ORIGINAL ARTICLE

Fatigue Increases the Risk of Injury From Sharp Devices in Medical Trainees: Results From a Case-Crossover Study

David N. Fisman, MD, MPH; Anthony D. Harris, MD, MPH; Michael Rubin, MD, PhD; Gary S. Sorock, PhD; Murray A. Mittleman, MD, DrPH

BACKGROUND. Extreme fatigue in medical trainees likely compromises patient safety, but regulations that limit trainee work hours have been controversial. It is not known whether extreme fatigue compromises trainee safety in the healthcare workplace, but evidence of such a relationship would inform the current debate on trainee work practices. Our objective was to evaluate the relationship between fatigue and workplace injury risk among medical trainees and nontrainee healthcare workers.

DESIGN. Case-crossover study.

SETTING. Five academic medical centers in the United States and Canada.

PARTICIPANTS. Healthcare workers reporting to employee healthcare clinics for evaluation of needlestick injuries and other injuries related to sharp instruments and devices (sharps injuries). Consenting workers completed a structured interview about work patterns, time at risk of injury, and frequency of fatigue.

RESULTS. Of 350 interviewed subjects, 109 (31%) were medical trainees. Trainees worked more hours per week ($P < .001$) and slept less the night before an injury ($P < .001$) than did other healthcare workers. Fatigue increased injury risk in the study population as a whole (incidence rate ratio [IRR], 1.40 [95% confidence interval {CI}, 1.03-1.90]), but this effect was limited to medical trainees (IRR, 2.94 [95% CI, 1.71-5.07]) and was absent for other healthcare workers (IRR, 0.97 [95% CI, 0.66-1.42]) ($P = .001$).

CONCLUSIONS. Long work hours and sleep deprivation among medical trainees result in fatigue, which is associated with a 3-fold increase in the risk of sharps injury. Efforts to reduce trainee work hours may result in reduced risk of sharps-related injuries among this group.

Infect Control Hosp Epidemiol 2007; 28:10-17

Long work hours and extreme fatigue are common among interns and residents engaged in postgraduate medical and surgical training.[1-3] Fatigue resulting from such work practices is associated with decreased memory and cognition and with poor performance on multistep tasks by trainees.[4-7] Consequently, sleep deprivation and fatigue have been invoked as possible causative factors for medical errors committed by trainees and for motor vehicle accidents involving medical trainees.[8,9]

Although the causal roles played by sleep deprivation and fatigue in such incidents have not been definitively established, economic sectors that seek to minimize error occurrence (eg, commercial aviation) have regulated work hours for employees in an effort to prevent catastrophic errors caused by fatigue.[10-12] Recommendations that trainee work hours be limited, to reduce the risk of error occurrence, have been extant for approximately 20 years and have recently been mandated by the Accreditation Council on Graduate Medical Education (ACGME).[13] A recent randomized trial found that decreasing the length of interns' shifts in intensive care units decreased the incidence of serious medical errors, a finding that supports the ACGME recommendations.[8]

However, such restrictions have been controversial among the academic medical community, because of their potential economic impact and their potential negative impact on the educational experience of trainees.[1,14-16] For example, it has been argued that "night-float" systems and shift-based schedules reduce interactions between trainees and faculty, dilute the sense of camaraderie felt by trainees, and disrupt continuity of care.[17,18] A more definitive establishment of whether fatigue is a causal factor in adverse medical events would do much to inform this debate.[10]

Injuries caused by needles and other sharp medical instruments and devices (hereafter, "sharps-related injuries") are a major source of morbidity and economic cost in the healthcare environment. It has been estimated that 400,000-

From the Drexel University School of Public Health, Philadelphia, Pennsylvania (D.N.F.), the University of Maryland (A.D.H.) and Johns Hopkins Bloomberg School of Public Health (G.S.S.), Baltimore, Maryland, the University of Utah, Salt Lake City (M.R.), and the Harvard School of Public Health and Beth Israel Deaconess Medical Center, Boston, Massachusetts (M.A.M.).

Received May 27, 2005; accepted December 16, 2005; electronically published December 28, 2006.

800,000 sharps-related injuries occur annually in the United States, raising concerns about transmission of hepatitis B and C viruses and human immunodeficiency virus (HIV).[19-25] The estimated economic cost of such injuries ranges from $500 million to $1 billion annually.[26-28] Medical trainees, including interns, residents, and students, incur 7%-33% of reported sharps-related injuries,[29-32] and reported injuries among this group likely represent fewer than half the injuries actually sustained by trainees.[33-36]

We postulated that the fatigue experienced by healthcare workers (HCWs) in general, and medical trainees in particular, might play an important role in the occurrence of sharps-related injuries. A case-crossover study design, which was specifically developed to evaluate the effect of transient exposures on the risk of sudden-onset events, is a useful tool for identifying the causal factors in injury occurrence. This design is applicable when postulated risk factors (such as fatigue) are common and transient.[37] We made use of this study design to quantitatively estimate injury risk associated with fatigue in medical trainees and other HCWs.

