Assessment of Rapid-Blood-Culture-Identification Result Interpretation and Antibiotic Prescribing Practices

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ABSTRACT Rapid pathogen identification can alter antibiotic prescribing practices if interpreted correctly. Microbiology reporting can be difficult to understand, and new technology has made it more challenging. Nebraska Medicine recently implemented the BioFire FilmArray blood culture identification panel (BCID) coupled with stewardship-based education on interpretation. Physician BCID result interpretation and prescribing were assessed via an electronic survey, with a response rate of 40.8% (156/382 surveys). Seven questions required respondents to interpret BCID results, identify the most likely pathogen, and then choose therapy based on the results. The tallied correct responses resulted in a knowledge score. General linear models evaluated the effect of role, specialty, and utilization of the BCID interpretation guide on the mean knowledge score. The specialties of the respondents included 55.7% internal medicine, 19.7% family medicine, and 24.6% other. Roles included 41.1% residents, 5.0% fellows, and 53.9% faculty. Most reported that they reviewed antimicrobial susceptibility results (89.4%) and adjusted therapy accordingly (81.6%), while only 60% stated that they adjusted therapy based on BCID results. The correct response rates ranged from 52 to 86% for the interpretation questions. The most common errors included misinterpretation of *Enterobacteriaceae* and *Staphylococcus* genus results. Neither role nor specialty was associated with total knowledge score in multivariate analysis ($P = 0.13$ and 0.47 , respectively). In conclusion, physician interpretation of BCID results is suboptimal and can result in ineffective treatment or missed opportunity to narrow therapy. With the implementation of new technology, improved reporting practices of BCID results with clinical decision support tools providing interpretation guidance available at the point of care is recommended.

KEYWORDS antibiotic prescribing, antibiotic treatment, antimicrobial stewardship, bacteremia, blood culture, bloodstream infections, clinical decision support, microbiology laboratory results, rapid diagnostic testing, sepsis

Test results produced by the clinical microbiology laboratory provide fundamental data for the initiation and modification of effective antimicrobial therapy. Standard patient care can result if laboratory-generated data are not clearly reported in a format easily understood by the physician. While the laboratory may report accurate and sufficient data, the physician may not understand or interpret the data correctly based on the report's format or terminology. The potential disparity between report content and report cognition increases the potential for patient care issues. Communication with the physician through microbiology reports needs to be effective, with unambiguous interpretations that lead to optimal therapeutic choices.

Received 6 December 2016 Returned for
modification 22 December 2016 Accepted
21 February 2017

Accepted manuscript posted online 1
March 2017

Citation Donner LM, Campbell WS, Lyden E,
Van Schooneveld TC. 2017. Assessment of
rapid-blood-culture-identification result
interpretation and antibiotic prescribing
practices. J Clin Microbiol 55:1496–1507.
<https://doi.org/10.1128/JCM.02395-16>.

Editor Nathan A. Ledebauer, Medical College of
Wisconsin

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Studies have shown that 30% to 50% of antimicrobial treatment is inappropriate or unnecessary. This includes treatment indication, choice of agent, and incorrect duration of antibiotic therapy (1, 2). Inappropriate antibiotic use is an important problem. The use of antibiotics is the single most important factor for the development of antimicrobial resistance (1). Each year in the United States, at least two million people are infected with antibiotic-resistant bacteria, and at least 23,000 people die each year as a direct result of these infections (1). The use of antibiotics for the treatment of viral infections and the overuse of broad-spectrum antibiotics to treat bacterial infections promote antibiotic resistance, increase the likelihood of preventable drug-related adverse events (1), and increase the use and cost of health care services (3).

New technology introduced into the clinical microbiology laboratory presents increased challenges for reporting and result interpretation by clinicians. New technologies, such as matrix-assisted laser desorption ionization–time of flight (MALDI-TOF) mass spectrometry (MS) and PCR assays, rapidly provide highly specific information that clinicians may not be able to interpret or utilize (4, 5). While references regarding appropriate reporting practices and interpretation guidance exist for traditional culture reporting, none of the new technologies have well-standardized result reporting. Poor standardization of reporting leads to variation in test result formatting between health care facilities, which may result in physician confusion, leading to inaction or inappropriate action. As exhibited in one study, introduction of a rapid PCR-based system for the identification of staphylococcal bloodstream infections reduced the time to organism identification, but there was no significant benefit to patient outcome or time to optimal antimicrobial therapy (6). Alternatively, rapid testing enables physicians to initiate pathogen-directed therapy in shortened time frames, provided the results are interpreted correctly. A recent study demonstrated that providing templated interpretation comments of rapid PCR tests for bloodstream pathogen identification resulted in reduced treatment of contaminants and use of broad-spectrum antimicrobials. The same study also demonstrated that with the addition of active involvement of antimicrobial stewardship, there was more rapid antibiotic de-escalation or escalation of antibiotic therapy, as needed (7).

