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Clinical Utility of Blood Cultures Drawn from Indwelling Central Venous Catheters in Hospitalized Patients with Cancer

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Background: Because of concern about low specificity, the American College of Physicians guidelines and expert opinion discourage the use of a central venous catheter when obtaining blood for culture for bacteremia or fungemia. However, data on the reliability of cultures done with blood obtained from a central venous catheter are conflicting.

Objective: To determine the sensitivity, specificity, and positive and negative predictive values of cultures done with blood obtained through a central venous catheter compared with peripheral venipuncture.

Design: Retrospective cohort study of hospitalized patients with cancer in whom samples for paired cultures were drawn through a central venous catheter and peripheral venipuncture.

Setting: Tertiary care, university-affiliated medical center.

Patients: 185 patients hospitalized on a hematology–oncology ward between August 1994 and June 1996.

Measurements: Blinded assessments of culture results done by infectious disease experts were used as the gold standard. Sensitivity, specificity, and positive and negative predictive values were compared for culture of blood from central catheters and culture of blood from peripheral venipuncture.

Results: Of 551 paired cultures, 469 (85%) were catheter-negative/venipuncture-negative, 32 (6%) were catheter-positive/venipuncture-positive, 17 (3%) were catheter-negative/venipuncture-positive, and 33 (6%) were catheter-positive/venipuncture-negative pairs. For the 82 paired cultures with at least one positive result, blinded determination of true bacteremia or fungemia was made by two infectious disease specialists. For catheter draw compared with peripheral venipuncture, sensitivity was 89% (95% CI, 79% to 98%) and 78% (CI, 65% to 90%) (difference, 11 percentage points [CI, –6 to 28 percentage points]), specificity was 95% (CI, 93% to 97%) and 97% (CI, 96% to 99%) (difference, –2 percentage points [CI, –5 to 0.2 percentage points]), positive predictive value was 63% (CI, 50% to 75%) and 73% (CI, 60% to 86%) (difference, –10 percentage points [CI, –26 to 5 percentage points]), and negative predictive value was 99% [CI, 97% to 100%]

and 98% (CI, 96% to 100%) (difference, 1 percentage point [CI, –0.5 to 3 percentage points]).

Conclusions: In hospitalized hematology–oncology patients, culture of blood drawn through either the central catheter or peripheral vein shows excellent negative predictive value. Culture of blood drawn through an indwelling central venous catheter has low positive predictive value, apparently less than from a peripheral venipuncture. Therefore, a positive result from a catheter needs clinical interpretation and may require confirmation. However, the use of a catheter to obtain blood for culture may be an acceptable method for ruling out bloodstream infections.

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Long-term, indwelling central venous catheters are indispensable in the management of patients with cancer. Common indications for the placement of these catheters in patients with cancer include poor peripheral access; frequent need to administer blood products or antibiotics or to draw blood; continuous infusion of chemotherapeutic agents; a prolonged treatment course; and use of vesicant drugs (1). The convenience of these catheters makes them an obvious choice for frequent blood draws, and the reliability of routine laboratory data obtained from blood drawn through central venous catheters has been demonstrated (2). However, the American College of Physicians guidelines (3) and expert opinion (4) discourage the use of intravascular devices to obtain blood for culture. Such statements have evolved because of concern that contamination rates will increase (that is, specificity will decrease) when blood cultures are obtained through intravascular devices, leading to prolonged hospitalization and increased cost (5), and concern about possible line contamination. Results from studies supporting (6, 7) or refuting (8–11) such concerns have been inconsistent. Furthermore,

Table 1. Demographic and Clinical Characteristics of Patients from Whom 82 Paired Blood Cultures with at Least One Positive Result Were Obtained

