

Multicenter Study of Contaminated Percutaneous Injuries in Anesthesia Personnel

Elliott S. Greene, M.D.,* Arnold J. Berry, M.D., M.P.H.,† Janine Jagger, M.P.H., Ph.D.,‡ Eileen Hanley, B.A.,§ William P. Arnold III, M.D.,|| Melinda K. Bailey, M.D.,# Morris Brown, M.D.,** Patricia Gramling-Babb, M.D.,†† Anthony N. Passannante, M.D.,‡‡ Joseph L. Seltzer, M.D.,§§ Peter Southorn, M.B., B.S., F.R.C.A.,||| Martha A. Van Clief, M.D.## Richard A. Venezia, Ph.D.***

Background: Anesthesia personnel are at risk for occupational infection with bloodborne pathogens from contaminated percutaneous injuries (CPIs). Additional information is needed to formulate methods to reduce risk.

Methods: The authors analyzed CPIs collected during a 2-yr period at 11 hospitals, assessed CPI underreporting, and estimated risks of infection with human immunodeficiency virus and hepatitis C virus.

Results: Data regarding 138 CPIs were collected: 74% were associated with blood-contaminated hollow-bore needles, 74% were potentially preventable, 30% were considered high-risk

injuries from devices used for intravascular catheter insertion or obtaining blood, and 45% were reported to hospital health services. Corrected for injury underreporting, the CPI rate was 0.27 CPIs per yr per person; per full-time equivalent worker, there were 0.42 CPIs/yr. The estimated average 30-yr risks of human immunodeficiency virus or hepatitis C virus infection per full-time equivalent are 0.049% and 0.45%, respectively. Projecting these findings to all anesthesia personnel in the United States, the authors estimate that there will be 17 human immunodeficiency virus infections and 155 hepatitis C virus infections in 30 yr.

Conclusions: Performance of anesthesia tasks is associated with

This article is featured in "This Month in Anesthesiology." Please see this issue of ANESTHESIOLOGY, page 7A.

* Associate Professor of Anesthesiology, Department of Anesthesiology, Albany Medical College, Albany, New York.

† Professor of Anesthesiology, Department of Anesthesiology, Emory University School of Medicine, Atlanta, Georgia.

‡ Becton Dickinson Professor of Health Care Worker Safety; Professor of Neurosurgery, Department of Neurosurgery, University of Virginia Health Sciences Center, Charlottesville, Virginia.

§ Infection Control Analyst, Department of Epidemiology, Albany Medical Center Hospital, Albany, New York.

|| Associate Professor of Anesthesiology, Department of Anesthesiology, University of Virginia Health Sciences Center, Charlottesville, Virginia.

Associate Professor of Anesthesia and Perioperative Medicine, Medical University of South Carolina, Charleston, South Carolina.

**Professor of Anesthesiology, Wayne State University School of Medicine, Detroit, Michigan.

†† Assistant Professor of Anesthesiology, Department of Anesthesiology, Medical University of South Carolina, Charleston, South Carolina.

‡‡ Assistant Professor of Anesthesiology, Department of Anesthesiology, University of North Carolina at Chapel Hill, Chapel Hill, North Carolina.

§§ Professor and Chairman, Department of Anesthesiology, Jefferson Medical College, Thomas Jefferson University, Philadelphia, Pennsylvania.

||| Associate Professor of Anesthesiology, Department of Anesthesiology, Mayo Clinic, Rochester, Minnesota.

Assistant Professor of Anesthesiology, Department of Anesthesiology, Georgetown University Medical Center, Washington, DC. Current position: Chief of Anesthesia, Washington County Hospital, Hagerstown, Maryland.

***Professor, Department of Pathology and Laboratory Medicine, Albany Medical College, Albany, New York.

Received from Albany Medical Center Hospital, Albany, New York; Emory University School of Medicine, Atlanta, Georgia; University of Virginia Health Sciences Center, Charlottesville, Virginia; Medical University of South Carolina, Charleston County Memorial Hospital, and Veterans Administration Medical Center, Charleston, South Carolina; Mount Sinai Hospital, Detroit, Michigan; University of North Carolina at Chapel Hill, Chapel Hill, North Carolina; Thomas Jefferson University Hospital, Philadelphia, Pennsylvania; Mayo Clinic, Rochester, Minnesota; and Georgetown University School of Medicine, Washington, DC. Submitted for publication October 27, 1997. Accepted for publication July 16, 1998. Supported by a grant from Becton Dickinson and Company, Franklin Lakes, New Jersey. Presented in part at Frontline Health Care Workers: National Conference on Prevention of Sharps Injuries and Bloodborne Exposures, cosponsored by the Centers for Disease Control and Prevention, and the American Conference of Governmental Industrial Hygienists, August 15, 1995, Atlanta, Georgia; The International Anesthesia Research Society 70th Clinical and Scientific Congress, March 12, 1996, Washington, DC; The 16th Congress of the Japanese Society for Clinical Anesthesia, Tokyo, Japan, November 6, 1996.

Address reprint requests to Dr. Greene: Associate Professor of Anesthesiology, Department of Anesthesiology, Albany Medical College, 47 New Scotland Avenue, Albany, New York 12208. Address electronic mail to: elliott_greene@ccgateway.amc.edu

CONTAMINATED PERCUTANEOUS INJURIES IN ANESTHESIA PERSONNEL

CPIs from blood-contaminated hollow-bore needles. Thirty percent of all CPIs would have been high-risk for bloodborne pathogen transmission if the source patients were infected. Most CPIs were potentially preventable, and fewer than half were reported to hospital health services. The results identify devices and mechanisms responsible for CPIs, provide estimates of risk levels, and permit formulation of strategies to reduce risks. (Key words: Needlestick; occupational exposure; sharp device.)

THE risk of occupational infection with bloodborne pathogens depends on (1) the number and type of exposures to patients' blood or body fluids, (2) the prevalence of infected patients in the healthcare worker's practice, and (3) the risk of infection transmission after a pathogen-contaminated exposure.¹ The most efficient route for occupational transmission of human immunodeficiency virus (HIV), hepatitis B virus, and hepatitis C virus (HCV) is through a blood-contaminated percutaneous injury.¹⁻⁶ Although previous studies reported percutaneous injury rates, device-specific risks, and occupational risks of bloodborne infections, most of the healthcare workers were not anesthesia personnel.^{3,6-21} Studies of injuries in anesthesia personnel were based on limited data^{1,10,22-27}; consequently, the accuracy of derived contaminated percutaneous injury (CPI) rates and infection risks is limited, and the ability to formulate specifically targeted prevention strategies for anesthesia practices is restricted.

