The Risk of Bloodstream Infection in Adults With Different Intravascular Devices: A Systematic Review of 200 Published Prospective Studies

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OBJECTIVE: **To better understand the absolute and relative risks of bloodstream infection (BSI) associated with the various types of intravascular devices (IVDs), we analyzed 200 published studies of adults in which every device in the study population was prospectively evaluated for evidence of associated infection and microbiologically based criteria were used to define IVD-related BSI.**

METHODS: **English-language reports of prospective studies of adults published between January 1, 1966, and July 1, 2005, were identified by MEDLINE search using the following general search strategy: bacteremia [Medical Subject Heading, MeSH] OR septicemia [MeSH] OR bloodstream infection AND the specific type of intravascular device (eg, central venous port). Mean rates of IVD-related BSI were calculated from pooled data for each type of device and expressed as BSIs per 100 IVDs (%) and per 1000 IVD days.**

RESULTS: **Point incidence rates of IVD-related BSI were lowest with peripheral intravenous catheters (0.1%, 0.5 per 1000 IVD-days) and midline catheters (0.4%, 0.2 per 1000 catheter-days). Far higher rates were seen with short-term noncuffed and nonmedicated central venous catheters (CVCs) (4.4%, 2.7 per 1000 catheter-days). Arterial catheters used for hemodynamic monitoring (0.8%, 1.7 per 1000 catheter-days) and peripherally inserted central catheters used in hospitalized patients (2.4%, 2.1 per 1000 catheter-days) posed risks approaching those seen with short-term conventional CVCs used in the intensive care unit. Surgically implanted long-term central venous devices—cuffed and tunneled catheters (22.5%, 1.6 per 1000 IVD-days) and central venous ports (3.6%, 0.1 per 1000 IVD-days)—appear to have high rates of infection when risk is expressed as BSIs per 100 IVDs but actually pose much lower risk when rates are expressed per 1000 IVD-days. The use of cuffed and tunneled dual lumen CVCs rather than noncuffed, nontunneled catheters for temporary hemodialysis and novel preventive technologies, such as CVCs with anti-infective surfaces, was associated with considerably lower rates of catheter-related BSI.**

CONCLUSIONS: **Expressing risk of IVD-related BSI per 1000 IVD-days rather than BSIs per 100 IVDs allows for more meaningful estimates of risk. These data, based on prospective studies in which every IVD in the study cohort was analyzed for evidence of infection by microbiologically based criteria, show that *all* types of IVDs pose a risk of IVD-related BSI and can be used for benchmarking rates of infection caused by the various types of IVDs in use at the present time. Since almost all the national effort and progress to date to reduce the risk of IVD-related infection have focused on short-term noncuffed CVCs used in intensive care units, infection control programs must now strive to consistently apply essential control measures and preventive technologies with *all* types of IVDs.**

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BSI = bloodstream infection; CDC = Centers for Disease Control and Prevention; CVC = central venous catheter; ICU = intensive care unit; IV = intravenous; IVD = intravascular device; PA = pulmonary artery; PICC = peripherally inserted central venous catheter

Reliable vascular access is an essential feature of modern day health care. The variety and numbers of intravascular devices (IVDs) used for vascular access in the US health care system have increased greatly during the past 30 years. For example, the use of short-term central venous catheters (CVCs) of all types, such as the conventional noncuffed and nontunneled triple-lumen catheter, the pulmonary artery (PA) catheter, and the short-term percutaneously inserted noncuffed hemodialysis catheter, and arterial catheters for hemodynamic monitoring is now ubiquitous in modern day intensive care units (ICUs). On the other hand, there has been a substantial increase in the use of IVDs for stable long-term or indefinite vascular access, not only in the hospital but also increasingly in the outpatient setting, such as surgically implanted cuffed and tunneled CVCs, central venous ports, and peripherally inserted central venous catheters (PICCs). These devices are used for a wide range of indications, extending far beyond fluid and transfusion therapy, including total parenteral nutrition, chemotherapy, home antibiotic therapy, and, increasingly, chronic outpatient hemodialysis.[1] During the past decade, medicated CVCs with anti-infective surface activity have also come into clinical use.