Variable	Data
Patients, <i>n</i>	62
Admissions, <i>n</i>	76
Mean age ± SD, <i>y</i> *	45 ± 14.8
Men/women, <i>n/n</i>	28/34
Catheter type, <i>n</i> (%)	
Hickman catheter	68 (83)
Port catheter	5 (6)
Temporary central venous catheter	9 (11)
Median time from catheter placement to blood draw (range), <i>d</i> †	27 (0–536)
Median time difference between blood draws (range), <i>min</i>	20 (0–210)
Diagnosis, <i>n</i> (%)*	
Leukemia	29 (47)
Lymphoma	12 (19)
Multiple myeloma	10 (16)
Other malignant condition	7 (11)
Other	4 (6)
Patients who had had bone marrow transplantation, <i>n</i> (%)	58 (71)
Patients with neutropenia at time of blood draw, <i>n</i> (%)‡	44 (54)
Patients receiving antibiotics at time of blood draw, <i>n</i> (%)	58 (71)
Ciprofloxacin alone	25 (30)
Trimethoprim–sulfamethoxazole alone	5 (6)
Intravenous antibacterial therapy	22 (27)

* Determined by using number of patients.

† Date of catheter placement not available for four patients.

‡ Neutropenia was defined as absolute neutrophil count less than 500 cells/mm³.

none of these studies were blinded, and all lacked a clear “gold standard” definition of true bacteremia.

Because drawing blood through central venous catheters is convenient and prevents trauma to the veins, it is a potentially worthwhile means of obtaining samples for culture. We therefore conducted a retrospective evaluation of paired blood cultures from patients hospitalized on the hematology–oncology ward to determine the sensitivity and specificity of blood for culture drawn through a central venous catheter compared with that for culture samples obtained through peripheral venipuncture, using a predetermined definition for true bacteremia. We also examined antibiotic use and clinical outcomes for patients in whom a paired culture yielded discordant results.

Methods

We retrospectively screened all blood cultures from patients on an oncology ward at New England Medical Center, a 300-bed tertiary care university-affiliated hospital, between August 1994 and June 1996. Information collected from patient records included diagnosis, type and date of catheter placement, presence of neutropenia, antimicrobial use, other blood culture results, and relevant clinical data (presence of fever, rigors, or hypotension).

Definitions

A paired culture was defined as at least one blood culture set clearly labeled as drawn from a

central venous catheter and at least one blood sample drawn through a peripheral venipuncture. Blood samples had to be drawn within 4 hours of each other. Reasons for excluding cultures from our analysis included the following: only one blood sample was drawn (no paired culture), samples were not drawn within 4 hours of each other, or the source of the draw was not clearly marked. Aside from the presence of a central line, patients whose cultures were excluded did not differ from patients whose cultures were included in the analysis.

Guidelines were modified from published articles by Arbo and Snyderman (12) and Weinstein and colleagues (13) as follows: 1) Certain pathogens (such as *Staphylococcus aureus*, gram-negative bacilli, and *Candida* species) isolated from any culture sample represented true bacteremia or fungemia; 2) common skin contaminants (coagulase-negative staphylococci, diphtheroids, *Propionibacterium* species, *Bacillus* species, or *Micrococcus* species) or viridans streptococci isolated from two or more culture samples drawn from different sites and associated with fever (body temperature > 38.3 °C), rigors, or hypotension (systolic blood pressure < 90 mm Hg) were considered true bacteremias; and 3) polymicrobial infection with the same organisms in more than one culture sample and associated with fever (body temperature > 38.3 °C), rigors, or hypotension (systolic blood pressure < 90 mm Hg) were considered true bacteremias.

Analytical Framework

True bacteremia (or fungemia) or contamination was determined by two infectious diseases physicians who were blinded to the source from which the blood culture was drawn. The physicians had access to results of all other blood cultures (obtained from 7 days before to 7 days after the paired culture) and clinical data, including other sites of infection, antibiotic use, temperature and laboratory data (obtained from 2 days before until 2 days after the paired culture) to assist in their decisions. Both specialists evaluated the culture pairs together to reach complete agreement.

Outcome Measures

Sensitivity, specificity, and positive and negative predictive value for catheter draws and peripheral venipunctures were the main outcomes measured against the infectious disease experts’ assessment of culture and clinical information. In addition, any catheter draw or peripheral venipuncture that yielded one or more organisms not responsible for true bacteremia or fungemia was counted as a contaminant; these results were used to calculate a contamination rate. Finally, for paired cultures that yielded a discordant result, antibiotic use, length of

stay (time from paired blood cultures to discharge), and in-hospital mortality were examined.

