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ORIGINAL RESEARCH

Opportunities to Enhance Diagnostic Testing and Antimicrobial Stewardship: A Qualitative Multinational Survey of Healthcare Professionals

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ABSTRACT

Introduction: Antimicrobial resistance (AMR) is a global public health challenge. Global efforts to decrease AMR through antimicrobial stewardship (AMS) initiatives include education and optimising the use of diagnostic technologies and antibiotics. Despite this, economic and societal challenges hinder AMS efforts. The objective of this study was to obtain insights from healthcare professionals (HCPs) on current challenges and identify opportunities for optimising diagnostic test utilisation and AMS efforts.

Methods: Three hundred HCPs from six countries (representing varied gross national incomes per capita, healthcare system structure, and AMR rates) were surveyed between November 2022 through January 2023. A targeted literature

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review and expert interviews were conducted to inform survey development. Descriptive statistics were used to summarise survey responses.

***Results*:** These findings suggest that the greatest challenges to diagnostic test utilisation were economic in nature; many HCPs reported that AMS initiatives were lacking investment (32.3%) and resourcing (40.3%). High resistance rates were considered the greatest barriers to appropriate antimicrobial use (52.0%). Most HCPs found local and national guidelines to be very useful (≥ 51.0%), but areas for improvement were noted. The importance of AMS initiatives was confirmed; diagnostic practices were acknowledged to have a positive impact on decreasing AMR (70.3%) and improving patient outcomes (81.0%).

***Conclusion*:** AMS initiatives, including diagnostic technology utilisation, are pivotal to decreasing AMR rates. Interpretation of these survey results suggests that while HCPs consider diagnostic practices to be important in AMS efforts, several barriers to successful implementation still exist including patient/institutional costs, turnaround time of test results, resourcing, AMR burden, and education. While some barriers differ by country, these survey results highlight areas of opportunities in all countries for improved use of diagnostic technologies and broader AMS efforts, as perceived by HCPs. Greater investment, resourcing, education, and updated guidelines offer opportunities to further strengthen global AMS efforts.

PLAIN LANGUAGE SUMMARY

Antimicrobials are medications used to treat infections caused by bacteria (e.g. antibiotics), viruses, parasites, and fungi. Over time, these microbes may become resistant to antimicrobials, limiting how well they work. This often happens as a result of overuse, using antimicrobials when there is not an infection, or using an inappropriate antimicrobial. Antimicrobial resistance is a growing global problem. Antimicrobial stewardship programs aim to improve appropriate use of antimicrobials. Diagnostic testing plays an important role in these programs by identifying the microbes responsible for infections so patients can be given the right treatment as quickly as possible. We aimed to obtain the perspective of healthcare professionals from six countries on the challenges of and ways to improve diagnostic testing and antimicrobial stewardship programs. We found that some of the greatest challenges were related to costs. Approximately one-third of participants said that antimicrobial stewardship initiatives were lacking investment (32.3%) and resourcing (40.3%). High rates of antimicrobial resistance were identified as the greatest barriers to appropriate antimicrobial use (52.0%). Participants said that diagnostic practices have a positive impact on decreasing antimicrobial resistance (70.3%) and improving patient outcomes (81.0%). Overall, we found that healthcare professionals consider diagnostic tests to be an important part of antimicrobial stewardship, but there are several barriers to their success, including patient/hospital costs, turnaround time of test results, resourcing, antimicrobial resistance, and education. To overcome these barriers, increased funding, education, and resourcing, regular guideline updates, and development of optimised testing algorithms may help to improve antimicrobial stewardship and ultimately decrease antimicrobial resistance.

Keywords: Antimicrobial resistance; Antimicrobial stewardship; Bacteria and bacterial infections; Diagnostic technologies; Healthcare professional survey

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Key Summary Points

Why carry out this study?

Despite antimicrobial resistance being a topic of global importance and the reported positive impact of diagnostic technologies and antimicrobial stewardship efforts, barriers to appropriate use of diagnostic utilisation and effective antimicrobial stewardship practices widely exist.

This research aimed to obtain insights from healthcare professionals on current challenges and identify opportunities for optimising diagnostic and antimicrobial stewardship efforts.

What was learned from the study?

While healthcare professionals consider diagnostic practices to be important in antimicrobial stewardship efforts, there are several barriers to their successful implementation, including patient/institutional costs, turnaround time of test results, resourcing, antimicrobial resistance burden, and education.

To overcome these barriers, increased funding, education, and resourcing along with regular clinical guideline updates and development of optimised testing algorithms may help to improve antimicrobial stewardship efforts and ultimately decrease antimicrobial resistance.

INTRODUCTION

Antimicrobial resistance (AMR) is a prominent, global public health challenge; an estimated 1.27 million deaths annually are directly attributable to infections caused by drug-resistant bacteria [1]. Continued rise in AMR could, by 2050, place 10 million lives and US$100 trillion at risk each year globally [2]. In 2022, the World Health Organization (WHO) Global Antimicrobial Resistance and Use Surveillance System reported that AMR rates had increased globally by at least 15% between 2017 through 2020 for highly resistant pathogens [3].

A challenge is that wide variation in testing coverage and data representativeness presents a major limitation in interpreting AMR rates globally [3]. The Center for Disease Dynamics, Economics & Policy (now One Health Trust) published a 2021 report on global antibiotic use, which shows there are significant between-country variations on indicators for policy, AMR, antimicrobial use, and public health [4].

There are global efforts to reduce AMR through antimicrobial stewardship (AMS), aiming to meet recommendations from the WHO and the Review on AMR [2, 5], including enhancing infection prevention, awareness of AMR, surveillance, and prudent prescribing of antimicrobials, alongside optimising use of diagnostic technologies and medicines. The Review on AMR recommends promotion of "new, rapid diagnostics to cut unnecessary use of antibiotics" and published a thematic paper on rapid diagnostics [6]. Definitions of rapid diagnostics vary depending on application and time to result (TTR, time from sample collection to results returned) [6–8], but may include automated phenotypic tests [8], biomarker tests [7], and point-of-care tests [7]. Additionally, the Infectious Diseases Society of America has advocated for development of more quality outcomes research, education, and funding for the development of new diagnostics to ultimately help decrease AMR [9]. Strategic and data-driven utilisation (a data-driven approach for optimising the use of diagnostic testing and subsequent antimicrobials through the utilisation of hospital data and guidelines) of these technologies could transform the way antimicrobials are employed, reducing unnecessary use, slowing AMR, and making existing drugs effective for longer [2], with improved patient care and outcomes [6]. Evidence-based prescribing and dispensing should be the standard of care, supported by the appropriate use of rapid diagnostics [5, 6].