The current report is a multicenter study of occupational CPIs in anesthesia personnel. We investigated the devices and mechanisms responsible for CPIs, assessed CPI reporting rates, and calculated CPI rates with corrections to compensate for injury underreporting. In addition, we determined the fraction of CPIs that were potentially preventable and estimated the 1-yr and 30-yr risks of occupational infection with HIV or HCV. These data permit formulation of CPI prevention strategies appropriate for the practice of anesthesiology.

Methods

Data from anesthesia personnel (attending anesthesiologists [attendings], anesthesia residents [residents], certified registered nurse anesthetists [CRNAs], and student registered nurse anesthetists [SRNAs]) who experienced CPIs were collected prospectively from Injury Report Forms from mid-1993 (beginning times varied among the hospitals) through July 31, 1995 at 11 university-affiliated hospitals. Data from anesthesiology assistants and student trainees at one hospital were included with CRNA and SRNA data, respectively.

The study protocol was approved by each hospital's human investigation committee. At the beginning of and periodically throughout the investigation, anesthesia personnel were informed about the purpose and design of the study. Personnel with percutaneous injuries were advised to follow their institution's policy on occupational exposures. After initial management of the injury, personnel, who agreed to participate, anonymously completed a prospective Injury Report Form. Because these forms were available in several hospital locations, we compared completed forms to avoid duplicates. Injury Report Forms were included in our study if the device causing injury was contaminated with a patient's blood, other body fluid, or an unknown type of contaminant. To permit confidentiality, we did not investigate the serologic status of source patients and injured personnel. Each hospital's designated study investigator provided additional information about the number of personnel, anesthetics, and devices used during the study. Data and calculations for all hospitals are reported in aggregate form.

A retrospective reporting-rate survey was distributed anonymously to all anesthesia personnel in June 1995 to determine the number of CPIs experienced in the previous 12 months, the proportion of injuries reported to hospital health services, and the average number of hours per week spent in patient-care activities. These data were used to determine the hospital health service reporting rate and the Injury Report Form reporting rate (see appendix 1). Contaminated percutaneous injury rates from prospectively obtained Injury Report Form data were corrected to compensate for injury underreporting, where the corrected CPI rate = [uncorrected CPI rate]/[Injury Report Form reporting rate (%)/100].

An injury that transfers a larger volume of infected blood, blood with a higher viral titer, or both, results in a larger viral inoculum and an increased risk of bloodborne pathogen transmission.⁶ In our analysis of data from the prospective Injury Report Form, an injury was classified as high risk if, based on the purpose of the device, it was likely to have resulted in a larger volume of blood inoculum compared with other types of injuries. Thus, a high-risk CPI was defined as a CPI from a blood-contaminated hollow-bore needle where it was likely that the needle lumen was filled with undiluted blood (*i.e.*, intravascular catheter insertion or obtaining patient blood).

The mathematical model used to estimate 1-yr and 30-yr occupational HIV or HCV infection risks is presented in appendix 2. Our calculations used HIV and HCV seroprevalence rates representative of a wide range

of patient populations^{18,19,28,29} and assume that HIV and HCV seroprevalences in the patient populations do not change in 30 yr. These calculations also used corrected CPI rates from the current study and seroconversion rates of 0.003 HIV infections per HIV-infected CPI⁶ and 0.02 HCV infections per HCV-infected CPI.^{18,30-32}

Necessary sharp devices are used to pierce skin or tissue or for cutting.³³ In contrast, sharp devices not used for these purposes or glass items with nonbreakable alternatives are unnecessary (e.g., standard hypodermic needles used for intravenous tubing access and glass capillary tubes) because safety devices and nonbreakable plastic items are available.³³ By assuming that the only time the sharp part of any device must be exposed is during the use of a necessary device, the number of potentially preventable contaminated percutaneous injuries (PPCPIs) equals (1) CPIs from necessary sharp devices occurring between uses, after use, or related to disposal, but not occurring during use of the devices, plus (2) all CPIs from unnecessary sharp devices, where $PPCPIs (\%) = (PPCPIs \times 100) / (\text{all CPIs})$.³³

Statistical Analysis

Epi Info Version 6 (USD, Stone Mountain, GA) and SAS releases 6.11 and 6.12 (SAS Institute, Cary, NC) were used for data entry and analysis.

Device-specific injury rates (CPIs/100,000 devices used and 95% confidence intervals, corrected for injury underreporting) were calculated for needle devices. The number of CPIs from each hospital was considered to follow a Poisson distribution, so the sum of CPIs from the 11 hospitals is a Poisson count. Because the number of CPIs was small, a 95% confidence interval for each type of needle device was calculated for the Poisson mean for the sum using an exact method.³⁴ Finally, to correct for injury underreporting, the end points of the 95% confidence intervals were divided by the Injury Report Form reporting rate for all personnel combined (%) / 100, and then standardized per 100,000 devices used.

Generalized linear modeling was used for statistical comparison of corrected CPI rates for the four personnel groups. We assumed that the counts followed Poisson distributions because CPIs are statistically rare, but the frequency of occasions when they might occur (use of a sharp device) is high. First, the model assessed for differences of corrected CPI rates among personnel groups without controlling for the effect of different hospitals. Then the data were reanalyzed for differences of corrected CPI rates among personnel groups with the model controlling for hospital as a confounding variable.

Table 1. Contaminated Percutaneous Injuries in Anesthesia Personnel Groups

Anesthesia Personnel Group				
Group	Personnel* (n)	FTE (n)	All CPIs [n (%)]	High-risk CPIs [n (%)]
Residents	372	231.8	73 (53)	18 (43)
Attendings	311	189.1	37 (27)	12 (29)
CRNAs	198	129.6	19 (14)	8 (19)
SRNAs	91	50.5	9 (7)	4 (10)
Total	972	601.0	138 (100)	42 (100)

FTE = full-time equivalents; CPIs = contaminated percutaneous injuries; CRNAs = certified registered nurse anesthetists; SRNAs = student registered nurse anesthetists.

* All full-time and part-time anesthesia personnel.

A significance level of 0.0083 ($\alpha = 0.05/6$) was used to account for multiple comparisons.

Results

All Contaminated Percutaneous Injuries

A total of 138 CPIs were reported in prospectively obtained Injury Report Forms; 125 CPIs were associated with 361,943 anesthetics (903,661 h of anesthesia) and 13 CPIs were associated with an unknown number of nonanesthetic procedures (table 1). Seventy-three percent of CPIs occurred in the operating room, 9% occurred in the preoperative holding area, 5% occurred in the postanesthesia care unit or a procedure room, and 13% occurred in other areas. The source patient was known for 98% of CPIs, and the injured person was the original user of the sharp device for 82%.