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Unfortunately, the use of devices for vascular access is associated with an underappreciated risk of IVD-related bloodstream infection (BSI), caused by microorganisms that colonize the implanted device or contaminate the fluid pathway at the time of insertion or during its use.[2-14] Intravascular devices are now the single most important cause of health care–associated BSI,[3,4,10,11,14] with an estimated 250,000 to 500,000 IVD-related BSIs occurring each year throughout the United States.[6,14] Although there has been

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recent dispute whether IVD-related BSIs are associated with true attributable mortality,[15-18] there is universal agreement that IVD-related BSIs are associated with increased hospital length of stay, from 10 to 20 days, and excess health care costs, ranging from $4000 to $56,000 per episode.[14-18]

It is generally acknowledged that the various types of IVDs in use today pose disparate risks of IVD-related BSI[2-8]; however, the magnitude of this variability is largely unknown. We report a systematic analysis of published prospective studies of infection associated with the various types of IVDs in adults to determine the relative risks of IVD-related BSI, which can be used for decision making in the selection of IVDs and for benchmarking.

METHODS

Sources of Data

English-language reports of prospective studies of adults published between January 1, 1966, and July 1, 2005, were identified by MEDLINE search using the following general search strategy: bacteremia [Medical Subject Heading, MeSH] OR septicemia [MeSH] OR bloodstream infection AND the specific type of intravascular device (eg, central venous port). Additional studies of relevance were identified by reviewing the citations of reviews of IVD-related BSI published since 1973.[2-14] The following criteria were required for a study to be included in this analysis: (1) the exact type of device studied was described; (2) all data on IVD-related BSI were collected prospectively; (3) the criteria used for determining the presence of IVD-related BSI were clearly specified; (4) the study, at the minimum, used criteria consonant with those of the Centers for Disease Control and Prevention (CDC) and the National Nosocomial Infections Surveillance System[19]; and (5) the duration of device implantation in the study population was reported or could be determined from the data provided, permitting quantification of risk.

Subgroup Analyses

Given the variation in the criteria used to define IVD-related BSI in the studies reviewed, subgroup analyses of studies, stratified by the rigor of the criteria used, were undertaken.

For short-term percutaneously inserted devices, outcomes for 3 subgroups were compared: (1) all studies, including those that met only the most minimal CDC criteria (ie, primary BSI with an IVD in place, vis-à-vis, BSI without a plausible identifiable source other than the IVD); (2) studies in which an assessment of IVD-related BSI required microbial concordance between a culture of a segment of the removed catheter and a separate percutaneously drawn blood culture but the study protocol did not require culturing of removed devices in the study population unless there was clinical suspicion of infection; and (3) studies in which *all* the study cohort's devices were removed and cultured for evidence of colonization *and* criteria for IVD-related BSI required microbial concordance between a culture of the removed device and a separate percutaneously drawn blood culture.[20]

For long-term, surgically implanted IVDs, outcomes of 2 subgroups were analyzed: (1) all studies, including those that met minimal CDC criteria; and (2) studies in which the definition of IVD-related BSI required microbial concordance between a culture of the removed device and a separate percutaneously drawn blood culture *or* a 5-fold or greater differential quantitative positivity between paired quantitative blood cultures drawn from the IVD and from a peripheral vein *or* a quantitative blood culture from the device grew more than 1000 colony-forming units.[20]

Statistical Analyses

Best estimates of the risk of IVD-related BSI for each type of IVD—the point incidence with 95% confidence intervals—were calculated from the pooled rates of all studies that met inclusion criteria. Because there was considerable range in the sample sizes of the study populations, each study was weighted by its relative sample size in the IVD group. The resulting rates are identical to those that would be obtained by weighting studies by the inverse of their variance, assuming a common variance within IVD type.

These data satisfy the distributional assumptions for a Poisson distribution, a 1-parameter model in which the statistical mean and variance are identical, which is commonly used to model such data.[21] Because the pooled rate is identical to the weighted mean, the data are reported in terms of the pooled rate for all studies of each device and expressed per 100 devices and per 1000 device-days, with 95% confidence intervals calculated using Microsoft Excel v.X for Macintosh (Microsoft Inc, Redmond, Wash) and SAS 8.2 (SAS Institute Inc, Cary, NC).