METHODS

Subjects

Study design and subject recruitment have been described in greater detail elsewhere.[30] In brief, subjects were HCWs employed at academic medical centers in Boston, Baltimore, Salt Lake City, and Toronto who presented to hospital employee healthcare clinics between February 2000 and June 2004 after being injured by sharp medical devices that had been used for patient care. All participating institutions require annual standard-precautions training, which includes advice on avoidance of needle recapping and appropriate disposal of sharp devices. All US sites are compliant with current Occupational Safety and Health Administration regulations, with respect to assuring the availability of safer, engineered sharps devices.[38]

Individuals were invited to participate in the study by employee healthcare staff while undergoing postexposure assessment; workers were not invited to participate in the study if they had sustained only a skin or mucus membrane splash with blood or body fluids or if they had been injured by a clean device that had not yet been used for patient care. Workers who provided informed consent to participate underwent structured telephone interviews by trained interviewers within 7 days after injury.

Injury logs were maintained by participating employee healthcare staff. Review of these logs indicated that written informed consent was obtained from and interviews were performed for 46% of potentially eligible study subjects. When informed consent to participate was not given, the most common reason mentioned by occupational healthcare staff was lack of time (reported by 14%). Other reasons for nonconsent included lack of time among injured HCWs (reported by 11%), lack of interest (7%), emotional distress or upset experienced by the injured HCW (5%), and concerns on the part of HCWs that information obtained during the study would not remain confidential (0.5%).

Study Design

The case-crossover study design is an observational design characterized by self-matching, such that case and control data are obtained from the same subject.[37,39] This design implicitly adjusts for many of the differences between case and control subjects that could confound the results of a more traditional case-control study and permits statistical assessment of the relationship between brief, transient exposures and events (such as fatigue) and an acute event (in this case, the occurrence of a sharps-related injury). The case-crossover study design may be conceptualized as similar to a matched case-control study, in which case and control subjects are matched for all characteristics that remain constant over the period under study (eg, age, sex, and job description).

For all subjects, we assessed the presence of self-reported fatigue at the time of injury and the usual frequency of fatigue while at risk for sustaining sharps-related injuries. The structure and phrasing of the study questions, including questions about the presence of fatigue, are found in an appendix to a previously published article.[30] The degree of fatigue was estimated by self-report; subjects were also questioned about quantitative exposures (eg, hours of sleep, hours at work, and recent vacation time) that are likely to be associated with fatigue.

We distinguished injuries sustained during procedures of prolonged duration (such as those sustained in an operating room or a procedure suite) from those sustained during shorter procedures (such as those sustained during phlebotomy, catheter placement, and blood sugar testing). This distinction is important because the former injuries occur in a context of continuous risk, whereas the latter occur in a context of noncontinuous risk.

For workers at noncontinuous risk for sharps-related injuries, time at risk was estimated as the product of the number of procedures performed during the past month and the average time taken to perform a procedure. For workers at continuous risk for sharps-related injuries (eg, surgeons), time at risk was estimated as the number of hours spent after scrubbing in an operating room or procedure suite during the past week. Estimates of time at risk and exposure at the time of injury are highly reproducible in the context of this study.[30]

Statistical Analysis

Differences between trainees and other HCWs were evaluated using the χ^2 test for binary variables and the unpaired *t* test or Wilcoxon rank-sum test, as appropriate, for continuous variables. We assessed the construct validity of self-reported fatigue as a measure of true fatigue by assessing the correlation between the presence of fatigue at the time of injury and factors that could plausibly result in a higher likelihood of fatigue, such as number of work hours, number of hours of sleep, being on call, and vacation time. Degree of correlation was estimated by using the phi (ϕ) statistic,[40,41] and by calculating odds ratios (ORs) and 95% confidence intervals (CIs) for self-reported fatigue in the presence of such factors. In assessing the relationship between number of hours of sleep and self-reported fatigue, we constructed logistic regression models, with self-reported fatigue as the dependent variable.[42]

Usual frequency estimates were used to calculate the subject-specific person-time exposed and unexposed to each transient risk factor during the past week (for those at continuous risk) or during the past month (for those at noncontinuous risk). Data were analyzed using standard methods for case-crossover data.[37,39] We estimated the incidence rate ratio as a measure of relative risk by use of the Mantel-Haenszel estimators for person-time data[43]; its variance was computed using standard methods.[44]

It was anticipated that fatigue might be more extreme among trainees than among nontrainees. Therefore, we sought to explore whether the effect of fatigue on injury risk might differ between these two groups. Modification of the effect of self-reported fatigue by trainee status was assessed through stratification, and evidence for heterogeneity of effect estimates was assessed using the χ^2 test.[45] All statistical analyses were performed using SAS, version 8.01 (SAS Institute).