Hollow-bore needles caused most injuries, and blood was the predominant contaminant (table 2). Devices that caused CPIs were needles on syringes (41%), intravenous catheter stylets (20%), suture needles (19%), unattached hollow-bore needles (9%), regional anesthesia needles (4%), scalpel blades (3%), and others (4%). The purpose of the sharp device was for intravascular catheter insertion (28%); injection of intradermal local anesthesia (21%); suturing (19%); cutting (9%); intravenous tubing access (7%); administration of spinal, epidural, or caudal anesthesia (5%); peripheral nerve block (4%); obtaining blood (4%); intramuscular or subcutaneous injection (2%); and others (2%). Injuries occurred during use of the device (28%), between steps of a multistep procedure (23%), during or after needle recapping (14%), after the device was used but before disposal (25%), or during disposal (9%). The degree of injury was

CONTAMINATED PERCUTANEOUS INJURIES IN ANESTHESIA PERSONNEL

Table 2. Devices Causing Contaminated Percutaneous Injuries* and Type of Contaminant†

Type of Device	CPIs from Device [n (%)]	Blood-contaminated CPIs from Device [n (%)]
Needle devices	131 (95)	128 (97)
Hollow-bore needles	104 (75)	102 (77)
Solid needles	26 (19)	26 (20)
Unknown type of needle	1 (0.7)	—
Nonneedle devices‡	7 (5)	4 (3)
Total	138	132

CPIs = contaminated percutaneous injuries.

* No CPIs were caused by safety devices.

† A total of 132/138 (96%) CPIs: blood-contaminated devices; 6/138 (4%) CPIs: 1, cerebrospinal fluid (spinal needle); 1, saliva on scissors (potential for blood²⁶); 1, needle for intravenous tubing injection (potential for blood³⁵); 3, unknown type of contaminant.

‡ A total of 4 scalpel blades (blood-contaminated); 3, others.

superficial (little or no bleeding) in 26% (36 of 138) of CPIs, moderate (some bleeding) in 67% (93 of 138), and severe (deep injury with profuse bleeding) in 7% (9 of 138). Seventy-four percent (102 of 138) of CPIs were considered to be potentially preventable. Data regarding CPIs from needle devices, the number of devices used, and device-specific injury rates are presented in table 3.

High-risk Contaminated Percutaneous Injuries

Thirty percent (42 of 138) of CPIs were from blood-contaminated hollow-bore needles used for intravascular catheter insertion (38 of 138) or obtaining blood (4 of 138) and were presumed to be blood filled. Therefore, if the source patients were infected, these CPIs would have been high-risk for transmission of bloodborne pathogens (table 1). The devices included intravenous catheter stylets (60%, 25 of 42), needles on disposable syringes (36%, 15 of 42), and unattached hollow-bore needles (5%, 2 of 42). Fourteen percent (6 of 42) of injuries were superficial, 74% (31 of 42) were moderate, and 12% (5 of 42) were severe. Twenty-six of 31 moderate and all 5 severe injuries were associated with medium- to large-bore needles (22 to 14 gauge). Seventy-nine percent (33 of 42) of high-risk CPIs would have been potentially preventable if safety devices had been used.

Injury Reporting Rates

Retrospective reporting-rate surveys were returned by 500 personnel and indicated that 179 CPIs occurred in the previous 12 months. Survey respondents who in-

curred four CPIs did not answer the question regarding hours worked per week in patient care (used for deriving full-time equivalent [FTE] data). Therefore, for survey data, there were 0.38 CPIs per yr per FTE (*i.e.*, 175 CPIs per yr per 458.6 FTEs; see table 5). The respondents indicated that they reported 45% (81 of 179) of CPIs to the hospital health services for injury management.

During the 12 months assessed in the retrospective Reporting Rate Survey, personnel returned 59 prospective Injury Report Forms. Therefore, for this period, the Injury Report Form CPI rate, not corrected for underreporting, was 0.098 CPIs per yr per FTE (*i.e.*, 59 CPIs per yr per 601 FTEs; using 601 FTEs from table 1). Using CPIs per yr per FTE rates derived from both data collection instruments, our estimate of the prospective Injury Report Form reporting rate for all personnel combined (the percentage of all CPIs incurred for which prospective Injury Report Forms were returned) was 26% [(0.098/0.38) × 100] (see appendix 1). The Injury Report Form reporting rates for each personnel group were 29% for residents, 19% for attendings, 23% for CRNAs, and 64% for SRNAs. Reporting Rate Survey data were insufficient to calculate a reporting rate at each hospital for each personnel group. Therefore, in the generalized linear model analysis, CPI rates for each personnel group at each hospital were corrected for underreporting by using the reporting rate for each personnel group for all hospitals combined.

Contaminated Percutaneous Injury Rates

Corrected CPI rates were 0.27 CPIs per yr per person, 0.42 CPIs per yr per FTE, 1.35 CPIs per 1,000 anesthetics, and 0.54 CPIs per 1,000 h of anesthesia. Injury rates for personnel groups are shown in table 4.

Generalized linear model analysis of corrected CPI rates for the four personnel groups showed that CPI rates were partially dependent on the effect of different hospitals. However, our study was not conducted to investigate variance of CPI rates among different hospitals. When the variance among hospitals was controlled, there was a greater discrimination of CPI rate differences among personnel groups, with the following results. Relative corrected injury rates per person (CPIs per yr per person) were greatest for residents (arbitrarily set to equal 1.0), followed by attendings (0.83), CRNAs (0.41), and SRNAs (0.16). These rates were significantly different when comparing residents and CRNAs ($P = 0.0005$), residents and SRNAs ($P \leq 0.0001$), and attendings and SRNAs ($P \leq 0.0001$; table 4). The difference between rates for attendings and CRNAs approached statistical

Table 3. Contaminated Percutaneous Injuries from Needle Devices, Number of Devices Used, and Device-specific Injury Rates

Type of Device	CPIs (n)	Corrected CPIs* (n)	Devices Used (total for entire study period) (n)	Corrected CPIs/100,000 Devices Used* [n (95% CI)]†
Needle on syringe				
Disposable syringe	55	211.54	1,512,411	13.99 (10.54–18.21)
Prefilled cartridge	1	3.85	112,016	3.43 (0.087–19.13)
Arterial blood gas	0	0	5,251	0 (0.00–219.43)
Other type	1	3.85	79,663	4.83 (0.12–26.90)
Intravascular device				
IV catheter	27	103.85	541,395	19.18 (12.64–27.91)
Winged needle ("butterfly")	0	0	6,507	0 (0.00–177.07)
Suture needle	26	100.00	45,393	220.30 (143.91–322.79)
Unattached hollow-bore needle	13	50.00	2,391,430	2.09 (1.11–3.58)
Nerve block needle	4	15.38	8,206	187.48 (51.08–480.02)
Epidural needle	1	3.85	48,610	7.91 (0.20–44.08)
Spinal needle	1	3.85	38,129	10.09 (0.26–56.20)
IV infusion connection needle	1	3.85	13,608	28.26 (0.72–157.48)
Others	1	—	17,095	—
Total	131	503.87	4,819,714‡	—

CPIs = contaminated percutaneous injuries; IV = intravenous.

