The current state of clinical mycology in Africa: a European Confederation of Medical Mycology and International Society for Human and Animal Mycology survey

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Africa, although not unique in this context, is a favourable environment for fungal infections, given the high burden of risk factors. An online survey was developed asking about laboratory infrastructure and antifungal drug availability. We received 40 responses (24·4% response rate) of 164 researchers contacted from 21 African countries. Only five institutions (12·5%) of 40 located in Cameroon, Kenya, Nigeria, Sudan, and Uganda potentially fulfilled the minimum laboratory requirements for European Confederation of Medical Mycology Excellence Centre blue status. Difficulties included low access to susceptibility testing for both yeasts and moulds (available in only 30% of institutions) and *Aspergillus* spp antigen detection (available in only 47·5% of institutions as an in-house or outsourced test), as well as access to mould-active antifungal drugs such as amphotericin B deoxycholate (available for 52·5% of institutions), itraconazole (52·5%), voriconazole (35·0%), and posaconazole (5·0%). United and targeted efforts are crucial to face the growing challenges in clinical mycology.

Introduction

Approximately a fifth of the world's people live in Africa, a continent with a propitious environment for fungal infections. The continent is marked by social and health inequalities, with a national health insurance scheme absent in most countries. Additionally, a large proportion of its population live in rural settings and are exposed to environmental factors that increase the risk for fungal diseases.[1] Africa has the largest population living with HIV, AIDS, and tuberculosis globally, which are major risk factors for fungal infections.[2,3] Meanwhile, access to treatment for these three conditions is still low in many countries, and has become even worse with the COVID-19 pandemic.[4–6] This problem is mainly attributed to poorly funded and overburdened health systems in many African countries;[7,8] thus dealing with the probably high burden of fungal infections is a challenge.

Despite the global importance of superficial and invasive mycoses, there is still little information regarding the epidemiology of fungal infections in some areas of the world, including in Africa.[9] Medical mycology has made important advances, but non-specific signs and symptoms and the rapid progression of fungal disease in immunocompromised patients continue to present a challenge to clinicians and laboratories.[10] Notable limitations include few resources and investments in clinical mycology and diagnostic resources, as well as difficulties in accessing antifungal therapy. A poor awareness of fungal diseases among health-care professionals and policy makers, as well as the unaffordability of, toxicity of, and little access to antifungal treatment options are some of the challenges facing the continent.[11–13]

With few exceptions (such as testing for cryptococcal antigen), advances within the past 5 years in non-culture-based diagnostics have not reached most low-income and middle-income countries (LMICs). Therefore, it is necessary to assess the present status of the diagnosis of fungal infections in these regions to guide health professionals, patients, and policy makers.[12] Africa has not yet been comprehensively evaluated for its capability to diagnose and treat fungal diseases. These studies are important not only for epidemiological purposes, but also to guide the appropriate implementation of preventive, diagnostic, and therapeutic measures in medical mycology. Hence, under the umbrella of the European Confederation of Medical Mycology (ECMM) and the International Society for Human and Animal Mycology (ISHAM), we surveyed African institutions to obtain an overview of the current state of mycological laboratory capacities and availability of antifungal treatment in the field of invasive fungal diseases.

Procedure

We designed a cross-sectional survey with 29 questions (appendix pp 1–7) about the profile and size of institutions, antifungal drug availability, laboratory infrastructure, and methods used to identify pathogens and antifungal susceptibility, as well as antigen detection and molecular tests. The survey was open from June 1, 2019, to May 31, 2020, and was released online on the ISHAM and ECMM websites and sent out to their members based in Africa. We contacted 164 African researchers directly by email based on their email address from PubMed publications. Reminders were sent to the authors in cases of non-response.