RESULTS

Two hundred studies that prospectively examined the risk of IVD-related BSI with peripheral intravenous (IV) catheters and steel needles,[22-32] midline catheters,[33-35] arterial catheters for hemodynamic monitoring,[36-49] PA catheters,[37,50-61] PICCs,[35,62-75] nonmedicated CVCs,[33,37,44-46,49,54,63,76-148] medicated CVCs,[44,105-107,111-114,116,117,121-123,130,133,136,139-141,144,145,147-150] short-term noncuffed and nontunneled hemodialysis CVCs,[126,151-165] long-term cuffed and tunneled hemodialysis catheters,[165-180] cuffed and tunneled all-purpose Hickman-

TABLE 1. **Features of Patients Studied With Short-term Intravascular Devices***

Catheter type	No. of studies by patient care unit and/or patient characteristics						
	ICU	Medical	Surgical/ trauma	Hematology/ oncology	AIDS	TPN	Acute renal failure
Peripheral IV catheters							
Plastic catheters	2	7	7	4	…	…	…
Steel needles	…	…	…	1	…	…	…
Venous cutdown	…	…	1	…	…	…	…
Midline catheters	1	1	2	1	…	2	…
Arterial catheters for hemodynamic monitoring	15	6	11	1	…	…	…
Peripherally inserted central venous catheters	3	3	2	2	1	2	…
Central venous catheters							
Nonmedicated							
Nontunneled	44	32	47	23	6	19	…
Tunneled	2	2	3	3	1	3	…
Medicated							
Chlorhexidine-silver-sulfadiazine	11	5	11	5	…	6	…
Minocycline-rifampin	2	1	1	2	…	1	…
Silver	1	…	2	2	…	…	…
Silver iontophoretic	…	2	2	…	…	…	…
Benzalkonium chloride	…	1	…	1	…	…	…
Hemodialysis catheters							
Noncuffed and nontunneled	…	…	…	…	…	…	15
Cuffed and tunneled	…	1	2	26	6	8	…
Subcutaneous central ports							
Central	…	…	1	14	3	…	…
Peripheral	…	…	…	2	1	…	…
Intra-aortic balloon pumps	1	1	…	…	…	…	…
Left ventricular assist devices	3	3	3	…	…	…	…

*AIDS = acquired immunodeficiency syndrome; ICU = intensive care unit; IV = intravenous; TPN = total parenteral nutrition.

like CVCs,[35,128,181-207] central venous ports,[35,191,197,199,201,207-215] peripheral subcutaneous central venous ports,[207,216,217] left ventricular assist devices,[218-220] and intra-aortic balloon pumps[221] fulfilled criteria for inclusion in this systematic review. The patient populations in the studies included in the analysis are shown in Tables 1 and 2.

It can be seen that, when risk is expressed as BSIs per 100 devices (Table 3), the highest rates of infection were with percutaneous left ventricular assist devices (26.1%), surgically implanted cuffed and tunneled all-purpose CVCs (22.5%), and cuffed and tunneled hemodialysis catheters (21.2%). Rates were considerably lower with

TABLE 2. **Features of Patients Studied With Long-term Intravascular Devices***

Catheter type	No. of studies by outpatient use and/or patient characteristics				
	TPN	Hematology/ oncology	AIDS	Anti-infective therapy	Chronic renal failure
Midline catheters	…	1	…	1	…
Peripherally inserted central venous catheters	4	6	4	1	…
Central venous catheters					
Nonmedicated, nontunneled	1	4	…	…	…
Nonmedicated, tunneled	…	1	…	…	…
Hemodialysis catheters					
Noncuffed, nontunneled	…	…	…	…	9
Long-term cuffed and tunneled	…	…	…	…	15
Cuffed and tunneled all-purpose central venous catheters	7	19	3	…	…
Subcutaneous central ports					
Central	1	12	1	…	…
Peripheral	…	2	1	…	…

*AIDS = acquired immunodeficiency syndrome; TPN = total parenteral nutrition.