Nebraska Medicine's clinical microbiology laboratory began using the U.S. Food and Drug Administration (FDA)-approved BioFire FilmArray blood culture identification panel (BCID) in 2013. This instrument utilizes nested PCR technology to identify 21 bacterial and yeast pathogens and three specific antimicrobial resistance genes for bacteria (8). The technology is rapid and accurate and provides initial antimicrobial susceptibility data for some pathogens. The technology has the potential to improve patient care and reduce overall health care costs if test results are interpreted and acted upon appropriately.

The purpose of this survey (see the supplemental material) was to assess physicians' interpretation of rapid blood culture identification system results, as currently utilized at Nebraska Medicine, and assess their antimicrobial prescribing patterns. Understanding physician antimicrobial prescribing patterns and their ability to interpret rapid blood culture identification system test results is essential to improving microbiology laboratory reporting, developing effective education, and creating point-of-care clinical decision support to improve patient outcomes.

RESULTS

Of the 382 physicians who were emailed the survey, 156 (40.8%) physicians responded. Physician specialties included 55.7% internal medicine, 19.7% family medicine, 7.0% surgery, 7.0% critical care, 2.1% geriatrics, 0.7% cardiology, and 7.8% other. Physician roles included 41.1% residents, 5.0% fellows, and 53.9% faculty. Upon examination, we found a disproportion of the respondents' role within specialty. There was an association between department and role, as 19% of the respondents from the specialty of family medicine were attending physicians, compared to 63% of respondents from internal medicine ($P = 0.0002$). Fifty-six percent of the respondents indicated that more than half of their clinical care included inpatients.

TABLE 1 Resources utilized regularly when making decisions on how to prescribe antibiotics

Resource	% (no.) by role			P value
	All (n = 140)	Resident/fellow (n = 65)	Attending (n = 75)	
UpToDate	80 (112)	88 (57)	73 (55)	0.0368
Infectious disease specialists	71 (99)	55 (36)	84 (63)	0.0003
Hospital pharmacists	51 (71)	62 (40)	41 (31)	0.0188
Nebraska Medicine antimicrobial stewardship website	48 (67)	52 (34)	44 (33)	0.3968
Infectious Diseases Society of America guidelines	45 (63)	45 (29)	45 (34)	1.00
Sanford guide	37 (52)	37 (24)	37 (28)	1.00
Smartphone applications	32 (45)	45 (29)	21 (16)	0.0038
Peers	24 (33)	29 (19)	19 (14)	0.1650
Medical journals	23 (32)	15 (10)	29 (22)	0.0688
Other guidelines by professional organizations	23 (32)	14 (9)	31 (23)	0.0257
Non infectious disease specialists	12 (17)	20 (13)	5 (4)	0.0096
Johns Hopkins antibiotic guide	6 (8)	3 (2)	9 (6)	0.757
Wikipedia	4 (5)	8 (5)	0 (0)	0.0198
Textbooks or study guides	4 (6)	2 (1)	7 (5)	0.2159

Antibiotic prescribing patterns and microbiology result interpretation. Table 1 summarizes the resources regularly used by respondents when making decisions regarding antibiotic intervention. Overall, the top resources utilized were UpToDate, infectious disease (ID) specialists, hospital pharmacists, Nebraska Medicine's Antimicrobial Stewardship Program webpage, and Infectious Disease Society of America Guidelines. Residents and fellows were more likely to utilize pharmacists and online resources (UpToDate, smartphone applications, and Wikipedia), and attending physicians more often consulted ID experts and other guidelines.