Several international studies have demonstrated that diagnostics, including rapid diagnostics, decrease time to initiation of optimal antibiotic therapy [10–13]. Rapid diagnostics

have also been found to improve patient clinical outcomes [10], reduce mortality [11, 12, 14, 15], and improve economic outcomes, including reduced length-of-stay and healthcare costs [10–12, 14–16]. AMS initiatives play an essential role in these improved outcomes [12, 14, 15]. However, there is the need for implementation of effective AMS programs globally, including in lower-income countries [17].

Rapid diagnostic testing has been recognised as having a broad impact on multiple areas of AMS programs [18] as well as in reducing AMR [2, 9, 18]. However, headwinds exist regarding the implementation and use of diagnostic tests, especially rapid tests, which may vary by country [19]. A recent global survey of 81 members of the International Society of Antimicrobial Chemotherapy across 31 countries assessed patterns of use of rapid diagnostic tests and concluded that there is no "one size fits all" solution to rapid diagnostic test utilisation and requirements must be tailored to healthcare settings in which they are deployed [19]. Challenges include economic barriers (e.g. set-up costs and high per-test costs), quality assurance and regulatory issues, device performance and data management issues, and staff and operational issues [20, 21]. Implementation of AMS programs can also be difficult; a survey of 660 hospitals across 67 countries found that the main barriers were perceived to be lack of funding or personnel, lack of information technology support, and prescriber opposition [22].

It is important to understand the viewpoints of healthcare professionals (HCPs) on the current and anticipated challenges to optimal use of diagnostic technologies. This can support the development of strategies to improve appropriate diagnostic test and antibiotic use, subsequently improving patient outcomes. The objective of this study was to obtain insights from HCPs about the barriers they face and opportunities for optimising diagnostic testing practices to inform AMS in different country settings.

METHODS

In this cross-sectional study, 300 HCPs were surveyed across six countries, chosen to represent varied gross national incomes (GNI) per capita, healthcare system structures, and AMR rates: Brazil, China, Germany, Italy, India, and the USA [4, 23]. Four themes were explored: technology in infectious disease (ID) management, role of diagnostic testing in AMS, challenges in diagnostic technology utilisation, and the use of guidelines. Surveys were administered via email.

Survey Development

A targeted literature review (TLR) and expert interviews were conducted to inform survey development. Qualitative interviews with two local practice experts per country ($n=12$) took place between April and June 2022, which further explored findings of the TLR. Interviewees were experts in the field of AMR, AMS, or diagnostic practices.

A web-based survey, consisting of ten screener questions and 25 scientific questions, was developed (Appendix in the Supplementary Material). The same local practice experts ($n=12$) reviewed the survey questions prior to fielding, considering the applicability of the scientific questions in real-world practice, ease of responding, and relevance to country practices. The survey was translated into local language for Brazil, China, Germany, and Italy before online programming using Confirmit Survey Designer.

Survey Fielding

The survey was completed by 300 HCPs (50 per participating country) between November 2022 and January 2023. To gain a wholistic picture of where resources may be limited and define potential challenges in diagnostic testing, utilisation, and AMS efforts, responses were collected from four different HCP specialty groups across the continuum of acute care (clinicians with ID experience, intensive care unit [ICU] clinicians/hospitalists, pharmacists, and lab managers/supervisors; $n=12$ or 13 per specialty per country). All participants worked within an inpatient clinical setting with at least 100 beds and had experience in diagnostic use for infections (Table 1). Additional screening questions to assess AMS team/committee membership, role

Table 1 Characteristics of survey participants

	n **(%)** ***N*** **= 300**
How many beds are there in your hospital?	
100–250	81 (27.0%)
251–500	78 (26.0%)
501–750	57 (19.0%)
751–999	21 (7.0%)
≥ 1000	63 (21.0%)
Which of these roles best describes your primary role?	
Physician	40 (13.3%)
Infectious disease physician	37 (12.3%)
Hospitalist/ICU physician	78 (26.0%)
Pharmacist	73 (24.3%)
Lab manager/supervisor	72 (24.0%)
Are you or do you have experience as an infection control officer?	
Yes (current)	120 (40.0%)
Yes (former)	45 (15.0%)
No	135 (45.0%)
How would you describe your hospital?	
Rural	23 (7.7%)
Urban	277 (92.3%)

Table 1 continued

	n **(%)** ***N*** **= 300**
How would you describe your hospital?	
Private	111 (37.0%)
Public	189 (63.0%)
How would you describe your hospital?	
Academic	149 (49.7%)
Non-academic	151 (50.3%)
Does your hospital have an on-site microbiology lab?	
Yes	281 (93.7%)
No	18 (6.0%)
Don't know	1 (0.3%)
How many years of experience do you have since you completed your training/primary qualifications?	
1–2	2 (0.7%)
3–5	10 (3.3%)
6–9	65 (21.7%)
10+	223 (74.3%)
Are you part of an antimicrobial stewardship team/committee within your institution?	
Yes	162 (54.0%)
No	138 (46.0%)

ICU intensive care unit

as an infection control officer, and clinical setting description were used to ensure a balanced sample of responses and avoid bias.

Panel and custom recruitment were used to enrol participants. Descriptive analyses of the survey responses were performed, and no adjustments were made for missing data or non-response. No items were weighted to adjust for non-representativeness of the sample. Responses were summarised using descriptive statistics in R version 4.0.3 and Microsoft Excel.

Ethics

Ethics committee approval was not required for this study. Survey recruitment and administration was performed by Medefield, a market research company. Participants were limited to experienced HCPs and were recruited via email. An agreed upon honorarium was offered to the participants. Researchers did not have access to personally identifiable information of the participants.

