Failure of Disposable Domes to Prevent Septicemia Acquired from Contaminated Pressure Transducers*

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Between January and June 1976, eight cases of primary bacteremia due to Enterobacter cloacae occurred in patients after open-heart surgery in a hospital in Connecticut. Epidemiologic studies implicated radial arterial catheters as the route of acquisition of E. cloacae, and bacteriologic studies confirmed arterial pressure transducers as the sources of bacteria. Prospective studies indicated that the disposable domes from the pressure transducers did not prevent the spread of bacteria from contaminated transducers to the arterial catheters. This is the first report of transducer-acquired bacteremic infections occurring with the use of disposable domes. Although disposable domes may decrease the chances of cross-contamination of circuits for monitoring pressure, they do not, as previously thought, eliminate the risk of bacteremia from this source.

Pressure transducers used to monitor arterial and venous blood pressures have recently been identified as sources of nosocomial bacteremia.† To date, all cases of bacteremia associated with pressure transducers have been traced to faulty sterilization of these devices. Presterilized disposable "chamber-domes" with built-in membranes (Fig 1) have been developed, with the goal of eliminating this source of contamination.

In June 1976, we investigated an outbreak involving eight cases of postoperative bacteremia due to Enterobacter cloacae; the outbreak was traced to contaminated arterial pressure transducers, in which bacteria apparently crossed the membranes of disposable domes. This outbreak demonstrates the value of ongoing surveillance of nosocomial infections in intensive care units and emphasizes the potential hazards of infection of pressure monitoring systems, even when disposable domes are used.

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BACKGROUND

The Hartford Hospital in Hartford, Conn, is a 1,000-bed, university-affiliated teaching center that has had a program of active control of infection for ten years. Surveillance of nosocomial infections is performed by three full-time nurse-epidemiologists. A physician in the Infectious Diseases Section of the Department of Medicine serves as the hospital's epidemiologist.

The hospital's microbiology laboratory has used a rapid-test media system (Analytab Products API-20) for identification of gram-negative organisms since March 1, 1976. Before that system was instituted, positive cultures were reported to physicians only as containing Enterobacter species, although records from a full set of biochemical tests available since July 1975 established the exact biotype of Enterobacter.

Approximately 40 open heart operations are done each month by the hospital's six cardiovascular surgeons in two operating rooms. A standard protocol is used during open heart surgery to monitor arterial and venous pressures. The arterial catheter is connected to a disposable plastic manifold with a six-foot intravenous monitoring line made of "damp-proof" hard plastic (Fig 2). A pressure transducer is connected to each end point of the manifold. One transducer monitors the radial arterial pressure, while a second monitors perfusion pressure of the heart-lung machine when cardiopulmonary bypass is in progress. Until January 1976, reusable metal transducers were used; beginning in January 1976, a new type of transducer with a disposable plastic dome was put into use (Fig 1). A 500-ml bag of a sterile, commercially available 5 percent solution of dextrose in water, to which 1,000 units of heparin are added in the operating room, is connected to the manifold through the central port; this is used for flushing the monitoring lines.

In June 1976, four cases of bacteremia due to E. cloacae occurred in patients in the intensive care unit who had undergone open heart surgery. An investigation was immediately begun to determine the source of these infections.
THE INVESTIGATION

Epidemiologic Data

We reviewed the charts of all patients with cultures of blood that were positive for any Enterobacter species, and we classified infections retrospectively as community-acquired or nosocomial bacteremia. A case was defined as any patient having primary nosocomial bacteremia with *E. cloacae* in the period of July 1975 to June 1976. Primary bacteremia was defined as bacteremia in which a patient had a blood culture that was positive for *E. cloacae* and had no isolates of this organism from any other sites in the body. We reviewed the hospital's records of all cases and extracted the following information: age; sex; underlying diseases; dates of admission and discharge from the hospital and intensive care unit; dates and types of surgical pro-

![DIAPHRAGM DISPOSABLE DOMEPRESSURE TRANSDUCER](Figure 1. Parts of disposable dome of transducer.)
cedures; operating rooms used; length of surgical procedures; length of time on cardiopulmonary bypass; number of specimens of arterial blood for gas analysis that were taken in the operating room; names of participating anesthesiologists and surgeons; results of all cultures; dates and times of exposure to all intravenously administered medications; dates of placement and removal of all arterial and intravenous cannulae; and clinical course.