The institutions were classified according to whether the laboratories potentially met the ECMM criteria for blue, silver, gold, or diamond status, or did not meet the criteria. The minimal requirements for the blue status are the identification of relevant yeasts and moulds, susceptibility testing on yeasts and moulds according to standard procedures, and the performance of antigen

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Post-graduation Programme in Pathology, Federal University of Health Sciences of Porto Alegre, Porto Alegre, Brazil (C Driemeyer MD, A C Pasqualotto MD); **Molecular Biology Laboratory, Santa Casa de Misericordia de Porto Alegre, Porto Alegre, Brazil** (C Driemeyer, A C Pasqualotto); **Infectious Diseases Unit, Hospital de Clínicas de Porto Alegre, Porto Alegre, Brazil** (D R Falci MD); **Department of Medical Microbiology & Parasitology, College of Medicine, University of Lagos, Lagos, Nigeria** (R O Oladele PhD); **Department of Medical Microbiology and Immunology, Faculty of Medicine, Gulu University, Gulu, Uganda** (F Bongomin MBChB); **Division of Infection, Immunity, and Respiratory Medicine, School of Biological Sciences, Faculty of Biology, Medicine, and Health, University of Manchester, Manchester, UK** (B K Ocansey BSc, R Rautemaa-Richardson PhD); **National Institute for Communicable Diseases, A Division of the National Health Laboratory Service and School of Pathology, Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, South Africa** (Prof N P Govender MD); **Division of Infectious Diseases and Global Public Health, University of California San Diego, San Diego, CA, USA** (Prof M Hoenigl MD); **Division of Infectious Diseases, Medical University of Graz, Graz, Austria** (Prof M Hoenigl); **Centre Hospitalier Universitaire de Rennes, University of Rennes, Institut**

National de la Santé et de la Recherche Médicale, Institut de Recherche en Santé, Environnement et Travail, Rennes, France (Prof J P Gangneux PhD); Institute of Hygiene and Medical Microbiology, Medical University of Innsbruck, Innsbruck, Austria (Prof C Lass-Flörl MD); University of Cologne, Faculty of Medicine and University Hospital Cologne, Chair Translational Research, Cologne Excellence Cluster on Cellular Stress Responses in Aging-Associated Diseases, Cologne, Germany (Prof O A Cornely MD, C Bruns PhD, J Stemler MD); University of Cologne, Faculty of Medicine and University Hospital Cologne, Department I of Internal Medicine, Excellence Center for Medical Mycology, Cologne, Germany (Prof O A Cornely, J Stemler); Université de Paris, Paris, France (A Alanio PhD); Laboratoire de Parasitologie-Mycologie, Assistance Publique-Hôpitaux de Paris, Groupe Hospitalier Saint-Louis-Lariboisière-Fernand-Widal, Paris, France (A Alanio); Institut Pasteur, Centre National de la Recherche Scientifique, Unité de Mycologie Moléculaire, Centre National de Référence Mycoses Invasives et Antifongiques, Paris, France (A Alanio); Clinical Microbiology and Infectious Diseases Department, Hospital General Universitario Gregorio Marañón, Madrid, Spain (J Guinea PharmD); Instituto de Investigación Sanitaria Gregorio Marañón, Madrid, Spain (J Guinea); Centro de Investigación Biomédica en Red, Enfermedades Respiratorias, Centro de Investigación Biomédica en Red de Enfermedades Respiratorias, Madrid, Spain (J Guinea); Department of Infectious Diseases, Alfred Health & Monash University, Melbourne, VIC, Australia (Prof C O Morrissey MD); National Aspergillosis Centre, Wythenshawe Hospital, Manchester University NHS Foundation Trust, Manchester Academic Health Science Centre, Manchester, UK (R Rautemaa-Richardson); Mycology Reference Centre Manchester, Excellence Center

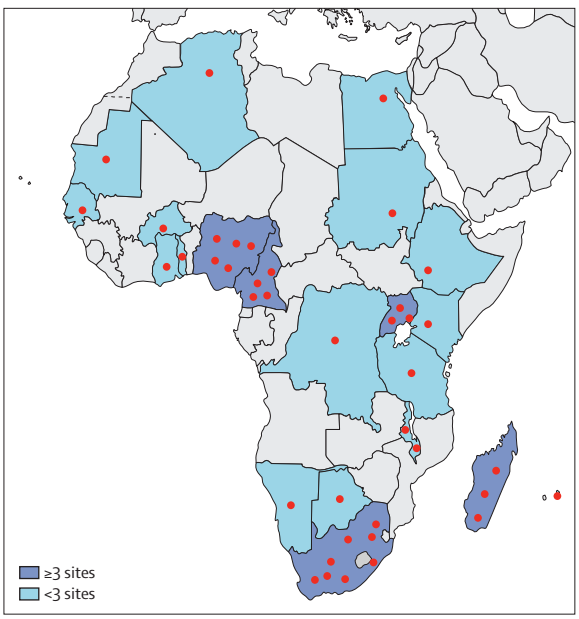

Figure 1: **Location of African institutions participating in this survey**
Key indicates the number of institutions that responded in each country.