RESULTS

Responses were obtained from 50 respondents per country across the four HCP groups of interest (Table S1 in the Supplementary Material). Participant characteristics are outlined in Table 1. A total of 189 (63.0%) worked in a public setting, and 288 (96.0%) had more than 6 years of experience in their field.

Providers View Diagnostic Practices to Have a Positive Impact on AMS Activities and Patient Outcomes

Participants were asked to outline how diagnostic technologies (Table S2 in the Supplementary Material) are used within their hospital inpatient setting. Traditional, culture-based testing was routinely used for all patients with symptoms of infection by 82.7% of participants. More advanced diagnostics were less frequently utilised for all patients with symptoms of infection (7.0–43.0%). Next-generation sequencing and matrix-assisted laser desorption/ionization-time of flight gas chromatography mass spectrometry (MALDI-TOF GC–MS) were rarely used routinely in all countries (0.0–16.0% and 4.0–20.0%, respectively). There was slightly higher routine usage of next-generation sequencing in China (16.0%) and MALDI-TOF GC–MS in the USA (20.0%). Instead, more participants considered these advanced diagnostics to be used on a case-by-case basis for selected or severely ill patients.

To gain insight into the impact and utility of current diagnostic practices at their hospital, participants were asked to select factors that in their opinion improved patient, economic,

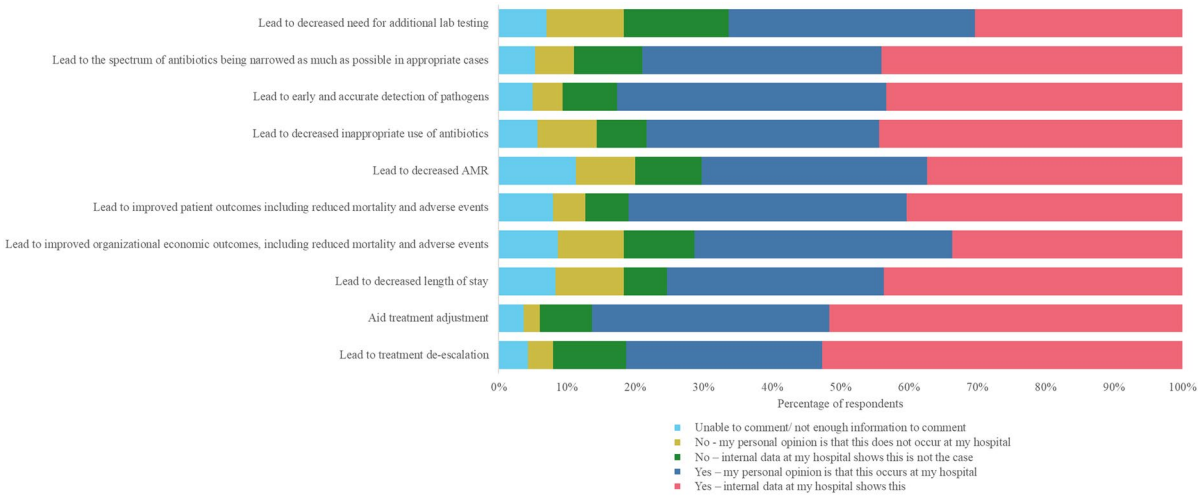

Fig. 1 Reported impact of current diagnostic testing landscape/practices on patient, economic and AMS outcomes. Participants were asked to select the most appropriate option for each outcome listed on the basis on the current diagnostic testing landscape/practices in your hospital. *AMR* antimicrobial resistance, *AMS* antimicrobial stewardship. $n = 300$ per outcome

and AMS outcomes. Most participants reported diagnostic practices led to the following outcomes at their hospital: treatment adjustment (86.3%), early and accurate detection of pathogens (82.7%), treatment de-escalation (81.3%), improved patient outcomes (81.0%), spectrum of antibiotics being narrowed (79.0%), decreased inappropriate use of antibiotics (78.3%), organisational economic outcomes (71.3%), decreased AMR (70.3%), and decreased need for additional lab testing (66.3%) (Fig. 1).

Barriers Were Identified That Inhibit Effective Use of Diagnostic Tests

When asked about challenges to the use of diagnostic tests, the most frequently selected responses were cost of individual tests (42.3%), cost of set-up/initial outlay to purchase equipment (35.7%), concerns relating to sensitivity/accuracy (29.0%), lack of education/awareness on new diagnostic tests (25.7%), and access to diagnostic tests (25.0%) (Fig. 2). "Cost of individual tests" was the most selected answer in India (74.0%) and the USA (50.0%), where private health insurance or patient out-of-pocket fees are common, and Brazil (54.0%), which has a universal healthcare system, but Brazilian citizens can also opt to buy private insurance or pay out-of-pocket. The most common responses were "lack of clinical data" for China (48.0%), "concerns around accuracy and sensitivity/specificity of the diagnostic test" for Germany (44.0%), and "access to diagnostic tests" for Italy (34.0%).

Participants were asked to estimate the average time between sample collection of bacterial, fungal, and viral specimens to results being returned per diagnostic step at their hospital. Over half of participants selected turnaround times of 12 h or less for identification (54.2%) and initial antimicrobial susceptibility testing (AST) (53.6%); whereas slower turnaround times were more frequently reported for comprehensive AST and resistance gene identification (Table S3a in the Supplementary Material). Forty-seven participants (15.8%) estimated a TTR of 2 h or less for identification. Additional analyses found that 85% ($n=40$) of these participants had access to multiple rapid diagnostic tests for identification and, of the remaining 15% ($n=7$) who estimated a TTR of 2 h or less based on one diagnostic test, 85% were pharmacists. Many participants indicated that turnaround times were suboptimal to inform antimicrobial prescribing decisions: 46.9% considered TTRs were "sometimes" or "not" quick enough for identification, 48.0% for initial AST, 60.9% for comprehensive AST, and 63.4% for resistance gene identification (Table S3b in the Supplementary Material). This pattern was also present in higher-income countries like the USA and Italy. In the USA, 57.1% of participants reported suboptimal TTR for identification, 53.1% for initial AST, 79.6% for comprehensive AST, and 67.3%