The survey respondents reported high confidence levels when interpreting microbiology results, knowing when to start antimicrobial therapy, selecting the best antimicrobial agent for infection, de-escalating therapy, and finding reliable sources of information for antibiotic prescribing practices (Tables 2 and 3). Confidence levels decreased in the areas of spectrum of antimicrobial agents, mechanisms of antimicrobial resistance, and prescribing a combination of antimicrobial agents. Overall, the attending physicians were more confident in antimicrobial decision-making and interpretation of microbiology results than residents or fellows.

Most respondents reported reviewing antimicrobial susceptibility results when available (89.4%) and adjusted therapy when indicated (81.6%), while only 60% stated they adjusted therapy based on BCID results. Fifty-six percent ($n = 87$) of the respondents had reviewed BCID test results on at least one of their patients. All respondents were allowed to interpret the BCID knowledge questions, but only those who answered "yes" to having experience with interpretation of BCID test results were allowed to answer the BCID therapy questions. Of those respondents who had reviewed BCID test results, the most frequent changes made based on BCID results (see Fig. 1) were stopped some but not all antibiotics, added additional antibiotics, and stopped all antibiotics.

After receiving initial notification of the Gram stain result from a positive blood culture, 77% of the respondents reported reviewing BCID results within a few hours, while 19% reviewed them more than a few hours later but still during the same day, and 5% reviewed results the next day. In addition, 99% of the respondents indicated they always or almost always view the corresponding final blood culture and susceptibility report when it is available, with 1% indicating they rarely review the final report after review of the initial results.

Knowledge questions. Ninety-seven survey respondents completed all seven of the knowledge questions, 22 respondents answered at least one of the questions, and

% (no.) by role and confidence level										
	Very confident		Fairly confident		Somewhat confident		A little confident		Not at all confident	
	Attending	Resident/fellow	Attending	Resident/fellow	Attending	Resident/fellow	Attending	Resident/fellow	Attending	Resident/fellow
Practice										
Interpreting microbiological results, including susceptibility testing	45 (60)	18 (24)	48 (63)	55 (73)	5 (7)	23 (31)	1 (1)	3 (4)	1 (1)	0 (0)
Knowing when to start antimicrobial therapy	44 (58)	25 (33)	49 (65)	50 (66)	6 (8)	17 (23)	1 (1)	8 (11)	0 (0)	0 (0)
Selecting best antimicrobial for a specific infection	23 (31)	5 (7)	62 (81)	44 (58)	14 (18)	32 (42)	1 (1)	17 (23)	0 (0)	2 (3)
Describing spectrum of antimicrobial agents	27 (36)	5 (7)	46 (61)	25 (33)	20 (26)	33 (44)	6 (8)	28 (37)	1 (1)	8 (11)
Understanding mechanisms of antimicrobial resistance	18 (24)	12 (16)	34 (45)	28 (37)	37 (48)	35 (46)	8 (11)	20 (26)	3 (4)	5 (7)
De-escalating from broad-spectrum antimicrobials to more-narrow-spectrum agents based upon culture results	34 (45)	17 (23)	52 (69)	51 (68)	10 (13)	18 (24)	3 (4)	13 (17)	1 (1)	0 (0)
Finding reliable sources of information to guide treatment of infections	43 (57)	28 (37)	50 (66)	42 (55)	6 (8)	22 (29)	1 (1)	8 (11)	0 (0)	0 (0)
Deciding when and how to prescribe a combination of antimicrobials	24 (32)	12 (16)	48 (63)	30 (40)	25 (33)	37 (48)	2 (3)	14 (18)	1 (1)	7 (10)

TABLE 3 Confidence in prescribing antibiotics and interpretation of microbiology results stratified by specialty (*n* = 132)