Calculation of Excess Fractions

We estimated the excess fraction of sharps-related injuries attributable to fatigue by using traditional calculations for estimation of population-attributable risk percent.[46] The excess fraction of injuries, in this instance, represented the proportion of injuries among trainees that would be expected not to occur at a given point in time if fatigue were eliminated from the trainee work environment. Excess fraction calcu-

TABLE 1. Characteristics of Participating Trainees and Other Healthcare Workers (HCWs)

Variable	All subjects (n = 350)	Medical trainees (n = 111)	Other HCWs (n = 239)	P
Female sex	231 (66)	43 (39)	188 (79)	<.00
Age, median y (range)	31 (18-69)	29 (24-51)	34 (18-69)	<.001
Postgraduate year,[a] median (range)	...	3 (1-9)	...	
Student[b]	12 (3)	6 (5)	6 (3)	.21
Device that caused injury				<.001
Hollow-bore needle	190 (54)	42 (38)	148 (62)	
Solid-bore needle	73 (21)	39 (35)	34 (14)	
Scalpel or blade	32 (9)	14 (13)	18 (8)	
Stylette or trocar	16 (5)	10 (4)	6 (5)	
Continuous exposure[c]	95 (27)	45 (41)	50 (21)	<.001
Location where injury occurred[d]				<.001
Patient room	98 (28)	14 (21)	84 (44)	
Intensive care unit	27 (8)	12 (18)	15 (8)	
Emergency department	25 (7)	17 (26)	8 (4)	
Outpatient clinic	18 (5)	4 (6)	14 (7)	
Injured during sharps disposal	120 (34)	18 (16)	102 (43)	<.001
High-risk exposure[e]	130 (37)	50 (45)	80 (33)	.04
Past injuries				
No. of past injuries, median (range)	1 (0-24)	1 (0-10)	1 (0-24)	.17
Ever injured	193 (55)	63 (57)	130 (54)	.66
Percentage of injuries reported,[f] median (range)	50 (0-100)	37 (0-100)	100 (0-100)	.001
Shift work[g]	102 (29)	17 (15)	85 (36)	<.001
Frequency of call duty,[h] median (range)	...	1:4 (1:2-1:30)	...	

NOTE. Data are no. (%) of individuals, unless otherwise indicated. P values are based on comparison between medical trainees and other HCWs.

[a] Among interns and residents.

[b] Students not classified as medical trainees included nursing and dental students.

[c] Individuals were scrubbed at the time of injury, and injuries were considered to have been sustained in the context of continuous risk, as defined in Methods.

[d] Restricted to the 255 individuals not scrubbed in the operating room or procedure suite at the time of injury.

[e] Source patient for current injury known or believed by subject likely to have human immunodeficiency virus and/or hepatitis C virus infection.

[f] Among 62 medical trainees and 131 other HCWs reporting at least 1 previous injury.

[g] Information was not obtained from 16 individuals.

[h] Among 59 medical trainees on duty rotations requiring "in-hospital call" at the time of injury (see Methods for details).

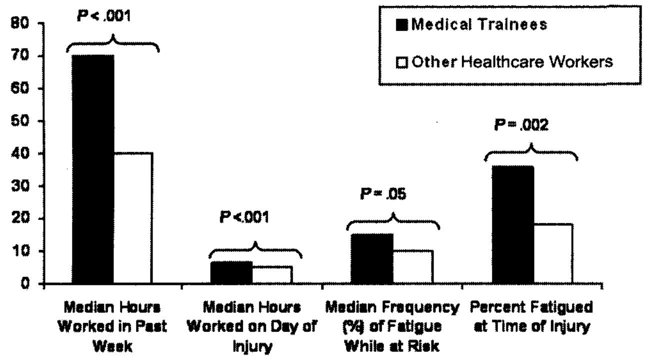

FIGURE 1. Median hours worked in the week before injury, hours worked on day of injury, and frequency of fatigue for trainees *(black bars)* and nontrainees *(white bars)*. The percentage of subjects who reported being fatigued at the time of injury is also shown. Trainees worked longer hours and were more likely to be fatigued than were nontrainees.

lations depended not only on the increase in risk associated with fatigue but also on the usual frequency of fatigue while at risk of sharps injury. Because baseline levels of fatigue varied among study subjects, we calculated excess fractions across a broad range of fatigue frequencies. As such, excess fraction estimates presented here should be individualized to reflect an individual worker's usual frequency of fatigue while at risk of sharps injury.

RESULTS

A total of 350 subject interviews were available for analysis. Most subjects had been injured with a hollow-bore needle. Other classes of device commonly associated with injury included solid-bore needles, scalpels, stylettes, and trocars. Most subjects had been injured either in a patient's room or while scrubbed in an operating room or procedure suite. Other common injury locations included the intensive care unit, the emergency room, and outpatient clinic exam rooms. A third of the study population had sustained their injuries while disposing of a used sharp device (Table 1).

A total of 111 subjects (31%) were medical trainees (medical students, interns, residents, and fellows), of which 59 were on duty rotations requiring "in-hospital call" (ie, assignment to patient care beyond the normal workday with a requirement to be immediately available in the hospital) at the time of injury. The median frequency of such on-call duty among medical trainees was 1 day in 4. Medical trainees were younger, less likely to be female, less likely to be injured with hollow-bore devices, and less likely to be injured while disposing of a used sharp device than were other HCWs. Most injuries sustained by medical trainees occurred in operating rooms and procedure suites or in the emergency department, whereas nontrainees were more frequently injured in patient rooms. No difference was seen between medical trainees and other HCWs in the likelihood of having experienced a previous sharps-related injury; however, medical trainees had reported a significantly smaller proportion of past injuries to hospital occupational healthcare services than had other workers (Table 1).

