Editorial

Epidemic Bloodstream Infections From Hemodynamic Pressure Monitoring: Signs of the Times

Leonard A. Mermel, DO, ScM; Dennis G. Maki, MD

but can ye not discern the signs of the times.

Matthew 16:3

It was ordained at the beginning of the world that certain signs should prefigure certain events.

D. DE Divinatione I
Marcus Tullius Cicero

Arterial pressure monitoring is an essential feature of the care of approximately 80% of the millions of patients cared for in hospital intensive care units in this country each year.[1,2] Despite numerous reports of epidemic bloodstream infection traced to pressure monitoring[3-21] and published guidelines for safe use of hemodynamic monitoring,[22,23] outbreaks of nosocomial bacteremia have continued to plague unwary users of this special application of infusion therapy. In this issue of *Infection Control and Hospital Epidemiology* (pp 54-59), Beck-Sague and Jarvis report eight outbreaks of nosocomial bloodstream infection traced to contamination of transducers used for arterial pressure monitoring investigated by the Centers for Disease Control (CDC) during the past decade.[24] Whereas contamination of pressure monitoring systems accounted for 11% of 97 epidemics of nosocomial bacteremia reported in the world literature between 1968 and 1978,[25] fully 33% of CDC-investigated outbreaks of nosocomial bacteremia between 1977 and 1987 derived from arterial infusions used for pressure monitoring.[24]

The continued occurrence of these epidemics might well be regarded as a "sign of the times" that unfortunately has not yet been widely recognized. Invasive devices of all types, which are an integral feature of the sophisticated high-tech care rendered in modern intensive care units (ICUs), are associated with an awesome capacity to cause iatrogenic infection [26-30] not just sporadic endemic infections, but clusters, outbreaks, and in the case of pressure monitoring, prolonged and insidious epidemics of life-threatening bacteremia or fungemia stemming from inadequate infection control practices.[25]

There are two potential sources of invasive infection associated with any intravascular device: infection of the catheter wound, causing catheter-related sepsis, and contamination of the infusate administered through the cannula.[23] Most physicians now keenly appreciate the hazard of catheter-related infection and the need to limit the period of cannulation in one site. In contrast, it has been our collective personal experience that very few physicians, including most intensivists and infectious disease specialists, realize that the fluid used in infusions for hemodynamic monitoring is vulnerable to contamination and comprises the most important cause of epidemic hospital-acquired gram-negative bacteremia in ICU patients. How often does a seasoned clinician or nurse confronting a septic patient in an ICU consider the fluid column of the pressure-monitoring infusion as the cause of fever or gram-negative septicemia? How many physicians or nurses have cultured fluid from a patient's pressure-monitoring system?

Beck-Sague and Jarvis's finding that epidemics associated with pressure monitoring last four times longer on the average before being recognized and controlled than nosocomial epidemics deriving from other sources (11 versus 3 months)[24] attests to the insidious nature of nosocomial bloodstream infections from this source and the need for greater awareness of the unique microbiologic hazards of hemodynamic monitoring in modern ICUs. In this editorial we strive to point out the features of these

From the Infection Control Department, University of Wisconsin Hospital and Clinics and the Section of Infectious Diseases, Department of Medicine, University of Wisconsin Medical School, University of Wisconsin-Madison, Madison, Wisconsin.

Address reprint requests to Dennis G. Maki, MD, University of Wisconsin Hospital and Clinics—H4/574, 600 Highland Avenue, Madison, WI 53792.

infusions that make them more vulnerable to contamination, and the microbiologic profile and reported sources of epidemic infection to enable users and epidemiologists to better recognize these infections and more expeditiously undertake appropriate investigations. We also review basic control measures for preventing contamination of these systems.

An infusion designated for arterial pressure monitoring consists of the intra-arterial catheter, an extended length of tubing connecting to a chamber that interfaces with an electromechanical transducer, and a continuous-flow device in the line, to permit periodic flushes that maintain patency of the system, connected to a pressurized bag of heparin-containing flush solution. It further differs from most other types of infusions used in clinical practice: the fluid characteristically runs very slowly—the infusion can almost be thought of as a stagnant stream; the fluid column interfaces with the electromechanical transducer through the diaphragm of the chamber-dome; the system contains multiple stopcocks and characteristically is heavily manipulated by caregivers for calibrations and for drawing blood specimens; and in many centers, most of the apparatus above the catheter, particularly the chamber-dome and transducer, is attached to the patient's arm. Moreover, infusions for pressure monitoring are used in the sickest patients, almost exclusively in ICU or operating room patients who are intubated and receiving mechanical ventilatory support and who have urinary catheters and other intravascular lines. These patients are more likely to be heavily colonized by nosocomial organisms and are much more vulnerable to nosocomial infections of all types.[26-30]