% (no.) by specialty and confidence level															
	Very confident			Fairly confident			Somewhat confident			A little confident			Not at all confident		
	Family medicine	Internal medicine	Other	Family medicine	Internal medicine	Other	Family medicine	Internal medicine	Other	Family medicine	Internal medicine	Other	Family medicine	Internal medicine	Other
Practice															
Interpreting microbiological results, including susceptibility testing	11 (15)	39 (55)	32 (42)	71 (95)	43 (57)	56 (74)	17 (23)	14 (18)	9 (12)	0 (0)	3 (4)	3 (4)	0 (0)	1 (1)	0 (0)
Knowing when to start antimicrobial therapy	17 (23)	43 (57)	29 (38)	62 (81)	42 (55)	59 (78)	17 (23)	8 (11)	12 (16)	4 (5)	7 (9)	0 (0)	0 (0)	0 (0)	0 (0)
Selecting best antimicrobial for a specific infection	0 (0)	18 (24)	18 (24)	46 (61)	57 (76)	53 (70)	37 (48)	14 (18)	29 (38)	17 (23)	10 (13)	0 (0)	0 (0)	1 (1)	(0)
Describing spectrum of antimicrobial agents	0 (0)	22 (29)	18 (24)	17 (23)	46 (61)	29 (38)	50 (66)	13 (17)	38 (42)	33 (43)	11 (15)	15 (20)	0 (0)	8 (11)	0 (0)
Understanding mechanisms of antimicrobial resistance	8 (11)	16 (21)	18 (24)	21 (27)	35 (46)	29 (38)	50 (66)	27 (36)	47 (62)	17 (23)	16 (21)	6 (8)	4 (5)	6 (8)	0 (0)
De-escalating from broad-spectrum antimicrobials to more-narrow-spectrum agents based upon culture results	13 (17)	27 (36)	32 (42)	67 (87)	49 (65)	47 (62)	13 (17)	11 (15)	21 (27)	8 (11)	11 (15)	0 (0)	0 (0)	1 (1)	0 (0)
Finding reliable sources of information to guide treatment of infections	21 (27)	42 (55)	32 (42)	58 (77)	40 (53)	50 (66)	13 (17)	12 (16)	18 (24)	8 (11)	6 (8)	0 (0)	0 (0)	0 (0)	0 (0)
Deciding when and how to prescribe a combination of antimicrobials	8 (11)	22 (29)	18 (24)	34 (45)	43 (56)	35 (46)	46 (61)	22 (29)	41 (54)	8 (11)	8 (11)	6 (8)	4 (5)	5 (7)	0 (0)

FIG 1 Self-reported changes in antibiotic therapy frequently made based on BCID results.

37 skipped all of the questions. There was no difference in knowledge scores between those who answered all of the questions and those who skipped all the questions with respect to specialty ($P = 0.77$), role ($P = 0.63$), or having viewed the BCID interpretation guide ($P = 1.00$). When calculating the knowledge score, if a respondent did not select a response for a question, it was counted as incorrect, and if the respondent skipped all of the questions, they were excluded from the analysis.

The correct response rates for the knowledge interpretation questions ranged from 52 to 86%. For each respondent, a mean score was calculated by dividing the number of questions correct by the total number of questions (number correct/7). The mean score was stratified by physician specialty, role, and utilization of the BCID interpretation guide. The mean score for residents and fellows was 4.23 (standard deviation [SD], 2.01) and for attending physicians, it was 4.73 (SD, 1.81) ($P = 0.16$). Comparison of physician specialty resulted in a mean score of 3.88 for family medicine (SD, 1.83), 4.86 for internal medicine (SD, 1.84), and 4.23 for other (SD, 2.0) ($P = 0.06$). In multivariate analysis, neither role nor specialty was independently associated with total knowledge score ($P = 0.13$ and 0.47 , respectively).

Only 29.4% of the respondents indicated they had viewed the Nebraska Medicine antimicrobial stewardship website for the BCID interpretation guide. There was a statistically significant difference in the mean scores between those who had viewed the BCID interpretation guide and those physicians who had not; those physicians who viewed the antimicrobial stewardship resources (i.e., answered "yes") had a higher mean score, 5.59 (SD, 1.68), than those who had not utilized the resource, with a mean score of 4.65 (SD, 1.61) ($P = 0.01$).

Eighty-seven respondents reported having previously reviewed BCID results on a patient. There was a statistically significant difference in the mean knowledge scores between those who had viewed BCID results for a patient previously and those physicians who had not ($P < 0.0001$). Those physicians who had had a patient with BCID results (i.e., answered "yes") had a higher mean score, at 5.12 (SD, 1.60), than those who had not had a patient with BCID results, with a mean score of 3.32 (SD, 1.92).

