The Effects of Prolonged Ethanol Exposure on the Mechanical Properties of Polyurethane and Silicone Catheters Used for Intravascular Access •

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THE EFFECTS OF PROLONGED ETHANOL EXPOSURE ON THE MECHANICAL PROPERTIES OF POLYURETHANE AND SILICONE CATHETERS USED FOR INTRAVASCULAR ACCESS

Christopher J. Crnich, MD, MS; Jeremy A. Halfmann, BS; Wendy C. Crone, PhD; Dennis G. Maki, MD

ABSTRACT

BACKGROUND: Products containing alcohol are commonly used with intravascular devices at insertion, to remove lipids from occluded intravascular devices used during parenteral nutrition, and increasingly for the prevention and treatment of intravascular device–related bloodstream infection. The effects of alcohol on the integrity of intravascular devices remain unknown.

METHODS: Two types of widely used commercial peripherally inserted central catheters, one made of polyetherurethane and one made of silicone, were exposed to a 70% ethanol lock solution for up to 10 weeks. Mechanical testing was performed to identify force-at-break, stress, strain, modulus of elasticity, modulus of toughness, and wall area of ethanol-exposed and control catheters.

RESULTS: No significant differences between exposed and unexposed catheters were identified for any of the mechanical parameters tested except for a marginal reduction in the modulus of elasticity for both polyetherurethane and silicone catheters and minor increases in the wall area of polyetherurethane catheters.

CONCLUSIONS: These data indicate that exposure to a 70% ethanol lock solution does not appreciably alter the integrity of selected commercial polyetherurethane and silicone catheters. Given the greatly expanded use of alcoholic solutions with intravascular devices of all types, we believe that manufacturers would be well advised to subject their catheters and other intravascular devices to formal testing of the type employed in this study (*Infect Control Hosp Epidemiol* 2005;26:708-714).

The use of intravascular devices in clinical practice has greatly expanded during the past two decades; more than 200 million intravascular devices are now used in hospitals, clinics, and the outpatient setting each year.[1] The wide array of available intravascular devices has enhanced our capacity to administer a large number of parenteral medications and total parenteral nutrition as well as intravenous fluids and blood products.

Unfortunately, every intravascular device, no matter the type, carries some risk of associated bloodstream infection (BSI).[2] As a result, the Healthcare Infection Control Practices Advisory Committee of the Centers for Disease Control and Prevention has periodically published evidence-based guidelines for the prevention of intravascular device–related BSI. The 2002 guidelines[3] now recommend, for the first time, use of a 2% solution of chlorhexidine for cutaneous antisepsis at the time of intravascular device insertion. Currently, the only chlorhexidine-based antiseptic commercially available for use with intravascular devices approved by the Food and Drug Administration contains 2% chlorhexidine gluconate in 70% isopropyl alcohol (Chloraprep, Medi-Flex, Leawood, KS). Many hospitals across the United States have adopted this product for vascular access. Medical-grade ethanol has also been used for many years for the removal of insipissated lipids from occluded intravascular devices used for parenteral nutrition.[4-6] Moreover, recent reports suggest that 25% to 70% ethanol used as a lock solution may be of value both as an adjunct to the treatment of intravascular device–related BSI[7] and for the prevention of infection with the use of long-term intravascular devices.[8]

The increasing use of alcohols for vascular access raises questions about their effects on the mechanical integrity of catheters. However, the studies addressing this important issue have been limited. McHugh et al. reported that luminal surfaces and wall thickness of polyurethane catheters exposed to ethanol for as long as 19 days were not significantly different from those of control

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catheters exposed to normal saline when examined by scanning electron microscopy; however, qualitative softening was observed for catheters exposed to ethanol.[9] The authors did not undertake formal mechanical testing of the catheter materials evaluated. Studies performed in Japan found that the constant infusion of etoposide, which incorporates ethanol into its vehicle, was associated with microcracking of polyurethane catheters[10]; similar degradation was not seen for catheters made of polyvinyl chloride or silicone.

Given the rapidly growing exposure of all types of intravascular devices to alcohols, we studied the effects of prolonged exposure to 70% ethanol on the mechanical integrity of polyetherurethane and silicone intravascular catheters commonly used for long-term vascular access.