Because the extra components needed for infusions designated for hemodynamic monitoring are relatively expensive, during the first decade of widescale arterial pressure monitoring in this country, chamber-domes were routinely reused. When it was recognized that failure to reliably decontaminate chamber-domes between patients was causing epidemics of gram-negative septicemia, manufacturers developed disposable chamber-domes which became widely used. Following recognition that the permanent transducers that interface with disposable chamber-domes also could become contaminated and lead to contamination of infusate and epidemic bacteremias, manufacturers developed modular systems incorporating a continuous-flow device, chamber-dome, and electronic transducer that are completely disposable. Whereas many hospitals yet use permanent transducers that must be decontaminated between patients, increasing numbers of hospitals have moved toward exclusive use of disposable transducer systems.

During the first decade of hemodynamic monitoring in this country, the most common cause of epidemic nosocomial bacteremia was failure of chemical disinfection of reusable plastic chamber-domes (Table 1),[3,4,7-9,15] primarily because of use of dilute quaternary ammonium solutions that are ineffectual against many nosocomial gram-negative bacilli. However, despite the availability and wide acceptance of disposable chamber-domes, which were believed to circumvent the need for reprocessing and resterilization of transducer assembly components, epidemics continued to occur. Two epidemics were linked to reuse of disposable chamber-domes[11,24]; despite the aforementioned reports and available guidelines to the contrary, a 1986 survey found that approximately 40% of Canadian hospitals regularly reused medical devices meant for single use and nearly 10% reused disposable chamber-domes.[31]

An epidemic investigated by Donowitz et al in 1979 demonstrated the presence of epidemic organisms on the metal transducer heads,[13] pointing out that a transducer might become a veritable microbial "trojan horse"[32]—a reservoir of gram-negative organisms that ultimately gain access to fluid in the monitoring circuit. Since that outbreak, there have been nine additional outbreaks in which transducer heads were found to be contaminated with the epidemic organism in systems that used disposable domes,[11-13,16,19,20,24] including those reported by Beck-Sague and Jarvis,[24] and measures aimed at assuring reliable decontamination of transducers between patients curtailed epidemic infections (Table 1). In 1982, the CDC's infection control guidelines recommended as a Category I preventive measure that reusable transducer components be subjected to high-level disinfection or sterilization with ethylene oxide after each use.[22]

Because centralized reprocessing of reusable transducers and particularly, using high-level disinfection or sterilization is logistically complex and expensive, many centers have relied upon chemical disinfection of transducer heads by nurses or other technical personnel in patient care units. Talbot et al[33] and Platt et al[34] have reported studies of the efficacy of decontaminating transducer heads with 70% alcohol, with or without the addition of cleansing with a phenolic solution. Although these authors found that transducer heads can be reliably decontaminated with alcohol pledgets, which appeared to be as effective as sterilization with ethylene oxide, all transducers in these studies were reprocessed and disinfected in a hospital central supply department. The numerous outbreaks since 1980, investigated by the CDC, associated with disinfection of transducers with alcohol, phenolics, or benzalkonium[24] in our minds raise serious questions as to the safety of decontaminating pressure transducers chemically, especially on busy patient care units where harried personnel may have had little formal training in reprocessing and decontamination. The advantage of centralized reprocessing and decontamination of transducers is that very few items fail to be subjected to a rigorous decontamination procedure and reprocessing is routinely done by trained personnel. The studies of Talbot et al[33] and Platt et al[34] suggest, however, that in an emergency, when the supply of reusable transducers is short, it may be acceptable for ICU or operating

https://doi.org/10.2307/30146456 Published online by Cambridge University Press

room personnel to decontaminate transducers with an alcohol wipe. We have reservations, however, about the practice of allowing users on patient care units to carry out reprocessing and decontamination of transducers on a routine basis.