TABLE 3. **Rates of Intravascular Device–Related Bloodstream Infection Caused by Various Types of Devices Used for Vascular Access***

Device	No. of studies	No. of catheters	No. of IVD (d)	No. of BSIs	Rates of IVD-related bloodstream infection			
					Per 100 devices		Per 1000 IVD-days	
					Pooled mean	95% CI	Pooled mean	95% CI
Peripheral IV catheters								
Plastic catheters	110	10,910	28,720	13	0.1	0.1-0.2	0.5	0.2-0.7
Steel needles	1	148	350	3	2.0	0.0-4.3	8.6	0.0-18.2
Venous cutdown	1	27	111	1	3.7	0.0-10.8	9.0	0.0-26.6
Midline catheters	3	514	9251	2	0.4	0.0-0.9	0.2	0.0-0.5
Arterial catheters for hemodynamic monitoring	14	4366	21,397	37	0.8	0.6-1.1	1.7	1.2-2.3
Peripherally inserted central catheters								
Inpatient and outpatient	15	3566	105,839	112	3.1	2.6-3.7	1.1	0.9-1.3
Inpatient	6	625	7137	15	2.4	1.2-3.6	2.1	1.0-3.2
Outpatient	9	2813	98,702	97	3.5	2.8-4.1	1.0	0.8-1.2
Short-term noncuffed central venous catheters								
Nonmedicated								
Nontunneled	79	20,226	322,283	883	4.4	4.1-4.6	2.7	2.6-2.9
Tunneled	9	741	20,065	35	4.7	3.2-6.2	1.7	1.2-2.3
Medicated								
Chlorhexidine-silver-sulfadiazine	18	3367	54,054	89	2.6	2.1-3.2	1.6	1.3-2.0
Minocycline-rifampin	3	690	5797	7	1.0	0.3-1.8	1.2	0.3-2.1
Silver impregnated	2	154	1689	8	5.2	1.7-8.7	4.7	1.5-8.0
Silver iontophoretic	2	396	4796	16	4.0	2.1-6.0	3.3	1.7-5.0
Benzalkonium chloride	1	277	2493	12	4.3	1.9-6.7	4.8	2.1-7.5
Pulmonary artery catheters	13	2057	8143	30	1.5	0.9-2.0	3.7	2.4-5.0
Hemodialysis catheters								
Temporary, noncuffed	16	3066	51,840	246	8.0	7.0-9.0	4.8	4.2-5.3
Long-term, cuffed and tunneled	16	2806	373,563	596	21.2	19.7-22.8	1.6	1.5-1.7
Cuffed and tunneled central venous catheters	29	4512	622,535	1013	22.5	21.2-23.7	1.6	1.5-1.7
Subcutaneous venous ports								
Central	14	3007	983,480	81	3.6	2.9-4.3	0.1	0.0-0.1
Peripheral	3	579	162,203	23	4.0	2.4-5.6	0.1	0.1-0.2
Intra-aortic balloon pumps	1	101	414	3	3.0	0.0-6.3	7.3	0.0-15.4
Left ventricular assist devices	3	157	19,653	41	26.1	19.2-33.0	2.1	1.5-2.7

*BSI = bloodstream infection; CI = confidence interval; IV = intravenous; IVD = intravascular device.

temporary noncuffed hemodialysis catheters (8.0%), silver-impregnated CVCs (5.2%), noncuffed but tunneled CVCs (4.7%), noncuffed and nontunneled CVCs (4.4%), benzalkonium chloride–coated CVCs (4.3%), silver iontophoretic CVCs (4.0%), peripheral subcutaneous central venous ports (4.0%), central venous ports (3.6%), outpatient PICCs (3.5%), intra-aortic balloon pumps (3.0%), chlorhexidine-silver-sulfadiazine–impregnated CVCs (2.6%), inpatient PICCs (2.4%), PA catheters (1.5%), minocycline-rifampin–impregnated CVCs (1.0%), arterial catheters (0.8%), midline catheters (0.4%), and peripheral IV catheters (0.1%).

