

# Surgeon Fatigue

## A Prospective Analysis of the Incidence, Risk, and Intervals of Predicted Fatigue-Related Impairment in Residents

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**Hypothesis:** A novel approach to identify at-risk periods among orthopedic surgical residents may direct fatigue risk mitigation and facilitate targeted interventions.

**Design:** A prospective cohort study with a minimum 2-week continuous assessment period. Data on sleep and awake periods were processed using the sleep, activity, fatigue, and task effectiveness model.

**Setting:** Rotations at 2 academic tertiary care centers.

**Participants:** Twenty-seven of 33 volunteer orthopedic surgical residents (82%) completed the study, representing 65% (33 of 51) of the orthopedic residency program.

**Intervention:** Residents' sleep and awake periods were continuously recorded via actigraphy, and a daily questionnaire was used to analyze mental fatigue.

**Main Outcome Measures:** Percentage of time at less than 80% mental effectiveness (correlating with an in-

creased risk of error), percentage of time at less than 70% mental effectiveness (correlating with a blood alcohol level of 0.08%), the mean amount of daily sleep, and the relative risk of medical error compared with chance.

**Results:** Residents were fatigued during 48% and impaired during 27% of their time awake. Among all residents, the mean amount of daily sleep was 5.3 hours. Overall, residents' fatigue levels were predicted to increase the risk of medical error by 22% compared with well-rested historical control subjects. Night-float residents were more impaired ( $P=.02$ ), with an increased risk of medical error ( $P=.045$ ).

**Conclusions:** Resident fatigue is prevalent, pervasive, and variable. To guide targeted interventions, fatigue modeling can be conducted in hospitals to identify periods, rotations, and individuals at risk of medical error.

*Arch Surg.* 2012;147(5):430-435

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**I**N 1999, THE INSTITUTE OF MEDICINE reported in *To Err Is Human: Building a Safer Health System*<sup>1</sup> that up to 98 000 of annual patient deaths are caused by medical error, making medical error the sixth to eighth leading cause of death in the United States and ranking it more lethal than breast cancer, AIDS, and motor vehicle crashes. Medical error is a significant problem worldwide<sup>2-7</sup> and does not seem to be abating.<sup>8</sup>

### See Invited Critique at end of article

A growing body of literature indicates that fatigue may have a substantial role in medical error. In 2008, the Institute of Medicine stated in *Resident Duty Hours: Enhancing Sleep, Supervision, and Safety* that "the science on sleep and human performance is clear that fatigue makes errors more likely to occur."<sup>9(p2)</sup> The report called

for further resident work-hour restrictions and improved supervision. However, the incidence and severity of surgical resident fatigue remain unclear.

Recent scientific advances allow for fatigue measurement and prediction of fatigue-related impairment. The sleep, activity, fatigue, and task effectiveness (SAFTE) model and the Fatigue Avoidance Scheduling Tool (Nova Scientific Corporation)<sup>10,11</sup> have been used for other safety-sensitive occupational settings. Individuals' sleep and awake schedules, the amount of daily sleep, and quality of sleep<sup>12</sup> are obtained using a wrist-worn validated<sup>13</sup> and operationally feasible sleep and circadian rhythm monitoring device. Data are then processed using the SAFTE model, which calculates the risk of error based on data gathered by the National Transportation Safety Board on human factors related to train accidents.<sup>14</sup> This method allows for the identification of fatigue-related at-risk periods. It also establishes the cumulative effects of different work and

rest schedules on overall performance capability and accident risk.<sup>15</sup>

The objective of this study was to apply a novel approach in the clinical setting to measure the incidence and severity of orthopedic surgical resident fatigue and the predicted risk of medical error. The clinical relevance of the approach is that it may direct fatigue risk mitigation by identifying at-risk periods and facilitate targeted interventions.

## METHODS

### STUDY DESIGN

Following institutional review board approval and endorsement by the program director and chairman (H.R.) at our study sites, we performed a prospective cohort study in which orthopedic surgical residents (postgraduate years [PGYs] 1-5) undergoing rotations at 2 large academic tertiary care centers were continuously monitored for 2 weeks between April 1, 2010, and November 1, 2011. Residents' sleep and wake periods were recorded via actigraphy, and a daily questionnaire was used to analyze mental fatigue. Data were processed using the SAFTE model.