METHODS

Experimental Procedure

Standard tensile tests were conducted to evaluate the effects of prolonged exposure to ethanol on the mechanical integrity of two types of widely used peripherally inserted central catheters (PICCs): a 4 French single-lumen catheter (Arrow International Inc., Reading, PA) made of an aromatic thermoplastic polyetherurethane containing 20% barium sulfate for radiopacity and a 5 French single-lumen catheter (Cook Critical Care, Bloomington, IN) made of silicone. The inner and outer diameters of both types of catheter were determined after cross-sectioning by optical measurement using a Nikon Eclipse Optical Microscope (Nikon USA, Melville, NY) and Metamorph imaging software (version 5.02; Universal Imaging Corp., Downington, PA); the average cross-sectional area was 0.85 mm^2 for the polyetherurethane catheter and 1.75 mm^2 for the silicone catheter.

One set of catheters (15 polyetherurethane and 16 silicone catheters) was locked with 70% ethanol, whereas control catheters (17 polyetherurethane and 17 silicone catheters) were left empty (ie, were not locked with any solution). Study catheters in both groups were then immersed in prepared Hank's balanced salt solution held at 37°C, to simulate the effect of the human bloodstream, for 1 to 10 weeks. Mechanical testing was performed on ethanol-exposed and control catheters after 1, 2, 3, 5, 6, and 9 weeks for polyetherurethane catheters and after 1, 2, 3, 4, 7, 9, and 10 weeks for silicone catheters.

Preparation of Catheter Segments

At the time of mechanical testing, two or three test catheters from each treatment arm were removed from the Hank's balanced salt solution. The ethanol was drained from the treated catheters, and the catheters were allowed to air dry at room temperature. A minimum of three but as many as nine 25-mm segments were prepared from the tubular portion distal to the hub of each catheter, excluding the tip (Table). A solid steel core was introduced into each of the gripped ends to minimize the stress concentration effects and reduce the risk of failure due to pinching of the ends of the segment (Fig. 1). If such a failure occurred, the data were discarded and an additional specimen from the same catheter was tested. Mechanical testing of catheter segments was conducted on an Instron 5566 Universal Testing Machine (DatapointLabs, Ithaca, NY).

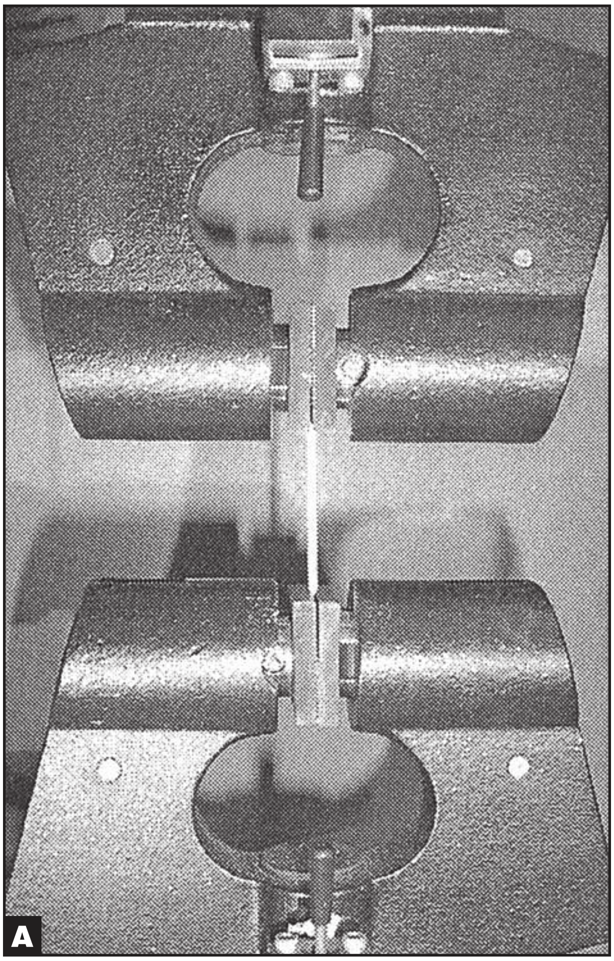
TABLE
NUMBER OF CATHETER SEGMENTS USED AT EACH EXPOSURE INTERVAL FOR POLYETHERURETHANE AND SILICONE CATHETERS