A summary of the individual knowledge questions with the corresponding proportion of correct responses by role and specialty is summarized in Tables 4 and 5. Common errors included misinterpretation of *Enterobacteriaceae* and *Staphylococcus* genus results for organism identification based on BCID result questions. The most common error for the appropriate treatment based on clinical history and BCID results questions was de-escalation of antimicrobial treatment when indicated. Attending physicians and residents/fellows within the specialty of internal medicine demon-

TABLE 4 Knowledge questions with corresponding proportion of correct responses

Competency assessed in question	n	% (no.) by role			P value
		Overall	Residents/fellows	Attending	
Organism identification based on BCID results					
<i>Escherichia coli</i> detected	119	60 (71)	55 (65)	65 (77)	0.35
Coagulase-negative <i>Staphylococcus</i> species detected	118	71 (84)	63 (74)	79 (93)	0.07
Methicillin-resistant <i>Staphylococcus aureus</i> detected	116	81 (94)	78 (90)	83 (96)	0.64
Appropriate treatment based on clinical history and BCID results					
Discontinue therapy, contaminated blood culture, coagulase-negative <i>Staphylococcus</i> species detected	113	76 (86)	75 (85)	76 (86)	1.00
Need to initiate therapy, vancomycin-resistant <i>Enterococcus</i> detected	110	86 (95)	83 (91)	89 (98)	0.41
De-escalate therapy indicated, <i>S. aureus</i> (methicillin susceptible) detected	102	53 (54)	43 (44)	62 (63)	0.07
De-escalate therapy indicated, <i>Streptococcus agalactiae</i> detected	98	52 (51)	52 (51)	53 (52)	1.00

strated no significant difference between scores ($P = 0.47$ to 1.00) on the individual knowledge questions.

It should be noted there was a technical limitation for the knowledge questions for some respondents when viewing the BCID microbiology report, depending on which Internet browser and device they used. This was a barrier for some respondents, as they could not view the image to answer the knowledge questions. This did not affect the responses of the physicians who submitted a response but did decrease the total number of responses for data interpretation.

DISCUSSION

The results from this study suggest that misinterpretation of BCID results may be occurring at rates approaching 50%. Incomplete physician understanding of information contained in the microbiology patient report or in the BCID reference material may have contributed to this phenomenon. Another explanation may be that the presentation of the microbiology data on the patient report is neither concise nor clear, containing microbiological terminology unfamiliar to physicians. Misinterpretation obviates the benefits of rapid pathogen identification and may result in ineffective treatment or overuse of broad-spectrum antibiotics. For physicians to implement proper therapy, communication of patient results must be as clear as possible, providing detailed necessary information for appropriate interpretation.

De-escalation of antimicrobial therapy represented the most common clinical scenario in which respondents did not make appropriate changes to therapy. This is unfortunate, as antimicrobial de-escalation has been associated with improved clinical outcomes (9, 10). A possible cause for not de-escalating treatment may be a gap in physician knowledge concerning areas of result interpretation and targeted antimicrobial therapy, when necessary. When the current antibiotic is proving to be effective in

TABLE 5 Knowledge questions with corresponding proportion of correct responses by specialty

Competency assessed in question	n	% (no.) by specialty				P value
		Overall	Family medicine	Internal medicine	Other	
Organism identification based on BCID results						
<i>Escherichia coli</i> detected	119	60 (71)	38 (45)	70 (83)	45 (54)	0.02
Coagulase-negative <i>Staphylococcus</i> species detected	118	71 (84)	50 (59)	80 (94)	70 (83)	0.03
Methicillin-resistant <i>Staphylococcus aureus</i> detected	116	81 (94)	75 (87)	84 (97)	80 (93)	0.60
Appropriate treatment based on clinical history and BCID results						
Discontinue therapy, contaminated blood culture, coagulase-negative <i>Staphylococcus</i> species detected	113	76 (86)	65 (73)	80 (90)	76 (86)	0.37
Need to initiate therapy, vancomycin-resistant <i>Enterococcus</i> detected	110	86 (95)	87 (96)	88 (97)	82 (90)	0.71
De-escalate therapy indicated, <i>S. aureus</i> (methicillin susceptible) detected	102	53 (54)	33 (34)	61 (62)	52 (53)	0.10
De-escalate therapy indicated, <i>Streptococcus agalactiae</i> detected	98	52 (51)	60 (59)	52 (51)	46 (45)	0.63

treatment, physicians often do not recognize the need to de-escalate antimicrobial therapy. The benefits of de-escalating antibiotics to a more targeted therapy include preventing the toxic detrimental side effects of broad-spectrum antimicrobials, avoiding destruction of the patient's normal flora, and preventing antimicrobial resistance (11). While the literature is increasing, there are limited data regarding the effective promotion of appropriate prompt antibiotic de-escalation actions. More research is needed for physicians to support the practice of de-escalation and step-down concept of changing to a more targeted antibiotic protocol. Practices that need to be investigated and evaluated include active antimicrobial stewardship interventions, electronic reminders for physicians, clinical decision support systems to guide antibiotic prescribing practices at the time of microbiology result interpretation, and antibiotic time-outs prompting a reassessment of the prescribed empirical antibiotic.