In contrast, when risk is expressed as BSIs per 1000 IVD-days (Table 3), the level of risk differed, often substantially. The highest rates of IVD-related BSI occurred with peripheral IV catheters placed by surgical cutdown (9.0 per 1000 IVD-days), peripheral steel needles (8.6), intra-aortic balloon pumps (7.3), benzalkonium chloride–coated CVCs (4.8), short-term noncuffed hemodialysis catheters (4.8), silver-impregnated CVCs (4.7), PA catheters (3.7), and silver iontophoretic CVCs (3.3); rates were considerably lower with noncuffed, nontunneled multilumen CVCs (2.7), inpatient PICCs (2.1), left ventricular assist devices (2.1), tunneled but noncuffed CVCs (1.7), arterial catheters (1.7), chlorhexidine-silver-sulfadiazine–impregnated CVCs (1.6), cuffed and tunneled all-purpose Hickman-like CVCs (1.6), long-term cuffed and tunneled hemodialysis CVCs (1.6), minocycline-rifampin–impregnated CVCs (1.2), outpatient PICCs (1.0), peripheral IV catheters (0.5), peripheral central venous subcutaneous ports (0.1), and central venous ports (0.1).

TABLE 4. **Subgroup Analyses of Studies of Short-term Intravascular Devices***

Device	All studies		Studies requiring microbial concordance between catheter and blood cultures		Studies requiring microbial concordance and *all* devices cultured	
	No. of studies	IVD-related BSIs per 1000 IVD-days (95% CI)	No. of studies	IVD-related BSIs per 1000 IVD-days (95% CI)	No. of studies	IVD-related BSIs per 1000 IVD-days (95% CI)
Peripheral IV catheters	10	0.5 (0.2-0.7)	9	0.6 (0.2-0.9)	9	0.6 (0.2-0.9)
Midline catheters	3	0.2 (0.0-0.5)	2	0.2 (0.0-0.5)	1	0.2 (0.0-0.5)
Arterial catheters for hemodynamic monitoring	14	1.7 (1.2-2.3)	11	1.3 (0.8-1.9)	8	1.4 (0.8-2.0)
Peripherally inserted central catheters	15	1.0 (0.8-1.2)	5	0.8 (0.4-1.3)	4	0.8 (0.4-1.2)
Noncuffed central venous catheters						
Nonmedicated						
Nontunneled	79	2.7 (2.6-2.9)	63	2.9 (2.7-3.2)	50	2.9 (2.6-3.2)
Tunneled	9	1.7 (1.2-2.3)	7	0.9 (0.4-1.3)	5	2.1 (1.0-3.2)
Medicated						
Chlorhexidine-silver-sulfadiazine	18	1.6 (1.3-2.0)	16	1.3 (1.0-1.7)	16	1.3 (1.0-1.7)
Minocycline-rifampin	3	1.2 (0.3-2.1)	3	1.2 (0.3-2.1)	3	1.2 (0.3-2.1)
Pulmonary artery catheters	13	3.7 (2.4-5.0)	11	3.3 (2.0-4.6)	10	3.3 (1.9-4.6)
Noncuffed, nontunneled hemodialysis catheters	16	4.8 (4.2-5.3)	11	5.0 (4.2-5.8)	9	6.1 (4.9-7.4)

*BSI = bloodstream infection; CI = confidence interval; IV = intravenous; IVD = intravascular device.

Risk estimates of IVD-related BSI in the subgroups of studies of short-term devices that used the most rigorous study design and criteria for determination of infection differed little from the overall group of prospective studies of each device, including those fulfilling only minimal CDC criteria (Table 4). With long-term IVDs (Table 5), the pooled estimates of risk of IVD-related BSI with cuffed and tunneled CVCs were approximately 30% lower when studies requiring microbial concordance between a culture of the explanted device and peripheral blood cultures or a differential count greater than 5-fold in paired quantitative blood cultures or more than 1000 colony-forming units of growth from an IVD-drawn quantitative blood culture were analyzed, but the relative level of risk for these device types among all the IVD types studied remained essentially unchanged.