* Corrected for CPI underreporting.

† The 95% confidence interval for mean corrected CPIs/100,000 devices.

‡ A total of 2,380,130 devices/yr. The number of devices used does not include any safety devices.

significance ($P = 0.0141$). Relative corrected injury rates per FTE (CPIs per yr per FTE) were greatest for residents (arbitrarily set to equal 1.0), followed by attendings (0.67), CRNAs (0.23), and SRNAs (0.08). These rates were significantly different when comparing residents and CRNAs ($P \leq 0.0001$), residents and SRNAs ($P \leq 0.0001$), attendings and CRNAs ($P = 0.0002$), and attendings and SRNAs ($P \leq 0.0001$; table 4).

Estimated 1-yr and 30-yr Risks of HIV or HCV Infection from Percutaneous Injuries

For patient populations with low (0.1%), average (1.3%), and high (25%) seroprevalence of HIV infection,

the estimated 1-yr risks of HIV infection per FTE are 0.00013%, 0.0016%, and 0.032%, respectively, and the 30-yr risks are 0.0038%, 0.049%, and 0.94%, respectively (fig. 1). For patient populations with low (0.1%), average (1.8%), and high (25%) seroprevalence of HCV infection, the estimated 1-yr risks of HCV infection per FTE are 0.00084%, 0.015%, and 0.21%, respectively, and the 30-yr risks are 0.025%, 0.45%, and 6.12%, respectively (fig. 1). These calculations used 0.42 CPIs per yr per FTE (table 4). When our infection risk model is applied to the 56,208 anesthesia personnel in the United States (using corrected CPIs per yr per person data from table 4), we estimate a rate of 0.56 HIV infections per yr and 5.18

Table 4. Contaminated Percutaneous Injury Rates

CPI Rate	Anesthesia Personnel				
	All	Residents	Attendings	CRNAs	SRNAs
CPIs/yr/person	0.070	0.096	0.060	0.048	0.050
Corrected CPIs/yr/person*†	0.27	0.33	0.31	0.21	0.077
CPIs/yr/FTE	0.11	0.15	0.098	0.073	0.089
Corrected CPIs/yr/FTE*‡	0.42	0.53	0.52	0.32	0.14

CPIs = contaminated percutaneous injuries; FTE = full-time equivalent; CRNAs = certified registered nurse anesthetists; SRNAs = student registered nurse anesthetists.

* Corrected for Injury Report Form reporting rates.

Generalized linear model analysis indicates significant differences comparing the following:

† Residents and CRNAs ($P = 0.0005$), residents and SRNAs ($P \leq 0.0001$), and attendings and SRNAs ($P \leq 0.0001$);

‡ Residents and CRNAs ($P \leq 0.0001$), residents and SRNAs ($P \leq 0.0001$), attendings and CRNAs ($P = 0.0002$), and attendings and SRNAs ($P \leq 0.0001$).

CONTAMINATED PERCUTANEOUS INJURIES IN ANESTHESIA PERSONNEL

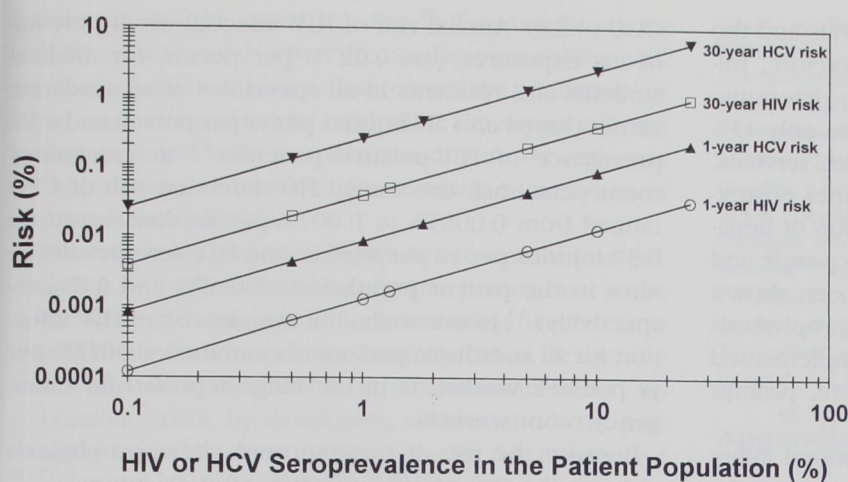


Fig. 1. Estimated 1-yr and 30-yr risks of human immunodeficiency virus (HIV) or hepatitis C virus (HCV) infection in a full-time equivalent anesthesia worker as a function of HIV or HCV seroprevalence in the patient population. The calculations for estimated risks assume that (1) 0.42 contaminated percutaneous injuries (CPIs) per yr per full-time equivalent (CPI rate for all personnel combined, corrected for the 26% reporting rate: table 4), (2) 0.003 HIV infections per HIV-infected CPI,⁶ (3) 0.02 HCV infections per HCV-infected CPI,^{18,30-32} and (4) the HIV or HCV seroprevalence in the patient population does not change in 30 yr. These data are not adjusted for (1) potential decreased CPI rates resulting from increased use of safety devices and other precautions taken, (2) a decreased HIV

seroconversion rate from postexposure chemoprophylaxis,^{6,37-39} or (3) a decreased HCV seroconversion rate if postexposure anti-HCV therapy is developed in the future. The graphs also illustrate several selected points for HIV and HCV seroprevalence rates in representative patient populations (0.1%, 0.5%, 1%, 5%, 10%, and 25%).^{18,19,28,29} In addition, in the United States, the average HIV seroprevalence rate in the patient population is 1.3%,²⁸ and the average HCV seroprevalence rate for the general population is 1.8% (the average HCV seroprevalence in the patient population is not available; personal oral communication, October 25, 1996, M. Alter, PhD; CDC).

HCV infections per yr, with 17 HIV infections and 155 HCV infections expected in 30 yr.

Use of Safety Devices

At least one type of needleless or shielded needle safety device was being used at nine hospitals during the study. A total of 392,946 safety devices were used per year (362,902 intravenous access devices [e.g., three-way stopcocks, Luer lock valves, recessed needles] at nine hospitals, plus 30,000 intravenous catheters and 24 phlebotomy devices at one of these hospitals and 20 syringes at another). No CPIs involved safety devices.