Medical trainees worked more hours than did other HCWs in the week before injury (median, 70 vs 40 hours, respectively; $P < .001$) and had been at work longer than had other HCWs at the time of injury (median, 6.5 vs 5 hours, respectively; $P < .001$). Medical trainees reported a greater usual frequency of fatigue while at risk of injury (15% of time at risk) than did other HCWs (10% of time at risk; $P = .05$) and were also more likely to report fatigue at the time of injury (relative risk, 2.03 [95% CI, 1.41-2.94]; $P = .002$) (Figure 1).

Among all study subjects, the median reported average nighttime sleep duration during the week before injury was 6.2 hours (interquartile range, 5.5-7.0 hours). Trainees slept fewer hours in the week before injury (median, 6 vs 6.75 hours; $P < .001$) and on the night before injury (median, 6 vs 6.5 hours; $P < .001$) than did nontrainees. The likelihood of fatigue at the time of injury was inversely associated with the average number of hours of sleep in the past week (OR, 0.77 per additional hour of sleep [95% CI, 0.65-0.91]) and with the average number of hours of sleep the night before injury (OR, 0.72 per additional hour of sleep [95% CI, 0.63-0.82]) (Figure 2). No difference was seen between trainees and nontrainees in the effect of the number of hours of sleep on the likelihood of fatigue at the time of injury.

Self-reported fatigue at the time of injury was 8 times more common among those who had been at work more than 12 hours at the time of injury and was 4 times more common among those who had worked more than 5 days or more

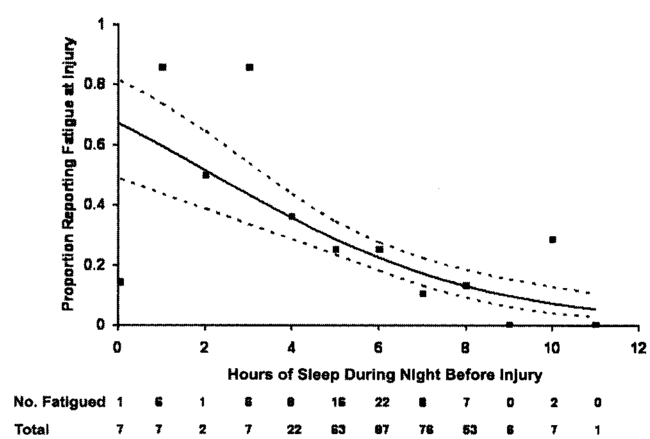

FIGURE 2. Association between the probability of reporting fatigue at the time of injury and the number of hours of sleep obtained the night before injury. *Black squares,* proportion of individuals reporting fatigue at a given sleep duration; absolute counts are presented below the horizontal axis. *Solid curve,* predicted probability of fatigue on the basis of a logistic regression model. *Dashed curves,* upper and lower 95% confidence limits.

TABLE 2. Agreement Between Self-Reported Fatigue at the Time of Injury and Surrogate Measures of Fatigue

Surrogate measure of fatigue	OR (95% CI)	ϕ Statistic	P
Worked >40 h in the past week	3.50 (2.06-5.92)	0.26	<.001
Worked >5 d in the past week	4.20 (4.46-7.15)	0.29	<.001
At work >12 h before injury	8.58 (3.70-19.86)	0.31	<.001
Slept <5 h the night before injury	4.33 (2.35-7.95)	0.27	.004
Less sleep than usual the night before injury	1.97 (1.19-3.28)	0.14	.008
Usual duration of sleep <5 h	2.50 (1.14-5.48)	0.13	.02
On call at the time of injury[a]	3.77 (0.66-21.62)	0.15	.11
On rotation requiring in-hospital call[a] at injury	2.53 (1.10-5.81)	0.21	.03
No vacation in the past year	1.29 (0.61-2.73)	0.04	.50

NOTE. P values are based on χ^2 test for 2 × 2 contingency table. CI, confidence interval; OR, odds ratio.

[a] Being on call was defined as intermittently remaining in the hospital between 6 PM and 6 AM, in addition to the usual daytime work.

than 40 hours in the past week. Trainees were more likely to report fatigue at the time of injury if they were on rotations requiring in-house call or if they had had less sleep than usual on the night before injury. A nonsignificant increase in risk of fatigue was seen in those who had been on call the night before injury; fatigue at the time of injury was not associated with failure to take vacation time of 1 week or more in the past year (Table 2).

Fatigue was associated with an increase in injury risk in the study population as a whole (incidence rate ratio [IRR], 1.40 [95% CI, 1.03-1.90]). Stratified analysis found this association to be strong among medical trainees (IRR, 2.94 [95% CI, 1.71-5.07]) and absent in other HCWs (IRR, 0.97 [95% CI, 0.66-1.42]) ($P = .001$ for heterogeneity). Stratified analyses suggested that this difference was not attributable to differences in age ($P = .72$) or sex ($P = .10$) between medical trainees and other HCWs. The effect of fatigue in the second half of the training year (IRR for January to June, 3.38 [95% CI, 1.68-6.83]) was not different from that in the first half of the year (IRR for July to December, 2.41 [95% CI, 1.01-5.75; $P = .55$).