DISCUSSION

An analysis of this type is inherently limited by the heterogeneity of patient populations, protocols for catheter insertion and site care, and manufacturers' devices used in the studies analyzed. Moreover, the criteria used for defining IVD-related BSI varied across studies, although all the studies met published and widely accepted definitions of IVD-related BSI.[10,19,20] Finally, because of differing degrees of severity of illness, a particular type of device may be associated with a higher risk of infection if used prefer-

TABLE 5. **Subgroup Analyses of Studies of Surgically Implanted Long-term Intravascular Devices***

Device	All studies		Studies requiring microbial concordance between IVD and blood cultures ***or*** >5-fold differential positivity in paired quantitative blood cultures ***or*** >1000 CFU from a catheter-drawn blood culture	
	No. of studies	IVD-related BSIs per 1000 IVD-days (95% CI)	No. of studies	IVD-related BSIs per 1000 IVD-days (95% CI)
Cuffed and tunneled hemodialysis catheters	16	1.6 (1.5-1.7)	5	1.2 (1.0-1.4)
Cuffed and tunneled central venous catheters	29	1.6 (1.5-1.7)	12	1.1 (1.0-1.2)
Central venous ports	14	0.1 (0.0-0.1)	2	0.1 (0.0-0.1)

*BSI = bloodstream infection; CFU = colony-forming unit; CI = confidence interval; IVD = intravascular device.

entially in a more critically ill or vulnerable patient population. We were unable to adjust for these confounding factors since most of the studies did not provide sufficient data to perform an assessment of severity of illness or comorbid illnesses across all the included studies. However, the subgroup analyses of studies using the most rigorous criteria for determination of infection did not differ materially from the overall study population, which included studies using the most minimal CDC criteria (Tables 4 and 5). Given these limitations, we believe it is important to be cautious about making formal comparisons of risk between different types of devices except when they appear to have been studied in similar patient populations. The primary purpose of our review is to point out that *all* types of IVDs pose significant but often widely differing risks of IVD-related BSI.

Despite these limitations, we believe these data in adults, and similar data we have analyzed in children,[222] provide a useful database that defines relative and representative risks of IVD-related BSI with the various types of devices in use at the present time. Within hospitals, rates of nosocomial BSI are based on clinical surveillance of nosocomial infections.[4,19,223] We believe that clinical surveillance data in general overestimate the true risk of catheter-related BSI with CVCs while underestimating the actual risk of IVD-related BSI with other types of IVDs because each device in use in the hospital during the surveillance period is not routinely scrutinized, as occurs in a prospective research study of IVD-related infection. Thus, we believe that our analysis defines *upper-level* benchmarks for representative rates of device-related BSI for all types of IVDs.

In most hospitals, as now recommended by the CDC,[4,12,19,224] the Joint Commission on Accreditation of Healthcare Organizations,[225] and the Agency for Healthcare Research and Quality,[226] risk of CVC-related BSI is expressed as catheter-*associated* BSIs per 1000 CVC-days; in essence, all health care–associated BSIs that cannot reasonably be linked to a site of local infection are attributed to the patient's CVC. The implication of this practice, as noted, is that the true risk of CVC-related BSI is usually overestimated because some BSIs are actually *secondary* BSIs deriving from unrecognized sites of local infection, such as an intra-abdominal abscess, nosocomial pneumonia, or urinary tract infection; moreover, in granulocytopenic and other severely immunocompromised patients, primary BSIs may occasionally derive from microbial translocation,[227,228] also unrelated to a CVC. Finally, as noted, concomitant use of other IVDs, such as arterial catheters in an ICU —which are underappreciated for their potential to cause catheter-related BSI—further inflates estimates of the risk of CVC-related BSI. We believe that hospitals conducting surveillance for benchmarking and to assess intramural trends and progress would be better served to also report their rates of BSI *originating from* IVDs as IVD-*related* BSIs per 1000 device-days, particularly with central venous devices. This can be easily accomplished using the more rigorous diagnostic methods and criteria for IVD-related BSI used by most of the studies analyzed in this review.[10,20]