ELISA for *Aspergillus* spp (galactomannan) and cryptococcal antigen. The criteria used for the classification of mycology centres are not restricted to the laboratory, but also consider the clinical and epidemiological dimensions, involvement in clinical trials, and in part depend on the type of patients cared for (appendix p 8).[14] This classification procedure was not an accreditation visit or round organised by the ECMM. Instead, we only checked the level at which centres were likely to be accredited if they had formally applied.

Findings

We received 40 responses (24·4% response rate) of the 164 researchers contacted, encompassing 40 different institutions from 21 different countries with all African sub-regions represented (figure 1). Countries with researchers that responded were South Africa (n=8), Nigeria (n=5), Cameroon (n=4), Madagascar (n=3), Uganda (n=3), Malawi (n=2), Algeria (n=1), Botswana (n=1), Burkina Faso (n=1), Democratic Republic of the Congo (n=1), Egypt (n=1), Ethiopia (n=1), Ghana (n=1), Kenya (n=1), Mauritania (n=1), Mauritius (n=1), Namibia (n=1), Senegal (n=1), Sudan (n=1), Togo (n=1), and Tanzania (n=1). Our survey was answered by laboratory professionals (n=22), professors (n=11), attending physicians (n=4), infection control practitioners (n=1), and other professionals who did not fit any of these categories (n=2).

Among responders, 29 (72·5%) were from university hospitals or national institutes of research, seven (17·5%) were from public hospitals not related to universities, two (5%) were private hospitals not related to universities, and one (2·5%) was an oncology clinic. One institution (2·5%) was an independent laboratory that served both private and public hospitals. The number of beds per institution ranged from 10 to 2880 (median, 300 beds), the number of adult intensive care unit beds ranged from 6 to 125 (median, 19 beds), and the number of paediatric and neonatal intensive care unit beds ranged from 4 to 300 (median, 20 beds).

Institutions served patients living with HIV or AIDS (n=38 [95·0%]), patients with oncological (n=33 [82·5%]) and haematological malignancies (n=35 [87·5%]), patients requiring parenteral nutrition (n=24 [60·0%]), and patients who had received a solid organ transplantation (n=6 [15·0%]) or a haematopoietic stem-cell transplantation (n=4 [10·0%]).

Nearly all institutions (n=39 [97·5%]) reported having a microbiology laboratory in place, although one institution outsourced general laboratory services. Focusing specifically on mycological diagnostic tools, three (7·5%) institutions reported no access at all to such services, 14 (35·0%) performed some tests within the institution and outsourced some tests to other laboratories, and 23 (57·5%) always perfomed the tests within the institution.

When asked about the most relevant fungi affecting patients in their institutions, most responses were: *Candida* spp (n=34 [85·0%]), followed by *Cryptococcus* spp (n=22 [55·0%]), *Aspergillus* spp (n=16 [40·0%]), *Fusarium* spp (n=8 [20·0%]), *Histoplasma* spp (n=5 [12·5%]), and Mucorales (n=4 [10·0%]).

When a fungal infection was suspected, 21 (52·5%) institutions reported always performing direct microscopy on clinical specimens, five (12·5%) reported performing it most of the time, seven (17·5%) reported performing it half of the time, five (12·5%) reported performing it rarely, and two (5·0%) reported that direct microscopy was never performed. Although 34 (85·0%) used microscopy to diagnose cryptococcosis, only eight (20·0%) performed a silver stain when pneumocystosis was suspected. Access to fluorescent dyes was also restricted, being available in only nine (22·5%) institutions. India or China ink was available for 31 (77·5%) institutions, followed by potassium hydroxide (n=28 [70·0%]), silver stain (n=28 [70·0%]), Giemsa stain (n=22 [55·0%]), and calcofluor white (n=4 [10·0%]).