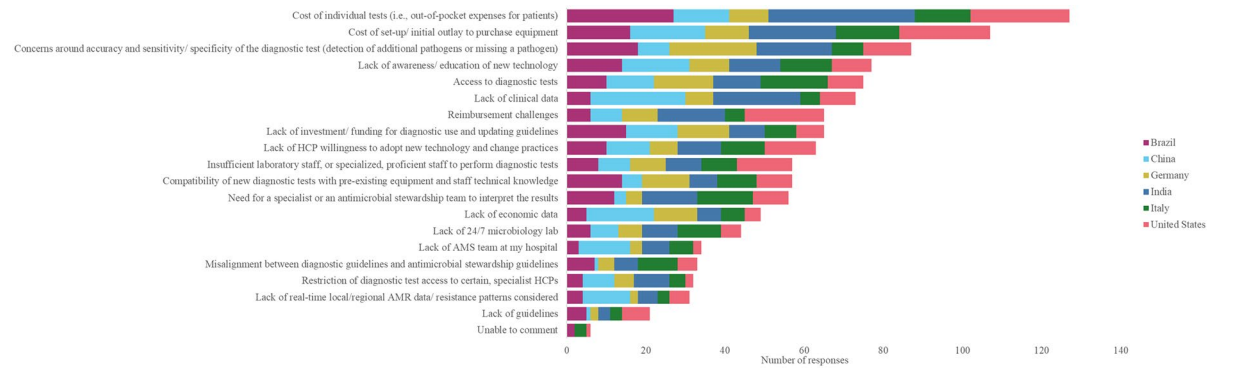

Fig. 2 Most commonly reported challenges to the use of diagnostic tests across the treatment pathway. *AMR* antimicrobial resistance, *AMS* antimicrobial stewardship, *HCP* healthcare professional. $n=50$ respondents per country. Respondents could select up to five answers

for resistance gene identification. In Italy, 55.1% of participants reported suboptimal TTR for identification, 51.0% for initial AST, 63.3% for comprehensive AST, and 61.2% for resistance gene identification. In Germany, suboptimal TTRs were more frequently reported for comprehensive AST (64.0%) and resistance gene identification (76.0%) compared with identification (36.0%) and initial AST (28.0%).

Further, participants selected factors (from a provided list) that lead to diagnostic testing and/or return of results being too slow to impact patient care. Lack of a 24 h a day/7 days a week (24/7) microbiology lab (24.9%), shortage of laboratory staff (21.6%), and a lack of rapid diagnostic testing (18.8%) were most frequently reported as the main reason for suboptimal turnaround times (Table 2). There were country-level differences in the primary issues relating to turnaround time: "lack of rapid diagnostic testing" was most common for Brazil (45.5%) and the USA (29.5%); "lack of 24/7 microbiology lab" for India (39.5%) and Italy (33.3%); "shortage of laboratory staff" for Germany (31.9%) and the USA (29.5%); and "lack of protocols" for China (22.2%) (Table S4 in the Supplementary Material).

There Are Barriers to Ensuring the Appropriate Use of Antimicrobials and Efficient Stewardship, with Country-Specific Challenges

Survey participants were asked to comment on their level of agreement with the following statements:

- "The appropriate use of newly released antimicrobials may depend on suitable diagnostics being available."

Table 2 Factors which are considered to lead to diagnostic testing and/or return of results being too slow to impact patient care

Factors	*n* (%)[a]
Lack of 24–7 microbiology lab	61 (24.9)
Shortage of laboratory staff	53 (21.6)
Lack of rapid diagnostic testing for patients that would benefit from a rapid turnaround time	46 (18.8)
Lack of protocols for efficient diagnostic testing (diagnostic stewardship)	20 (8.2)
Lack of internal processes to report diagnostic test results to HCP	16 (6.5)
HCP workload preventing results being acted on in real-time	15 (6.1)
Restriction of diagnostic test use to certain HCPs (i.e. ID clinicians, AMS team members)	12 (4.9)
Lack of system to alert HCP of available diagnostic test result	9 (3.7)
Diagnostic test outsourcing (sending to off-site labs)	9 (3.7)
Unable to comment	4 (1.6)

AMS antimicrobial stewardship, *HCP* healthcare professional, *ID* infectious diseases

[a] $N = 245$

- "The lack of diagnostic test availability is a barrier to the appropriate use of new antimicrobials."

Among participants, 82.0% agreed (29.0% completely; 53.0% somewhat) and 61.3% agreed (16.7% completely; 44.7% somewhat) with these statements, respectively (Fig. S1 in the Supplementary Material). "Agree" responses to the latter statement varied considerably by country: 92.0% in Brazil, 82.0% in India, 68.0% in Italy, 60.0% in China, 48.0% in the USA, and 18.0% in Germany. Furthermore, lack of diagnostic test availability resulted in a specific challenge for India, where participants reported guidelines were always/frequently not followed because of a lack of diagnostic test availability (42.0%, compared to 6.0–18.0% for the other five countries) and as a result of antibiotics not being available because of access restrictions (38.0%, compared to 6.0–16.0% for the other five countries; Fig. S2 in the Supplementary Material).

Participants were asked to select the greatest challenges to the use of narrow-spectrum antibiotics. The most commonly reported obstacle across all countries was "high resistance rates" (52.0% overall). Other common challenges included "slow turnaround time to receiving AST data" (31.7%), "presence of multidrug resistant organisms (MDROs) based on local AMR data" (31.0%), "fear of not treating the causative organism conclusively due to sensitivity and specificity of diagnostic tests" (31.0%), and "slow turnaround time to receiving diagnostic test results" (27.0%) (Fig. 3).