For many years, the risk of nosocomial BSI originating from an IVD was expressed solely by IVD-related BSIs per 100 devices, vis-à-vis, the percentage of devices studied.[2-6] However, in recent years, as now widely recommended,[223-226] US hospitals have been calculating and reporting rates, particularly with CVCs, as BSIs per 1000 catheter-days. Our analysis provides the first rigorous data to support this practice. As shown in Table 3, cuffed and tunneled CVCs appear to be far more hazardous (22.5% risk of catheter-related BSI) than short-term nonmedicated, noncuffed, and nontunneled CVCs (4.4%); PICCs used in outpatients (3.5%), mainly for home antimicrobial therapy, appear to be more hazardous than PICCs used in inpatients (2.4%). However, when risk is expressed per 1000 catheter-days, cuffed and tunneled all-purpose CVCs, used primarily for long-term access in patients with leukemia, bone marrow transplant recipients, and other immunocompromised patients, pose only half the risk of catheter-related BSI (1.6 per 1000 IVD-days) over time as noncuffed and nontunneled multilumen CVCs (2.7 per 1000 IVD-days), used most often in immunocompetent patients in an ICU. When used in inpatients, PICCs cause considerably more catheter-related BSIs (2.1 per 1000 catheter-days) than when used in outpatients (1.0 per 1000 catheter-days). Similarly, in the ICU, short-term noncuffed multilumen CVCs might appear to be considerably more hazardous (4.4%) than PA catheters (1.5%); however, when rates are expressed per 1000 catheter-days, PA catheters (3.7 per 1000 catheter-days) actually pose higher risks of catheter-related BSI than noncuffed multilumen CVCs (2.7 per 1000 catheter-days).

Arterial catheters, which permit continuous blood pressure monitoring and ready access for blood specimens, especially for arterial blood gas measurements, are used in more than 6 million patients in US hospitals each year.[6,14] The CDC does not advocate surveillance of arterial catheter–related BSIs,[12,224] and many clinicians consider arterial catheters to pose little risk of catheter-related BSI, in contrast to their patients' CVCs, and do not regularly culture arterial catheters in patients suspected of line sepsis. Our analysis suggests that this practice is not justified (Table 3). Arterial catheters are among the most heavily manipulated catheters in the ICU or the operating room and, as a result, the risk of arterial catheter–related BSI (1.7 per 1000 cath-

eter-days) is close to that seen with short-term nonmedicated, noncuffed, and nontunneled multilumen CVCs (2.7 per 1000 catheter-days). Novel technologies for prevention of infection, which have shown efficacy with CVCs,[229] deserve to be studied and applied with arterial catheters.

Many clinicians believe that PICCs are much safer for intermediate-term access than conventional percutaneously inserted noncuffed CVCs placed in the subclavian or internal jugular vein, probably because most of the earlier studies of PICCs were conducted in outpatients in whom PICCs are used primarily for home IV antimicrobial therapy. The results of the current analysis suggest that PICCs used in inpatients (2.1 per 1000 catheter-days) pose a slightly lower risk of catheter-related BSI than standard noncuffed and nonmedicated CVCs placed in the subclavian or internal jugular vein (2.7 BSIs per 1000 catheter-days). This may well derive from the considerably lower levels of cutaneous colonization on the arms vs the base of the neck, the upper anterior area of the chest, or the groin,[230] although we caution against a wholesale conversion to PICCs in the inpatient setting. A large prospective study by Safdar and Maki[75] found that PICCs used exclusively in the inpatient setting (3.5 BSIs per 1000 catheter-days) posed risks of catheter-related BSI at least as high as those seen with noncuffed and nontunneled CVCs (2.7 BSIs per 1000 IVD-days) and considerably higher than with cuffed and tunneled all-purpose Hickman-like CVCs (1.6 BSIs per 1000 catheter-days). These findings suggest that the role for PICCs in hospitalized patients warrants greater scrutiny, and randomized trials comparing PICCs with noncuffed short-term CVCs, especially in the ICU, or with cuffed and tunneled CVCs in patients with malignancy who require longer-term central access are needed.[33]

An estimated 500,000 patients require temporary hemodialysis each year because of the occurrence of acute renal failure.[231] These patients are now widely managed with noncuffed, percutaneously inserted, double-lumen hemodialysis catheters, most commonly placed in the internal jugular vein.[1] Our analysis shows that the use of noncuffed hemodialysis catheters is associated with a substantial risk of infection (4.8 BSIs per 1000 catheter-days). Placing a cuffed and tunneled hemodialysis catheter greatly reduces the risk of catheter-related BSI (1.6 per 1000 catheter-days). It must be questioned why noncuffed hemodialysis catheters are used at all, beyond an occasional unstable patient who requires urgent pheresis at night or on weekends or who has bacteremic sepsis and requires urgent hemodialysis; when the infection has been controlled in the latter circumstance, a cuffed and tunneled hemodialysis catheter should be placed to reduce the risk of catheter-related BSI during the necessary period of hemodialysis.