To identify fungi at the species level, biochemical tests were the most commonly used tools, in 28 (70%) institutions. Automated identification by a VITEK system (an automated system for antibiotic susceptibility testing and microbiology identification; bioMérieux, Marcy-l'Étoile, France) or other commercial methods were accessible in 18 (45·0%) institutions, followed by mounting medium (n=11 [27·5%]), Matrix-Assisted Laser Desorption or Ionization-Time of Flight (MALDI-ToF; n=7 [17·5%]), and DNA sequencing (n=8 [20·0%]). Automated blood culture monitoring was available for 19 institutions (47·5%).

Susceptibility testing was available for 25 (62·5%) participants, but only in 12 (30%) institutions was access

to susceptibility tests covering both yeasts and moulds available. E-test strips were available in 14 (35·0%) institutions, 14 (35·0%) had access to VITEK, 11 (27·5%) to broth microdilution following Clinical and Laboratory Standards Institute standards, and seven (17·5%) to broth microdilution following European Committee on Antimicrobial Susceptibility Testing standards.

When serological testing was considered, antibody detection was mostly available for *Aspergillus* spp (n=9 [22·5%]), and in ten (25·0%) institutions antibody detection for *Aspergillus* spp was available at an outsourced laboratory. Anti-*Aspergillus* IgE was not evaluated in the survey. *Candida* spp antibody detection was available for five (12·5%) institutions, the same number had access to the test for *Candida* spp at an outsourced laboratory, *Histoplasma* spp antibody detection was performed in one institution only (2·5%), and 12 (30%) had access to the test for *Histoplasma* spp at an outsourced laboratory.

The availability of antigen detection tests was low in the study, as illustrated in figure 2. Regarding *Histoplasma* species, only two (5·0%) centres indicated access to in-house antigen testing, even though 12 (30·0%) had access through an outsourced laboratory. *Cryptococcus* lateral flow assay was available for 24 (60·0%) institutions, three of which were exclusively through an outsourced laboratory, whereas *Cryptococcus* latex testing was performed in 16 (40·0%) institutions, and another two (5·0%) had access to the test through an outsourced laboratory. *Aspergillus* antigen detection (by galactomannan enzyme immunoassay, lateral flow assay, or lateral flow device) was available for 11 (27·5%) institutions locally and for eight (20·0%) exclusively through an outsourced laboratory. 16 (40·0%) of all institutions that answered the survey did not have access to antigen testing even through outsourced laboratories.

Access to fungal molecular diagnostics was even more restricted, as shown in table 1. For example, in-house molecular tests for *Pneumocystis* spp were available for seven (17·5%) institutions, and six (15·0%) had access to these methods through an outsourced laboratory.

Only five (12·5%) institutions fulfilled the minimum laboratory requirements for blue status according to ECMM criteria. These five institutions were located in Cameroon, Kenya, Nigeria, Sudan, and Uganda. Seven (17·5%) other institutions fulfilled three of four blue status criteria, whereas 16 (40%) fulfilled two, 11 (27·5%) institutions fulfilled one criterion, and only one (2·5%) institution did not fulfil any of the criteria. Although South Africa is the only African country with a surveillance system for fungal infections and a national mycology reference laboratory,[8] none of the responders from this country performed an antigen ELISA for *Aspergillus* spp or equivalent assays instead.

The availability of antifungal therapy in Africa is detailed in table 2. Therapeutic drug monitoring (TDM) was available for itraconazole in seven (17·5%) institutions in house and in two (5%) institutions at an outsourced laboratory. Regarding TDM for other antifungal agents, voriconazole was available in four (10·0%) institutions, posaconazole in one (2·5%) institution, and 5-flucytosine in three (7·5%) centres in total, both in-house and outsourced.