An additional analysis was done to determine the clinical impact of a culture result in which either a peripheral venipuncture or catheter draw failed to detect a true bacteremia. Two infectious diseases specialists, each blinded to the source of true bacteremia, determined the need for additional antibiotic therapy beyond that which the patient was receiving before or on the same day that the samples for paired culture were obtained. For discordant paired cultures that yielded a contaminant, two infectious diseases physicians, blinded to the source of contaminant, determined how often antibiotic therapy was specifically directed at the contaminant. Because many patients were receiving antibiotic therapy when the paired culture in question was obtained (for example, empirical treatment of neutropenic fever or treatment of a previously diagnosed infection), specific therapy directed at the contaminant was defined as 1) initiation of antibiotics within 72 hours of the paired culture in response to the contaminant or 2) the continuation of specific therapy directed at the contaminant beyond the time when another indication to administer antibiotics had resolved (such as neutropenia or fever).

Blood Culture Technique

Blood for culture was obtained by using the following general guidelines. For samples drawn through a central venous catheter, a nurse caring for the patient obtained the sample. The port was disinfected with either 70% isopropyl alcohol or a povidone-iodine swab, and 10 mL of blood was drawn. All peripheral venipunctures were performed by housestaff caring for the patient. Ten milliliters of blood was obtained after skin antisepsis with povidone-iodine. Blood samples from each draw were inoculated in aerobic and anaerobic media and processed by using the ESP 384 Blood Culture System (Accumed International, Inc., Westlake, Ohio).

Statistical Analysis

In this study, multiple blood culture pairs could be drawn from a single person during one or more hospitalizations. To more accurately estimate the confidence intervals for the central catheter (*c*), peripheral venipuncture (*p*), and central catheter minus peripheral venipuncture (*c - p*) differences, we used bootstrap methods to adjust for potential clustering around patient, hospital admission, and blood culture (14). To perform the bootstrapped analysis, we drew 2000 samples of size 552 with replacement from the original data set (*n* = 552 pairs). From each sample, we calculated sensitivity, specificity, positive predictive value, and negative predictive value for *c*, *p*, and *c - p*. We then ranked these results and found the lower and upper 2.5% values that represent the 95% confidence, or percentile, intervals. Exact two-sided *P* values were calculated. Differences in length of stay were analyzed by using the Kruskal-Wallis test. All statistical analyses were performed by using the SAS system for Windows, version 6.12 (SAS Institute, Inc., Cary, North Carolina).

Role of the Funding Source

Support for this study was provided by a training grant from the National Institutes of Health. The decision to undertake the study was made solely by the authors.

Results

Culture Results and Clinical Characteristics

During the period studied, 551 paired blood cultures met our criteria for a paired blood draw from a central venous catheter and peripheral venipuncture. These 551 paired cultures were obtained from 185 patients with 306 admissions to a hematology-oncology service. Catheter-negative/venipuncture-negative results accounted for 469 (85%) of the

Table 2. Comparison of Cultures of Blood Obtained through a Central Venous Catheter or Peripheral Venipuncture

Culture Sample Source	Culture Result	True Bacteremia*		Sensitivity (95% CI)†	Specificity (95% CI)†	Positive Predictive Value (95% CI)	Negative Predictive Value (95% CI)
		Yes	No				
		<i>n</i>					
Catheter draw	Positive	41	24	89 (79 to 98)	95 (93 to 97)	63 (50 to 75)	99 (97 to 100)
	Negative	5	482				
Peripheral venipuncture	Positive	36	13	78 (65 to 90)	97 (96 to 99)	73 (60 to 86)	98 (96 to 100)
	Negative	10	493				
Difference between catheter draw and peripheral venipuncture‡				11 (-6 to 28)	-2 (-5 to 0.2)	-10 (-26 to 5)	1 (-0.5 to 3)
<i>P</i> value†				>0.2	0.08	0.19	>0.2

* One pair had both a contaminant and an organism causing a true bacteremia. This pair was therefore counted two times, making the total sample size for these analyses 552 pairs.
 † Ninety-five percent CIs and *P* values were determined using bootstrap methods.
 ‡ Expressed as percentage points.