Discussion

The Centers for Disease Control and Prevention (CDC) have identified significant risk factors for occupationally acquired HIV infections after percutaneous exposure to HIV-infected blood. These include (1) a deep injury, (2) a device visibly contaminated with the source patient's blood, (3) a procedure involving a needle placed directly in the source patient's vein or artery, and (4) exposure to a source patient who died of acquired immunodeficiency syndrome within 2 months.⁶ Although the average risk of HIV infection after all types of reported percutaneous exposures to HIV-infected blood is 0.3%, the risk, although not quantified, exceeds 0.3% for an exposure involving a greater infectious dose resulting from transfer of a larger

blood volume, a higher HIV titer in the source patient's blood, or both.⁶

Our definition of a high-risk CPI is consistent with one of the four significant risk factors identified by the CDC but did not include all severe CPIs or visibly contaminated devices (not queried on the Injury Report Form). In addition, we did not determine the source patient's infection status. Therefore, at least four more CPIs would have been high-risk if we had included all severe CPIs and had gathered information to assess for the two other criteria identified by the CDC. Our finding that 30% of all CPIs in anesthesia personnel are high risk is comparable to the 25% rate reported from a nationwide study that included all hospital personnel.¹⁹ In contrast, a previous study²⁷ reported that only 0.55% of injuries in nonanesthesia operating room personnel were high risk. Our data emphasize the unique risk profile of anesthesia personnel compared with others working in the operating room.

The Injury Report Form reporting rate permitted correction of CPI rates obtained from prospective data, and thereby provided better estimates of true CPI rates. Reporting rates in other studies of percutaneous injuries range from 3% to 71%.^{1,19,36} Because nonreporting of injuries is notoriously common, any data analysis that does not consider underreporting would underestimate the true number and rate of injuries and the risk of occupational infection. Because personnel may be more likely to report high-risk or severe injuries, these could be overrepresented in our data, but this source of bias

was not assessed. Both the Injury Report Forms and the retrospective surveys were anonymous; therefore, follow-up questionnaires could not be used to determine factors associated with the responses. Because only 45% of all CPIs were reported to employee health services, most injured personnel failed to receive proper postexposure treatment. Postexposure administration of hepatitis B immunoglobulin for hepatitis B virus exposure and chemoprophylaxis for HIV exposure have been shown to be effective.^{4,6,37-39} Postexposure chemoprophylaxis for HIV is most likely to be effective when implemented as soon after exposure as possible; therefore, prompt reporting and follow-up of CPIs is essential.^{6,37-39}

Compared with our data, other studies reported injury rates of 4.2 CPIs per 1,000 h in the operating room for surgeons,¹² 0.95 CPIs per yr per medical student in an emergency medicine clerkship,¹³ 1.87 CPIs per yr per person for residents and medical students during a training year,¹⁴ and 0.37 CPIs per yr per emergency room worker.¹⁵ This suggests that the overall CPI rate for anesthesia personnel is not greater than that for other workers. Because we investigated CPIs at university-affiliated hospitals, we do not know whether our findings can be generalized to anesthesia practices in community hospitals.¹⁹

The rate of CPIs per yr per FTE was statistically greater for residents or attendings than for CRNAs or SRNAs, with residents having the greatest relative rate. Previous reports documented needlestick injuries in residents in various hospital departments,^{14,16,17,23} but none has compared injury rates of anesthesia residents with the rates of other anesthesia personnel. All personnel performing procedures involving sharp devices require adequate training and supervision so they learn appropriate work practices to minimize injuries.

Several studies assessed HIV infection risks in health-care personnel, but those results may vary from ours because of differences in one or more of the following variables pertinent to the calculations: method of data collection, verification that each injury was from a contaminated device, personnel category used for denominator data, injury rate used and correction for injury underreporting, infection prevalence rates in the source patient populations, and seroconversion rate used for a pathogen-contaminated exposure. In a previous report,²² the estimated 30-yr HIV infection risks in anesthesia personnel, for clinical conditions relevant to our study, were approximately four times greater than our risk estimates, but they used 1.3 injuries per yr per worker and a higher seroconversion rate per HIV-infected CPI (0.42%) than established currently by the

CDC (0.3%). Annual risk of HIV infection from percutaneous exposures was 0.027% per person for medical students and residents in all specialties at an academic center (based on 1.87 injuries per yr per person and a 5% prevalence of HIV-positive patients).¹⁴ In emergency room personnel, the annual HIV infection risk of CPIs ranged from 0.0005% to 0.007% per worker (based on 0.37 injuries per yr per worker and HIV seroprevalence rates in the patient population of 0.47% and 6.7%, respectively).¹⁵ In our study, the average risk of HIV infection for all anesthesia personnel combined, 0.0016% per yr per FTE worker, is in the range reported for emergency room workers.

Because the use of postexposure chemoprophylaxis reduces the risk of HIV infection after an injury,^{6,37-39} greater use of these regimens should reduce future risk. Because CPI rates have been shown to decrease with the use of safety devices,^{36,40-44} widespread implementation of various safety devices and other precautions should reduce the risk of occupational infections from all bloodborne pathogens. Our study did not consider infection risk from nonpercutaneous exposures, such as blood contact with mucous membranes or nonintact skin. Inclusion of these events would increase the estimated number of infections. The risk of hepatitis B virus in unvaccinated anesthesia personnel has been well documented, and the hepatitis B vaccine has been shown to be safe and effective and is recommended for anesthesia personnel.^{1,4,18,45} Several recent surveys indicate that approximately 78% of anesthesiologists have been vaccinated against hepatitis B virus,^{23,24} and we expect that the proportion of unvaccinated anesthesia personnel will continue to decrease. No vaccine or postexposure prophylaxis are available to prevent HCV infection.³⁰

Although recapping injuries in nonanesthesia personnel have decreased from 33% in 1986⁸ to 4% in 1994-95,⁴¹ we found that 14% of CPIs were related to recapping. Although our Injury Report Form did not query for this information, many of these injuries probably were attributable to two-handed recapping. When recapping is necessary, a one-hand technique or use of a mechanical device is recommended.⁴⁶

Injuries from contaminated solid suture needles may be associated with a lower rate of disease transmission than hollow-bore needles, but our data indicate that they represent a significant proportion of CPIs in anesthesia personnel. Although the injury rate for straight suture needles is more than seven times the rate associated with conventional instrument-held curved suture needles,⁴⁷ intravascular cannulation kits commonly contain

CONTAMINATED PERCUTANEOUS INJURIES IN ANESTHESIA PERSONNEL

hand-held straight suture needles.⁴⁸ If a straight suture needle must be used, when the needle is passed through tissue, it should not be directed toward the nondominant hand, and it should not be held while the suture is being tied. Needleless adhesive skin attachment devices may be appropriate alternatives for securing some types of intravascular catheters.