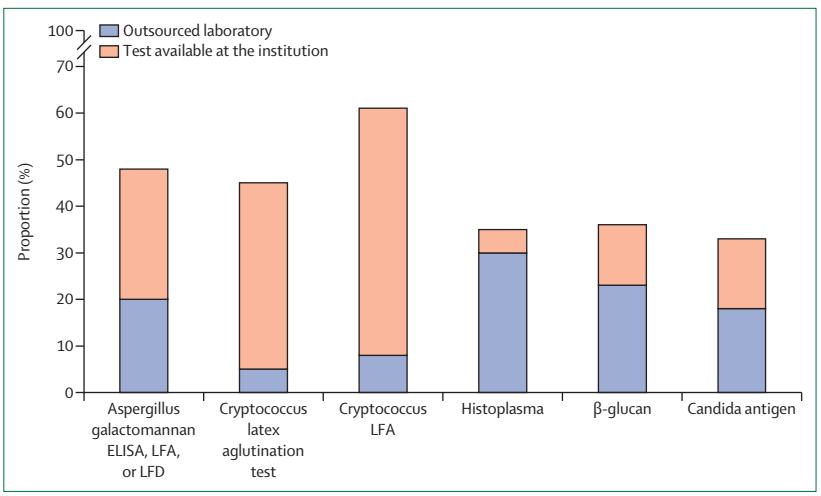

Figure 2: **Antigen detection availability in African institutions**
LFA=lateral flow assay. LFD=lateral flow device.

	Number of institutions with molecular tests available in-house	Number of institutions with molecular tests performed at outsourced laboratories	Total
Candida spp	8 (20·0%)	7 (17·5%)	15 (37·5%)
Aspergillus spp	5 (12·5%)	7 (17·5%)	12 (30·0%)
Pneumocystis spp	7 (17·5%)	6 (15·0%)	13 (32·5%)
Other fungi	5 (12·5%)	6 (15·0%)	11 (27·5%)

Data shown as n (%). Percentages calculated out of 40 responses.

Table 1: **Molecular test (of any sort) availability in-house and at outsourced laboratories according to the fungal pathogen**

Discussion

We report for the first time the availability of diagnostic tools and capacity for treatment of fungal infections in Africa. Other investigators have indicated some of the African laboratories' strengths and weaknesses, but they usually focused on specific African sub-regions (sub-Saharan Africa mainly) and diseases, such as HIV or AIDS.[15–18] Our survey included institutions with distinct profiles (such as university hospitals and public and private hospitals with different numbers of beds) and from different sub-regions of Africa.

The low numbers of responders might reflect the fact that there are few mycologists on the continent. Even though the sample in this survey was a convenience sample, it did provide a snapshot from the entire

for Medical Mycology, Wythenshawe Hospital, Manchester University NHS Foundation Trust, Manchester, UK (R Rautemaa-Richardson); **Department of Medical Microbiology, Postgraduate Institute of Medical Education and Research, Chandigarh, India** (A Chakrabarti MD); **Department of Medical Microbiology and Infectious Diseases and Centre of Expertise in Mycology Radboudumc/Canisius Wilhelmina Hospital, Excellence Center for Medical Mycology, Nijmegen, Netherlands** (J F Meis MD); **German Centre for Infection Research, Partner Site Bonn-Cologne, Cologne, Germany** (C Bruns, J Stemler, Prof O A Cornely); **University of Cologne, Faculty of Medicine and University Hospital Cologne, Clinical Trials Centre Cologne, Cologne, Germany** (Prof O A Cornely)

Correspondence to:
Alessandro C Pasqualotto, Molecular Biology Laboratory, Santa Casa de Misericordia de Porto Alegre, Porto Alegre 90020-090, Brazil
pasqualotto@santacasa.org.br

See **Online** for appendix

For the **ECMM criteria** see https://www.ecmm.info/ecmm-excellence-centers/

	Number of institutions with antifungal drug availability in Africa (n=40)
Fluconazole	36 (90·0%)
Isavuconazole	1 (2·5%)
Itraconazole	21 (52·5%)
Posaconazole	2 (5·0%)
Voriconazole	14 (35·0%)
Amphotericin B deoxycholate	21 (52·5%)
Liposomal amphotericin B	7 (17·5%)
Amphotericin B lipid complex	4 (10·0%)
Other lipid formulations of amphotericin B	4 (10·0%)
Anidulafungin	2 (5·0%)
Caspofungin acetate	8 (20·0%)
Micafungin sodium	9 (22·5%)
5-flucytosine	11 (27·5%)
Terbinafine	25 (62·5%)

Data shown as n (%). Percentages calculated out of 40 responses.