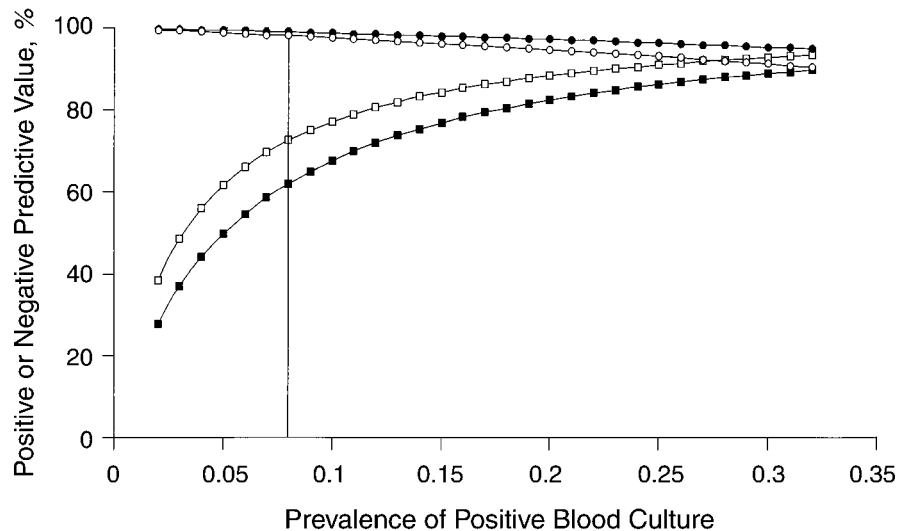


Figure. Comparison of positive (squares) and negative (circles) predictive value of blood drawn for culture by peripheral venipuncture (white squares) or through an indwelling central venous catheter (black circles) using sensitivity and specificity for each test result over a prevalence range of bacteremia. The vertical line represents the prevalence of 8% observed in the study.

paired cultures. Eighty-two paired cultures had a positive result; of these, 32 (6%) were catheter-positive/venipuncture-positive, 17 (3%) were catheter-negative/venipuncture-positive, and 33 (6%) were catheter-positive/venipuncture-negative.

Eighty-nine percent of the 82 paired cultures with a positive result were drawn from long-term, indwelling Hickman or port catheters (Table 1). Leukemia was the most common diagnosis (47%), and 71% of the paired cultures were taken from patients who had had bone marrow transplantation. Fifty-four percent of patients were neutropenic at the time of blood draw, and 71% of patients were receiving antibiotic therapy at the time of blood draw.

All 469 catheter-negative/venipuncture-negative paired cultures were accepted as true negatives. All 32 catheter-positive/venipuncture-positive paired cultures showed true bacteremia or fungemia. In one paired culture in this group, *S. aureus* was isolated from the venipuncture and *S. epidermidis* was isolated from the catheter. Therefore, the *S. aureus* infection was included in the catheter-negative/venipuncture-positive group as a true bacteremia and the *S. epidermidis* infection was included in the catheter-positive/venipuncture-negative group as a contaminant, making our sample size 552 pairs. Among the remaining 31 catheter-positive/venipuncture-positive paired cultures, gram-positive cocci accounted for 52% (16 of 31) of the true bacteremias (Appendix Table 1). True bacteremia occurred in 5 of 18 catheter-negative/venipuncture-positive pairs and in 10 of 34 catheter-positive/venipuncture-negative pairs. The pathogens responsible for true bacteremia or fungemia in these two groups were more evenly distributed among organism categories. Gram-positive cocci accounted for 86% (21 of 26)

of contaminants in catheter draws and 78% (14 of 18) of contaminants in peripheral venipunctures (Appendix Table 2).