The addition of rapid diagnostic testing to identify bloodstream infections combined with an active antimicrobial stewardship team decreases the time to effective therapy and improves antimicrobial use. A study by MacVane and Nolte (12) evaluated the incremental impact of antimicrobial stewardship and BCID by analyzing three groups: conventional organism identification (control group), conventional organism identification with antimicrobial stewardship intervention, and BCID with antimicrobial stewardship intervention. This study showed that antimicrobial stewardship intervention with bloodstream infections improved antibiotic de-escalation but had little impact on the time to effective antimicrobial therapy compared with the control group (12). More striking was the finding that BCID with the antimicrobial stewardship group had a significantly reduced time to effective antibiotic therapy (4.9 h) versus the conventional organism identification/antimicrobial stewardship group (13 h) and the control group (15 h) (12).

While active antibiotic stewardship intervention has been shown to improve antibiotic use and clinical outcomes when coupled with rapid-pathogen-identification systems, less-resource-intensive methods of prompting changes have rarely been evaluated. Banerjee et al. (7) found that templated comments provided with the BCID results improved antibiotic use but not as effectively as direct intervention by the stewardship team. As rapid-pathogen-identification systems become available in more-diverse and less-resource-rich settings, direct interventions by an Antimicrobial Stewardship Program (ASP) team member may not be feasible. Our survey relied on physician interpretation of the BCID results and how they react to these data. The results revealed correct interpretation of the knowledge questions in only 52 to 86% of the cases, and only 60% of those surveyed adjusted therapy based on the BCID results. This suggests that physician interpretation and utilization of BCID results are suboptimal, and a less-resource-intensive intervention to facilitate result interpretation could improve utilization of the BCID results. Further studies are needed regarding how to best present results and drive practice change in more-resource-limited settings.

Although an online BCID interpretation guide is available for physician reference, very few physicians (29%) reported using this resource. This could be due to the way the information is presented. The BCID interpretation guide is accessed from the ASP's online webpage, and a physician must go out of the patient results within their electronic health record to another location to find the resource. When examining the mean scores between those physicians who used the BCID interpretation guide and those who did not, the mean score in the viewing group is consistently higher than in the nonviewing group. This indicates there is an association between having reviewed the BCID interpretation guide and implementing appropriate clinical actions. These findings suggest the BCID interpretation guide is a useful resource, but, as deployed, was not effective in promoting good antimicrobial stewardship behavior because so few physicians took the time to access it. Given the low rate of access to the reference material, the current deployment of the BCID interpretation guide and its format and/or presentation are ineffective. This strongly indicates the need for an alternative method of BCID knowledge transfer. While education may have some utility, a real-time interactive

clinical decision support system at the point of care, providing active antimicrobial stewardship to support physicians presented with microbiology BCID result data, may improve result interpretation and physician prescribing patterns.

The study results indicated that level of training (i.e., resident, fellow, or attending) did not correlate with better antimicrobial intervention decisions. Medical specialty was not associated with improved prescribing performance. These findings suggest that no matter the level of training or medical specialty, all physicians are unprepared to interpret test results from the new emerging technology utilized in the clinical microbiology laboratory for patient testing. Medical schools can implement problem-based learning to teach the new technologies, and continuing education sessions can be offered to practicing physicians, which might positively influence antibiotic prescribing practices. During implementation of the BCID test at our institution, the ASP provided extensive education. Penetration of the education was low, with only 29% of the respondents reporting having accessed the BCID interpretation guide, which indicates that an alternative solution and approach are needed for test result reporting, which includes the decision support found within the guide. In addition, 34% ($n = 45$) of the respondents had no experience with BCID result interpretation on patients. Familiarity with BCID result interpretation was associated with a higher mean score on the knowledge questions ($P < 0.0001$). For those without BCID result interpretation experience, it is expected when their patient has a BCID test result, a real-time clinical decision support system could facilitate interpretation and antimicrobial prescribing. All physicians would benefit from improved clinical decision support tools in the domain of microbiologic result interpretation and guidance for antimicrobial treatment decisions.

