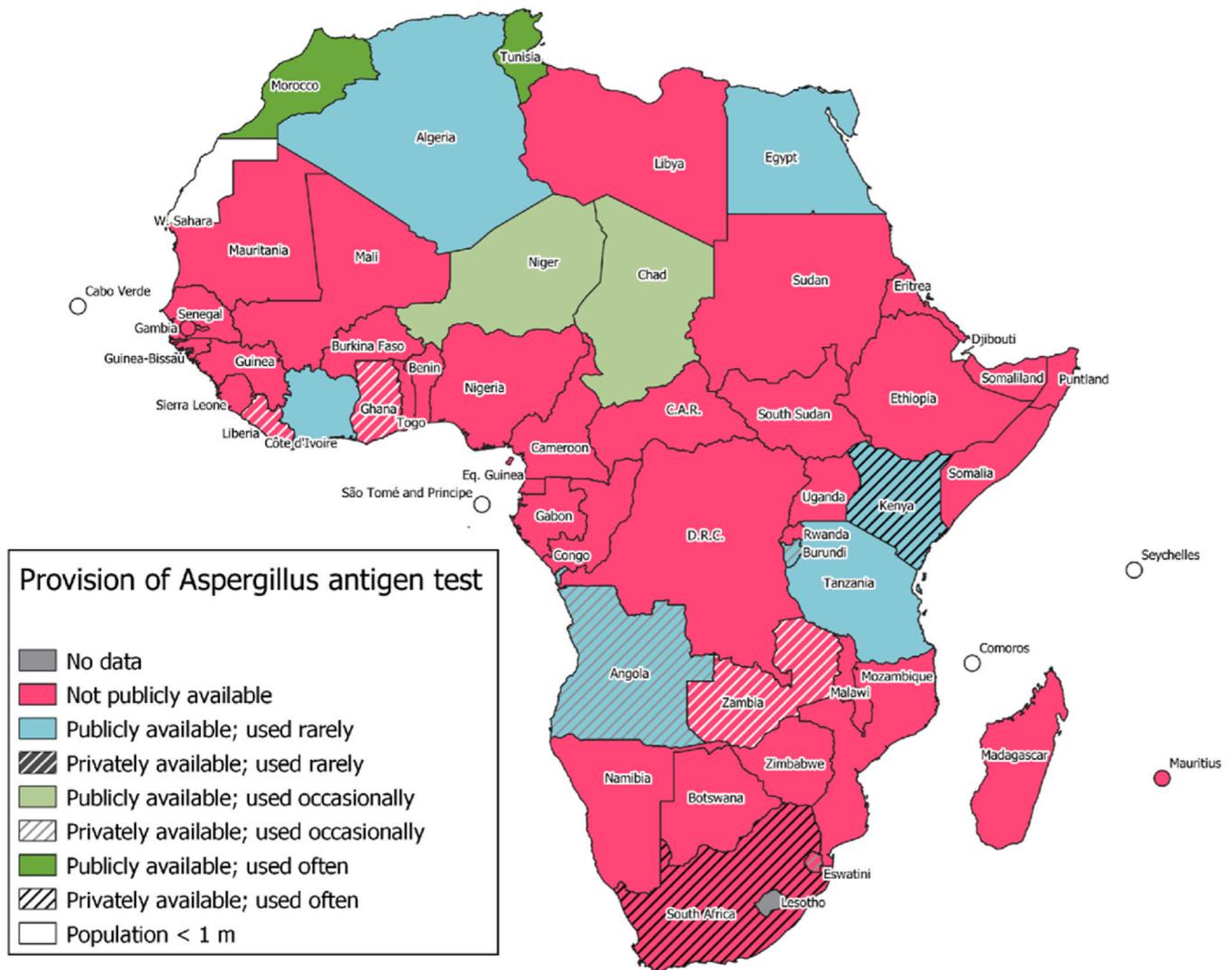


Fig. 2. *Aspergillus* antigen availability in Africa, in each country that was surveyed. Unless indicated by stripes, private provision was not in a better category than public provision.

[17] occurring concurrently with both *Pneumocystis* pneumonia and intraabdominal sepsis. Patients of all ages are affected, including premature infants.

The diagnosis of IFIs in patients with cancer involves a multifaceted approach [18]. Early recognition and prompt antifungal treatment are crucial. Standard diagnostic procedures include blood cultures, cultures and microscopic examination of appropriate specimens, and imaging studies [19]. Detection of fungal antigens, such as galactomannan, in serum, bronchoalveolar lavage fluid, and cerebrospinal fluid can aid in the diagnosis of invasive aspergillosis [12]. In addition, the presence of β -D-glucan in the serum can be used as a mycological criterion for probable invasive candidiasis and pneumocystosis and other IFIs. PCR-based and MALDI-ToF methods are used for confirmation and species identification. CT imaging of the chest is recommended for early detection and response prediction. However, imaging findings in paediatric patients may be non-specific [20–22]. The use of these diagnostic tools should be tailored to the individual patient's clinical presentation and risk factors, and results should be interpreted carefully considering their limitations. Collaboration between clinicians and experienced mycology laboratories with appropriate follow-up are essential for accurate diagnosis and management [23]. The GAFFI report details the published international guidelines for each laboratory assay, radiology and bronchoscopy, useful [24] as a resource for readers.