All the orthopedic surgical residents (PGYs 1-5) working at study units during active phases of data collection were eligible. Eligible residents were contacted by e-mail and in person 1 week before the commencement of the study, provided informed consent to participate, were given a brief tutorial presentation, and received \$100 as an incentive to complete the study. Actigraphy watches were collected in person at the end of the 2 weeks. Specific emphasis was given to enrolling residents on rotations involving inpatients, high-risk heavy workloads, and variable schedules. Eligible orthopedic rotations included night float, trauma, hand, oncology, spine, joints, sports, and foot and ankle. Rotations were further categorized as night float (6 PM to 8 AM) or as day shift (6 AM to 6 PM). Weekend call was included in both schedules, which consists of weekend coverage every other weekend for two 12-hour shifts or one 24-hour shift. Residents were screened for sleep disorders, depression, and overall general good to excellent health. No residents were excluded on the basis of the results of this screening. Study size was determined by the amount of funding.

### TOOLS

Data collection consisted of the following: (1) an initial confidential and secure online questionnaire addressing demographics, sleep and exercise habits, and alcohol, sedative, or stimulant use; (2) daily self-reported sleep and work logs via a confidential and secure online questionnaire during a 2-week to 3-week period of monitoring; (3) an actigraphy watch (ReadiBand; Fatigue Science); and (4) an individual mental fatigue analysis using the actigraphy watch data, which was independently and blindly performed by the manufacturer of the actigraphy watches.

The initial demographic questionnaire included the following: baseline demographics (age, sex, height, and weight), screening questions on mental health and sleeping disorders, screening for the use of depressants or stimulants, and screening for overall physical fitness. This questionnaire was available online via confidential and secure means. In addition, residents completed a daily self-reported questionnaire on work, sleep, and awake periods. Residents were asked to complete a 24-hour grid each day showing periods when they were at work and awake, at work and asleep, not at work and awake, and not at work and asleep. Residents also reported time spent read-

ing and time spent moonlighting. This questionnaire was available online using secure sockets layer technology, protecting the confidentiality of the residents' encrypted information. Residents were sent daily e-mail reminders that contained a link to the questionnaire.