When asked about their views on investment in AMS compared with investment in other healthcare issues at their facility/institution, overall responses were similar for investment being "much greater/greater" (27.7%), "comparable with other healthcare issues" (36.0%), and "somewhat/seriously lacking" (32.3%) (Fig. S3a in the Supplementary Material). However, at a country-level, 46.0% and 56.0% of participants in China and India, respectively, considered that investment in AMS was much greater/greater than other healthcare issues, whereas investment in AMS was perceived as somewhat/seriously lacking by 44.0% of participants in both Brazil and Germany. Participants were also asked about their views on resourcing (staff, funding, and equipment) of the AMS program and broader AMS efforts at their facility/institution. Overall, 54.3% responded that resources were "abundant/sufficient," while 40.3% felt that resources were "somewhat/seriously lacking" (Fig. S3b in the Supplementary Material). In Germany, 22.0% of participants reported that resources were seriously lacking, compared to 0.0–8.0% in other countries. The most common resource that was lacking varied by country: "diagnostic test availability" in China (80.0%) and Brazil (60.9%), "AMS team staffing" in Italy (94.4%) and the USA (52.9%), and "clinical staff

Fig. 3 Most commonly reported challenges to the use of narrow-spectrum antibiotics. *AMR* antimicrobial resistance, *AMS* antimicrobial stewardship, *AST* antimicrobial susceptibility testing, *HCP* healthcare professional, *ID* infectious diseases, *MDROs* multidrug resistant organisms. $n = 50$ respondents per country. Respondents could select up to five answers

to manage the AMS program and broader AMS efforts" in India (66.7%) and Germany (62.9%) (Fig. S3c in the Supplementary Material).

Guidelines Are Important for HCPs in All Countries Surveyed, But Opportunities Exist for Guideline Improvements to Aid AMS

Participants indicated that guidelines are highly consulted in clinical practice, with international, national, regional, and local guidelines being "always" or "sometimes" consulted by at least 87.0% of participants and with slightly greater emphasis placed on local and national guidelines (Table S5a in the Supplementary Material). Guideline adherence was considered high, with 46.3% of participants selecting "high adherence" and 48.0% selecting "some adherence" for antimicrobial recommendations, and 41.0% selecting "high adherence" and 48.3% selecting "some adherence" for diagnostic recommendations (Fig. S4a in the Supplementary Material). In China, perceived adherence to antimicrobial and diagnostic guidelines was higher (74.0%) in comparison to other countries (36.0–44.0%; Fig. S4b, c in the Supplementary Material). Participants considered current guidelines to be useful, with at least 80% rating all types of guidelines as "very useful" or "somewhat useful," again, with greater utility ascribed to local and national guidelines (Table S5b in the Supplementary Material). Only 18.0% believed guidelines were "very recent and up to date" (Table S5c in the Supplementary Material). When asked what could improve guidelines, "more frequent guideline updates" was selected by half of all responders (50.6%) whilst the most frequent country-level responses were for guideline recommendations to "follow local data/resistance patterns" (Brazil, 80.0%; India, 76.9%; USA, 64.3%; Italy, 60.0%), "greater education" (Germany, 51.0%), and "capabilities in detecting AMR" (China, 75.0%) (Table 3).

DISCUSSION

This survey provides perspectives from HCPs on current challenges and opportunities for the use of strategic and data-driven diagnostic technologies and broader AMS efforts for optimised antimicrobial use in inpatient care. Diagnostic practices were widely reported by participants to have a positive impact on AMS activities and on economic and patient outcomes. Despite this, the survey results highlighted that barriers exist relating to the widespread use of diagnostic tests to enhance patient care. While some barriers are universal to all countries surveyed, we also found that obstacles differ by country. Cost remains a prominent challenge across all surveyed countries, including the cost of individual tests (42.3%) and initial outlay of costs to purchase equipment (35.6%). The Infectious Diseases Society of America describes expense as a key challenge for integration of diagnostic tests into clinical care including cost of running individual tests and cost of new equipment to process tests [9, 24]. Cost challenges are also reported in recent literature [20, 21]. There may be an opportunity for the positive economic impact of advanced diagnostic testing to be demonstrated, in terms of patient cost savings, institutional cost savings from shorter hospital stays, benefits in patient care, and AMS [11, 12, 14–16]. Demonstration of the value of diagnostic tests is needed to encourage wider test utilisation and AMS efforts [6, 24]. Further investigations into cost burdens by country/healthcare system may enable the positive economic impact of new diagnostics to be decisively demonstrated.

In addition to costs, common challenges for diagnostic test uptake identified in the survey included lack of knowledge of new and emerging diagnostic tests, concerns relating to sensitivity/specificity, and access, which have also been reported in published literature [6]. While most participants reported that their hospital has an on-site microbiology lab, with little variability by country, differences emerged by country when assessing staffing of the microbiology lab. Lack of a microbiology lab that is staffed 24/7 was a primary issue relating to turnaround time for India and Italy. Both laboratory staff shortage and lack of a 24/7 microbiology lab were reported as factors in Germany. Different aspects of diagnostic test barriers were noted in higher-income countries. While cost was the most common concern for participants in the

Table 3 Factors which survey participants believe would make guidelines more useful

Factor[a]	Brazil (*n* = 35)	China (*n* = 40)	Germany (*n* = 43)	India (*n* = 39)	Italy (*n* = 40)	USA (*n* = 42)
Guideline recommendations to follow local data/resistance patterns	28 (80.0)	16 (40.0)	18 (41.9)	30 (76.9)	24 (60.0)	27 (64.3)
More frequent guideline updates	24 (68.6)	17 (42.5)	11 (25.6)	21 (53.8)	22 (55.0)	26 (61.9)
Inclusion of evidence sources, such as peer-reviewed publications	20 (57.1)	15 (37.5)	18 (41.9)	24 (61.5)	22 (55.0)	17 (40.5)
Greater education	9 (25.7)	14 (35.0)	22 (51.0)	17 (43.6)	20 (50.0)	20 (47.6)
Diagnostic and antimicrobial access options	19 (54.3)	18 (45.0)	6 (14.0)	24 (61.5)	16 (40.0)	11 (26.9)
Capabilities in detecting AMR	13 (37.1)	30 (75.0)	6 (14.0)	19 (48.7)	15 (37.5)	10 (23.8)
Guidance on efficient and appropriate use of antimicrobials	18 (51.4)	8 (20.0)	9 (20.9)	17 (43.6)	18 (45.0)	19 (45.2)
Ease of use at point of care (mobile apps, searchability etc.)	13 (37.1)	2 (5.0)	12 (27.9)	21 (53.8)	9 (22.5)	14 (33.3)
Mechanisms to track compliance	13 (37.1)	7 (17.5)	7 (16.3)	21 (53.8)	10 (25.0)	13 (31.0)
Addressing country-specific challenges	11 (31.4)	11 (27.5)	12 (27.9)	15 (38.5)	9 (22.5)	6 (14.3)
Accurate global MDR burden	6 (17.1)	22 (55.0)	4 (9.3)	10 (25.6)	9 (22.5)	7 (16.7)
Preanalytical and analytical lab specimen processing guidance	12 (34.3)	7 (17.5)	2 (4.7)	19 (48.7)	7 (17.5)	4 (9.5)
Unable to comment	1 (2.9)	0 (0.0)	5 (11.6)	0 (0.0)	0 (0.0)	1 (2.4)