We calculated excess fractions of injury attributable to fatigue, using the approach described in Methods. On the basis of the median frequency of fatigue among trainees in this study (15%), we could estimate that approximately one-quarter of sharps-related injuries in trainees might not occur in the absence of fatigue. Under the assumption of a constant relative risk, the excess fraction of fatigue-associated injuries would increase among trainees who experienced fatigue more commonly while at risk of sharps-related injury (Figure 3).

DISCUSSION

In this study, our primary aim was to evaluate the relationship between fatigue and risk of sharps-related injury among HCWs. We found that fatigue was associated with a moderate but statistically significant increase in the risk of needlestick injury and other sharps-related injuries in the healthcare workplace. Our secondary objective was to determine whether the magnitude of fatigue-associated risk was greater for trainees, who are likely to be exposed to more extreme fatigue, than for nontrainees. We found this to be the case: among trainees, self-reported fatigue was associated with a 3-fold increase in injury risk, whereas no increase in risk was associated with fatigue in nontrainees.

Because of the use of self-matching in the case-crossover study design, an association between fatigue and injury reflects a higher incidence of fatigue at the time of injury than would be expected on the basis of the usual prevalence of fatigue in the workplace among these workers. Although the experience of fatigue is subjective, self-reported fatigue had substantial construct validity in this study and was strongly associated with long work hours and lack of sleep in study participants. Sleep deprivation and long work hours were significantly more common among medical trainees than

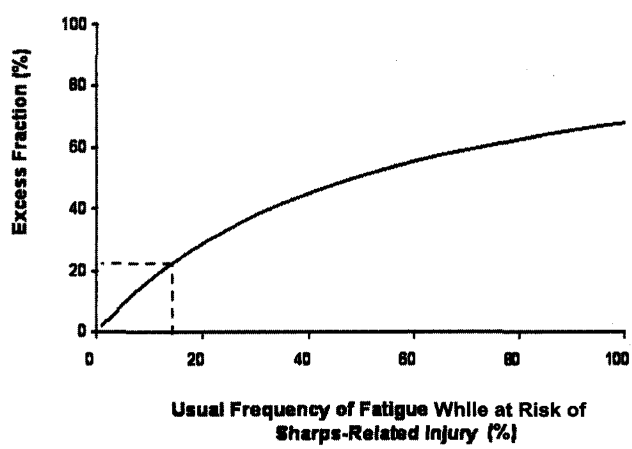

FIGURE 3. Excess fraction of sharps-related injuries due to fatigue while at risk of sharps-related injury, with a varying frequency of fatigue, expressed as the percentage of time at risk of injury, among trainees. The curve is based on a relative risk of injury of 2.94. *Dashed lines*, median frequency of fatigue among trainees in this study (15%) and associated excess fraction of injuries (23%).

among nontrainees, which suggests that the differential effect of fatigue on injury risk may have been the result of more extreme fatigue in the former group.

Extreme fatigue among medical trainees has long been acknowledged as a factor that could contribute to errors in the healthcare workplace,[47] and regulations aimed at reducing workplace fatigue already exist in many industries that place a high premium on error avoidance.[12,48] In 2003, the ACGME instituted standards for all accredited postgraduate medical training programs, which capped work hours at 80 per week, with no more than 24 hours worked continuously.[13] Critics have suggested that limited evidence linking fatigue and medical errors makes these standards excessively stringent.[16] However, the data presented here, combined with a recent randomized controlled trial that showed a reduction in serious medical errors when care was provided by better-rested trainees[8] and a case-crossover study that demonstrated an increase in motor vehicle accidents in overly tired trainees,[9] constitute a growing body of rigorous epidemiologic evidence that supports regulation of trainee work hours in the interests of both trainee and patient safety.

Such a relationship is also supported by a recent report by the National Institute for Occupational Health and Safety (NIOSH), which identified associations between extended work hours and illness and injury rates in workers, including those working in health care.[49] The report noted that prolonged work hours have been associated with increased rates of illness, injury, and even mortality in the majority of available studies. A single cohort study of injury risk in HCWs was cited by the NIOSH report; the study found a statistically significant 1.7-fold increase in risk of any type of work-related injury among workers who worked more than 2,000 hours per year.[50] Such a finding is consistent with and complementary to the findings reported here.

In this study, self-reported fatigue at the time of injury was associated with both acute sleep deprivation and chronic sleep deprivation, suggesting that the genesis of HCW fatigue in general, and of trainee fatigue in particular, is complex. Thus, our finding of an association between fatigue and injury does not simply represent increased risk as a result of inadequate sleep the night before injury.