There are numerous resources to guide the reporting and interpretation of traditional cultures within the clinical microbiology laboratory. Included in these resources are the American Society for Microbiology (ASM) Cumitech series and the Clinical and Laboratory Standards Institute (CLSI) published guidelines. These organizations provide relevant resources and guidelines for clinical considerations, including specimen collection, transport, processing, and interpretive guidelines for clinical microbiology and immunology laboratory testing. Additional resources from these entities focus on clinical conditions requiring laboratory testing and the diagnostic, prognostic, and therapeutic implications of the test results, which define the laboratories' approach to provide clinically relevant high-quality patient data for physicians.

There appears to be a lack of knowledge and resources, however, to guide the clinical microbiology laboratory on best result reporting practices when using rapid-pathogen-identification methods in the microbiology laboratory. The new automated methods used in the microbiology laboratory are also new to the physicians who must make clinical decisions based on the results of these devices. Improvements in test reporting processes and guidance for antimicrobial treatment are necessary for the adoption of this new technology. In addition, standards for reporting practices and interpretation guidelines need to be published.

Several limitations exist within the study. The clinical scenarios presented in the survey knowledge questions represented scenarios with clear-cut interpretations and antimicrobial treatment decisions, but how physicians prescribe antibiotics can vary greatly, which may have affected the study results. All prescribing practices were self-reported and did not evaluate actual clinical decision-making. The survey response rate, at 40.8% ($n = 156$), was only adequate. No information was collected about nonrespondents. Only 66% ($n = 132$) of the survey respondents interpreted the BCID knowledge questions, further limiting response rates. Furthermore, a large proportion of the study survey respondents were residents (41.1%). The limited experience of these practitioners may have decreased their ability to interpret the BCID test results. However, this also highlights a major clinical care issue, as residents are often the ones making clinical decisions, emphasizing the need for clear-cut reporting that will facilitate actions necessary for alterations to antimicrobial therapy. This survey was a

preliminary study performed to pinpoint current BCID result misinterpretations and physician antibiotic prescribing practices. The results from the survey generated a testable hypothesis in which antimicrobial stewardship intervention(s) would be optimal in our clinical setting.

In conclusion, physician interpretation of BCID results is suboptimal, and this may result in ineffective treatment or missed opportunity to narrow therapy. Survey respondents exhibited relatively poor performance in discontinuing or deescalating antibiotic therapy when indicated. Rapid pathogen identification can improve antibiotic prescribing practices but only when the results are interpreted correctly. Microbiology report data can be time-consuming and difficult to understand. Patient reports should be clear, concise, and contain actionable information for the physician for diagnosis and treatment. With the advent of new technology, improved reporting practices of BCID results with clinical decision support tools providing interpretation guidance available at the point of care can improve patient outcomes.

MATERIALS AND METHODS

A multidisciplinary team of investigators, including an infectious disease physician, a clinical microbiologist, an informaticist, a behavioral scientist, and a statistician, developed a 22-item electronic survey (see the supplemental material). The survey was distributed by email to physicians at Nebraska Medicine, a 621-bed acute-care academic medical center. Medical specialties that commonly treat inpatients for bloodstream infections (BSIs) were chosen, which included family medicine, internal medicine, surgery, cardiology, and critical care. All physicians within these specialties were sent the survey email link; participation was voluntary, and the responses were anonymous. The institutional review board approved the survey. The survey was available online for a period of 4 weeks between 15 October and 15 November 2015.

The survey solicited demographic information, including medical specialty, level of training (resident, fellow, or attending), and percentage of time spent on inpatient clinical care. Factors collected that may have influenced antimicrobial prescribing patterns included the type and level of training on antibiotic prescribing, resources regularly utilized when prescribing antibiotics, confidence in microbiological data interpretation, and utilization of microbiologic data in prescribing.

The survey included seven knowledge questions that required interpretation of clinical information, including BCID results. These questions addressed organism identification, potential misinterpretation errors, and determination of appropriate antimicrobial treatment based on the clinical scenario and BCID results. The themes of the knowledge questions stemmed from clinical observations of the Antimicrobial Stewardship Program (ASP) at our institution, but no formal patient-level data were collected.