Performance of Catheter Draw and Peripheral Venipuncture

With use of our strict definition of true bacteremia, sensitivity was 89% (95% CI, 79% to 98%) for a central venous catheter draw and 78% (CI, 65% to 90%) for peripheral venipuncture, based on bootstrap analysis (Table 2). The catheter draw and peripheral venipuncture were similar in specificity (95% [CI, 93% to 97%] and 97% [CI, 96% to 99%]). The positive predictive value was 63% (CI, 50% to 75%) for catheter draw and 73% (CI, 60% to 86%) for peripheral venipuncture; the respective negative predictive values were 99% (CI, 97% to 100%) and 98% (CI, 96% to 100%) (Table 2). The bootstrap analyses yielded results that were almost identical to those from analyses that did not adjust for potential clustering (data not shown).

The point estimate difference in negative predictive value—1 percentage point (CI, -0.5 to 3 percentage points)—between culture samples drawn through a central venous catheter and those obtained through peripheral venipuncture when the population has an 8% prevalence of true bloodstream infection suggests that a negative culture from either method has similar ability to rule out bloodstream infection, although a catheter culture carries a 0.5-percentage point disadvantage. Examination of the effect of prevalence of true-positive bloodstream infection over a range from 2% to 30% demonstrated very little change in the negative predictive values (Figure).

Examination of the effect of misclassification of true-negative cultures as true positive over a range from 1% to 3% showed essentially no change in the negative predictive value of catheter and peripheral culture, and the difference between them remained 0.9 percentage points (data not shown). Misclassification also had minimal effect on the differences in sensitivity and specificity between catheter draw and peripheral venipuncture (data not shown). Because positive predictive value is based only on cultures initially found to be positive, it is not changed at all by misclassification analysis; this analysis reclassified true negatives (negative results for peripheral and catheter cultures) to true positives.

Discordant Blood Culture Results and Antibiotic Use and Outcome

Additional antibiotics were given to 5 of 10 (50%) patients when peripheral venipuncture failed to detect true bacteremia or fungemia and to 1 of 5 (20%) patients when a central venous catheter draw failed to detect true bacteremia or fungemia (**Appendix Table 3**). Length of stay for patients who had true bacteremia with detection only from the peripheral blood culture was similar to that in patients in whom blood from the catheter was the only positive culture ($P > 0.2$). The in-hospital mortality rate was 20% for both groups.

When blood from a central venous catheter yielded a contaminant, 10 of 24 (42%) patients received specific antibiotic therapy directed at the contaminant (antibiotic use for 1 patient could not be evaluated). When peripheral venipuncture yielded a contaminant, 5 of 12 (42%) patients received specific antibiotic therapy directed at the contaminant. Length of stay in these two groups was similar ($P > 0.2$). In-hospital mortality was similar between groups (1 of 24 for central catheter compared with 2 of 13 for peripheral draw).

Discussion

Our results indicate that in hospitalized hematology–oncology patients with long-term, indwelling central venous catheters, blood for culture drawn through the catheter may provide clinically useful information. We found that the negative predictive value of blood drawn for culture through a catheter is 99%, even over a range prevalences of positive blood culture, and that this method is comparable to peripheral venipuncture, which had a negative predictive value of 98%. However, the positive predictive value of culture done from catheter-drawn blood was only 63% compared with 73% for blood drawn through peripheral venipuncture. Given that the lower 95% CI is only 50%, a positive culture from a catheter draw may be inconclusive. This

study also suggests that there may also be a problem with interpreting a positive blood culture from a peripheral venipuncture because we found a positive predictive value of only 73% (CI, 60% to 86%) with a lower boundary of the CI of 60%. This is particularly true when the prevalence of bloodstream infection is less than 8%. In general, among febrile, neutropenic patients hospitalized on the hematology–oncology ward, a 20% prevalence of documented true bacteremia can be expected (15); with this prevalence, the positive predictive value of the culture samples obtained through catheter draw increases and approaches that seen with culture samples obtained through peripheral venipuncture. As with any test, the clinical interpretation must be made in the context of the a priori likelihood of infection, the type of organism isolated, and the positive and negative predictive value of the test. On the basis of our results, we propose that additional blood cultures may be warranted if the only result available is a positive blood culture from a catheter draw, because it may not necessarily indicate the existence of bloodstream infection.