Catheter Material	Test Day	Ethanol	Control
Polyurethane	6	7	5
	14	9	7
	21	5	7
	36	7	6
	47	8	6
	67	5	3
Silicone	7	6	5
	15	6	6
	21	8	3
	29	5	5
	50	4	9
	67	3	4
	72	6	6

Tensile Testing

Tensile strength testing to determine force-at-break was conducted as delineated in standard 10555-1 of the International Organization for Standardization.[11] The conditioning procedure described in the standard was replaced by the experimental immersion procedure described above. Catheter junctions and hubs were not subjected to testing. All testing was conducted at room temperature. Force was measured in newtons (N), stress—the force per unit area—was recorded in megapascals (MPa), and strain—a dimensionless property characterizing stretch—was measured as the ratio of the change in length of the catheter segment to the original length of the catheter segment. Catheter segments were loaded while force and strain data were continuously recorded at 0.5-second intervals. A strain rate of 500 mm/min was employed to satisfy the 20 mm/min/mm strain rate recommended by the International Organization for Standardization standard.[11]

The mechanical properties of segments, including force-at-break (N), failure stress (MPa), elongation at failure (mm), maximum strain (change in length [mm]/original length [mm]), modulus of elasticity (MPa), modulus of toughness (MPa), and wall thickness, were measured for each of the study catheters. The elongation of catheter segments at failure (mm) was measured as the displacement of the grips at the time of breakage; direct placement of an extensometer on segments was not possible because they were too soft. Standard stress–strain curves were created from data generated during displacement-controlled loading of the catheter



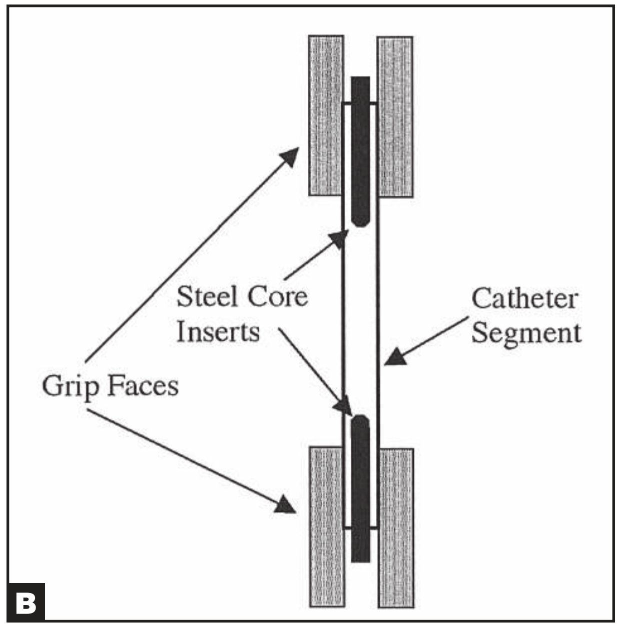


FIGURE 1. (A) A catheter segment loaded into an Instron 5566 Universal Testing Machine (DatapointLabs, Ithaca, NY) and (B) the location of the steel core inserts within the catheter segment to facilitate gripping within the testing apparatus.

segments. These curves were then used to calculate the modulus of elasticity (Young's modulus) and modulus of toughness.

Figure 2 shows a typical stress–strain curve for a silicone catheter segment. The initial slope of the curve is taken to be the elastic modulus, beyond which the specimen undergoes plastic deformation. Typically, after significant strain, the slope of the curve changes again. Rubbery polymers, such as polyurethanes and silicones, may exhibit an increase in stress prior to breakage as a result of strain-induced crystallization caused by molecular orientation in the direction of applied stress.[12] The modulus of elasticity was calculated from the slope of the linear region of the curve below 0.25 strain for silicone catheters and below 0.10 strain for polyurethane catheters. The modulus of toughness of a material represents the total amount of work the specimen is able to withstand before it fails and is proportional to the area under the entire stress–strain curve.