Eight epidemics have been traced to introduction of organisms into closed monitoring systems from external sources of contamination in the hospital: contaminated ice used to chill syringes used for drawing arterialized blood for blood gas measurements,[5] contamination of heparinized saline from multidose vials,[3,6,17] and use of contaminated external devices to calibrate the pressure-monitoring system (Table 1).[7,9] Relatively few epidemics, however, particularly those implicating contaminated transducer heads as the source of epidemic organisms, have satisfactorily delineated the mechanism by which microorganisms on transducer heads gain access to fluid within the monitoring circuit. Only one study has demonstrated actual breaks in the integrity of the chamber-dome.[11] Donowitz et al provide sonic evidence that organisms can be transmitted from the hands of nurses handling the system into the fluid column during manipulations of the system,[13] and Beck-Sague and Jarvis report that epidemic strains were found on the hands of caregivers in most of their eight outbreaks.[24] Most reports, however, do not provide sufficient data to establish dearly the actual mechanism of fluid contamination.

We believe a contaminated transducer is a "sentinel canary," reflecting heavy environmental contamination in the vicinity of the monitoring system, including the hands of personnel caring for the infusion, and these environmental contaminants gain access during the numerous manipulations of the system. Future studies. however, must strive to better delineate the actual mechanisms by which microorganisms gain access to the fluid column from the external environment, including from contaminated transducer heads.

Many ICU personnel have intuitive concerns about the presence of stopcocks in infusions for pressure monitoring and their potential for facilitating entry of microorganisms into the system. At least four studies have examined the frequency of stopcock contamination in hemodynamic monitoring,[35-38] and two have attempted further to ascertain its clinical relevance as regards stopcock-associated infection in patients. Shinozaki et al[37] found that 16.2% of stopcock cultures were positive for microbial growth and that the rate of contamination rose with prolonged continuous use of the infusion; in only a single case, however, did they identify the same microorganism in a stopcock culture that was found in percutaneous blood cultures from a patient with documented primary bacteremia. In contrast, Walrath et al[36] found that 48% of intravenous and intra-arterial stopcock cultures showed microbial contamination and that 14% of the organisms recovered from blood cultures appeared to be the same species isolated from a stopcock used in the patient's infusion. The frequency and, more important, the relevance of stopcock contamination in the pathogenesis of fluid contamination and particularly, pressure-monitoring-associated bacteremia, remains unknown because of the lack of sufficiently large, well-designed studies.

Whether cleansing of stopcocks after or before use should be done is also unknown, although many nurses wipe off the stopcock with an alcohol pledget after entering the system. However, Abbott et al[38] failed to demonstrate in a small study that cleansing stopcocks with povidone-iodine after entry had an influence on the rate of contamination. There are simply no guidelines for using stopcocks in pressure monitoring that are based on scientific study.

The availability of disposable transducers as well as chamber-domes—viz, totally disposable monitoring circuits—should in theory eliminate contamination of transducer heads as a potential reservoir of nosocomial bacteremia. To our knowledge, there have been no epidemics of nosocomial bloodstream infection traced to contaminated infusions for pressure monitoring in a hospital exclusively utilizing disposable transducers, but this most recent technologic innovation to prevent infection will probably not prevent epidemics traced to organisms introduced from external sources, such as contaminated heparin solutions, calibration devices, or especially. nosocomial organisms carried on the hands of nursing and medical personnel handling these systems.

The importance of handwashing before handling any part of the pressure-monitoring system cannot be overemphasized. Nine epidemics in the past decade have been linked to carriage of epidemic organisms on the hands of ICU personnel managing the infusions (Table 1),[9,13,17-20,24] including the three epidemics of *Candida* septicemia in pressure monitoring[9,19,20]—all of which occurred in neonates, two in part because of the practice of using umbilical catheters for administration of parenteral hyperalimentation as well as for pressure monitoring.[19,20] Whether the current wide use of disposable gloves in patient care as part of universal precautions will reduce the risk of contamination of pressure-monitoring infusions is unknown; we are doubtful.

The mere occurrence of cryptogenic gram-negative rod bacteremia in an ICU patient who has an arterial infusion for pressure monitoring should always raise the question of possible sepsis from the arterial infusion. But the identity of the bloodstream pathogen is even more useful clinically; certain organisms should sound a loud alarm.