Strengths of our study included the use of an explicit, predefined, strict definition of true bacteremia that guided two infectious diseases specialists in their interpretation of blood culture results. With this definition, positive blood culture results were interpreted as true bacteremia (or fungemia) or contamination while the specialists were blinded to the source of blood culture; therefore, classification bias was avoided. Our sample size of 551 patients was substantial, more than two times as large as that in the next largest study of its kind, which involved 234 paired blood cultures (9).

In addition, we evaluated antibiotic use for those patients in whom a paired culture yielded a discordant result. In 306 patient admissions to a hematology–oncology ward, a contaminant from a catheter draw resulted in unnecessary antibiotic treatment in 10 patients compared with 5 patients in whom a peripheral venipuncture yielded a contaminant. However, a catheter draw was more likely to detect true bacteremia or fungemia, and in 5 such patients, the antibiotic regimen they were receiving at the time would not have treated the pathogen recovered from the catheter draw. Such a scenario occurred only once, when a peripheral venipuncture recovered a pathogen that was not cultured from a central venous catheter draw. Thus, although a catheter draw may result in a few more blood culture contaminants and unnecessary antibiotic therapy in a small number of hospitalized patients with cancer, it may actually detect more true pathogens.

Our study has limitations. The analysis was retrospective, and patients were treated at a single institution. In addition, we did not evaluate the 469

Appendix Table 1. Organisms Responsible for True Bacteremia or Fungemia in Paired Cultures

Study Group and Infectious Organism	Infections, n
Catheter-positive/venipuncture-positive pairs	
Gram-positive cocci	
Viridans streptococci	5
Coagulase-negative staphylococci	4
<i>Enterococcus faecium</i>	3
<i>Staphylococcus aureus</i>	2
<i>S. epidermidis</i>	2
Gram-negative bacilli	
<i>Klebsiella pneumoniae</i>	1
<i>Pantoea agglomerans</i>	1
<i>Pseudomonas aeruginosa</i>	1
Nonfermenting gram-negative bacilli	1
<i>Candida</i> species	
<i>Candida albicans</i>	4
<i>Candida glabrata</i>	1
Polymicrobial	
Viridans streptococci, <i>Micrococcus</i> species	1
Viridans streptococci, <i>S. epidermidis</i>	1
<i>Candida glabrata</i> , <i>Enterococcus faecium</i>	1
<i>S. epidermidis</i> , <i>Pseudomonas aeruginosa</i>	1
<i>Candida krusei</i> , <i>Clostridium</i> species	1
<i>Serratia marcescens</i> , <i>S. aureus</i> , viridans streptococci	1
Catheter-negative/venipuncture-positive pairs	
Gram-positive cocci: <i>S. aureus</i>	1
Gram-negative bacilli: <i>Escherichia coli</i>	2
<i>Candida</i> species	
<i>Candida albicans</i>	1
<i>Candida parapsilosis</i>	1
Catheter-positive/venipuncture-negative pairs	
Gram-positive cocci	
<i>S. epidermidis</i>	2
Coagulase-negative staphylococci	1
Gram-negative bacilli	
<i>Acinetobacter calcoaceticus</i>	1
<i>Pantoea agglomerans</i>	1
<i>Pseudomonas aeruginosa</i>	1
<i>Stenotrophomonas maltophilia</i>	1
<i>Candida</i> species: <i>Candida glabrata</i>	2
Other: <i>Fusobacterium nucleatum</i>	1

catheter-negative/peripheral-negative paired cultures to determine whether any of these pairs represented false-negative results. However, if one assumes a false-negative result rate of 1% (based on data from a study in which 99.3% of bacteremic episodes were detected by the first two blood culture sets [16]), application of these estimates to our data revealed a negative predictive value of 98% for catheter draws and 97.1% for peripheral venipuncture. The difference of 0.9 percentage point between these negative predictive values is almost identical to that found in the analysis that does not assume misclassification. Furthermore, this difference remains over a range of 1% to 3% results misclassified as false negative.