Wall Area

Wall area in square nanometers (nm^2) was determined by subtracting the inner wall area from the outer wall area, as determined by the optical measurement methods described above. The initial intent was to obtain multiple measurements from a single catheter segment and take the average of these measurements. However, within the first week of testing of silicone catheters, it became apparent that the wall area was not uniform throughout the length of the catheter lumen. Based on this knowledge, measurements were obtained from several different catheter segments along the length of the catheter lumen and the average of these measurements was recorded as the wall area for each exposure interval. As a result, the wall areas for silicone catheters at day 7 of exposure were not included in the final analysis. This modified method of assessing wall area was used at all exposure intervals for tested polyetherurethane catheters. Mislabeling of polyetherurethane catheter segments selected for wall area determination on day 36 of exposure did not allow for accurate identification of exposed and control catheters, and wall area measurements of polyetherurethane catheters on day 36 of exposure were not included in the final analysis.

Statistical Analysis

The measurements obtained at each exposure interval from each treatment group were averaged for polyetherurethane and for silicone catheters. Unpaired Student's *t* tests with Welch correction were used to compare mean values for each mechanical property measured.

RESULTS

The mechanical properties of polyetherurethane catheters exposed to a 70% ethanol lock solution for as long

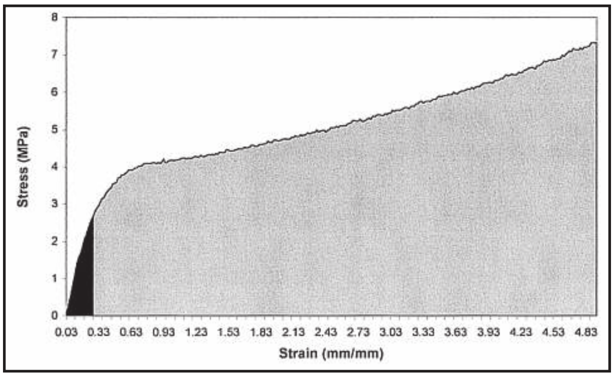


FIGURE 2. Typical stress–strain curve for a silicone catheter segment. The area under the entire curve represents the modulus of toughness, whereas the slope of the portion of the curve highlighted in black represents the modulus of elasticity (Young's modulus). MPa = megapascals.

as 67 days and of silicone catheters exposed to a 70% ethanol lock solution for as long as 72 days are depicted in Figures 3 through 5.

The force-at-break or stress-at-break was consistently higher in the polyetherurethane catheters compared with the silicone catheters, and the force or stress required to break the silicone catheters tended to decrease the longer they remained in the Hank's solution (Figs. 3 and 4). No significant difference in the force required to break segments was found between the catheters exposed to ethanol and the unexposed, control catheters within each group, regardless of the exposure time (Fig. 3). The maximum stress-at-break was found to be reduced at a single exposure interval in both types of catheter (day 47 of exposure for the polyetherurethane catheters and day 7 of exposure for the silicone catheters), but no significant differences between exposed and control catheters were found at any of the other exposure intervals (Fig. 4).

The maximum segment elongation and strain immediately prior to breakage tended to be greater for the silicone catheters than for the polyetherurethane catheters, although this difference diminished the longer the catheters were immersed in Hank's solution. No differences in elongation and strain were seen between the catheters exposed and those unexposed to a 70% ethanol lock solution, for either the polyetherurethane or the silicone catheters, regardless of the exposure time.

As expected, the modulus of elasticity (Fig. 5) and the modulus of toughness were higher for the polyetherurethane than for the silicone catheters. The modulus of toughness of the polyetherurethane catheters exposed to ethanol was not significantly different from that of the unexposed, control catheters. Although the modulus of toughness of the silicone catheters exposed to ethanol was found to be reduced at a single exposure interval (day 21), no differences were seen between the catheters exposed to ethanol and the unexposed, control catheters at any of the other testing intervals. In contrast, the modulus of elasticity of both the polyetherurethane and the silicone catheters exposed to 70% ethanol was found to