Data are presented as *n* (%)

AMR antimicrobial resistance, *MDR* multidrug resistance

[a]Participants (*n* = 239) could select multiple answers

USA, access to diagnostic tests was reported as the most common challenge for participants in Italy. Concerns around accuracy and sensitivity/specificity of the diagnostic test were the most common challenge for participants in Germany.

The survey results also indicate that some HCPs may not have a thorough understanding of TTR of diagnostic tests, highlighting that additional education may be needed to help better understanding of the entire diagnostic pathway and the related workflow efficiencies that may influence downstream clinical outcomes. This aligns with the WHO Global Action Plan strategic objective to improve awareness and understanding of AMR through effective communication, education, and training [5]. Moreover, the survey results suggest that TTR for diagnostic testing is suboptimal, particularly

for advanced diagnostic investigations, such as comprehensive AST (60.9%) and resistance gene identification (63.4%). Reasons varied by country but largely related to workflow processes such as lack of a 24/7 microbiology lab, shortage of laboratory staff, and availability of rapid diagnostic testing. These barriers are present in both low- and high-income countries. Over one-half of participants from the USA and Italy reported that turnaround times were suboptimal to inform antimicrobial prescribing decisions. A recent report from the European Centre for Disease Prevention and Control suggests that national preparedness to combat AMR should include activities to ensure hospitals can screen samples in a timely manner [25]. Given that the results of diagnostic tests drive definitive therapy choices, improved workflow processes and greater education for HCP groups appear to be opportunities where time to definitive therapy could be improved, thereby informing the earlier use of the most effective and appropriate antibiotics and improving patient care.

Despite guidelines advocating narrowing the spectrum of antimicrobial treatment as much as possible [26, 27], HCPs face several challenges regarding the use of limited-spectrum antibiotics. This survey highlighted that challenges include high resistance rates, fear of not treating the causative organism, presence of MDROs in the community and/or hospital, and slow turnaround time to receive AST data and diagnostic test results. Narrow-spectrum agents have the potential to reduce selection and spread of resistance across multiple bacterial species. However, their use relies on rapid and accurate diagnostic tests to correctly identify causative pathogens and their susceptibilities, as well as good education about the use and associated benefits of tailored therapies [28]. Investment in optimised diagnostic testing algorithms and appropriate diagnostic technologies alongside development of limited-spectrum antimicrobials may help combat the high AMR rates that were identified as the main barrier to use of narrow-spectrum agents reported in the survey. Indeed, 82.0% of survey participants agreed that appropriate use of newly released antimicrobials may depend on suitable diagnostic tests being available. Lack of diagnostic test availability may be a greater concern in countries with high resistance rates [4]. Survey respondents in India reported that lack of diagnostic test availability impacted the ability of providers to follow guidelines and use newly released antimicrobials. HCPs highlighted that guidelines could be improved if recommendations followed local data/resistance patterns. These findings demonstrate the importance of the availability of local/regional AMR data to HCPs, which may increase overall awareness of resistance patterns and confidence in the use of appropriate narrow-spectrum antimicrobials and diagnostic tests.

Survey participants had varied views on investment and resourcing for AMS at an institutional level across the different countries. Of survey participants, 32.3% believed investment in AMS to be lacking (somewhat/seriously) with German and Brazilian participants selecting this answer more frequently than other countries surveyed. In the instrument-development interviews with experts from China, AMS was described as part of the daily work for doctors. These differences in perceptions and practice may explain why most survey respondents from China (84.0%) believed investment in AMS to be comparable to/greater than other healthcare issues. A lack of diagnostic test availability and adequate staffing were the most reported AMS resource challenges. Previous literature further highlighted resourcing challenges, especially in resource-limited settings [29, 30]. These findings suggest that greater funding for AMS activities, including resourcing, would positively benefit the utilisation of rapid diagnostics and may contribute to decreasing AMR.

The results of this survey suggest guidelines—especially local and national guidelines—are highly consulted by HCPs, perceived to have high adherence for both antibiotic and diagnostic recommendations, and considered useful. Where appropriate, guideline improvements could include more frequent updates, inclusion of local data/resistance patterns, and accurate global MDRO burden, alongside better education. Published literature, including an article that utilised key stakeholders to propose a value framework for diagnostic technologies, also describes a lack of guideline awareness and availability, especially for guiding the type of

diagnostic test to use in different clinical settings [29, 31]. Improvements or updates to guidelines may support HCPs, enabling earlier diagnoses and faster switch from initial empiric therapy to guided or definitive therapies.

Limitations of this study include potential survey responder bias as participants were asked to report on the basis of their own experiences and interpretation of survey questions. The survey included 50 participants per country, which may not be representative of all inpatient settings within a country. Furthermore, the survey was limited to six countries, which does not offer representation at a global level. However, the study design aimed to mitigate this by selecting countries with varied GNI per capita and AMR rates; focusing on countries that represent middle- to high-income countries. Practices in low-income countries were not explored in this study. Another limitation was survey length, which precluded analysis by infection type. For example, findings may have been more aligned if urinary tract infections (which are common and a major source of antimicrobial utilisation but are not often subject to rapid diagnostics [32]) had been differentiated from bloodstream infections.