Table 2: **Antifungal drug availability in Africa**

continent. Only three (7·5%) institutions, located in Ethiopia (n=1), Nigeria (n=1), and Togo (n=1), reported no access to mycological diagnosis. However, we should highlight that some countries are not represented in our sample and might have an even more vulnerable situation when it comes to the diagnosis and treatment of fungal infections, mainly if we consider those countries with a lower human development index, lower gross national income per person, and worse indicators related to multidimensional poverty, than the countries included here.[1,2] Nevertheless, the high prevalence of university hospitals and national centres of research (72·5%) among responders might overestimate the available resources. In Africa, challenges posed by fungal infection are huge and diverse. The burden of fungal infection, both cutaneous and invasive, is high, and is well documented in many studies.[19–30] Deaths due to cryptococcal disease, which are associated with HIV infection, exceed 200 000 per year.[29,31] A study evaluating non-culture-based methods, performed with inpatients in South Africa, showed that one in ten inpatients had evidence of an invasive mycosis (including cryptococcosis, pneumocystosis, and histoplasmosis).[32] Additionally, a high incidence of co-infection with tuberculosis was observed, complicating the diagnosis and management of these patients, particularly because of drug–drug interactions. The authors of this previous study estimated that 60% of invasive fungal diseases were missed,[32] corroborating the urgent need for improving diagnostic capacities in this region.

Few studies assessing mycological practices around the world have been performed,[33–37] and fewer so in LMICs.[18,38,39] Sufficient numbers of responders are a challenge in this type of approach: the sample size was also a limitation for Falci and Pasqualotto[38] (129 responses from 14 countries [96 from Brazil, nine from Mexico, five from Colombia, three from Uruguay, three from Guatemala, two from Argentina, two from Chile, two from Paraguay, two from Venezuela, one from Barbados, one from Ecuador, one from Honduras, one from Peru, and one from French Guiana], of which 74% were from one country only) and Chindamporn and colleagues[39] (241 laboratories from seven countries answered the survey out of nearly 900 who were directly contacted, a response rate of approximately 26%). Despite this, data from these snapshots are interesting tools to be used for the advocacy of laboratory capacity improvements. Our data can be combined with those from these previous papers, indicating that there is an unequivocal absence of adequate diagnostic tools to manage fungal disease burden in these regions (Asia, Africa, and Latin America).

In many mycoses, choosing the most appropriate therapy and accurately identifying the causative fungal species is crucial. One example is *Candida auris*, a multidrug resistant pathogen that was retrospectively identified in 2009 in South Africa and in 2011 in Kenya.[40,41] Nevertheless, few laboratories reported having the capacity to correctly identify *C auris*, which includes modern technology such as MALDI-ToF or molecular methods. Institutions that answered the survey here seemed to be reasonably prepared for HIV-associated infections such as cryptococcosis, reporting rates of more than 75% for cryptococcal antigen test and India ink availability. However, opportunistic infections with an unclear epidemiological characterisation in Africa, such as histoplasmosis[42] and emergomycosis,[43] are under-recognised, with less than 40% of institutions reporting access to *Histoplasma* antigen detection.

It is to be noted that it is necessitated that tertiary hospitals attending to patients with non-HIV immunocompromising conditions are aware of the rampant increase of antifungal resistance. However, a concerning 37·5% of institutions in this study do not perform antifungal susceptibility tests. Consequently, we anticipate a catastrophic scenario because multiple risk factors for fungal infections in Africa are combined with an absence of diagnostic tools and limited resources, which in turn is likely to exaggerate the global trend in antifungal resistance, not only in medicine but also in agriculture, with deficient epidemiological tools to monitor its advance in the continent.[44]

The worldwide rise of antifungal resistance as a threat not only to public health but also to food security has been previously noted,[45,46] but not enough action has been taken in the field, especially from policy makers. The use of antifungal agents in agriculture is common and necessary, but their unadvertised use and few regulations might aggravate the problem, mainly in LMICs, which economically depend on crops and commodities.[47] Thus, antifungal resistance has become a problem in onychomycosis and other superficial mycoses, as well as in systemic mycoses.[48]