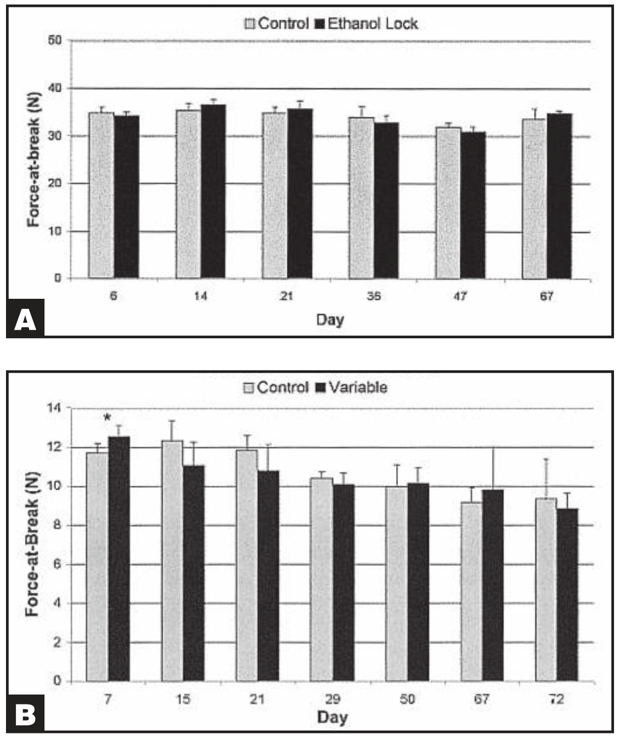


FIGURE 3. Force-at-break (in newtons [N]) at various exposure intervals for (A) polyetherurethane and (B) silicone catheters. Data are the mean force-at-break (N) of catheter segments tested (the table contains the number of segments tested at each exposure interval). Vertical bars represent standard error. *$P < .05$.

be slightly but significantly lower at several of the exposure intervals (Fig. 5).

Wall areas of segments of the control polyetherurethane and silicone catheters did not change appreciably over time during prolonged immersion in Hank's solution at 37°C. On comparison of the ethanol-exposed catheters with the unexposed, control catheters, the wall area of the silicone catheter segments was not consistently altered by exposure to 70% ethanol. In contrast, the polyetherurethane catheters exposed to 70% ethanol showed a consistent trend toward increasing wall thickness with prolonged exposure times, although statistical significance was reached at only one of the testing intervals (day 47 of exposure).

DISCUSSION

Ethanol and other alcohol-containing solutions are commonly used with intravascular devices as topical antiseptics during insertion or at the time of dressing changes[13,14] and as flush solutions to remove insipissated lipids from occluded catheters.[4-6] Moreover, there is growing interest in the use of ethanol as a novel intraluminal disinfectant for the treatment[7] and prevention[8] of intravascular device–related BSI.

Previous studies have raised questions about the effects of ethanol exposure on the mechanical integrity of polyurethane catheters,[9,10] although, to our knowledge, no studies have examined the effect of ethanol on silicone

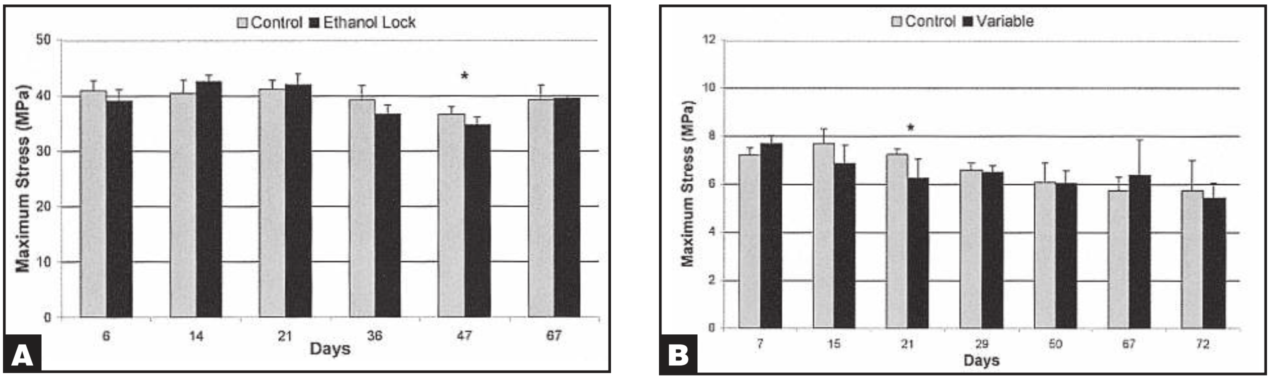


FIGURE 4. Maximum stress (in megapascals [MPa]) at break at various testing intervals for (A) polyetherurethane and (B) silicone catheters. Data are the mean stress (MPa) of catheter segments tested (the table contains the number of segments tested at each exposure interval). Vertical bars represent standard error. $^{*}P < .05$.