The use of panel and custom recruitment may have led to recruitment bias, with individuals who are more interested/qualified in the area of AMS and diagnostic testing participating. While this study aimed to obtain a wholistic picture of diagnostic testing and AMS efforts by surveying HCPs across the continuum of acute care, strengths and potential knowledge gaps may differ by specialty and could bias the study. Additionally, close to one-half of the participants in the survey were not part of their institutional AMS team, but just over one-half of respondents reported that internal data at their hospital shows that diagnostic practices lead to treatment de-escalation and aid treatment adjustment. This suggests that many hospitals disseminate internal data on AMS to staff members, but we were not able to confirm if that is the case as this was not a question in the survey. Future studies could explore how data on AMS is disseminated within hospitals.

CONCLUSION

Improved understanding of the role of diagnostics in optimised antibiotic utilisation and patient care are critical to reducing AMR. This study highlighted that, while HCPs consider diagnostic practices to be important in AMS efforts, there are several barriers to their successful implementation, including patient/institutional costs, turnaround time of test results, resourcing, AMR burden, and education. While some barriers differ by country, these survey results highlight areas of opportunities in all countries for improved use of diagnostic technologies and broader AMS efforts, as perceived by HCPs. To overcome these barriers, increased funding, education (including personnel training), and resourcing (including staffing) should be adopted. Regular guideline updates and development of optimised testing algorithms and local policies for guideline use offer further opportunities. Inclusion of diagnostics into guidelines may increase their use in AMS activities and guide clinicians in envisioning their optimal place in treatment management. Collectively, these efforts may further optimise strategic and data-driven diagnostic test utilisation and appropriate antimicrobial use, resulting in efficient stewardship and improved patient outcomes.

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Data Availability. The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request. An HTML link containing anonymised, aggregated survey data collected is available upon request to the corresponding author, subject to appropriate justification of data needs.

Declarations

Conflict of Interest. The work on this manuscript was funded by a consortium of partner organisations including Becton, Dickinson and Co (Diane Flayhart, Timothy Kelly, and Kalvin Yu), Pfizer Inc (Bruce M. Altevogt and Andy Townsend), The Wellcome Trust (Timothy Jinks and Sumithra Subramaniam), bioMérieux SA., and the AMR Industry Alliance (AMRIA). Timothy Jinks and Sumithra Subramaniam disclose they are employees of The Wellcome Trust. Diane Flayhart, Timothy Kelly, and Kalvin Yu disclose they are employees and shareholders of Becton, Dickinson and Co. Andy Townsend discloses that they are an employee and shareholder of Pfizer Inc. Bruce M. Altevogt's current affiliation is bioMérieux. Bruce M. Altevogt was an employee of Pfizer Inc. during the planning and start of the study and he is currently a shareholder of Pfizer Inc. Clare Willis, Jacqueline Michel, and Kristen Downs disclose they are employees of Genesis Research, a company that received funding for its role in conducting the study and developing the manuscript. Charlotte Marsh was an employee of Genesis Research at the time of the study. Charlotte Marsh's current affiliation is RJW & partners Ltd. Harald Seifert, Aruna Poojary, Ana C. Gales, Mark L. Metersky, Ravina Kullar, Matteo Bassetti, and Anup Warrier disclose that they received consultancy fees in relation to this project. Ana C. Gales discloses that she has received grants or contracts from Eurofarma within the last 36 months. Harald Seifert, Ana C. Gales, and Matteo Bassetti disclose that they have received payment or honoraria for lectures, presentations, speakers' bureaus, manuscript writing or educational events within the last 36 months. Bruce M. Altevogt, Kalvin Yu, and Timothy Jinks discloses their leadership or fiduciary role in other board, society, committee, or advocacy group. Ana C. Gales and Timothy Jinks discloses that they have received support for attending meetings and/or travel within the last 36 months. Matteo

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REFERENCES

1. Antimicrobial Resistance Collaborators. Global burden of bacterial antimicrobial resistance in 2019: a systematic analysis. Lancet. 2022;399(10325):629–55. https://doi.org/10.1016/s0140-6736(21)02724-0.

2. O'Neill J. Tackling drug-resistant infections globally: final report and recommendations. Government of the United Kingdom; 2016. https://apo.org.au/node/63983. Accessed 28 May 2024.

3. World Health Organization. Global antimicrobial resistance and use surviellance system (GLASS) report. 2022. https://iris.who.int/bitstream/handle/10665/364996/9789240062702-eng.pdf?sequence=1. Accessed 28 May 2024.

4. Sriram A, Kalanxhi E, Kapoor G, et al. In: Atwater S, editor. The state of the world's antibiotics 2021: a global analysis of antimicrobial resistance and its drivers. Washington, DC: Center for Disease Dynamics, Economics & Policy; 2021.

5. World Health Organization. Global action plan on antimicrobial resistance. 2015. https://iris.who.int/bitstream/handle/10665/193736/9789241509763_eng.pdf?sequence=1. Accessed 28 May 2024.

6. O'Neill J. Rapid diagnostics: stopping unnecessary use of antibiotics. 2015. https://amr-review.org/sites/default/files/Paper-Rapid-Diagnostics-Stopping-Unnecessary-Prescription-Low-Res.pdf. Accessed 28 May 2024.

7. Apisarnthanarak A, Bin Kim H, Moore LSP, et al. Utility and applicability of rapid diagnostic testing in antimicrobial stewardship in the Asia-Pacific region: a Delphi consensus. Clin Infect Dis. 2022;74(11):2067–76. https://doi.org/10.1093/cid/ciab910.

8. European Committee on Antimicrobal Suceptibility Testing (EUCAST). Rapid AST directly from blood culture bottles. https://www.eucast.org/rapid_ast_in_bloodcultures. Accessed 16 May 2023.

9. Trevas D, Caliendo AM, Hanson K, Levy J, Ginocchio CC, for the Infectious Diseases Society of America. Diagnostic tests can stem the threat of antimicrobial resistance: infectious disease professionals can help. Clin Infect Dis 2020;72(11):893-900. https://doi.org/10.1093/cid/ciaa1527.

