Prospective Evaluation of Consultant Surgeon Sleep Deprivation and Outcomes in More Than 4000 Consecutive Cardiac Surgical Procedures

Michael W. A. Chu, MD, FRCSC; Larry W. Stitt, MSc; Stephanie A. Fox, BSc, RRCP; Bob Kiaii, MD, FRCSC; Mackenzie Quantz, MD, FRCSC; Linrui Guo, MD; M. Lee Myers, MD, FRCSC; Janice Hewitt, RDH; Richard J. Novick, MD, FRCSC

Objective: To determine the effect of consultant surgeon sleep hours on patient outcomes in cardiac surgery.

Design: Prospective observational cohort study.

Subjects: Between January 2004 and December 2009, we prospectively collected sleep hours of 6 consultant surgeons, ranging in age from 32 to 55 years, working in a tertiary care academic institution. The prospective study cohort included all patients undergoing coronary artery bypass, valve, combined valve–coronary artery bypass, and aortic surgery. The predicted risk of death and/or any of 10 major complications was calculated using our institutional multivariable model, which was then compared with observed values. Additional prespecified analyses examined the interaction between surgeon age, sleep hours, and postoperative outcomes. This study had more than 90% power to detect a 4% (clinically important) difference in overall complication rates among groups.

Main Outcome Measures: Complication and mortality rates in operations performed by surgeons with 0 to 3, 3 to 6, or more than 6 hours’ sleep the evening prior to surgery.

Results: Of 4047 consecutive surgical procedures, 83 were performed by a consultant with 0 to 3 hours, 1595 with 3 to 6 hours, and 2369 with more than 6 hours of sleep. Rates of mortality (3 [3.6%], 44 [2.8%], and 80 [3.4%], respectively; P = .53) were similar in the 3 groups, as were the observed vs expected ratios of major complications (1.20, 0.95, and 1.07, respectively; P = .25). There was no significant interaction between surgeon age, hours of sleep, and occurrence of death or any of 10 major complications (P = .09).

Conclusion: This well-powered prospective study showed no evidence that consultant surgeon sleep hours had an effect on postoperative outcomes.


See Invited Critique at end of article

Sleep deprivation has been shown to have negative effects on mood and cognitive and psychomotor function in recent meta-analyses, but the clinical relevance of these findings in the high-hazard domain of surgical practice remains controversial. Controlled studies of surgical trainees using laparoscopic or virtual reality stimulators while acutely sleep deprived have shown no performance or cognitive impairment, significant decrements in cognitive and psychomotor skills, or mixed results. Two retrospective studies by the University of Virginia cardiac surgical group demonstrated that sleep deprivation of consultant and resident surgeons had no effect on the morbidity or mortality of patients after cardiac surgical operations. However, the definition of sleep deprivation in these 2 clinical studies was imprecise and was assigned retrospectively if a surgeon was on record as having performed an operative case that started after 10 AM the night before or began prior to 7:30 AM on the morning of surgery. Furthermore, this surrogate definition of sleep deprivation did not account for the fact that cardiac surgeons are frequently interrupted at night by patient care issues from the hospital, referring physicians, transplant donor coordinators, and others. We therefore designed a well-powered, observational study in which surgeon sleep hours were recorded prospectively by the consultant surgeon involved. Our primary research question was as follows: did moderate (3-6 hours) or severe (<3 hours) acute sleep deprivation in consultant surgeons result in an adverse effect on post-

Author Affiliations: Division of Cardiac Surgery, London Health Sciences Centre and the University of Western Ontario (Drs Chu, Kiaii, Quantz, Guo, Myers, and Novick and Ms Fox and Hewitt); and the Department of Clinical Epidemiology and Biostatistics, University of Western Ontario (Mr Stitt), London, Ontario, Canada.

©2011 American Medical Association. All rights reserved.
operative cardiac surgical outcomes? We also decided a priori to analyze the interaction between consultant surgeon age and hours of sleep on the outcomes of cardiac surgical procedures because practitioner age and experience may be potential modifiers of the effect of sleep deprivation on performance.

**METHODS**

This study was performed at the London Health Sciences Centre, University Hospital, an academic health sciences center affiliated with the University of Western Ontario that currently performs 1300 to 1400 cardiac surgical procedures per year. Approval for data collection for this study was granted by the research ethics board of the University of Western Ontario, which waived the requirement for informed consent from individual patients. Six of our 8 consulting surgeons consented to participate in this study; 4 were younger than 45 years and 2 were 50 to 55 years of age during the study.

The study cohort included all 4047 consecutive patients undergoing coronary artery bypass grafting (CABG), valve, combined valve-CABG, and aortic surgery by the 6 participating surgeons between January 2004 and December 2009. Patients undergoing heart transplantation, primary arrhythmia surgery, and operations for congenital heart disease were excluded. Our institutional database has prospectively recorded data on all cardiac surgical patients for the past 10 years, including the rates of hospital mortality and 10 major complications; in 2004 we added the variable “consultant surgeon sleep hours” to the database. This variable was prospectively recorded on the day of surgery by participating surgeons who specified the total number of sleep hours, exclusive of interruptions, that they had the night prior to performing surgery. The baseline incidence of a patient developing 1 or more of the 10 major complications in our database is approximately 16%, and an a priori sample size calculation indicated that a 4000-patient study would have more than 90% power to detect a clinically important 4% difference in overall complication rates among groups.