The rate of injuries from sharp devices and the associated risk of exposure to bloodborne pathogens can be reduced by use of safety devices, including needleless or shielded needle devices, by better product design, by restricting sharp device use to situations in which no alternative exists, by developing safer methods for procedures involving sharp devices, and by use of standard precautions.^{1,8,19,25,27,33,36,40-44,46-51} Many safety devices that have shown effectiveness are marketed,^{36,40-44} and others are continually being developed and improved. Although safety devices do not exist for use in all types of procedures performed during the practice of anesthesiology,^{1,51} practitioners should evaluate available safety devices as possible replacements for the sharp devices they use that lack safety features.

In conclusion, most CPIs in anesthesia personnel were from blood-contaminated hollow-bore needles. The largest categories of CPIs were related to intravascular catheter insertion, injection of intradermal local anesthesia, and suturing of intravascular catheters. Nearly one third of CPIs were high-risk injuries related to intravascular catheter insertion or obtaining blood. Most CPIs were potentially preventable, and fewer than half were reported to hospital health services for follow-up care. If the risk levels observed in our study remain constant, the estimated average 30-yr risks of HIV or HCV infection from percutaneous injuries for an FTE anesthesia worker are 0.049% and 0.45%, respectively. Risks to anesthesia personnel could be greatly reduced by eliminating the use of unnecessary sharp devices, reducing the use of necessary sharp devices to a minimum, and increasing the use of safety devices, including needleless or shielded needle devices and protective barriers. Anesthesia personnel should follow standard precautions and promptly report percutaneous injuries and other types of blood or body fluid exposures for appropriate postexposure treatment. Future surveillance studies should be directed toward assessing the efficacy of injury prevention devices and strategies.

The authors thank the following persons for their contributions to this study: from the Albany Medical Center Hospital: Gregory Lees, Chief Anesthesia Technician, Department of Anesthesiology; Kevin Reilly, M.D., Department of Emergency Medicine; from the Employee

Health Service: Alwin Steinmann, M.D., Karen Putnam, R.P.A., Ari Fisher, P.A.-C., Andrea Fisher, P.A.-C., Denise Lisi, P.A.-C., and Kathleen Van Bramer; Jeanne Culver, B.S., R.N., C.O.H.N., Director of Employee Health, Emory University School Medicine; Beverly Henderson, R.N., Preventative Medicine/Employee Health Services, Mayo Clinic; Jane Ellickson, Department of Anesthesiology, Medical University of South Carolina, Charleston, South Carolina; and Geri Mitchell, R.N., B.S.N., M.S.A., Department of Anesthesiology, Mt. Sinai Hospital, Detroit, Michigan. For the statistical analysis the authors thank Virginia G. Rovnyak, Ph.D., Research Scientist in the Nursing School and Shyamal Peddada, Ph.D., Associate Professor of Statistics from the Division of Statistics, both at the University of Virginia, Charlottesville, Virginia. The authors also thank Melanie B. Bentley, Statistical Analyst at the International Health Care Worker Safety Center, University of Virginia.

Appendix 1: Definitions

Anesthesia Personnel

Anesthesia personnel includes all full-time and part-time personnel involved in patient-care activities with a potential risk for blood or body fluid exposure *via* contaminated sharp objects (e.g., one full-time person plus one half-time person equals a total of two personnel).

Full-time Equivalents

For Injury Report Form data, the number of FTEs was provided by the study investigators and is the number of anesthesia personnel working on an average weekday in the multicenter study hospitals (e.g., one full-time person plus one half-time person equals 1.5 FTEs). In contrast, the Reporting Rate Survey's FTE count was derived from data regarding hours worked per week in patient-care activities on returned Reporting Rate Survey questionnaires (this also includes any work at night, during weekends, or at hospitals not included in the multicenter study). Because we do not have an exact relation between the study investigators' FTE count and the Reporting Rate Survey's FTE count, we adjusted for the different methods used to obtain FTEs as follows. For Reporting Rate Survey data, we defined one FTE as ≥ 40 h/week worked, and < 1 FTE as < 40 h/week (e.g., 40 h/week = 1 FTE, 60 h/week = 1 FTE, 20 h/week = 0.5 FTE). These definitions permit a comparison of CPIs per yr per FTE from the Injury Report Forms to CPIs per yr per FTE from the Reporting Rate Survey.

Reporting Rates

Hospital Health Service Reporting Rate. The hospital health service reporting rate was calculated from Reporting Rate Survey data and equals the number of CPIs that survey respondents indicated they reported to hospital health services divided by the total number of CPIs that the respondents indicated they actually sustained in the 1-yr survey period.

Injury Report Form Reporting Rate. Because it was likely that injured personnel would not report all CPIs *via* prospective Injury Report Forms, the Injury Report Form reporting rate was calculated as follows. For the Reporting Rate Survey respondents, CPIs per yr per FTE equals the sum of CPIs in the survey (CPIs/yr) divided by the number of FTEs (where FTEs equals [the number of survey respondents working ≥ 40 h/week] plus [(the sum of hours worked for respondents working < 40 h per week)/40]). For the prospectively obtained Injury Report Form data, the number of CPIs (for the same 12-month interval as the Reporting Rate Survey) divided by the number of FTEs equals CPIs per yr per FTE not corrected for underreporting. The ratio of these two CPIs per yr per FTE

Table 5. Retrospective Reporting Rate Survey Data*

Type of Data	Anesthesia Personnel				
	All	Residents	Attendings	CRNAs	SRNAs
All survey respondents (n = 500)					
Number of surveys returned/number distributed†	500/959	140/372	190/310	118/191	37/86
	52%	38%	61%	62%	43%
CPIs/12 mo	179	59	78	35	5
CPIs reported to hospital health services	81/179	27/59	32/78	17/35	4/5
	45%	46%	41%	49%	80%
Survey respondents who provided hours worked per week data (n = 490)‡					
Survey respondents (n)§	490	133	190	117	36
Hours worked/(week in patient care activities)/survey respondent					
Mean	45.6	58.8	43.4	37.0	36.5
Median	40	60	40	40	40
Range	8-100	10-100	8-90	8-90	20-50
FTEs (n)	458.6	131.4	175.6	106.5	32.1
CPIs/12 mo	175	55	78	35	5
CPIs/yr/FTE	0.38	0.42	0.44	0.33	0.16

CPIs = contaminated percutaneous injuries; FTEs = full-time equivalents; CRNAs = certified registered nurse anesthetists; SRNAs = student registered nurse anesthetists.

* Data are for all CPIs (the survey did not query whether CPIs were high-risk or non-high-risk).

† A total of 959 personnel were working when the survey was distributed; 15 survey respondents, accounting for two CPIs, did not indicate personnel category.

‡ A total of 490 of 500 respondents answered the survey question on hours worked per week.