In conclusion, use of a long-term, indwelling catheter is clinically useful for ruling out bloodstream infections in hospitalized hematology-oncology patients. The small increase in the number of contaminants and unnecessary antibiotic use is offset by the potential to detect more true pathogens in this population. The American College of Physicians guidelines should be revised to allow for the use of a long-term, indwelling catheter when obtain-

ing blood for culture. To avoid the theoretical risk for contaminating central lines, guidelines should also be devised for a uniform method of drawing blood for culture from indwelling central venous catheters; such procedures are not addressed in recent reviews (4, 17). These results or conclusions should not be applied to other patient populations who frequently have central venous catheters (such as patients in the intensive care unit or dialysis unit) until the clinical utility has been studied.

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Appendix Table 2. Organisms Responsible for Contaminants from Central Venous Catheter Draws and Peripheral Venipuncture

Source	Infectious Organism	Infections, n
Central venous catheter		
	Gram-positive cocci	
	Coagulase-negative staphylococci	16
	<i>Staphylococcus epidermidis</i>	2
	Viridans streptococci	1
	<i>Enterococcus faecalis</i>	1
	Group G streptococcus	1
	Polymicrobial*	3
	Other	
	<i>Propionibacterium acnes</i>	1
	Diphtheroids	1
Peripheral venipuncture		
	Gram-positive cocci	
	Coagulase-negative staphylococci	5
	<i>S. epidermidis</i>	5
	Viridans streptococci	4
	Polymicrobial†	2
	Other	
	<i>P. acnes</i>	1
	<i>Acinetobacter calcoaceticus</i>	1

* *S. haemolyticus* and *S. epidermidis* (1 case), *S. epidermidis* and *E. faecalis* (1 case), and coagulase-negative staphylococci, viridans streptococci, and nonfermenting gram-negative bacilli (1 case).

† *S. epidermidis* and coagulase-negative staphylococci (1 case) *E. avium* and coagulase-negative staphylococci (1 case).

Appendix Table 3. Need for Further Antibiotic Therapy in Patients with True Bacteremia or Fungemia from Catheter-Positive/Venipuncture-Negative or Catheter-Negative/Venipuncture-Positive Paired Cultures

Patient	Infectious Organism	Antibiotic Therapy Used before or Initiated on Day of Blood Draw	Further Antibiotic Therapy Necessary?*
Catheter-positive/ venipuncture-negative pair			
1	<i>Stenotrophomonas maltophilia</i>	Vancomycin, imipenem	Yes
2	<i>Pantoea agglomerans</i>	Trimethoprim-sulfamethoxazole	No
3	<i>Acinetobacter calcoaceticus</i>	Vancomycin	Yes
4	<i>Fusobacterium nucleatum</i>	Imipenem	No
5	<i>Pseudomonas aeruginosa</i>	Ciprofloxacin, vancomycin, imipenem	Yes
6	<i>Staphylococcus epidermidis</i>	None	Yes
7	Coagulase-negative staphylococci	Vancomycin, ceftazidime, metronidazole, amphotericin-B	No
8	<i>Candida glabrata</i>	Ciprofloxacin, vancomycin, imipenem, amphotericin-B	No
9	<i>C. glabrata</i>	Imipenem, tobramycin	Yes
10	<i>Staphylococcus epidermidis</i>	Imipenem, vancomycin	No
Catheter-negative/ venipuncture-positive pair			
11	<i>Escherichia coli</i>	None	Yes
12	<i>C. albicans</i>	Vancomycin, ceftazidime, fluconazole	No
13†	<i>Staphylococcus aureus</i>	Amoxicillin, vancomycin	No
14	<i>E. coli</i>	Vancomycin, imipenem	No
15	<i>C. parapsilosis</i>	Trimethoprim-sulfamethoxazole, vancomycin, imipenem, amphotericin-B	No

* Based on culture result and susceptibility as determined by two infectious diseases specialists who were blinded to source of true bacteremia.

† This patient also had *Staphylococcus epidermidis* in the catheter draw from this paired culture. This infection was classified as catheter-negative/venipuncture-positive because *S. epidermidis* was considered a contaminant and did not contribute to true bacteremia.

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