For long-term central venous access, these data show that surgically implanted central and peripheral venous ports pose far less risk than cuffed and tunneled catheters (0.1 vs 1.6 BSIs per 1000 IVD-days), a finding that is consonant with a large prospective observational study of complications with both types of devices.[197] However, it must be cautioned that clinicians making decisions on types of devices to use for long-term access should recognize that, if the patient will need continuous access for many days or intermittent access day after day, a cuffed and tunneled catheter is preferable to a subcutaneous central port,[12,14] which becomes much more vulnerable to becoming infected if accessed repeatedly or continuously for prolonged periods.

For intermediate-term central access, such as in patients in an ICU, this analysis suggests that tunneling a noncuffed CVC reduces the risk of CVC-related BSI by 33% (1.7 vs 2.7 per 1000 IVD-days), a finding consistent with a recent meta-analysis.[232] However, the added time and effort to tunnel a noncuffed CVC, particularly in patients who may be coagulopathic and vulnerable to excessive bleeding, has limited the practice of tunneling noncuffed standard CVCs in most US ICUs. The use of novel technology, such as CVCs with anti-infective surfaces[44,105-107,111-114,116,117,121-123,130,133,136,139-141,144,145,147-150] (Table 3) and chlorhexidine-impregnated site dressings,[233] is more simple and at least as effective at reducing the risk of CVC-related BSI [229] and can obviate the need to tunnel a CVC catheter as an infection control strategy.

Updated evidence-based recommendations for prevention of IVD-related BSI were published in 2002 by an expert panel convened by the CDC's Hospital Infection Control Practices Advisory Committee.[12] This guideline provides state-of-the-art recommendations, each scored by the quality of the underlying scientific evidence, ranging from consensus theoretical rationale to well-designed prospective, randomized clinical trials, and covers all aspects of IVD care, both in adults and children. Consistent application of these recommendations, especially if buttressed by the preventive technologies,[229] can greatly reduce the risk of IVD-related BSI.[224] Over the past decade, hospitals that have taken a highly organized, multidisciplinary systems approach that starts with formal training of all ICU personnel who insert and care for noncuffed CVCs and focuses on limiting femoral site insertions, routine use of maximal sterile barriers during catheter insertion, disinfection of insertion sites with tincture of chlorhexidine rather than iodine-based antiseptics, and prompt removal of unneeded catheters have reported striking reductions in the incidence of CVC-associated BSI within their ICUs.[234-238] However, these programs have focused on a small fraction of hospitalized patients with IVDs, those in an ICU with

short-term noncuffed CVCs. The median incidence of CVC-associated BSI in the medical-surgical ICUs of the hospitals of CDC's National Nosocomial Infection Surveillance System study between 1992 and 2002 was nearly 5 cases per 1000 catheter-days,[223] and it is clear that quality improvement programs aimed to make vascular access as safe as possible must address all forms of vascular access and all types of IVDs, not only devices used throughout the hospital but also those used in the outpatient setting, where up to 2 million persons in the United Sates have an implanted IVD that is used daily or intermittently.[14,239] This systematic review can provide a database on which institutional quality improvement efforts can benchmark and against which studies of preventive strategies can be assessed.

CONCLUSIONS

These data, based on prospective studies in which every IVD was analyzed for evidence of infection using microbiologically based criteria, show that *all* types of IVDs pose a risk of IVD-related BSI and can be used for benchmarking rates of infection caused by various types of IVDs in use at the present time. Expressing risk of IVD-related BSI per 1000 IVD-days allows for more meaningful estimates of risk than measuring BSIs per 100 IVDs. Since almost all the national effort to date to reduce the risk of IVD-related infection has focused on short-term CVCs used in ICUs, we believe that infection control programs must begin to strive to consistently apply essential control measures and preventive technologies with *all* types of IVDs.

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