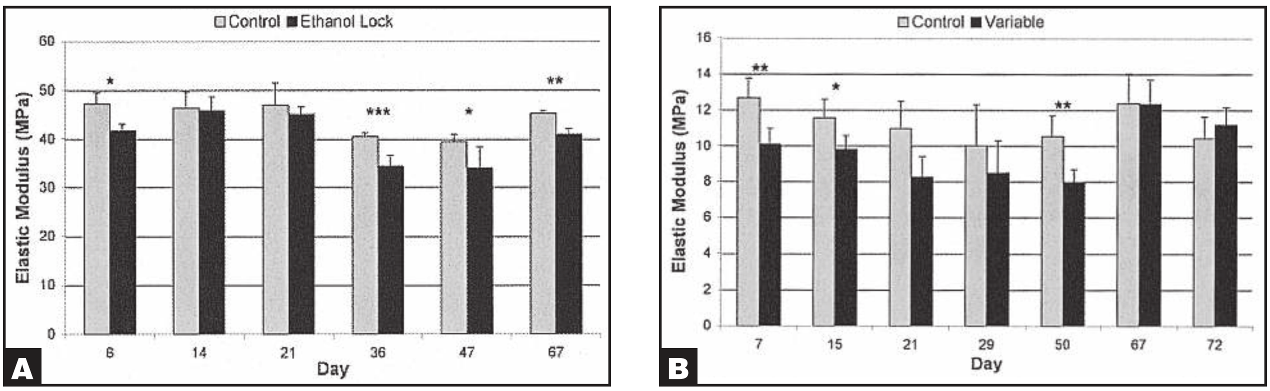


FIGURE 5. Modulus of elasticity (in megapascals [MPa]) of catheter segments at various exposure intervals for (A) polyetherurethane and (B) silicone catheters. Data are the mean modulus of elasticity (MPa) of catheter segments tested (the table contains the number of segments tested at each exposure interval). Vertical bars represent standard error. $^{*}P < .05$; $^{**}P < .01$; and $^{***}P < .001$.

catheters. Our study went beyond the qualitative assessments made in these earlier studies by rigorously assessing the effects of prolonged ethanol exposure on the mechanical integrity of widely used polyetherurethane and silicone catheters, employing industry standards wherever possible.[11] Although it has been reported that polyurethanes may dissolve in polar organic solvents,[12] our study failed to show any consistent reductions in the mechanical integrity of polyetherurethane or silicone catheters exposed to a 70% ethanol lock solution for as long as 10 weeks.

Our study was designed to provide a worse-possible-case challenge to the mechanical integrity of the catheters tested: the durations of continuous exposure to 70% ethanol were hundreds of times greater than an intravascular device material is likely to experience in clinical practice. We did find minimal differences in the modulus of elasticity between the ethanol-exposed and the control polyetherurethane catheter segments at several of the exposure intervals (Fig. 5). However, no consistent trend toward a sustained reduction in the modulus of elasticity was found for the silicone catheters (Fig. 5). Prolonged ethanol exposure appeared to produce slight swelling of the walls of the polyetherurethane catheters, but no consistent effect was seen for the silicone catheters tested. These findings may represent a type I error or may be the result of measurement error. However, the latter seems unlikely given that the exposed and unexposed catheters were measured in a similar fashion.

Even if the modest differences seen in the modulus of elasticity and wall thickness are real, their effect on the clinical performance of these catheters in practice is likely to be negligible because the force required to break a catheter segment (Fig. 3), the stress at break (Fig. 4), the maximum elongation before breakage, the maximum strain before breakage, and the modulus of toughness were unaffected by prolonged exposure to 70% ethanol. We believe these properties are more reliable predictors of the integrity of intravascular devices during clinical use. In fact, the sole mechanical property of catheter lumens recommended for testing in the International Organization for Standardization standard is the force-at-break.[11] As such, we interpret our findings as strong evidence supporting the safety of using ethanol and alcohol-containing solutions with selected polyetherurethane and silicone catheters in clinical practice.