We began our analysis by determining the predicted risk of death and/or any of the 10 major complications using a previously developed institutional multivariable model that had a C statistic of 0.74 and a Hosmer-Lemeshow goodness of fit $P$ value of 0.12. Variables used in this model included patient age, sex, body mass index, preoperative ejection fraction, urgency of surgery, primary or redo surgery, chronic obstructive pulmonary disease, recent myocardial infarction (within 30 days), peripheral vascular disease, preoperative Canadian Cardiovascular Society–New York Heart Association functional class, diabetes, cerebrovascular disease, coronary anatomy, preoperative creatinine level, congestive heart failure, ascending aortic atherosclerosis, planned on- vs off-pump CABG surgery, the presence or absence of a preoperative intra-aortic balloon pump, and consultant surgeon. The predicted values were then compared with observed values in the 0 to 3 hours’, 3 to 6 hours’, and more than 6 hours’ sleep groups using $\chi^2$ tests. Given the relatively small number of patients in the 0 to 3 hours’ sleep group, the analyses were also repeated for the combined 0 to 6 hours vs more than 6 hours’ sleep groups. Furthermore, the prespecified interaction between consultant surgeon age, hours of sleep, and risk of mortality and/or any of 10 major complications was investigated via logistic regression. In addition, post hoc analyses included the effect of surgeon sleep hours (0-6 hours vs >6 hours) on the outcomes of high-risk patient cohorts with predicted complication rates of greater than 30%. Categorical data were analyzed using a $\chi^2$ test, whereas me-

<table>
<thead>
<tr>
<th>Table 1. Surgical Procedures and Predicted Risks of Mortality and/or 10 Major Complications Related to Surgeon Sleep Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients, No. (%) by Hours of Sleep</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>0-3 (n=83)</td>
</tr>
<tr>
<td>Isolated CABG</td>
</tr>
<tr>
<td>Isolated valve</td>
</tr>
<tr>
<td>CABG and valve</td>
</tr>
<tr>
<td>Aortic</td>
</tr>
<tr>
<td>Mean CPB time, min</td>
</tr>
<tr>
<td>Mean X-C time, min</td>
</tr>
<tr>
<td>Predicted risk (SD)</td>
</tr>
</tbody>
</table>

Abbreviations: CABG, coronary artery bypass grafting; CPB, cardiopulmonary bypass; SD, standard deviation; X-C, cross clamp.

From January 2004 to December 2009, 4047 patients underwent CABG, valve, combined valve-CABG, and thoracic aortic procedures by the 6 participating surgeons. Eighty-three of the operations (2.1%) were performed by severely sleep-deprived surgeons who had fewer than 3 hours’ sleep, 1595 (39.4%) by moderately sleep-deprived surgeons with 3 to 6 hours’ sleep, and 2369 (58.5%) by surgeons who had more than 6 hours’ sleep on the night before the operations. The different types of procedures and the predicted risks of mortality and/or any of the 10 major complications related to surgeon sleep hours are shown in Table 1. It is interesting that the predicted risk of patient mortality or major complications in the 3 groups was almost identical; the slightly higher percentage of aortic cases in the 0 to 3 hours’ sleep group was balanced out by the higher frequency of combined valve-CABG cases in the more than 6 hours’ sleep group.

Table 2 shows the observed incidence of mortality and each of the 10 major complications whose operational definitions have remained unchanged in our database since its inception 10 years ago. There was a statistically significantly higher incidence of septicemia in the 0 to 3 hours’ sleep group but no significant difference among groups in any of the other individual or composite outcomes. The median intensive care unit stay did not differ among groups, although the median postoperative hospital stay was 1 day shorter in the 3 to 6 hours’ sleep group than in the other 2 groups, a difference that was statistically significant. When data in the 0 to 3 hours’ and 3 to 6 hours’ sleep groups were combined, the major complication rate was 259 of 1678 (15.4%) in the 0 to 6 hours’ sleep group vs 403 of 2369 (17.1%) in the more than 6 hours’ sleep group ($P = .17$). Furthermore, the median hospital stay was 6.0 vs 7.0 days in the 0 to 6 hours’ vs more than 6 hours’ sleep groups, respectively ($P < .001$).

Table 3 shows the observed vs expected ratios for the occurrence of 1 or more of the 10 major complica-
The results of this well-powered, 6-year prospective study showed no important adverse effect of consultant surgeon sleep deprivation on the outcomes of cardiac surgical procedures. This finding was robust and held up even in a high-risk subgroup of 399 patients with a predicted risk of mortality and/or complication rate greater than 30%. Furthermore, there was no evidence that the effect of sleep hours on mortality or any of 10 major postoperative complications was affected by surgeon age. In this current era, when health care delivery is often scrutinized against benchmarks and vigilant outcomes analyses are performed, this study provides important reassurance to the general public that consultant surgeon sleep deprivation does not affect the quality of clinical outcomes or patient safety following cardiac surgery.