§ A total of 14 survey respondents with hours worked/week data answered did not indicate personnel category.

rates equals the Injury Report Form reporting rate, where Injury Report Form reporting rate (%) = (CPIs per yr per FTE from Injury Report Form data) \times 100/(CPIs per yr per FTE from Reporting Rate Survey data).

Appendix 2: Mathematical Model Used to Determine 1-yr and 30-yr Risks of HIV or HCV Infection from Percutaneous Injuries

The probability of an occupationally acquired HIV infection from percutaneous injuries in an FTE anesthesia worker in 1 yr, p_{HIV1} , is $p_{HIV1} = 1 - (1 - p_{S1CPI})^N$, where p_{S1CPI} is the probability of seroconversion from 1 CPI, where p_{S1CPI} = (seroprevalence of HIV-infected patients in the hospital's patient population) \times (probability of seroconversion from one percutaneous exposure to HIV-infected blood, 0.3%), and N = corrected CPIs per yr per FTE (table 4).^{21,52} Assuming the three determinants of p_{HIV1} remain unchanged over time, the probability of an HIV infection in 30 yr, p_{HIV30} , is $p_{HIV30} = 1 - (1 - p_{S1CPI})^{30N}$. Similarly, we calculated the 1-yr and 30-yr risks of HCV infection using 2% as the average risk of seroconversion from one percutaneous exposure to HCV-infected blood.^{18,30-32}

The estimated numbers of occupationally acquired HIV and HCV infections in 1 yr and 30 yr were calculated for the 56,208 anesthesia personnel in the United States. This was calculated based on the number of active members of the American Society of Anesthesiologists: 22,828 attendings and 4,858 residents,^{†††} and 23,174 CRNAs, 2,727 recent nurse anesthetist

graduates, and 2,051 SRNAs (personal oral communication, June 2, 1997, American Association of Nurse Anesthetists, May 1997 data), and 500 anesthesiology assistants and 70 student anesthesiology assistants (personal communication, National Commission for Certification of Anesthesiology Assistants, July 1997 data). The average HIV seroprevalence in patient populations in the United States (1.3%) was used.²⁸ Because corrected CPIs per yr per person differ among personnel groups (table 4), the estimated probability of infection per person also differs among personnel groups. For each group, the expected number of HIV infections in 1 yr equals the probability of HIV infection per yr per person times the number of personnel in the group; the sum of infections for all groups equals the total expected for US anesthesia personnel. Similarly, the estimated number of HIV infections in the United States for a 30-yr period equals the probability of HIV infection per 30 yr per person times the number of personnel in each group, summed for all groups (this calculation assumes the same number of personnel in each group during the 30 yr). Data for HCV infections were calculated analogously (with 1.8% as the average HCV seroprevalence in the US general population [personal oral communication, October 25, 1996, M. Alter, Ph.D., at the CDC]).

References

1. Berry AJ, Greene ES: The risk of needlestick injuries and needlestick-transmitted diseases in the practice of anesthesiology. *ANESTHESIOLOGY* 1992; 77:1007-21
2. Centers for Disease Control: Guidelines for prevention of transmission of human immunodeficiency virus and hepatitis B virus to health-care and public-safety workers. *MMWR Morb Mortal Wkly Rep* 1989; 38(S-6):3-37