We found that between January and June 1978, eight cases of primary bacteremia due to *E. cloacae* had occurred at Hartford Hospital (Fig 3). The first case occurred two weeks after the transducers with the disposable domes were put into use. All patients had recently undergone open heart surgery, and all had exposure to pressure monitoring systems using transducers with disposable domes. The average age of the patients was 58 years (range, 47 to 65 years), and six were men. The types of open heart surgical procedures performed on the patients were similar to those done during the same period on 188 patients who did not acquire bacteremia due to *E. cloacae* (Table 1). All isolates from the cases of bacteremia were resistant to therapy with ampicillin and cephalothin and were susceptible to gentamicin, kanamycin, and tobramycin.

Seven of the eight patients experienced the clinical onset of bacteremia at an average of 45 hours after surgery (range, 24 to 65 hours), while the eighth patient had bacteremia 15 months after surgery. Bacteremia was associated with spiking fever and shaking chills in all cases, and one patient experienced transient hypotension. The former seven patients were in the surgical intensive care unit at the time that bacteremia was recognized. At the time of the onset of bacteremia, all seven had radial arterial catheters in place. The fever abated in all within two to six hours and all patients had sterile cultures of blood after the arterial catheters were removed.

There was no correlation between the removal of any other intravascular catheters and defervescence. Several patients had central venous catheters cultured when they were removed, and all catheters were sterile. In all cases, cultures of blood taken before and after cardiopulmonary bypass were negative, and cultures of prosthetic valves taken at the time of insertion in the operating room were sterile.

Review of the records from the microbiology laboratory for the period of June 1975 to June 1976 revealed no increase in the number of blood cultures done or positive blood cultures. In contrast to the eight cases of primary nosocomial bacteremia due to *E. cloacae* that occurred from January to June 1976, there were no cases of nosocomial bacteremia due to this organism from July through December 1975 (Fig 3).

**Table 1—Open Head Surgical Procedures Performed at Hartford Hospital from January to June 1976**

<table>
<thead>
<tr>
<th>Surgery</th>
<th>Cases of Bacteremia</th>
<th>Other Patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aortocoronary bypass graft</td>
<td>4</td>
<td>148</td>
</tr>
<tr>
<td>Aortocoronary bypass graft plus valvular replacement</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>Valvular replacement</td>
<td>1</td>
<td>30</td>
</tr>
<tr>
<td>Ventricular aneurysmectomy</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>8</td>
<td>188</td>
</tr>
</tbody>
</table>

**Microbiologic Studies**

We cultured 85 samples of the environment and medications in the operating rooms, recovery room, and intensive care units. The diaphragms of the...
transducers and other surfaces were sampled with swabs premoistened with brain-heart infusion broth containing 0.5 percent polysorbate 80 (Tween 80) and 0.07 percent lecithin. In addition, we cultured pooled handwashings, obtained by a broth-rinse method from the anesthesiologists during open-heart surgery and from the nurses caring for cardiac surgical patients in the recovery room and the intensive care unit.

On three separate days, E. cloacae (with uniform biochemical patterns and uniform patterns of antibiotic sensitivity that matched the patients' isolates) was recovered from the diaphragms of all transducers in the operating rooms and recovery room. Because these diaphragms were wet at the 5 percent solution of dextrose in water at the time of connection with the disposable dome before surgery (to provide a tight connection between the diaphragm and membrane) and were not cleaned between operations, the diaphragms of the transducers tended to remain moist continually. Enterobacter cloacae with the epidemic biotype and antibiogram was not recovered from any personnel of the hospital or from other environmental cultures.

We then conducted a prospective surveillance study of cultures from 27 patients over an eight-day period. All patients undergoing open heart surgery (total of 13) and all patients in the intensive care unit (14) had daily samples of all intravenously administered fluids and arterial fluids obtained by aspiration through side arms on intravenous tubing or from radial arterial stopcocks. In addition, all patients had cultures of urine, rectal swabs, and pharyngeal swabs or sputum examined for E. cloacae. The patients who underwent open heart surgery had a sample of the flushing solution aspirated from the radial arterial catheter and the manifold of the arterial monitoring system at three different times. Samples were taken when the patients arrived in the recovery room and one day after they arrived in the intensive care unit. In addition, for four of them, serial cultures were taken of the flushing solution from the manifold of the pressure monitoring system as it was being set up in the operating room; this was done by aspirating specimens of flushing solution from the side ports (A in Fig 1) of the manifold, from the stopcock attached to the radial arterial catheter (C in Fig 2), and from the side arm of the disposable dome (B in Fig 2) while the patients were in the recovery room after surgery. A 5-ml sample of fluid from each site was inoculated into a 40-ml flask of brain-heart infusion broth.