Regarding treatment, the unavailability of WHO essential drugs[49] is concerning. Fundamental agents had low availability in the institutes included here. Amphotericin B deoxycholate was available in only 21 (52·5%) institutions, and liposomal amphotericin B in seven (17·5%; table 2). Itraconazole was available only in 21 (52·5%), voriconazole in 14 (35·0%), and posaconazole in two (5·0%) institutions. 5-flucytosine was available in 11 (27·5%) institutions. Only fluconazole had a reasonable availability (90·0%), but this is insufficient to overcome the great burden of fungal infection in Africa, especially without the other components of the antifungal armamentarium. For example, in cryptococcal meningitis, monotherapy with fluconazole is related to substantially higher mortality[50] in comparison with the combination of 5-flucytosine and amphotericin B. Additional issues include *Cryptococcus neoformans* resistance and immune reconstitution inflammatory syndrome in patients living with HIV; however, fluconazole is unfortunately the only treatment available in many African settings.[51,52] When considering dermatophytosis, a high burden and growing resistance in Africa also represents a challenge. According to Bongomin and colleagues,[53] one in every five children in Africa has tinea capitis. If the availability of the appropriate diagnosis tools is low, then adequate treatment seems to be an equally relevant debility. The low availability of TDM is also a worrying sign, because the appropriate use of necessary drugs such as voriconazole and itraconazole is largely dependent on it.[54] TDM is an important tool to adjust drug doses, control toxicity, and result in the rational use of drugs, and is even more necessary in scenarios with reduced resources. Few institutions reported access to TDM and most only had access to TDM testing from outsourced institutions (which results in long turnaround times and, consequently, a lessening in the clinical usefulness of these tests). Moreover, it would also be necessary to consider the access to routine laboratory results to better treat and prevent antifungal toxicity, such as monitoring liver and kidney function. Delay in obtaining such results might result in worse outcomes in patients with fungal diseases.[55]

We aimed to contact as many African institutions and researchers as possible, and the small number of responders in such a diverse continent is probably the most notable limitation of our study. We tried to reach them through their institutional email addresses available in published papers and also through ISHAM and ECMM, which also advertised the study on social media. Additionally, the questionnaire was in English only, which might have created language barrier difficulties for some of the participants. The questionnaire also had to be kept short to facilitate the answers, and some important points were left out, such as the cost of treatments and capabilities of obtaining rapid results of laboratory tests, which might be imperative to handling antifungal toxicity. In addition to the sample size, we were not able to include all relevant mycoses in Africa in the questionnaire, such as dermatophytosis and blastomycosis.[53,56]

In Africa there is an urgent need to improve the structure of health laboratories and overall capacity of the system to tackle the burden of fungal infection. Efforts and collaborations have been made in the last few decades, mainly against fungal infections related to HIV and AIDS, and accomplished many objectives (such as access to cryptococcal antigen tests) through partnerships and structured networks. However, our survey shows that there is more work yet to be done to achieve the necessary framework to address the challenges of all fungal infections, especially non-HIV related infections.[57] There are notable deficits in the availability of diagnostic tests, especially newer technologies such as MALDI-ToF and molecular methods, and non-culture-based methods for the diagnosis of invasive mycoses. Chromogenic media could also optimise the diagnosis at a lower cost. Furthermore, access to adequate treatment is hampered by the low availability of essential drugs. Efforts from and collaborations between health-care professionals, academia, researchers, policy makers, and all other stakeholders are necessary to support the improvement of the diagnostic and therapeutic capacity in caring for people affected by all fungal infections in Africa.

Search strategy and selection criteria

We searched for articles written in English in the PubMed database from May 1, 2019, to May 31, 2021, without any restrictions on the date of publication of the articles included in the search, considering combined terms such as "Africa", "antifungal", "invasive fungal infections", "dermatophytosis", "mycology", "resistance", "agriculture", "laboratory", "access", "treatment", "susceptibility testing", "toxicity", "fluconazole", "amphotericin", "therapeutic drug monitoring", "epidemiology", "burden", "low- and middle-income countries", "cryptococcus", and "HIV". We used guidelines (the WHO guidelines for diagnosing and managing disseminated histoplasmosis among people living with HIV and WHO guidelines for the diagnosis, prevention and management of cryptococcal disease in HIV-infected adults, adolescents, and children) and the essential medicine list from WHO as consult material as well as the 2019 UN Report on Human Development and Multidimensional Poverty Index to better contextualise our data. When pertinent, we revised the references of the selected articles.