Bacteraemia, fungaemia and sepsis are common in hospitalised patients and a common of death globally. In 2017, there were an annual 48.9 million episodes of sepsis with 11 million deaths, mostly in low and middle-income countries [25]. Blood culture is a key investigation for sepsis, but we found that 7 countries have no blood culture capability, and another 10 countries do this investigation rarely, affecting nearly 25 % of the population of Africa. While most significant isolates from blood culture are bacteria, including some highly resistant to antibacterial agents, *Candida* spp. are the 3rd to 6th most common isolate in different series from various countries outside Africa. Documentation of candidaemia is critical for patient survival, especially with the increasingly frequent fluconazole-resistant *Candida* spp. (i.e., *C. auris* and *C. parapsilosis*) [26]. The patients at highest risk for candidaemia include premature neonates, those with diabetes mellitus and/or chronic kidney disease, those with pancreatitis or profound neutropenia and complex surgical patients [27–29]. The diagnosis of candidemia is often missed. Candidaemia rates rise with each additional antibiotic class used, a significant occurrence when diagnostics are absent [30]. We did not consider detection of beta-D-glucan in serum, as it is not listed as an essential diagnostic by the WHO and carries a relatively high per test cost.

Invasive aspergillosis is often a difficult diagnosis to make, but even its suspicion is commonly delayed as it rarely has distinctive

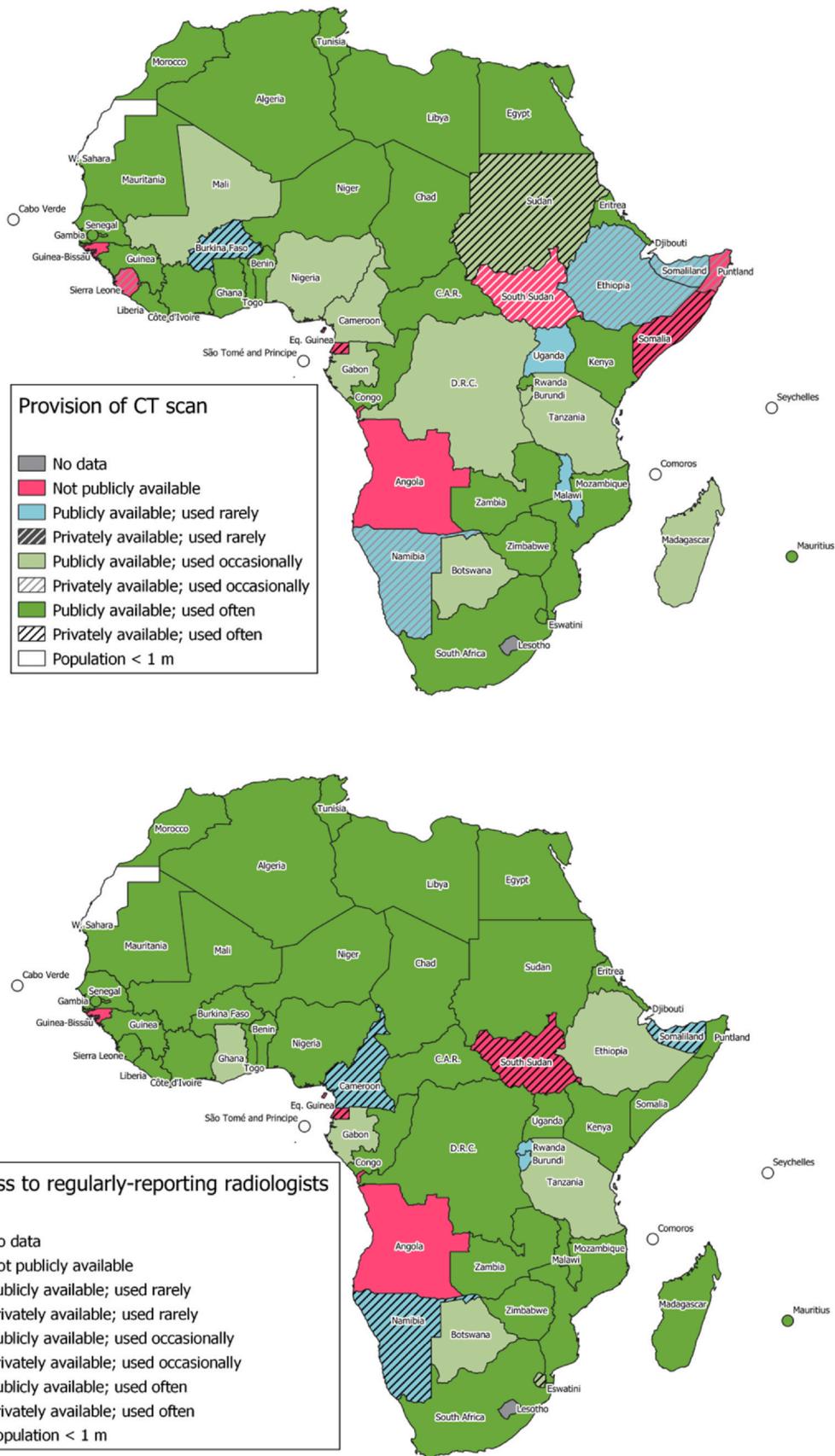


Fig. 3. Imaging provision in Africa A. CT scan availability in each surveyed country with some countries having more accessibility in the private sector as indicated by the hatched lines. B. Reporting by radiologists is widely available; in a few countries reporting is mostly or only done in the private sector. This map refers to all radiological and MR investigations, not just CT scans. Unless indicated by stripes, private provision was not in a better category than public provision.