Table 2 lists the microbial pathogens implicated in 23 epidemics of nosocomial bloodstream infection traced to arterial pressure monitoring and reported between 1971 and 1988. *Pseudomonas cepacia* and *Seratia marcescens* account for nearly half of the reported epidemics. Comparing the microbial profile of epidemic bacteremia traced to hemodynamic monitoring systems with epidemics traced to other sources,[25] it is clear that bloodstream infection caused by S *marcescens* or non-aeruginosa pseudomonads—

Table 1
Epidemiology of Epidemic Bloodstream Infections Traced to Arterial Pressure Monitoring

Epidemiology*	Epidemics (No.)
Faulty decontamination of transducer components:[1,4 5 7-10,12,13,16 17,19]	16
Reusable transducer heads, used with disposable chamber-domes[11-13 16,19,20,24]	10
Reusable chamber-domes[3,4 7-9 15]	5
Reuse of disposable chamber-domes[11,24]	2
Carriage of epidemic organisms on hands of users[13,17-20,24]	9
Contaminated heparinized saline solutions[3,6 17]	3
Use of dextrose-containing fluids instead of saline[12 19 20]	3
Contaminated disinfectant solution[4,8]	2
Contaminated calibration system[16 21]	2
Contaminated ice used to chill syringes for blood-gas specimens[5]	1

* *In many of the outbreaks, more than one source or probable mechanism of contamination was implicated*

particularly *P cepacia*, but also *Pseudomonas acidovorans* or *Pseudomonas maltophilia*—or by *Enterobacter* species, *Flavobacterium*, *Citrobacter*, or *Acinetobacter* should immediately make ICU and operating, room nurses, critical care physicians, and hospital infection control personnel highly suspicious that the bacteremia derived from an infusion used for pressure monitoring. A single bacteremia may reflect a sporadic endemic case, but two or more bacteremias should prompt immediate investigations to discern the etiology and, if due to infusions used for pressure monitoring, to identify the hospital reservoir and mechanism of introduction of organisms into the monitoring systems.

Probably the major reason for the preeminence of gram-negative bacilli in these epidemics lies in the differential growth abilities of these organisms in heparinized saline solutions.[17,39] Glucose-containing solutions support luxurious growth of microorganisms that grow poorly, if at all, in normal saline,[10] and at least three epidemics have been ascribed in part to use of dextrose-containing solutions[3,12,19,20] rather than saline, in pressure-monitoring infusions.

Comprehensive guidelines are now available to guide workup of a suspected epidemic by hospital infection control personnel.[25,41] Probably most important immediately, even with a single, cryptogenic nosocomial bacteremia, is to retrieve the isolate or isolates of the bloodstream pathogen from the laboratory for further testing and later subtyping. Laboratory personnel should be requested to continue to save all clinical isolates of the same species. Thereafter, the investigation is directed toward confirming the existence of an epidemic, defining the reservoirs and modes of transmission and, most important, controlling it.

Table 2
Microbial Profile of Epidemic Nosocomial Bacteremias Deriving from Contamination of Arterial Pressure-Monitoring Systems

Pathogens	Epidemics (No.)	
	Single Pathogen	Multiple-Organisms Outbreaks
Serratia marcescens[6,11 13 17,18,24]	6	
Pseudomonas cepacia[3 8,15,24]	4	—
Pseudomonas acidovorans[7 9]		2
Pseudomonas fluorescens[4,8]		2
Pseudomonas aeruginosa[9]	1	
Pseudomonas maltophilia[16]	1	
Pseudomonas spp[14]		1
Enterobacter cloacae[7,9 12]	1	2
Enterobacter aerogenes[21]	1	
Enterobacter spp[14]		1
Acinectobacter calcoaceticus[24]	1	
Acinectobacter spp[14]		1
Klebsiella oxytoca[24]	1	—
Citrobacter diversus[14]		1
Flavobacterium sp group IIb[3]	1	
Candida parapsilosis[19 20]	2	
Candlda spp[9]	1	

We believe the 23 reported epidemics reaffirm the importance of a number of control measures to prevent invasive infection in hemodynamic pressure monitoring, exclusive of those measures aimed at preventing catheter-related infection:

1. Arterial pressure monitoring should only be used with clear-cut indications, in patients in whom it is necessary to continuously monitor the arterial pressure, who have respiratory failure and for whom it is necessary to obtain frequent arterialized blood specimens for blood gas measurements, or critically ill patients requiring frequent blood specimens for hour-to-hour clinical management (eg, severe diabetic ketoacidosis).