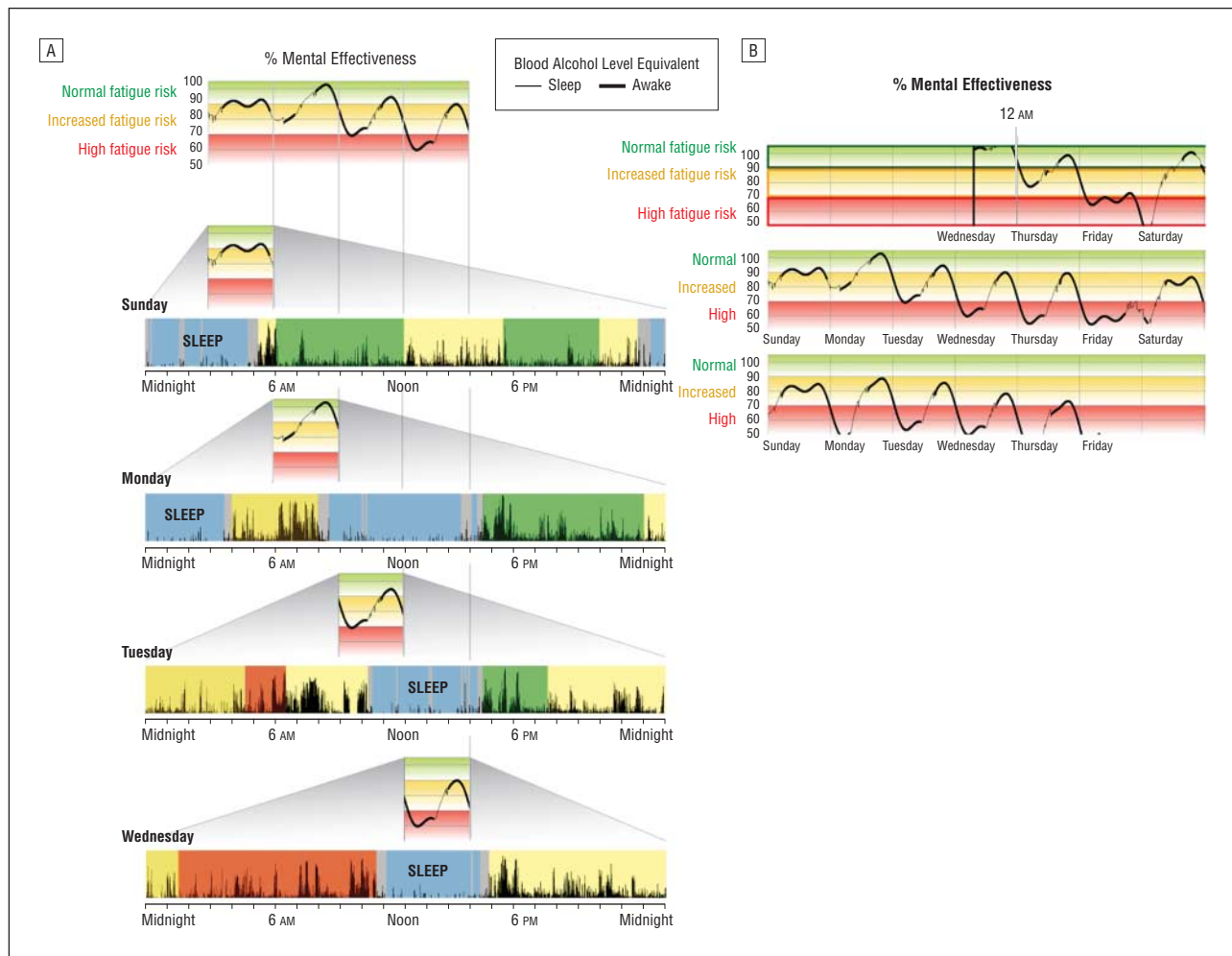
The actigraphy watch used is a commercially available continuously worn instrument that records the time of day and measures wrist movement. It stores data for sleep and awake interval calculation, which can then be used for individual mental fatigue analysis. The wrist-worn device contains an accelerometer that tracks the frequency of wrist movements and processes this information using an algorithm to measure sleep and awake periods and quality of sleep. It is worn during sleep and in the shower, on the nondominant hand, and serves as a watch. Most important, continuous wear enables accurate assessment of awake and rest periods. To obtain the most accurate data from our population, residents removed the device and placed it on a shelf during surgery, which was accounted for in the mental fatigue analysis by identifying prolonged periods of zero motion and cross-referenced with the daily questionnaire. Validity investigators reported that the actigraphy watch has an overall accuracy of 93% compared with the gold standard of polysomnography.<sup>13</sup> Because of its high validity as a measure of sleep and awake periods, actigraphy has been extensively used in prior studies<sup>16-19</sup> as a noninvasive means of measuring sleep and awake intervals. Residents for whom more than 4% of their time represented invalid periods of measurement or missing data were excluded from the study.

The SAFTE model has been independently validated against laboratory-controlled assessments and is able to predict performance degradation effects of fatigue and the rate of recovery, with excellent reliability in published scientific studies (with  $R^2$  values of 0.94, 0.89, and 0.98 in 3 studies,<sup>10,20,21</sup> respectively). The calculated performance effectiveness represents composite human performance on several cognitive tasks, scaled from 0 to 100, with 100 indicating fully awake and unimpaired by fatigue and with the effectiveness score correlating with the percentage of optimal effectiveness.<sup>22</sup> Moreover, the effectiveness score has been correlated with blood alcohol level<sup>23-25</sup> and has been validated to accurately predict the influences of sleep and scheduling on human factor accident risk and cost ( $R = -0.93$ ).<sup>14</sup> The SAFTE model is used by the US Department of Defense, the US Army, the US Air Force, the US Navy, the US Marine Corps, and the Federal Railroad Association.

The Fatigue Avoidance Scheduling Tool is a computer application of the SAFTE model prediction. This application provides a continuous record of predicted fatigue level at all times during periods of measurement using an easy-to-read chart. It can be used to mitigate fatigue risk, to manage scheduling, and to perform root-cause error analysis in accidents and mishaps.

The actigraphy watch data are converted to sleep and awake periods (**Figure 1A**), and the results are entered into the Fatigue Avoidance Scheduling Tool computer program based on the SAFTE model to create an individual mental fatigue analysis (**Figure 1B**). This model calculates an individual's amount of sleep, quality of sleep, time needed to fall asleep, and sleep interruptions. It then analyzes the total time functioning at specific fatigue levels and calculates the overall risk of error compared with a well-rested person. Actigraphy watches were shipped to the manufacturer, who independently and blindly performed this analysis for all the residents.