Contributors

CD contributed to the formal analysis, literature search, creating the figures, and writing of the original draft of the manuscript. DRF contributed to the formal analysis, literature search, and writing of the original draft. ROO, FB, BKO, NPG, JPG, CL-F, AA, JG, COM, RR-R, AC, and JFM contributed to writing, reviewing, and editing the manuscript. MH and OAC contributed to the conceptualisation, study design, literature search, data collection, and writing, reviewing, and editing of the manuscript. CB contributed to the data collection, and writing, reviewing, and editing of the manuscript. JS contributed to

creating the figures, and writing, reviewing, and editing of the manuscript. ACP contributed to the conceptualisation, study design, data collection, formal analysis, project administration, and writing of the original draft. CD, DRF, MH, and ACP verified the underlying data.

Declaration of interests

DRF received payments for educational material from Gilead Sciences; honoraria for lectures from Gilead Sciences, Merck Sharp & Dohme, Pfizer, and United Medical; support for attending meetings and travel from Merck, Sharp & Dohme, Gilead Sciences, Pfizer, and United Medical; and participated on an advisory board of Merck, Sharp & Dohme and GlaxoSmithKline, outside the submitted work. AA received honoraria from Gilead Sciences and Pfizer; and travel grants from Astellas, outside the submitted work. JS received research grants from the Ministry of Education and Research and Basilea Pharmaceuticals; and received travel grants from the German Society for Infectious Diseases and Meta-Alexander Foundation, outside the submitted work. JPG received funds for participating at educational activities organised on behalf of Astellas, Biotoscana, Gilead Sciences, Merck, Sharp & Dohme, and Scynexis; and received research funds from Cidara, Fabbrica Italiana Sintetici, Gilead Sciences, and Scynexis, outside the submitted work. OAC reports grants from Actelion, Amplyx, Astellas, Basilea, Cidara, Da Volterra, The Deutsche Forschungsgemeinschaft, F2G, German Federal Ministry of Research and Education, German Research Foundation, Gilead Sciences, Immunic, Janssen, Medicines Company, MedPace, Melinta Therapeutics, Merck, Sharpe & Dohme, Pfizer, and Scynexis; and personal fees from Actelion, Allecra Therapeutics, Al-Jazeera Pharmaceuticals, Amplyx, Astellas, Basilea, Biosys, Cidara, Da Volterra, Entasis, F2G, Gilead Sciences, Grupo Biotoscana, IQVIA, Matinas, MedPace, Menarini, Merck, Sharpe & Dohme, Mylan, Nabriva, Noxxon, Octapharma, Paratek, Pfizer, Pharmaceutical Solutions Industry, Roche Diagnostics, Scynexis, and Shionogi, outside the submitted work. JFM received grants from F2G and Pulmozyme; has been a consultant to Merck Sharpe & Dohme and Scynexis; and has received speaker's fees from Gilead, Teva Pharmaceutical Industries, and United Medical. NPG received research grants from the National Institutes of Health, Centers for Disease Control and Prevention, Bill & Melinda Gates Foundation, and the UK Medical Research Council, outside the submitted work. ROO has received grants from Gilead Sciences and Pfizer; payment for lectures from Pfizer; and participated on an advisory board for Pfizer, outside the submitted work. BKO received research funds from The Foundation for Technological Innovation, outside the submitted work; and the funds to organise a symposium from Immuno-Mycologics. COM has received grants from Gilead Sciences and Merck Sharp & Dohme Australia; received payment for lectures from Gilead Sciences, Merck Sharp & Dohme, and Pfizer; and participated in a data safety monitoring board for Gilead Sciences and Merck Sharp & Dohme, outside the submitted work. ACP received research grants support from Gilead Sciences, Immuno-Mycologics, Merck, Sharp & Dohme, and Pfizer; and has given paid talks and consulted for Gilead Sciences, Immuno-Mycologics, Merck, Sharp & Dohme, Pfizer, Teva, and United Medical, outside the submitted work. MH received research funding from Astellas, Euroimmun, the National Institutes of Health US, Gilead, Pfizer, and Scynexis, outside the submitted work. All other authors declare no competing interests.

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