Of the 22 patients (out of 27) whose arterial pressure monitoring systems were cultured, four had cultures that yielded E. cloacae. From three, the organism was recovered from cultures of the stopcock of the radial arterial catheter at the time when the patients arrived in the recovery room from the operating rooms. The fourth positive culture was obtained by direct aspiration from the interior of the disposable dome (B in Fig 2). Simultaneous cultures from the ports of the pressure monitoring manifold (A in Fig 2) were negative at the time when all of these positive cultures were obtained. In addition, when the positive culture of the dome was obtained, a simultaneous culture of the flushing solution aspirated through the stopcock of the radial arterial catheter was sterile. No cultures of urine, pharyngeal samples, rectal samples, intravenous fluid, or central venous pressure catheters from these patients yielded E. cloacae.

Because of normal delays in obtaining the results of cultures, the four patients with cultures positive for E. cloacae in the arterial system did not have the radial arterial catheters removed until approximately 24 hours after the cultures were obtained; however, all four patients remained asymptomatic.

When the results of these cultures became available, we instituted the following measures of control: (1) physiologic saline solution replaced the 5 percent solution of dextrose in water as the flushing solution in the arterial pressure monitoring system; and (2) the diaphragm of the transducer was filled with 70 percent isopropyl alcohol (instead of the 5 percent solution of dextrose in water) to maintain contact with the membranes of the disposable dome. We then prospectively sampled the flushing solution through the stopcock of the radial arterial catheter in the subsequent 25 patients undergoing open-heart surgery. All cultures were sterile. Since June, no further cases of bacteremia due to E. cloacae have occurred at the hospital.

The possibility that structural defects were present in the disposable domes or that they were intrinsically contaminated with E. cloacae was investigated using a series of in vitro experiments. Eighteen unused domes from the lot used during the outbreak were sampled by flushing 5 ml of brain-heart infusion broth through the interior and then culturing the broth. Then a suspension of $10^9$ organisms of E. cloacae was placed on the diaphragm of the transducer. The diaphragm was screwed into place on the disposable dome, and the dome was filled with fresh sterile brain-heart infusion broth and was left undisturbed for 24 hours at room temperature. After 24 hours the broth was aspirated from the interior of the dome and was cultured at 37°C for 72 hours. All cultures were negative.

We then evaluated a second series of 18 disposable domes (from a different lot) in vivo by connecting them to catheters inserted into the central ear lobe artery of mature New Zealand white rabbits

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for two hours. During this time a suspension of approximately 10⁴ organisms of *E. cloacae* was placed between the membrane of the dome and the diaphragm of the transducer. After two hours the flushing solution filling the arterial catheter and dome was cultured as described previously. No defects in the domes were identified, and cultures of domes remained negative.

Next, we attempted to show transfer of contamination from the transducers to the dome in a prospective trial involving ten consecutive patients undergoing cardiac surgery. Gentamicin was chosen as a marker to mimic the flow of contamination from the diaphragms of the pressure transducer to the arterial line. Immediately before the operation, a suspension of sterile gentamicin (40 mg/ml) was applied to the diaphragms of the transducer prior to connection with the disposable domes. One-milliliter aliquots of the fluid from the arterial pressure monitoring system were aspirated serially from the dome (via port B in Fig 2), from the side ports on the manifold (A in Fig 2), and from the arterial catheter (C in Fig 2) during the operation and after surgery in the recovery room. The concentration of gentamicin in the samples of flushing solution was assayed by a radioimmunoassay with a sensitivity of 1μg/ml. Positive and negative controls were included. We could not recover gentamicin from any of the sites of sampling.

**Discussion**

*Enterobacter cloacae*, a motile fermentative gram-negative bacillus, is a frequent cause of infections of the respiratory and urinary tracts in hospitalized patients. Although species of *Enterobacter* have received much publicity as a cause of bacteremia associated with intrinsic contamination of commercial intravenous fluids, there have been few reports of septicemia due to these organisms that were not associated with fluids for infusion. The ability of the tribe, *Klebsielleae*, to multiply in dextrose-containing intravenous fluids for infusion is well documented. This knowledge and also the failure to isolate *E. cloacae* from other sites in patients suggested the possibility that the bacteremia arose from infusion of contaminated glucose-containing intravenous fluid; however, intrinsic contamination of the fluid for infusion was unlikely since (1) cultures of fluids were sterile and (2) bacteremia only occurred in patients undergoing open heart surgery, even though the same fluids for infusion were used throughout the hospital.