Our study has limitations. First, we assessed only the mechanical integrity of the tubular portion of the polyetherurethane and silicone catheters. As a result, the impact of prolonged ethanol exposure on the integrity of the catheter hub and junction (at the interface of the hub and the tubular portion of the catheter) remains unknown. However, 70% alcohols have long been used to clean catheter hubs prior to blood draws or connections to administration sets, and we have been unable to find any published reports of cracking or fracturing of catheter hubs linked causally to repeated exposure to alcohol. Moreover, a review of the Food and Drug Administration's Manufacturer and User Facility Device Experience Database (MAUDE),[15] which includes data on complications with devices in use from 1992 to 2004, failed to identify any reports of mechanical failure of catheter hubs linked to alcohol exposure. However, if such effects did occur, a damaged hub could be easily repaired without replacing the entire catheter.

The other limitation of our study was our testing of only one manufacturer's polyurethane catheter. Many intravascular device manufacturers have advised against exposure of their polyurethane catheters to alcohol and acetone because of concerns about accelerated environmental stress cracking.[16] We have been unable to identify any published studies that corroborate these concerns. However, MAUDE contains 195 reports, all except one submitted by three companies (Bard Access Systems, Salt Lake City, UT; Boston Scientific Corp., Salt Lake City, UT; and Medcomp Medical Components, Harleysville, PA), describing environmental stress cracking of central venous catheters, usually at the junction of the catheter hub and lumen, which was ascribed to exposure of the devices to alcohol-containing antiseptics or acetone. Because environmental stress cracking of vascular catheters may occur in clinical practice without any clear inciting cause, the causal relationship of exposure to alcohol in each of these reports is unclear.

Of the 195 reports in MAUDE, 154 involved a cuffed hemodialysis catheter (Ash Split I Hemodialysis Catheter, Medcomp Medical Components) manufactured from an aliphatic polyetherurethane called Tecoflex (Thermedics, Wilmington, MA), a compound that reportedly swells more than 25% in the presence of ethanol or isopropyl alcohol[17] and is known to develop microcracks after prolonged implantation times.[18] The manufacturer has since introduced a next-generation hemodialysis catheter (Ash Split Hemodialysis Catheter II) made of Carbothane (Carboline, St. Louis, MO), an aliphatic polycarbonate–based polyurethane that has been shown to be compatible with several cutaneous antiseptics, including chlorhexidine and isopropyl alcohol.[19] Fourteen reports pertained to a polyurethane PICC (Vaxcel PICC, Boston Scientific Corp.), although we have been unable to obtain information on the exact polyurethane formulation used in its manufacture; however, information in MAUDE indicates that the manufacturer recently modified the production procedure to make the catheter material more resistant to the effects of isopropyl alcohol.[20] Of the remaining 27 reports, 26 were from a manufacturer (Bard Access Systems) that apparently has not modified the material used in the manufacture of its catheter (Polyurethane Per-Q-Cath PICC) and, as a result, continues to recommend against the use of alcohol or alcohol-containing solutions with its catheter.

The type of polyurethane catheter evaluated in this study is manufactured from an aromatic thermoplastic polyetherurethane that is similar, but may not be identical, to polyurethanes used in the manufacture of intravascular devices produced by other companies. Aromatic polyurethanes may be more resistant to the effects of organic solvents than aliphatic polyurethanes,[12] but the effects of ethanol exposure on the integrity of other types of aromatic polyurethanes used in the manufacture of intravascular devices are unknown. Our findings combined with the reports submitted to MAUDE highlight the heterogeneity among polyurethanes and suggest potential differences in the effects of alcohols and other organic solvents on the integrity of these devices. They also point out that manufacturers must understand that alcohols will be used increasingly with their devices, regardless of labeling instructions, and the importance of using materials in the manufacture of intravascular devices that are resistant to the degrading effects of these agents. Given the greatly expanded use of alcoholic solutions with intravascular devices of all types, we believe that manufacturers would be well advised to subject their catheters and other intravascular devices to formal testing of the type employed in this study.

This was the first study to systematically evaluate the effect of ethanol on the integrity of two types of vascular catheters commonly used in clinical practice. The findings suggest that a 70% ethanol lock solution has a negligible impact on the mechanical properties of polyetherurethane and silicone catheters, despite continuous exposure times as long as 10 weeks. These findings should allay fears about the use of alcohol-containing antiseptic solutions with vascular catheters made of silicone and aromatic polyetherurethanes and should prompt further study of ethanol as an anti-infective lock solution for the prevention[8] and treatment[7] of intravascular device–related BSI in clinical practice.