Descriptive statistics were used to characterize the study population. An analysis of variance was used to compare differences between night-float rotations and day-shift rotations in the risk of medical error based on the SAFTE model and to identify outliers. Because of the high rate of study completion, no comparison was performed between residents who did not complete the study vs those who successfully completed the study.



**Figure 1.** Individual mental fatigue analysis with corresponding actigraphy watch data. A, The top row shows time on the x-axis and a resident's predicted fatigue level and correlated risk of medical error on the y-axis, based on the sleep, activity, fatigue, and task effectiveness (SAFTE) model at that given time. The bottom rows show daily actigraphy watch data with corresponding SAFTE predictions for a resident starting a night-float rotation over a 4-day period. The predicted fatigue levels are highlighted, while the amount of daily sleep is indicated in blue. The more active one is, the taller the bars are for that interval. As the resident converts from a standard day-shift rotation to a night-float rotation, by the fourth day, the resident becomes critically fatigued during a significant period of the work shift. B, Continuous fatigue assessment with correlated risk of medical error and the color-coded magnitude of predicted fatigue. Dark lines indicate awake periods; narrow lines indicate sleep periods. This allows for the identification of specific intervals affected by fatigue and facilitates targeted interventions. This example shows a resident on a night-float rotation and illustrates the daily fluctuation in fatigue, the influence of inadequate rest with circadian rhythm disruption, and its cumulative effect on the risk of medical error.

## RESULTS

### PARTICIPANTS

Thirty-three of 34 orthopedic surgical residents (97%) who were invited to participate in the study consented to participate. Twenty-seven of 33 volunteers (82%) completed the study. Four residents completed 2 separate sessions of the study, and 1 resident completed 3 separate sessions of the study. For those who completed the study twice, each session occurred in different PGYs. For the resident who completed the study 3 times, 2 sessions were completed as a PGY-4 and 1 session as a PGY-5, each while on different rotations. The total number of residents who participated twice represented 4 residents in the entire orthopedic residency program. Two residents were excluded from the study for noncompliance with wearing the actigraphy watch, 2 were excluded for actigraphy me-

chanical failure, and 2 were excluded for completing less than 14 days of consecutive wear.

Demographics of the participating residents were reflective of the overall orthopedic residency demographics. Five women (15%) and 28 men (85%) participated in the study. The orthopedic residency program is 16% (8 of 50) female. Twelve residents were monitored when working at hospital A and 21 residents when working at hospital B. This mirrors the distribution of residents between hospital A and hospital B in our program. Participating residents' level of training ranged from PGY-1 to PGY-5, including 2 in PGY-1 (6%), 17 in PGY-2 (52%), 6 in PGY-3 (18%), 5 in PGY-4 (15%), and 3 in PGY-5 (9%). Overall, residents were reading less than an hour a day 85% of the time, and they were not involved in moonlighting activities 99.8% of the time. In total, 72% (20 of 28) of residents had at least 1 cup of coffee per day (31% [8] had 2-3 cups), and 65% (18 of 28) of resi-

**Table. Calculation of the Dependent Variable Based on Actigraphy Watch Monitoring and Sleep, Activity, Fatigue, and Task Effectiveness Modeling**

Variable	Group Mean (SD)	Individual Mean Range
Amount of daily sleep, h	5.3 (0.8)	3-7
Time awake at <80% mental effectiveness, %	48 (24)	20-88
Time awake at <70% mental effectiveness, %	27 (21)	0-74
Predicted risk of medical error, %	22 (10)	7-49

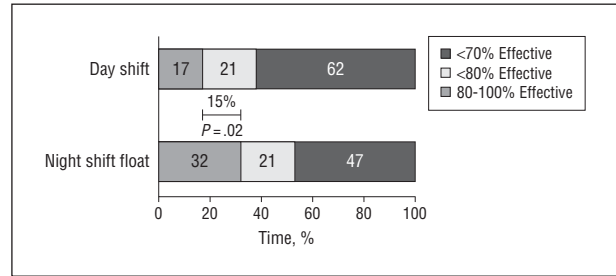
dents had at least 1 caffeinated soda per day (43% [12 of 28] had >1).