The complexity of fatigue as it relates to trainee injury risk suggests future avenues for clinical research, including time-series studies that evaluate rotation-specific injury rates and the acute effect of sleep deprivation on injury risk. Furthermore, institution of the ACGME trainee work-hour standards constitutes a de facto natural experiment of the impact of fatigue on risk of trainee injury. Although the interpretability of emerging surveillance data may be limited by concurrent trends in injury reporting and the use of safer medical devices, our findings suggest that the frequency of sharps-related injuries among trainees should have declined with the adoption of the ACGME standards. Documentation of such an effect is another important avenue for future research.

If modification of trainee work hours proves to be an effective means of reducing the number of sharps-related injuries, this would be a desirable achievement, even in the absence of reduction in other types of medical errors. Sharps-related injuries are associated with transmission of bloodborne infectious agents, including HIV and hepatitis C virus, with costs and toxicity from postexposure prophylaxis, and with intangible costs associated with distress among injured individuals.[22,23,26,51,52] Transmission of HIV to a medical trainee through an occupational needlestick has also been the subject of at least 1 personal injury lawsuit.[53] On the basis of an estimated per-injury direct medical cost of $600,[26] a conservative assumption that 7% of sharps injuries are incurred by trainees,[29] and the excess fraction calculations presented in this report, we estimate that reduction of workplace fatigue in trainees would eliminate at least 7,000-13,000 injuries annually, with societal cost savings of at least $4-8 million. The tendency of trainees to underreport their injuries[33-35] suggests that the true cost savings would be much greater.

Our study has several limitations. As in any study that relies on a subject's ability to recall past exposures, our study may have been influenced by inaccuracies in subject exposure estimates. However, it should be stressed that this study would be vulnerable to "recall bias" only if subject misclassification of exposure status applied differentially to case and control periods. Given the high degree of reproducibility of exposure reporting in this study,[30] the substantial construct validity of self-reported fatigue described above, and the fact that case and control exposures are assessed by the same individual,[39] this study is probably less vulnerable to recall bias than is a traditional case-control study design.

The known frequency of the under-reporting of sharps-related injuries could have caused selection bias in this study if fatigued individuals are more likely to report injuries. However, selection bias would not explain the differential effects of fatigue between the trainee and nontrainee populations observed here. For this to be the case, one would have to posit a scenario whereby exhausted trainees are more likely than nonfatigued trainees, and other HCWs generally, to report injuries, because reporting might permit them to leave work early, to sleep. Such a convoluted explanation for the difference in effect seems less satisfying than attribution of this difference to the observed differences between these groups in fatigue-associated work practices and sleep patterns.

In summary, we present data that support the hypothesis that extreme work hours adversely affect the workplace safety of medical trainees. By increasing the risk of sharps-related injuries, excess fatigue will heighten subsequent trainee distress and increase healthcare costs and the risk of occupational transmission of bloodborne infectious diseases. These effects of fatigue and sharps injury need to be assimilated into the ongoing debate about the restructuring of medical trainee work hours. The effect of fatigue on injury risk, as documented in the present study, is strong, is biologically plausible, has substantial face validity, and is consistent with effect estimates in other, complementary studies.[8,9,49,50]

Furthermore, because of reporting requirements,[38] sharps-related injuries may serve as a "sentinel medical error," providing insight into the role of fatigue in the genesis of other medical errors by trainees. As the reduction of nosocomial infection risk and the surveillance of hospital-acquired sharps injuries are the purview of infection control practitioners and occupational healthcare providers, our findings suggest that such professionals can and should serve as local champions for trainee work-hour restructuring, may play an important role in educating more senior colleagues about the importance of adhering to ACGME standards, and are likely to be important sources of "health intelligence" with respect to the impact of restructured work hours on injury risk in trainees in their local institutions.

Address reprint requests to David N. Fisman, MD, Drexel University School of Public Health, 1505 Race St., Mail Stop 660, Philadelphia, PA 19102-1192 (df62@drexel.edu).

ACKNOWLEDGMENTS

We gratefully acknowledge support from the National Institute for Occupational Safety and Health (grant R01-OH007489); the Ontario Public Health Research, Education, and Development Program; and the Liberty-Mutual/Harvard Program in Occupational Safety and Health, Harvard School of Public Health. We also acknowledge the invaluable assistance of Patsy Mittleman, Cindy Aiello, and Lydia Napper in the conduct of this study.

Additional investigators were as follows. Beth Israel Deaconess Medical Center, Boston, MA: Karen Bithell, RN; Jill Rougan, RN; Judith Panos, RN; Mary O'Brien, RN. Johns Hopkins Hospital, Baltimore, MD: Arjun Srinivasan, MD; Sara Cosgrove, MD. University of Maryland Medical Center, Baltimore, MD: Gail Brandt, RN; Clare Rawlings, RN. University Health Network, Toronto, Ontario, Canada: Jane Sloggett, MSN; Michael Gardam, MD, FRCPC; Maureen McWilliams, RN. University of Utah, Salt Lake City: Patricia Larkin, RN, BSN; Marian Reed, LPN; Matthew Samore, MD.