   The use of noninvasive transcutaneous PaO_2 and $PaCO_2$ monitors may obviate some of the need for drawing frequent arterial blood gas specimens.[42]
2. All infusions, including those used for pressure monitoring, should be manipulated as little as possible. Persons handling or entering the system should first wash their hands or don clean gloves. Efforts should be made to limit entry into the monitoring circuit for the purpose of drawing blood for other tests.
3. The number of stopcocks in the system should be kept to an absolute minimum. Wiping the stopcock, after entering it, with an alcohol- or povidone-iodine-impregnated pledget may be of value.

   Rubber diaphragms are now available to use

in place of stopcocks, permitting entry into the system through the diaphragm with a sterile needle. In an unpublished study these devices were found to hold promise for significantly diminishing the risk of contaminating fluid in the monitoring circuit (personal communication, Sue Crow, RN).

4. Whereas we are not aware of published data dealing with the issue, we have concerns regarding the practice of attaching the continuous flow device or transducer assembly to the patient's arm or elsewhere on the patient's body, as is done in many hospitals.

   We think that these infusion components, which are highly vulnerable to contamination that can introduce organisms directly into the patient's bloodstream, should be attached to a stand next to the bed, and should not be in direct contact with the patient.

5. The use of totally disposable transducer assemblies seems preferable, if economically feasible.[43]

6. If reusable transducers are used, the transducer should be cleaned and subjected to high-level chemical disinfection or sterilization with ethylene oxide at periodic intervals,[22] always between patients and for patients requiring prolonged monitoring, each time the monitoring circuit. including the chamber-dome and continuous-flow device, is replaced.

   We believe centralized decontamination provides more consistent quality control and is most desirable. Reprocessing and decontamination of reusable transducers on patient care units with 70% alcohol should he done only in emergencies.

7. The entire monitoring system—including the tubing, continuous flow device, bag of flush solution, chamber-dome and transducer—should be replaced at periodic intervals. The 1981 CDC guidelines recommend every 48 hours as a Category II measure.[22]

   With disposable transducers, Luskin et al have shown that it is not necessary to replace the monitoring system-including the tubing, flush solution, and continuous flow device—more frequently than every four days.[44]

   In an ICU using permanent, reusable transducers, Maki and Hassemer found a high rate of in-use contamination of pressure-monitoring infusate, often associated with concordant bacteremia, when the entire delivery system of arterial infusions was used continuously for more than 48 hours; a policy requiring routine change of the system every 48 hours reduced the prevalence of contamination and eliminated septicemias caused by extrinsically contaminated fluid.[45] Three more recent studies,[37,44,46] however, suggest that if the infusion for hemodynamic monitoring is set up so that a long, blind, stagnant column of fluid is eliminated, extrinsic contamination can be greatly reduced, and it may be unnecessary to replace the administration set, chamber-dome, and other components of the monitoring circuit at such frequent intervals. However. the optimal interval for replacement of the monitoring circuit when reusable transducers are used has not been determined.

8. Although CDC guidelines recommend that the container of heparinized flush solution be changed every 24 hours,[22] very low contamination rates have been reported in intravenous therapy with changing delivery systems at 48- or 72-hour intervals,[47-49] and Luskin et al[41] found very low rates of contamination in their study of' disposable transducers with flush solutions changed at 48-hour intervals. We can see no reason to require flush solutions to be changed more frequently than the monitoring circuit, which is far more heavily manipulated than the bag of flush solution.

   If disposable transducers are used, we believe flush solutions can be replaced with the transducer every four days. If reusable transducers are used, the flush solution should he replaced when the monitoring circuit is replaced, such as every 48 hours.

   Terminal in-line microfilters have been advocated as an additional means of reducing the hazard of contaminated infusate. However, filters must be changed at periodic intervals, are expensive, and we are unaware of controlled studies that have demonstrated clear-cut benefit in a reduction of morbidity associated with hemodynamic monitoring using these devices.

9. Calibration devices, heparinized solutions, and other apparatus that comes into direct contact with fluid within the monitoring circuit must be reliably sterile.

10. Heparinized normal saline should always he used, rather than dextrose-containing solutions, in infusions for pressure monitoring. Similarly, hypertonic glucose solutions for total parenteral nutrition should never be given through an infusion used for pressure monitoring.

11. In many hospitals, blood cultures are often drawn through arterial lines. We believe this practice should be discouraged.