clinical features. Undiagnosed it is almost always fatal [31]. The most sensitive diagnostic test is the *Aspergillus* antigen assay, particularly when the sample is taken by bronchoscopy. Until the last 3 years, the only assays were ELISA tests, but point of care lateral flow tests have now been commercialized, greatly simplifying detection [32]. Blood cultures are always negative for *Aspergillus* spp., but antigen can be detected in serum and/or respiratory samples in up to 90 % of neutropenic patients, 60 % of ventilated patients with influenza, and ~25 % of other at risk patients, such as solid organ transplant recipients and general intensive care patients [31]. Unfortunately, only 4 countries in Africa offer *Aspergillus* antigen testing often or occasionally. As Africa develops more advanced medicine capabilities, so the need for testing of *Aspergillus* antigen will rise.

Another key tool for the diagnosis of filamentous fungal infection and *Pneumocystis* pneumonia is the CT scan. Invasive aspergillosis and mucormycosis of the lungs have some distinctive radiological features including cavitation, the 'halo' sign in invasive aspergillosis and in the case of mucormycosis the 'reverse halo' sign [33]. In the paranasal sinuses, bone erosion, orbital and cerebral invasion are characteristic of acute invasive fungal rhinosinusitis. In modern leukaemia treatment units, patients with suspected fungal lung infection will undergo CT scanning within 48 h of suspicion, and chest X-rays are no longer done as they are insensitive (missing ~10 % of cases, and many smaller (earlier) lesions). CT scanning is also a critically important tool in the diagnosis of many forms of cancer, and for staging it. Most countries in Africa have frequent access to CT scanning covering about 590 million and another 11 countries covering 550 million have some CT scanning capability. Respondents often noted equipment breakdowns and some countries have power supply issues, further limiting access. There are 5 countries without CT scanners.

Equally crucial to the ability to scan patients, is the interpretation of CT images. Specialist radiologists are a core member of any oncology unit, supervising the correct CT scan modality, the appropriate use of contrast and reporting any abnormalities. Most countries in Africa have routine reporting by radiologists, with a few exceptions (4 countries have none and another 4 very few). Coverage and frequency of reporting is partial in another 7 countries, and within many countries service is much better in capital cities and major urban centres and limited in more remote and rural areas (as across the world). Fiberoptic transfer of CT scan images from areas without a radiologist to a university hospital, which is staffed by radiologists, could overcome some of the lack of reporting in remote areas, but the scanner itself requires highly trained staff to run it efficiently and safely.

Confirmation of IFIs relies on histopathological demonstration of fungi in tissue [34]. However, the diagnosis of almost all forms of cancer is made histologically. There are nine African countries with no histopathological service and another eight with a very limited service. Building these services where they are lacking or scarce may require part training of technical staff to screen and photograph slides for remote reading (even internationally). As the African population ages, a higher cancer incidence is likely, requiring an expansion of this highly trained workforce.

This study has some limitations. First, the number of respondents from each country were between 1 and 5 who provided information based on their own awareness and may not entirely represent the diagnostic capabilities of their countries. Secondly, the 78 health facilities sampled may not represent the thousands of health facilities on the continent: therefore, findings from this study may not be generalisable at a continent level. However, the final validation step led by Africa CDC engaging ministries and high-level country expertise mitigates some of these concerns. The responses about frequency of testing were only semi-quantitative (by design) and even the highest level of usage does not represent routine usage: hence there may be large gaps even in countries apparently with good

diagnostic provision. This report does provide baseline data to inform policy for cancer and fungal disease diagnosis and care, along with public health mycology. The full details of the survey, including other tests not covered in this paper, can be found on the GAFFI website [24].

In conclusion, this large survey covering over 99.65 % of the African population across private and public health facilities, finds critical gaps in the availability of essential diagnostics for IFIs, particularly *Aspergillus* antigen testing and modern medical imaging modalities. We recommend that key stakeholders and policy makers across Africa prioritise public health mycology and invest in essential diagnostics for IFIs to allow early diagnosis and commencement of targeted anti-fungal therapy. Optimal outcomes from complex cancer therapies and ICU patients will not be possible without good fungal diagnostic testing availability and capabilities across Africa.

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Declaration of Competing Interest

There is no conflict of interests with diagnostic companies or imaging/medical equipment companies.

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Authors' contribution

Author's contributions removed.

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