††† American Society of Anesthesiologists: Newsletter, May 1997; 61(5):31

CONTAMINATED PERCUTANEOUS INJURIES IN ANESTHESIA PERSONNEL

3. Marcus R, CDC Cooperative Needlestick Surveillance Group: Surveillance of health care workers exposed to blood from patients infected with the human immunodeficiency virus. *N Engl J Med* 1988; 319:1118-23
4. Centers for Disease Control: Protection against viral hepatitis: recommendations of the Immunization Practices Advisory Committee (ACIP). *MMWR Morb Mortal Wkly Rep* 1990; 39(RR-2):1-26
5. Centers for Disease Control: Public health service inter-agency guidelines for screening donors of blood, plasma, organs, tissues, and semen for evidence of hepatitis B and hepatitis C. *MMWR Morb Mortal Wkly Rep* 1991; 40:1-17
6. Cardo DM, Culver DH, Ciesielski C, Srivastava PU, Marcus R, Abiteboul D, Heptonstall J, Ippolito G, Lott F, McKibben PS, Bell DM, Centers for Disease Control and Prevention, and Needlestick Surveillance Group: A case-control study of HIV seroconversion in health care workers after percutaneous exposure. *N Engl J Med* 1997; 337:1485-90
7. Ippolito G, DeCarli G, Puro V, Petrosillo N, Arici C, Bertucci R, Bianciardi L, Bonazzi L, Cestroni A, Daglio M, Desperati M, Francesconi M, Migliori M, Monti A, Perna MC, Pietrobon F, Jagger J: Device-specific risk of needlestick injury in Italian health care workers. *JAMA* 1994; 272:607-10
8. Jagger J, Hunt EH, Brand-Elnaggar J, Pearson RD: Rates of needlestick injury caused by various devices in a university hospital. *N Engl J Med* 1988; 319:284-8
9. Tokars JL, Bell DM, Culver DH, Marcus R, Mendelson MH, Sloan EP, Farber BF, Fligner D, Chamberland ME, McKibben PS, Martone WJ: Percutaneous injuries during surgical procedures. *JAMA* 1992; 267:2899-904
10. Patel N, Tignor GH: Device-specific sharps injury and usage rates: An analysis by hospital department. *Am J Infect Control* 1997; 25:77-84
11. McCormick RD, Meisch MG, Ircink FG, Maki DG: Epidemiology of hospital sharps injuries: A 14-year study in the pre-AIDS and AIDS eras. *Am J Med* 1991; 91(suppl 3B):301S-7S
12. Lowenfels AB, Wormser GP, Jain R: Frequency of puncture injuries in surgeons and estimated risk of HIV infection. *Arch Surg* 1989; 124:1284-6
13. Koenig S, Chu J: Medical student exposure to blood and infectious body fluids. *Am J Infect Control* 1995; 23:40-3
14. O'Neill TM, Abbott AV, Radecki SE: Risk of needlesticks and occupational exposures among residents and medical students. *Arch Intern Med* 1992; 152:1451-6
15. Marcus R, Culver DH, Bell DM, Srivastava PU, Mendelson MH, Zalenski RJ, Farber B, Fligner D, Hassett J, Quinn TC, Schable CA, Sloan EP, Tsui P, Kelen GD: Risk of human immunodeficiency virus infection among emergency department workers. *Am J Med* 1993; 94:363-70
16. McGeer A, Simor AE, Low DE: Epidemiology of needlestick injuries in house officers. *J Infect Dis* 1990; 162:961-4
17. Heald AE, Ransohoff DF: Needlestick injuries among resident physicians. *J Gen Intern Med* 1990; 5:389-93
18. Short LJ, Bell DM: Risk of occupational infection with blood-borne pathogens in operating and delivery room settings. *Am J Infect Control* 1993; 21:343-50
19. Ippolito G, Puro V, Petrosillo N, Pugliese G, Wispelwey B, Tereskerz PM, Bentley M, Jagger J: Prevention, Management & Chemoprophylaxis of Occupational Exposure to HIV. Charlottesville, International Health Care Worker Safety Center, University of Virginia, 1997, pp 6-25, 44-60
20. Gerberding JL, Littell C, Tarkington A, Brown A, Schecter WP: Risk of exposure of surgical personnel to patients' blood during surgery at San Francisco General Hospital. *N Engl J Med* 1990; 322:1788-93
21. McKinney WP, Young MJ: The cumulative probability of occupationally-acquired HIV infection: The risks of repeated exposures during a surgical career. *Infect Control Hosp Epidemiol* 1990; 11:243-7
22. Buegler JM, Kim R, Thisted RA, Cohn SJ, Lichter JL, Roizen MF: Risk of human immunodeficiency virus in surgeons, anesthesiologists, and medical students. *Anesth Analg* 1992; 75:118-24
23. Rosenberg AD, Bernstein DB, Bernstein RL, Skovron ML, Ramanathan S, Turndorf H: Accidental needlesticks: Do anesthesiologists practice proper infection control precautions? *Am J Anesthesiol* 1995; 22:125-32
24. Tait AR, Tuttle DB: Prevention of occupational transmission of human immunodeficiency virus and hepatitis B virus among anesthesiologists: A survey of anesthesiology practice. *Anesth Analg* 1994; 79:623-8
25. Berry AJ: The use of needles in the practice of anesthesiology and the effect of a needleless intravenous administration system. *Anesth Analg* 1993; 76:1114-9
26. Kristensen MS, Sloth E, Jensen TK: Relationship between anesthetic procedure and contact of anesthesia personnel with patient body fluids. *ANESTHESIOLOGY* 1990; 73:619-24
27. Greene ES, Berry AJ, Arnold WP, Jagger J: Percutaneous injuries in anesthesia personnel. *Anesth Analg* 1996; 83:273-8
28. St. Louis ME, Rauch KJ, Peterson LR, Anderson JE, Schable CA, Dondro TJ, The Sentinel Hospital Surveillance Group: Seroprevalence rates of human immunodeficiency virus infection at sentinel hospitals in the United States. *N Engl J Med* 1990; 323:213-8
29. Kelen GD, Green GB, Purcell RH, Chan DW, Qaqish BF, Sivertson KT, Quinn TC: Hepatitis B and hepatitis C in emergency department patients. *N Engl J Med* 1992; 326:1399-404
30. Centers for Disease Control and Prevention: Recommendations for follow-up of health-care workers after occupational exposure to hepatitis C virus. *MMWR Morb Mortal Wkly Rep* 1997; 46:603-6
31. Puro V, Petrosillo N, Ippolito G, Jagger J: Hepatitis C virus infection in health care workers (letter). *Infect Control Hosp Epidemiol* 1995; 16:324-5
32. Lanphear BP, Linnemann CC, Cannon CG, DeRonde MM, Pendy L, Kerley LM: Hepatitis C virus infection in health care workers: Risk of exposure and infection. *Infect Control Hosp Epidemiol* 1994; 15:745-50
33. Jagger J: Risky procedures, risky devices, risky job. *Adv Exposure Prev* 1994; 1:4-9
34. Blum J, Rosenblatt J: Probability and Statistics. Philadelphia, WB Saunders, 1972, pp 343-4
35. Manian FA, Meyer L, Jenne J: Puncture injuries due to needles removed from intravenous lines: Should the source patient routinely be tested for bloodborne infections? *Infect Control Hosp Epidemiol* 1993; 14:325-30
36. Centers for Disease Control and Prevention: Evaluation of safety devices for preventing percutaneous injuries among health-care workers during phlebotomy procedures—Minneapolis-St. Paul, New York City, and San Francisco, 1993-1995. *MMWR Morb Mortal Wkly Rep* 1997; 46:21-5
37. Centers for Disease Control and Prevention: Update: Provisional public health service recommendations for chemoprophylaxis after

- occupational exposure to HIV. *MMWR Morb Mortal Wkly Rep* 1996; 45:468-72
38. Gerberding JL: Prophylaxis for occupational exposure to HIV. *Ann Intern Med* 1996; 125:497-501
39. Centers for Disease Control and Prevention: Public health service guidelines for the management of health-care worker exposures to HIV and recommendations for postexposure prophylaxis. *MMWR* 1998; 47(RR-7):1-33
40. ECRI: Needlestick-prevention devices. *Health Devices* 1994; 23: 316-69
41. Jagger J: Reducing occupational exposure to blood-borne pathogens: Where do we stand a decade later (editorial)? *Infect Control Hosp Epidemiol* 1996; 17:573-5
42. Gartner K: Impact of a needleless intravenous system in a university hospital. *Am J Infect Control* 1992; 20:75-9
43. Yassi A, McGill ML, Khokhar JB: Efficacy and cost-effectiveness of a needleless intravenous access system. *Am J Infect Control* 1995; 23:57-64
44. Younger B, Hunt EH, Robinson C, McLemore C: Impact of a shielded safety syringe on needlestick injuries among health care workers. *Infect Control Hosp Epidemiol* 1993; 13:349-53
45. Lemon SM, Thomas DL: Vaccines to prevent viral hepatitis. *N Engl J Med* 1997; 336:196-204
46. Occupational Safety and Health Administration: Occupational exposure to bloodborne pathogens; final rule (29 CFR Part 1910.1030). *Federal Register* 1991; 56:64004-182
47. Centers for Disease Control and Prevention: Evaluation of blunt suture needles in preventing percutaneous injuries among health-care workers during gynecologic surgical procedures—New York City March 1993–June 1994. *MMWR Morb Mortal Wkly Rep* 1997; 46:25-9
48. Tomkins DP, Van Der Walt JH: Needleless and sharp-free anaesthesia. *Anaesth Intensive Care* 1996; 24:164-8
49. Simpkins SM, Haiduvan DJ, Stevens DA: Safety product evaluation: Six years of experience. *Am J Infect Control* 1995; 23:317-22
50. Garner JS, Hospital Infection Control Practices Advisory Committee: Guideline for isolation precautions in hospitals. *Infect Control Hosp Epidemiol* 1996; 17:53-80
51. Berry AJ: Injury prevention in anesthesiology. *Surg Clin North Am* 1995; 75:1123-32
52. Ross S: *Introduction to Probability and Statistics for Engineers and Scientists*. New York, Wiley, 1987, p 28