    Whereas drawing blood cultures through lines eliminates the need for uncomfortable venipunctures, especially in patients with limited sites for percutaneous venous access, and has sensitivity for detecting true bacteremia comparable to percutaneously-drawn cultures,[50-55] catheter-drawn cultures are also associated with a higher rate of contamination (poorer specificity in diagnosis of bactereniia). But our greatest concern about the practice

bears on the risk of contaminating fluid in the monitoring circuit by blood-borne microorganisms if the patient has true bacteremia unrelated to the infusion—eg, *Enterobacter* in blood, originating from a urinary tract infection, can contaminate the catheter[54] or fluid within the monitoring circuit.[8,45] resulting in a later "rebound" bacteremia or perpetuation of the original bloodstream infection even though the urinary tract infection has been successfully treatecf.

12. Similarly, in pressure-monitored patients found lo have bacteremia originating from a remote, unrelated source of infection, we believe that the arterial catheter and entire monitoring system should be replaced 24 to 48 hours after treatment has begun and the bloodstream is presumably cleared of microorganisms, to prevent later "rebound" bacteremias.[51,55]

In sum, the outbreaks reported by Beck-Sague and Jarvis and others in the past decade must be regarded as "signs of the time." If it is possible to better educate users of pressure monitoring of the unique microbiologic risks of this form of infusion therapy, we think that contaminated fluid from infusions used for pressure monitoring will be found to be a major cause of sporadic *endemic* nosocomial bacteremias in ICU patients. Equally important, epidemics ought to become less frequent and detected much earlier.

We believe that technologic advances will ultimately greatly reduce the risks of contamination and infection associated with hemodynamic monitoring: incorporation of nontoxic antiseptics into the catheter material or onto its surface holds promise for reducing the incidence of catheter-related infection;[56-58] addition of nontoxic biodegradable or easily metabolized antiseptics to infusate might eliminate the risk of fluid contamination altogether and obviate the need for periodic replacement of monitoring systems.[59]

All things are filled with signs, and it is a wise man who can learn about one thing from another.