The practice of wetting the diaphragms of the transducer with the flushing solution of heparin and 5 percent dextrose in water and the observation that the permanent portions of the devices that were screwed into the membranes of the disposable dome remained moist between cases and were never cleaned or sterilized explain why *E. cloacae* could be recovered from such surfaces. The original source of contamination of the diaphragms of the transducer is unknown, but once contaminated, these diaphragms probably served as the continuing reservoir of microbial contamination.

*Enterobacter cloacae* could have been transferred from the diaphragm of the transducer into the arterial monitoring system by one of the following two routes: (1) either directly across the membrane of the disposable dome; or (2) indirectly by contact with contaminated hands during assembly of the devices in the operating room. Cultures from anesthesiologists’ hands taken immediately after they had handled the system failed to grow *E. cloacae*. Although extensive manipulations are required for the anesthesiologists to set up the system for arterial and central venous pressure monitoring, serial cultures from the manifolds and central venous pressure lines during and after this procedure were all sterile. If the organisms of *E. cloacae* were introduced into the system by contaminated hands, we would have expected (with 95 percent confidence limits) to have recovered the organism from at least three of the central venous pressure lines and manifolds sampled prospectively, since 18 percent of the arterial lines were positive for *E. cloacae*. In addition, simultaneous cultures from central venous pressure lines and the manifold were sterile in the patients with positive cultures of arterial lines or disposable domes. Other evidence against introduction of bacteria from hands into the system is the observation that we could not recover the tracer of gentamicin that was placed on the diaphragms of the transducer from anywhere in the manifold’s system of arterial lines (over 100 serial specimens were taken from various sites for the ten patients whose procedures were monitored in this manner).

It would appear most likely that *E. cloacae* was transferred from the diaphragms of the transducer to the arterial lines across the membranes of the disposable dome by a mechanism as yet undetermined. Examination of the domes used in the patients with positive cultures of the arterial lines did not show any gross defects. The experiments in the laboratory argue against intrinsic contamination or defects in the disposable domes; however, not all domes used in these experiments were from the lot used during the epidemic. The possibility remains that defects in the membranes of the dome were produced during the surgical procedures.

Pressure transducers recently have been implicated in several outbreaks of nosocomial bacteremia. Past experiences with these problems have all
involved reusable transducers that can be sterilized, and infections have been traced to ineffective sterilization of the reusable domes. It had been hoped that the use of sterile disposable domes that have a thin membrane to keep the monitoring fluid within a disposable circuit would eliminate such problems. Although disposable domes may decrease the chances of cross-contamination of arterial pressure monitoring circuits, this present outbreak suggests that they may not always be effective.

Contamination of arterial pressure monitoring systems, like systems for intravenous infusion, may occur at multiple sites and by several mechanisms. Such contamination may occur from the use of intrinsically contaminated solutions or medications for infusion or from medications dispensed from multi-dose vials that have become contaminated in use. We excluded contamination of the flushing solution (5 percent solution of dextrose in water) as the source of this outbreak by epidemiologic evaluation. Review of the hospital's central record of supplies revealed that 500-ml bottles of the 5 percent solution of dextrose in water were widely distributed (3,503 bottles were used in the intensive care unit and operating room during the epidemic period vs 23,843 bottles used in the rest of the hospital). Thus, it appeared unlikely that the source of the bacteremia was intrinsic contamination of this fluid, as one would have expected 54 cases of bacteremia due to Enterobacter in patients who did not undergo open-heart surgery. The only other medication present in the pressure monitoring system was heparin. Among the cultures obtained during the microbiologic survey in the operating room were samples from 24 multi-dose vials of heparin (some partly used and others unopened), and all were sterile. Manipulation of pressure monitoring systems while in use may also introduce contamination; contaminated ice used for cooling syringes for specimens of arterial blood for gas analysis has led to bacteremia, but this practice was not observed during the present outbreak.

Pressure transducers should be considered potential sources of infection in any patient who acquires primary bacteremia, even if they are not still in use at the time of the onset of bacteremia. The risk of bacteremia can be decreased by using fluids for infusion that do not contain glucose (when possible) and by effectively disinfecting any nondisposable components of the transducer that have potential contact with fluids for infusion. Alcohol cannot now be recommended as the disinfectant, since the long-term effects of repeated exposure to this solvent on the integrity of the transducer are unknown. In addition, it may be useful to change all tubing and fluids for infusion every 24 to 48 hours.

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