Descriptive statistics include counts and percentages for survey questions and means and standard deviation (SD) for the knowledge-based scores. A total knowledge score was created based on summing the correct responses to the knowledge questions ranging from 0 to 7, with 7 being the best score. We compared mean scores according to specialty and role using an independent sample *t* test or analysis of variance (ANOVA), as appropriate, with Turkey's method for pairwise comparisons when the overall ANOVA was significant. Associations of responses to survey questions with role, specialty, and utilization of Nebraska Medicine's BCID interpretation guide (13) located on the antimicrobial stewardship webpage were assessed with Fisher's exact test. Multiple linear regression assessed the independent association of role and specialty with knowledge scores. A *P* value of <0.05 was considered statistically significant. All analyses were done using SAS version 9.4 (SAS Institute, Inc., Cary, NC).

BCID reporting at Nebraska Medicine and antimicrobial stewardship involvement. Our practice was to call the Gram stain result of a positive blood culture to the health care provider immediately after it was obtained. Gram results are reported in the blood culture microbiology report, along with a statement referring clinicians to the BCID results, which appear in a separate report. BCID test results are not called to the physician, as they are reported in the electronic record <2 h after the initial Gram stain. An example BCID report is seen in Fig. 2. The BCID report does contain some comments which accompany specific results. These include a comment for "*Staphylococcus* genus detected," which states "detection of *Staphylococcus* genus but not *S. aureus* is interpreted as detection of coagulase-negative *Staphylococcus* sp.," a comment for "*mecA* detected," which states "*mecA* confers methicillin resistance," and a comment for "*vanA/B* detected" which states "*vanA/B* confers vancomycin resistance." The BCID results imbedded in the knowledge questions in the survey were exact replicas of how they appear in a patient's medical record, including the comments.

The ASP was involved with the rollout of the BCID and developed an education document which includes interpretation guidance and common misinterpretations of BCID results (<http://www.nebraskamed.com/careers/education-programs/asp/clinical-microbiology>) (13, 14). This resource was made available to all physicians via a hospital-wide physician notification campaign, which included emails sent to all physicians, including a link to the guide. Additionally, a short didactic session was provided to major provider groups, including intensive care unit (ICU) physicians, hospitalists, and residents. The ASP reviews all positive blood cultures starting at the time of BCID results and intervenes

Direct blood pathogen identification panel	
Status: Final result	Visible to patient: This result is not viewable by the patient. Next appt: None
	1d ago
KPC	Not Applicable
mecA	Not Detected
vanA/B	Not Applicable
Enterococcus genus	Not Detected
Listeria monocytogenes	Not Detected
Staphylococcus genus	DETECTED
Comments: Detection of Staphylococcus genus but not <i>S. aureus</i> is interpreted as detection of coagulase negative Staphylococcus sp.	
Staphylococcus aureus	Not Detected
Streptococcus genus	Not Detected
Streptococcus agalactiae	Not Detected
Streptococcus pneumoniae	Not Detected
Streptococcus pyogenes	Not Detected
Acinetobacter baumannii	Not Detected
Enterobacteriaceae family	Not Detected
Enterobacter cloacae complex	Not Detected
Escherichia coli	Not Detected
Klebsiella oxytoca	Not Detected
Klebsiella pneumoniae	Not Detected
Proteus	Not Detected
Serratia marcescens	Not Detected
Haemophilus influenzae	Not Detected
Neisseria meningitidis	Not Detected
Pseudomonas aeruginosa	Not Detected
Candida albicans	Not Detected
Candida glabrata	Not Detected
Candida krusei	Not Detected
Candida parapsilosis	Not Detected
Candida tropicalis	Not Detected

FIG 2 Example of rapid blood culture pathogen identification (BCID) results within patient's electronic health record.

with clinicians as needed. This resource is open-access and available to all physicians but is not included in the patient's electronic health record with the BCID test results.

SUPPLEMENTAL MATERIAL

Supplemental material for this article may be found at <https://doi.org/10.1128/JCM.02395-16>.

SUPPLEMENTAL FILE 1, PDF file, 0.1 MB.

ACKNOWLEDGMENTS

We thank Nebraska Medicine's clinical microbiology laboratory for generating BCID reports.

We declare no conflicts of interest.

No funding was obtained for this research.

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