### SLEEP AND AWAKE PERIODS AND INDIVIDUAL MENTAL FATIGUE ANALYSIS

The mean (SD) amount of daily sleep for the cohort of residents was 5.3 (0.8) hours, with individual mean amounts of daily sleep ranging from 2.8 to 7.2 hours. Overall, based on the SAFTE model, residents were functioning at less than 80% mental effectiveness due to fatigue during a mean (SD) of 48% (24%) of their time awake. Residents were functioning at less than 70% mental effectiveness (equivalent to a blood alcohol level of 0.08%) due to fatigue during a mean (SD) of 27% (21%) of their time awake. This cohort of residents was predicted to have a mean (SD) of 22% (10%) (individual range, 3%-49%) increased risk of medical error attributable to fatigue (**Table**).

One busy service stood out for having high levels of fatigue. The 2 residents who participated in the study when on this service were less than 80% effective during 86% of their time awake and were less than 70% effective during 74% of their time awake. Their predicted risk of medical error due to fatigue was increased by 43%. Residents averaged 4.2 hours of daily sleep when on this service. These outliers were excluded from the night-float vs day-shift analysis given that their experience of daytime work often crossed into nighttime work and did not reflect the experience of residents involved in the other daytime rotations. All other daytime services had roughly similar fatigue profiles as one another.

In subgroup analysis, night-float rotations resulted in higher levels of fatigue than day-shift rotations. Night-float residents slept a mean of 5.1 hours daily, while day-shift residents slept a mean of 5.7 hours daily ( $P = .08$ ). Night-float residents were functioning at less than 80% mental effectiveness during 53% of their time awake, while day-shift residents were functioning at this level during 38% of their time awake ( $P = .08$ ). Night-float residents were functioning at less than 70% mental effectiveness during 32% of their time awake, while day-shift residents were functioning at this level during 17% of their time awake ( $P = .02$ ) (Figure 1B). Night-float residents had a 24% increased risk of medical error due to fatigue (compared with well-rested historical control data), while day-shift residents had a 19% increased risk of medical error due to fatigue ( $P = .045$ ).



**Figure 2.** Cumulative fatigue levels for day-shift rotations vs night-float rotations. Compared with a typical day-shift rotation, a night-float rotation carries a clinically and statistically significant increase in resident fatigue and corresponding risk of medical error.

### COMMENT

We found that orthopedic surgical residents were fatigued during almost half of their time awake. They were critically impaired during more than one-quarter of their time awake. This impairment was as severe as that expected from a blood alcohol level of 0.08%. These data indicate that orthopedic surgical residents in this study were at high risk of making medical errors due to fatigue that could injure their patients or themselves. Overall, residents' fatigue levels were predicted to increase their risk of medical error by 22% (individual range, 7%-49%) compared with well-rested historical control subjects.

Our findings substantiate the results of studies in other industries demonstrating the high prevalence and potential hazards of fatigue. In a review of all US naval aviation mishaps from 1990 to 2004, Davenport and Lee<sup>26</sup> found that fatigue was the most frequently cited contributing factor and was 4 times more likely to impair than drugs or alcohol. In a National Transportation Safety Board study<sup>27</sup> of major US air carriers, fatigue was addressed as a significant flight hazard (**Figure 2**).

Although not all studies have found that physician fatigue leads to patient harm,<sup>28</sup> the literature as a whole suggests that fatigue increases the risk of medical error, including patients or the residents themselves. Recent studies of residents in surgical and acute care settings found that extended shifts and circadian rhythm disruptions increase medical error<sup>29</sup> and cognitive decline.<sup>30,31</sup> Interns working extended shifts are at increased risk of making medical errors,<sup>29</sup> injuring patients,<sup>32</sup> experiencing needlestick and scalpel injuries at work,<sup>33</sup> and having motor vehicle crashes on the drive home from work.<sup>34</sup> West et al<sup>35</sup> found an association between resident fatigue and perceived medical error. A large-scale retrospective comparison of surgical outcomes before and after implementation of resident work-hour restrictions found a decrease in complication rates associated with reduced surgical service workload.<sup>36</sup> Finally, Rothschild et al<sup>37</sup> found that surgeons and obstetricians obtaining less than a 6-hour opportunity to sleep when on call experienced a near tripling in complication rates when performing elective procedures the following day. Despite these data, reducing work hours is challenging in health care settings given concerns about discontinuity of care, turnover errors, insufficient training expe-



rience, and increased hospital costs, which often serve as barriers to fatigue management interventions.<sup>38</sup>

In addition, our data indicate that not all schedules implemented with the intent of reducing fatigue will succeed. Compared with day-shift rotations, night-float rotations induced more critical impairment and greater predicted risk of medical error. This risk is likely exacerbated by working independently and cross-covering many patients, which frequently occurs on night-float rotations. Night-float residents in our study achieved a similar amount of daily sleep compared with residents in 1998, before the 2003 Accreditation Council for Graduate Medical Education work-hour restrictions.<sup>39</sup> Moreover, circadian rhythm disruptions can further degrade performance. If residents continue to achieve low levels of sleep despite a schedule redesign, work-hour restrictions will not lead to safer care. Scheduling systems need to be carefully developed, monitored, and iteratively improved as needed to reduce the risk of fatigue-related errors.