Enneads, Book II
Plotinius

REFERENCES

1. Donowitz LG, Wenzel RP, Hoyt JW: High risk of hospital-acquired infection in the ICU patient. *Crit Care Med* 1982; 10:355-357.
2. Pinilla JC, Ross DE, Martin T, et al: Study of the incidence of intravascular catheter infection and associated septicemia in critically ill patients. *Crit Care Med* 1983; 11:21-25.
3. Phillips I, Eykyn S, Curtis MA, et al: *Pseudomonas cepacia* (multivorans) septicemia in an intensive-care unit. *Lancet* 1971; 1:375-377.
4. McKinley TW, McCroan JE: Epidemiologic notes and reports. Nosocomial *Pseudomonas cepacia* bacteremia caused by contaminated pressure transducers. *MMWR* 1974; 23:123.
5. Stamm WE, Colella JJ, Anderson RL, et al: Indwelling arterial catheters as a source of nosocomial bacteremia—An outbreak caused by *Flavobacterium* species. *N Engl J Med* 1975; 292:1099-1102.
6. Walton JR, Shapiro BA, Harrison RA, et al: *Serratia* bacteremia from mean arterial pressure monitors. *Clin Reports* 1975; 43:113-114.
7. Higgins MV, Dzubay D: Transducer-associated bacteremia. *MMWR* 1975; 24:295.
8. Weinstein RA, Emori TG, Anderson RL, et al: Pressure transducers as a source of bacteremia after open heart surgery. Report of an outbreak and guidelines for prevention. *Chest* 1976; 69:338-344.
9. Weinstein RA, Stamm WE, Kramer L, et al: Pressure monitoring devices. Overlooked source of nosocomial infection. *JAMA* 1976; 236:936-938.
10. Centers for Disease Control Methods of Prevention and Control of Nosocomial Infections. National Nosocomial Infections Study Report. 1974-1977. 1988; 15-21.
11. West CM, Wayler B, Tonneson A, et al: Nosocomial *Serratia marcescens* bacteremia associated with reuse of disposable pressure-monitoring domes. Proceedings of the Seventeenth Interscience Conference on Antimicrobial Agents and Chemotherapy. 1977; Abstract no. 429.
12. Buxton AE, Anderson RL, Klimek J, et al: Failure of disposable domes to prevent septicemia acquired from contaminated pressure transducers. *Chest* 1978; 74:508-513.
13. Donowitz LG, Marsik FJ, Hoyt JW, et al: *Serratia marcescens* bacteremia from contaminated pressure transducers. *JAMA* 1979; 242:1749-1751.
14. Cortez LM, Hadley K, Schluter I: Transducer-associated nosocomial primary bacteremias: Identification and control. Proceedings of the Nineteenth Interscience Conference on Antimicrobial Agents and Chemotherapy. 1979; Abstract no. 209.
15. Aduan RP, Iannini PB, Salaki J: Nosocomial bacteremia associated with contaminated blood pressure transducers. Report of an outbreak and a review of the literature. *Am J Infect Control* 1980; 8:33-40.
16. Fisher MC, Long SS, Roberts EM, et al: *Pseudomonas maltophilia* bacteremia in children undergoing open heart surgery. *JAMA* 1981; 246:1571-1574.
17. Cleary TJ, MacIntyre DS, Castro M: *Serratia marcescens* bacteremias in an intensive care unit. Contaminated heparinized saline solution as a reservoir. *Am J Infect Control* 1981; 9:107-111.
18. Liu Y-C, Shi F-W, Cheng D-L: *Serratia marcescens* nosocomial outbreak through intra-arterial cannulae. *J Formosan Med Assoc* 1983; 82:1055-1059.
19. Solomon SL, Alexander H, Elev JW, et al: Nosocomial fungemia in neonates associated with intravascular pressure-monitoring devices. *Pediatr Infect Dis* 1986; 5:680-685.
20. Weems JJ, Chamberland ME, Ward J, et al: *Candida parapsilosis* fungemia associated with parenteral nutrition and contaminated blood pressure transducers. *J Clin Microbiol* 1987; 25:1029-1032.
21. Meyers HB, Fontanilla E, Mascola L: Brief Reports: Risk factors for development of sepsis in a hospital outbreak of *Enterobacter aerogenes*. *Am J Infect Control* 1988; 16:118-122.
22. Atlanta Centers for Disease Control: Guideline for prevention of infections related to intravascular pressure-monitoring systems. *Infect Control* 1982; 3:61-72.
23. Maki DG: Infections associated with intravascular lines, in Remmington J, Swartz M (eds): *Current Clinical Topics in Infectious Disease*. New York, McGraw-Hill, 1982, pp 309-363.
24. Beck-Sague CM, Jarvis WR: Epidemic bloodstream infections associated with pressure transducers: A persistent problem. *Infect Control Hosp Epidemiol* 1989; 10:54-59.
25. Maki DG: Epidemic nosocomial bacteremias, in Wenzel RR (ed): *Handbook of Hospital Infection*. West Palm Beach, C.R.C. Press, Inc. 1981, pp 371-512.
26. Stamm WE: Infections related to medical devices. *Ann Intern Med* 1978; 89:764-768.
27. Wenzel RP, Osterman CA, Donowitz LG, et al: Identification of procedure-related nosocomial infections in high-risk patients. *Rev Infect Dis* 1981; 3:701-706.
28. Goldmann DA, Durbin WA Jr, Freeman J: Nosocomial infections in a neonatal intensive care unit. *J Infect Dis* 1981; 144:449-459.
29. Craven DE, Kunches LM, Lichtenberg DA, et al: Risk factors for nosocomial infection and fatality in medical surgical intensive care unit patients at Boston City Hospital. *Arch Intern Med* 1988; 148:1161-1168.
30. Maki DG: Risk factors for nosocomial infection in intensive care. *Arch Intern Med* 1988; 149:30-34.
31. Campbell BA, Wells GA, Palmer WN, et al: Reuse of disposable medical devices in Canadian hospitals. *Am J Infect Control* 1987; 15:196-200.
32. Maki DG, Band JD: Septicemia from disposable pressure-monitoring chamber domes. "Beware of Greeks bearing gifts." *Chest* 1978; 74:486-487.
33. Talbot GH, Skros M, Provencher M: 70% alcohol disinfection of transducer heads: Experimental trials. *Infect Control* 1985; 6:237-239.
34. Platt R, Lehr JL, Marino S, et al: Safe and cost-effective cleaning of pressure-monitoring transducers. *Infect Control Hosp Epidemiol* 1988; 9:409-416.
35. McArthur BJ, Hargiss C, Schoenknecht FD: Stopcock contamination in an ICU. *Am J Nurs* 1975; 75:96-97.
36. Walrath JM, Abbott NK, Caplan E, et al: Stopcock: Bacterial contamination in invasive monitoring systems. *Heart Lung* 1979; 8:100-103.
37. Shinozaki T, Deane RS, Mazuzan JE Jr, et al: Bacterial contamination of arterial lines. *JAMA* 1983; 249:223-225.
38. Abbott N, Walrath JM, Scanlon-Trump E: Infection related to phys-