REFERENCES

1. Mermel LA, Farr BM, Sherertz RJ, et al. Guidelines for the management of intravascular catheter-related infections. *Infect Control Hosp Epidemiol* 2001;22:222-242.
2. Kluger D, Maki D. The relative risk of intravascular device-related bloodstream infections with different types of intravascular devices in adults: a meta-analysis of 206 published studies. *Infect Control Hosp Epidemiol* 2000;21:95-96. Abstract.
3. O'Grady NP, Alexander M, Dellinger EP, et al. Guidelines for the prevention of intravascular catheter-related infections. *Clin Infect Dis* 2002;35:1281-1307.
4. Pennington CR, Pithie AD. Ethanol lock in the management of catheter occlusion. *JPEN J Parenter Enteral Nutr* 1987;11:507-508.
5. Johnston DA, Walker K, Richards J, Pennington CR. Ethanol flush for the prevention of catheter occlusion. *Clin Nutr* 1992;11:97-100.
6. Werlin SL, Lausten T, Jessen S, et al. Treatment of central venous catheter occlusions with ethanol and hydrochloric acid. *JPEN J Parenter Enteral Nutr* 1995;19:416-418.
7. Dannenberg C, Bierbach U, Rothe A, Beer J, Korholz D. Ethanol-lock

technique in the treatment of bloodstream infections in pediatric oncology patients with broviac catheter. *J Pediatr Hematol Oncol* 2003;25:616-621.
8. Maki DG, Crnich CJ, Safdar N. Successful use of a 25% alcohol lock solution for prevention of recurrent CVC-related bloodstream infection in a patient on home TNA. Presented at the 42nd Interscience Conference on Antimicrobial Agents and Chemotherapy; September 27-30, 2002; Washington, DC. Abstract.
9. McHugh GJ, Wild DJ, Havill JH. Polyurethane central venous catheters, hydrochloric acid and 70% ethanol: a safety evaluation. *Anaesth Intensive Care* 1997;25:350-353.
10. Yokoyama H, Aoyama T, Matsuyama T, et al. The cause of polyurethane catheter cracking during constant infusion of etoposide (VP-16) injection. *Yakugaku Zasshi* 1998;118:581-588.
11. International Organization for Standardization. *ISO 10555-1: Sterile, Single-Use Intravascular Catheters,* part 1, annex B. Geneva: International Organization for Standardization; 1995.
12. Lambda NMK, Woodhouse KA, Cooper SL. *Polyurethanes in Biomedical Applications*. New York: CRC Press; 1998.
13. Dettenkofer M, Jonas D, Wiechmann C, et al. Effect of skin disinfection with octenidine dihydrochloride on insertion site colonization of intravascular catheters. *Infection* 2002;30:282-285.
14. Parienti JJ, du Cheyron D, Ramakers M, et al. Alcoholic povidone-iodine to prevent central venous catheter colonization: a randomized unit-crossover study. *Crit Care Med* 2004;32:708-713.
15. Center for Devices and Radiological Health. *Manufacturer and User Facility Device Experience Database (MAUDE)*. Rockville, MD: U.S. Food and Drug Administration; 2004. Available at www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfMAUDE/search.CFM. Accessed July 21, 2004.
16. Agraharkar M. Failure of central vein catheters after prolonged use. *Semin Dial* 2000;13:205-206.
17. Noveon. *Medical Urethanes: Solvent Effects on Resins*. Cleveland, OH: Noveon; 2004. Available at www.estane.com/technology/MedicalSolventEffects.asp. Accessed July 21, 2004.
18. Reed A, Potter J, Szycher M. A solution grade biostable polyurethane elastomer: Chronoflex AR. *J Biomater Appl* 1994;8:210-236.
19. Medcomp. *Compatibility of Products With Site-Care Agents.* Harleysville, PA: Medcomp; 2004. Available at www.medcompnet.com. Accessed July 21, 2004.
20. Boston Scientific. *Vaxcel PICC With PASV Valve Technology.* Natick, MA: Boston Scientific; 2004. Available at www.bostonscientific.com/med_specialty/deviceDetail.jhtml?task=tskBasicDevice.jhtml&sectionId=4&relId=4,178,179,180&deviceId=13003&uniqueId=MPDB1420. Accessed July 25, 2004.