Leaders in medicine have found success in looking to other industries for sources of patient safety solutions, specifically high-reliability organizations. Despite functioning in complex hazardous environments, such organizations have low error rates.<sup>40-43</sup> These organizations have systems in place that are exceptionally consistent in accomplishing their goals and in avoiding potentially catastrophic errors.<sup>42</sup> Examples include the airline industry, nuclear power and chemical plants, and aircraft carriers. In these organizations, a small error can potentially lead to catastrophic consequences (eg, a nuclear reactor meltdown or an airplane crash).<sup>44</sup> High-reliability organizations share several characteristics: they have a well-developed safety culture, they perform system-based error analyses, and they maintain a preoccupation with failure. Most important, these organizations have generated significant safety gains by addressing workplace fatigue.

Recent translations of the high-reliability organization approach to health care settings have been remarkably successful. The World Health Organization's Universal Time-out policy was found in a study<sup>45</sup> to reduce surgical morbidity and mortality by 40% in 8 medical centers worldwide. Improvements might also be made by applying the lessons learned about fatigue management from high-reliability organizations to graduate medical education and surgical training.

This study has several limitations and sources of bias. First, given the high proportion of night-float residents enrolled, our study may have overestimated fatigue levels and the risk of error across the program. Moreover, orthopedic surgical residents involved in outpatient rotations, such as sports and foot and ankle, were underrepresented, and these rotations are less likely to have fatigued residents. Our data may be better reflective of the exposure of the hospitalized patient to the risk of medical error from surgical residents. This is relevant because the night-float resident serves as the inpatient responding physician almost 50% of the time that a patient remains hospitalized. Second, although our participation rate was very high, only 40% of the entire orthopedic residency program participated in the study because of the periodic nature of data collection. Although these residents seem to have been typical of the residency program as a whole, they may have

differed in certain unmeasured respects and introduced bias. Third, only orthopedic surgical residents were studied; it remains unclear how generalizable our findings may be to residents in other specialties or programs. Fourth, although the SAFTE model provided estimates of risk propensity, we did not directly measure medical errors, occupational injuries, or other downstream consequences of resident fatigue. Nevertheless, our study provides important data on the risk of such events using a tool validated in other high-risk settings.

In summary, we found that resident fatigue was prevalent, pervasive, and variable and accounted for an increased risk of medical error across the program. Our study describes an effective, feasible, and noninvasive method to study and quantify resident fatigue. This approach allows for the identification of specific periods, rotations, and individuals that could benefit from targeted interventions and overall risk reduction. Future studies should seek to determine whether schedule changes prompted by this tool in fact lead to improvements in residents' amount of daily sleep and alertness, reductions in occupational injuries, and enhancements in patient safety.

**Accepted for Publication:** December 20, 2011.

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**Financial Disclosure:** None reported.

**Funding/Support:** This study was supported by a grant from the Orthopedic Research and Education Foundation, by a departmental grant from an academic enrichment fund, and by hospital grant support from the Center for Quality and Patient Safety.

**Previous Presentation:** This paper was presented at the 92nd Annual Meeting of the New England Surgical Society; September 24, 2011; Bretton Woods, New Hampshire; and is published after peer review and revision.

**Additional Contributions:** Nicole Wolf assisted with the figures.

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## INVITED CRITIQUE

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# Surgical Fatigue—What Dreams May Come

There is a lot to like in this study by McCormick and colleagues.<sup>1</sup> Its authorship includes one of the best thinkers and doers in this field (Landrigan), with the mentorship of surgical leaders such as Herndon and Rubash. Heretofore, resident fatigue stud-

ies demonstrated few good established tools for physiological or cognitive real-time appraisals of fatigue. These authors measured fatigue through individual movement using analytic tools that are applied and validated across several professions and settings, including mili-