10. Briggs N, Campbell S, Gupta S. Advances in rapid diagnostics for bloodstream infections. Diagn Microbiol Infect Dis. 2021;99(1):115219. https://doi.org/10.1016/j.diagmicrobio.2020.115219.

11. Edmiston CE, Garcia R, Barnden M, DeBaun B, Johnson HB. Rapid diagnostics for bloodstream infections: a primer for infection preventionists. Am J Infect Control. 2018;46(9):1060–8. https://doi.org/10.1016/j.ajic.2018.02.022.

12. Timbrook TT, Morton JB, McConeghy KW, Caffrey AR, Mylonakis E, LaPlante KL. The effect of molecular rapid diagnostic testing on clinical outcomes in bloodstream infections: a systematic review and meta-analysis. Clin Infect Dis. 2016;64(1):15–23. https://doi.org/10.1093/cid/ciw649.

13. Ehren K, Meißner A, Jazmati N, et al. Clinical impact of rapid species identification from positive blood cultures with same-day phenotypic antimicrobial susceptibility testing on the management and outcome of bloodstream infections. Clin Infect Dis. 2020;70(7):1285–93. https://doi.org/10.1093/cid/ciz406.

14. Beganovic M, McCreary EK, Mahoney MV, Dionne B, Green DA, Timbrook TT. Interplay between rapid diagnostic tests and antimicrobial stewardship programs among patients with bloodstream and other severe infections. J Appl Lab Med.

2019;3(4):601–16. https://doi.org/10.1373/jalm.2018.026450.

15. Wenzler E, Timbrook TT, Wong JR, Hurst JM, MacVane SH. Implementation and optimization of molecular rapid diagnostic tests for bloodstream infections. Am J Health Syst Pharm. 2018;75(16):1191–202. https://doi.org/10.2146/ajhp170604.

16. Westwood M, Ramaekers B, Whiting P, et al. Procalcitonin testing to guide antibiotic therapy for the treatment of sepsis in intensive care settings and for suspected bacterial infection in emergency department settings: a systematic review and cost-effectiveness analysis. Health technology assessment. 2015;19(96):v-xxv, 1–236. https://www.ncbi.nlm.nih.gov/books/NBK327098/.

17. Antimicrobial stewardship programmes in healthcare facilities in low- and middle-income countries: a WHO practical toolkit. JAC Antimicrob Resist. 2019;1(3):dlz072. https://doi.org/10.1093/jacamr/dlz072.

18. Moore LSP, Villegas MV, Wenzler E, et al. Rapid diagnostic test value and implementation in antimicrobial stewardship across low-to-middle and high-income countries: a mixed-methods review. Infect Dis Ther. 2023;12(6):1445–63. https://doi.org/10.1007/s40121-023-00815-z.

19. Poole S, Townsend J, Wertheim H, et al. How are rapid diagnostic tests for infectious diseases used in clinical practice: a global survey by the International Society of Antimicrobial Chemotherapy (ISAC). Eur J Clin Microbiol Infect Dis. 2021;40(2):429–34. https://doi.org/10.1007/s10096-020-04031-2.

20. Erasmus R, Sahni S, El-Sharkawy R. Connectivity strategies in managing a POCT service. EJIFCC. 2021;32(2):190–4.

21. Quinn AD, Dixon D, Meenan BJ. Barriers to hospital-based clinical adoption of point-of-care testing (POCT): a systematic narrative review. Crit Rev Clin Lab Sci. 2016;53(1):1–12. https://doi.org/10.3109/10408363.2015.1054984.

22. Howard P, Pulcini C, Levy Hara G, et al. An international cross-sectional survey of antimicrobial stewardship programmes in hospitals. J Antimicrob Chemother. 2015;70(4):1245–55. https://doi.org/10.1093/jac/dku497.

23. The World Bank. GNI per capita, Atlas method (current US$). https://data.worldbank.org/indicator/NY.GNP.PCAP.CD. Accessed 18 Apr 2023.

24. Infectious Diseases Society of America (IDSA). Better tests, better care: the promise of next generation diagnostics. 2015. https://www.idsociety.org/globalassets/idsa/policy--advocacy/current_topics_and_issues/diagnostics/statements/better-tests-better-care-for-policymakers.pdf. Accessed 28 May 2024.

25. European Centre for Disease Prevention and Control. Antimicrobial resistance in the EU/EEA (EARS-NET) Annual Epidemiological Report 2021. Stockholm: ECDC; 2022.

26. Rhodes A, Evans LE, Alhazzani W, et al. Surviving Sepsis Campaign: international guidelines for management of sepsis and septic shock: 2016. Intensive Care Med. 2017;43(3):304–77. https://doi.org/10.1007/s00134-017-4683-6.

27. National Centre for Disease Control India. National Treatment Guidelines for Antimicrobial Use in Infectious Diseases. 2016. https://health.punjab.gov.in/sites/default/files/AMR_guideline7001495889.pdf. Accessed 28 May 2024.

28. Melander RJ, Zurawski DV, Melander C. Narrow-spectrum antibacterial agents. Medchemcomm. 2018;9(1):12–21. https://doi.org/10.1039/c7md00528h.

29. Apisarnthanarak A, Kim HB, Moore L, et al. Rapid diagnostic testing for antimicrobial stewardship: utility in Asia Pacific. Infect Control Hosp Epidemiol. 2021;42(7):864–8. https://doi.org/10.1017/ice.2021.149.

30. Drain PK, Hyle EP, Noubary F, et al. Diagnostic point-of-care tests in resource-limited settings. Lancet Infect Dis. 2014;14(3):239–49. https://doi.org/10.1016/s1473-3099(13)70250-0.

31. Augustovski F, Alfie V, Alcaraz A, García Martí S, Drummond MF, Pichon-Riviere A. A value framework for the assessment of diagnostic technologies: a proposal based on a targeted systematic review and a multistakeholder deliberative process in Latin America. Value Health. 2021;24(4):486–96. https://doi.org/10.1016/j.jval.2020.11.008.

32. Morado F, Wong DW. Applying diagnostic stewardship to proactively optimize the management of urinary tract infections. Antibiotics. 2022;11:3. https://doi.org/10.3390/antibiotics11030308.