REFERENCES

1. Niederee MJ, Knudtson JL, Byrnes MC, Helmer SD, Smith RS. A survey of residents and faculty regarding work hour limitations in surgical training programs. *Arch Surg* 2003; 138:663-669.
2. Daugherty SR, Baldwin DC Jr, Rowley BD. Learning, satisfaction, and mistreatment during medical internship: a national survey of working conditions. *JAMA* 1998; 279:1194-1199.
3. Defoe DM, Power ML, Holzman GB, Carpentieri A, Schulkin J. Long hours and little sleep: work schedules of residents in obstetrics and gynecology. *Obstet Gynecol* 2001; 97:1015-1018.
4. Smith-Coggins R, Rosekind M, Hurd S. Relationship of day versus night sleep to physician performance and mood. *Ann Emerg Med* 1994; 24:928-934.
5. Rollinson DC, Rathlev NK, Moss M, et al. The effects of consecutive night shifts on neuropsychological performance of interns in the emergency department: a pilot study. *Ann Emerg Med* 2003; 41:400-406.
6. Jacques CH, Lynch JC, Samkoff JS. The effects of sleep loss on cognitive performance of resident physicians. *J Fam Pract* 1990; 30:223-229.
7. Lockley SW, Cronin JW, Evans EE, et al. Effect of reducing interns' weekly work hours on sleep and attentional failures. *N Engl J Med* 2004; 351:1829-1837.
8. Landrigan CP, Rothschild JM, Cronin JW, et al. Effect of reducing interns' work hours on serious medical errors in intensive care units. *N Engl J Med* 2004; 351:1838-1848.
9. Barger LK, Cade BE, Ayas NT, et al. Extended work shifts and the risk of motor vehicle crashes among interns. *N Engl J Med* 2005; 352:125-134.
10. Gaba D, Howard S. Fatigue among clinicians and the safety of patients. *N Engl J Med* 2002; 347:1249-1255.
11. Sexton JB, Thomas EJ, Helmreich RL. Error, stress, and teamwork in medicine and aviation: cross sectional surveys. *BMJ* 2000; 320:745-749.
12. Goode JH. Are pilots at risk of accidents due to fatigue? *J Safety Res* 2003; 34:309-313.
13. Philibert I, Friedmann P, Williams WT. New requirements for resident duty hours. *JAMA* 2002; 288:1112-1114.
14. Johnson T. Limitations on residents' working hours at New York teaching hospitals: a status report. *Acad Med* 2003; 78:3-8.
15. Romano M. Lightening their load: as teaching hospitals grapple with new rules limiting residents' hours on the job, cost and management issues remain among the challenges. *Mod Healthc* 2003; 33:32-35, 47.
16. Fletcher KE, Davis SQ, Underwood W, Mangurlkar RS, McMahon LF, Saint S. Systematic review: effects of resident work hours on patient safety. *Ann Intern Med* 2004; 141:851-857.
17. Lowenstein J. Where have all the giants gone? Reconciling medical education and the traditions of patient care with limitations on resident work hours. *Perspect Biol Med* 2003; 46:273-282.
18. Charap M. Reducing resident work hours: unproven assumptions and unforeseen outcomes. *Ann Intern Med* 2004; 140:814-815.
19. Panlilio AL, Orelien JG, Srivastava PU, Jagger J, Cohn RD, Cardo DM. Estimate of the annual number of percutaneous injuries among hospital-based healthcare workers in the United States, 1997-1998. *Infect Control Hosp Epidemiol* 2004; 25:556-562.
20. National Institute of Occupational Safety and Health. *Alert: Preventing Needlestick Injuries in Healthcare Settings.* Document 2000-108. Washington, DC: Department of Health and Human Services; 1999.
21. Henry K, Campbell S. Needlestick/sharps injuries and HIV exposure among health care workers: national estimates based on a survey of U.S. hospitals. *Minn Med* 1995; 78:41-44.
22. Cardo DM, Culver DH, Ciesielski CA, et al., for Centers for Disease Control and Prevention Needlestick Surveillance Group. A case-control study of HIV seroconversion in health care workers after percutaneous exposure. *N Engl J Med* 1997; 337:1485-1490.
23. Jagger J, Puro V, De Carli G. Occupational transmission of hepatitis C virus. *JAMA* 2002; 288:1469-1471.
24. Lanphear B, Linemann C, Cannon C, DeRonde M, Pendy L, Kerley L. Hepatitis C virus infection in healthcare workers: risk of exposure and infection. *Infect Control Hosp Epidemiol* 1994; 15:745-750.
25. Petrosillo N, Puro V, Ippolito G, et al. Hepatitis B virus, hepatitis C virus and human immunodeficiency virus infection in health care workers: a multiple regression analysis of risk factors. *J Hosp Infect* 1995; 30:273-281.
26. Jagger J, Bentley M, Juillet E. Direct cost of follow-up for percutaneous and mucocutaneous exposures to at-risk body fluids: data from two hospitals. *Adv Expo Prev* 1998; 3:1-3.
27. Wong JB, Poynard T, Ling MH, Albrecht JK, Pauker SG. Cost-effectiveness of 24 or 48 weeks of interferon α-2b alone or with ribavirin as initial treatment of chronic hepatitis C. International Hepatitis Interventional Therapy Group. *Am J Gastroenterol* 2000; 95:1524-1530.
28. Pinkerton SD, Holtgrave DR, Pinkerton HJ. Cost-effectiveness of chemoprophylaxis after occupational exposure to HIV. *Arch Intern Med* 1997; 157:1972-1980.
29. Perry J, Parker G, Jagger J. EPINet report: 2001 percutaneous injury rates. *Adv Expo Prev* 2003; 6:33-36.
30. Fisman D, Harris A, Sorock G, Mittleman M. Sharps-related injuries in health care workers: a case-crossover study. *Am J Med* 2003; 114:688-694.
31. McCormick RD, Meisch MG, Ircink FG, Maki DG. Epidemiology of hospital sharps injuries: a 14-year prospective study in the pre-AIDS and AIDS eras. *Am J Med* 1991; 91:301S-307S.
32. Pettit L, Gee S, Begue R. Epidemiology of sharp object injuries in a children's hospital. *Pediatr Infect Dis J* 1997; 16:1019-1023.