iologic monitoring: Venous and arterial catheters. *Heart Lung* 1983; 12:28-34.
39. Carson LA, Petersen NJ, Favero MS, et al: Stimulatory effects of heparin on endotoxin production during growth of gram-negative bacteria in heparinized saline solutions. Abstracts of the Annual Meeting of the American Society for Microbiology, 1980; B31:22.
40. Maki DG, Martin WT: Nationwide epidemic of septicemia caused by contaminated infusion products: IV. Growth of microbial pathogens in fluids for intravenous infusion. *J Infect Dis* 1975; 131:267-272.
41. Wenzel RP: Epidemics—identification and management, in Wenzel RP (ed): *Prevention and Control of Nosocomial Infections*. Baltimore, Williams & Wilkins, 1987, pp 94-108.
42. Eberhart RC, Weigelt JA: New chemical sensing techniques for critical care medicine, in Shoemaker WC, Ayres S, Granvik A, et al (eds): *Textbook of Critical Care*, ed 2. Philadelphia, WB Saunders Co, 1989, pp 223-230.
43. Disposable pressure transducers. *Health Devices* 1984; 13:268-290.
44. Luskin RL, Weinstein RA, Nathan C, et al: Extended use of disposable pressure transducers: A bacteriologic evaluation. *JAMA* 1986; 255:916-920.
45. Maki DG, Hassemer CA: Endemic rate of fluid contamination and related septicemia in arterial pressure monitoring. *Am J Med* 1981; 70:733-738.
46. Platzner N, Marino JA, Cerra FB, et al: Eliminating the cul-de-sac from pressure cone infusion systems reduces fluid contamination. Proceedings of the 22nd Interscience Conference on Antimicrobial Agents and Chemotherapy, New Orleans, 1982.
47. Josephson A, Gombert ME, Sierra MF, et al: The relationship between intravenous fluid contamination and the frequency of tubing replacement. *Infect Control* 1985; 6:367-370.
48. Snydman DR, Reidy MD, Perry LK, et al: Safety of changing intravenous administration sets containing burettes at longer than 48 hour intervals. *Infect Control* 1987; 8:113-116.
49. Maki DG, Botticelli JT, LeRoy ML, et al: Prospective study of replacing administration sets for intravenous therapy at 48- vs 72-hour intervals. *JAMA* 1987; 258:1777.
50. Tonnesen A, Peuler M, Lockwood WR: Cultures of blood drawn by catheters vs. venipuncture. *JAMA* 1976; 235:1877.
51. Vaisanen IT, Michelsen T, Valtonen V, et al: Comparison of arterial and venous blood samples for the diagnosis of bacteremia in critically ill patients. *Crit Care Med* 1985; 13:664-667.
52. Tafuro P, Colbourn D, Gurevich I, et al: Comparison of blood cultures obtained simultaneously by venipuncture and from vascular lines. *J Hosp Infect* 1986; 7:283-288.
53. Bryant JK, Stand CL: Reliability of blood cultures collected from intravascular catheter versus venipuncture. *Am J Clin Pathol* 1987; 88:113-116.
54. Maki DG, Sarafin H, Jarrett F: A semiquantitative culture method for identification of catheter-related infection in the burn patient. *J Surg Res* 1977; 22:513-519.
55. Band JD, Maki DG: Infections caused by indwelling arterial catheters for hemodynamic monitoring. *Am J Med* 1979; 67-73.
56. Trooskin SZ, Donetz AP, Harvey RA, et al: Prevention of catheter sepsis by antibiotic bonding. *Surgery* 1985; 97:547-551.
57. Schaeffer AJ, Story KO, Johnson SM: Effect of silver oxide/trichloroisocyanuric acid antimicrobial urinary drainage system on catheter-associated bacteriuria. *J Urol* 1988; 139:69-73.
58. Maki DG, Cobb L, Garman JK, et al: An attachable silver-impregnated cuff for prevention of infection with central venous catheters: A prospective randomized multicenter trial. *Am J Med* 1988; 85:307-314.
59. Freeman R, Holden MP, Lyon R, et al: Addition of sodium metabisulfite to left atrial catheter infusate as a means of preventing bacterial colonization of the catheter tip. *Thorax* 1982; 37:142-144.