33. Perry J, Jagger J. Healthcare worker blood exposure risks: updating the statistics. In: Jagger J, Perry J, eds. *Preventing Occupational Exposures to Bloodborne Pathogens: Articles from Advances in Exposure Prevention, 1994-2003.* 1st ed. Charlottesville, VA: International Healthcare Worker Safety Center; 2004:203-207.
34. Choudhury RP, Cleator SJ. An examination of needlestick injury rates, hepatitis B vaccination uptake and instruction on "sharps" technique among medical students. *J Hosp Infect* 1992; 22:143-148.
35. Waterman J, Jankowski R, Madan I. Under-reporting of needlestick injuries by medical students. *J Hosp Infect* 1994; 26:149-150.
36. Melzer SM, Vermund SH, Shelov SP. Needle injuries among pediatric housestaff physicians in New York City. *Pediatrics* 1989; 84:211-214.
37. Maclure M. The case-crossover design: a method for studying transient effects on the risk of acute events. *Am J Epidemiol* 1991; 133:144-153.
38. Occupational Safety and Health Administration. Occupational exposure to bloodborne pathogens; needlesticks and other sharps injuries; final rule. *Fed Regist* 2001; 66:5318-5325.
39. Maclure M, Mittleman MA. Should we use a case-crossover design? *Annu Rev Public Health* 2000; 21:193-221.
40. Fleiss J. Sampling methods. I. Naturalistic or cross-sectional studies. In: Fleiss J. *Statistical Methods for Rates and Proportions.* 2nd ed. New York, NY: John Wiley and Sons; 1981:56-62.
41. Streiner D, Norman G. Validity. In: Streiner D, Norman G. *Health Measurement Scales.* 2nd ed. Oxford, United Kingdom: Oxford University Press; 1995:144-162.
42. Hosmer D Jr, Lemeshow S. *Applied Logistic Regression.* New York, NY: John Wiley and Sons; 1989.
43. Rothman K, Greenland S. Applications of stratified analysis methods. In: Rothman K, Greenland S, eds. *Modern Epidemiology.* 2nd ed. Philadelphia, PA: Lippincott-Raven; 1998:278-300.
44. Greenland S, Robins J. Estimation of a common effect parameter from sparse follow-up data. *Biometrics* 1985; 41:55-68.
45. Rothman K, Greenland S. Introduction to stratified analysis. In: Rothman K, Greenland S, eds. *Modern Epidemiology.* 2nd ed. Philadelphia, PA: Lippincott-Raven; 1998:253-277.
46. Greenland S, Robins JM. Conceptual problems in the definition and interpretation of attributable fractions. *Am J Epidemiol* 1988; 128:1185-1197.
47. Brensilver JM, Smith L, Lyttle CS. Impact of the Libby Zion case on graduate medical education in internal medicine. *Mt Sinai J Med* 1998; 65:296-300.
48. Morrow PC, Crum MR. Antecedents of fatigue, close calls, and crashes among commercial motor-vehicle drivers. *J Safety Res* 2004; 35:59-69.
49. Caruso CC, Hitchcock EM, Dick RB, Russo JM, Schmidt JM. *Overtime and Extended Work Shifts: Recent Findings on Illnesses, Injuries, and Health Behaviors.* Cincinnati, OH: National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention, U.S. Department of Health and Human Services; 2004. Available at: http://www.cdc.gov/niosh/docs/2004-143/pdfs/2004-143.pdf. Accessed December 2, 2005.
50. Simpson CL, Severson RK. Risk of injury in African American hospital workers. *J Occup Environ Med* 2000; 42:1035-1040.
51. Patel SM, Johnson S, Belknap SM, Chan J, Sha BE, Bennett C. Serious adverse cutaneous and hepatic toxicities associated with nevirapine use by non-HIV-infected individuals. *J Acquir Immune Defic Syndr* 2004; 35: 120-125.
52. Fisman DN, Mittleman MA, Sorock GS, Harris AD. Willingness to pay to avoid sharps-related injuries: a study in injured health care workers. *Am J Infect Control* 2002; 30:283-287.
53. Jury orders Yale to pay $12.2 million to doctor with HIV. *AIDS Policy Law* 1998; 13:8.