It has been hypothesized that sleep deprivation reduces surgical performance by affecting technical skills and cognitive abilities. Many studies have reported impaired fine motor skills following acute sleep deprivation, which may be particularly important in a technically demanding field such as cardiac surgery where small technical errors can contribute to significant complications. However, the generalizability of these studies to cardiac surgeons may be limited by the fact that most of these studies evaluated technical performance in laparoscopic simulators assessing skills that may not be transferable to cardiac operations. Unfortunately, there are no good studies evaluating the effects of sleep deprivation on the fine motor skills required to perform CABG, valve, or aortic operations. More important may be the effects of sleep loss on cognitive abilities such as problem solving and decision making. Disruption of normal circadian physiology may reduce alertness, wakefulness, and intellectual acuity. Fatigue has been demonstrated to impair performance and compromise safety in commercial airline pilots and professional truck drivers; however, similar evidence has yet to be proven in real-world surgery. Surgical simulator studies have demonstrated mixed findings of the effects of fatigue on cognitive abilities. It is certainly plausible that these effects could have impaired preoperative decision making or patient selection in our study. However, our results

### Table 1. Postoperative Adverse Outcomes and Median Lengths of ICU and Hospital Stay Related to Surgeon Sleep Hours

<table>
<thead>
<tr>
<th>Patient Outcomes</th>
<th>0-3 (n=83)</th>
<th>3-6 (n=1595)</th>
<th>&gt;6 (n=2369)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mortality</td>
<td>3.6 (3.6)</td>
<td>44.2 (2.8)</td>
<td>80.3 (3.4)</td>
<td>.53</td>
</tr>
<tr>
<td>Postoperative IABP</td>
<td>0</td>
<td>53.3 (3.3)</td>
<td>62.2 (2.6)</td>
<td>.12</td>
</tr>
<tr>
<td>Stroke or delirium</td>
<td>2.4 (2.4)</td>
<td>30.1 (19.9)</td>
<td>68.2 (2.9)</td>
<td>.14</td>
</tr>
<tr>
<td>Reoperation</td>
<td>3.6 (3.6)</td>
<td>60.8 (3.8)</td>
<td>76.3 (3.2)</td>
<td>.64</td>
</tr>
<tr>
<td>Arrest or permanent pacemaker</td>
<td>1.12</td>
<td>33.2 (2.1)</td>
<td>54.2 (2.3)</td>
<td>.75</td>
</tr>
<tr>
<td>New renal failure</td>
<td>2.4 (2.4)</td>
<td>17.1 (1.1)</td>
<td>46.1 (1.9)</td>
<td>.08</td>
</tr>
<tr>
<td>Septicemia</td>
<td>3.6 (3.6)</td>
<td>14.0 (0.9)</td>
<td>20.0 (0.8)</td>
<td>.03</td>
</tr>
<tr>
<td>Mediatinitis</td>
<td>1.12</td>
<td>20.1 (1.3)</td>
<td>30.1 (1.3)</td>
<td>.99</td>
</tr>
<tr>
<td>Sternal dehiscence</td>
<td>0</td>
<td>13.0 (0.8)</td>
<td>28.1 (1.2)</td>
<td>.34</td>
</tr>
<tr>
<td>Respiratory failure</td>
<td>7.2 (7.2)</td>
<td>87.5 (5.5)</td>
<td>160.6 (6.8)</td>
<td>.24</td>
</tr>
<tr>
<td>Postoperative MI</td>
<td>2.4 (2.4)</td>
<td>42.0 (2.6)</td>
<td>64.2 (2.7)</td>
<td>.98</td>
</tr>
<tr>
<td>Any of 10 complications</td>
<td>16.9 (1.3)</td>
<td>243 (15.2)</td>
<td>404 (17.1)</td>
<td>.24</td>
</tr>
<tr>
<td>ICU stay, d</td>
<td>7.0</td>
<td>6.0</td>
<td>7.0</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Hospital stay, d</td>
<td>7.0</td>
<td>6.0</td>
<td>7.0</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

### Table 2. Observed vs Expected Ratios of Mortality and/or 10 Major Complications

<table>
<thead>
<tr>
<th>Sleep, h</th>
<th>Observed</th>
<th>Expected</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-6</td>
<td>16 (19.3)</td>
<td>13.3 (16.0)</td>
<td>1.20</td>
</tr>
<tr>
<td>3-6</td>
<td>243 (15.2)</td>
<td>256.6 (16.1)</td>
<td>0.95</td>
</tr>
<tr>
<td>&gt;6</td>
<td>404 (17.1)</td>
<td>380.2 (16.0)</td>
<td>1.07</td>
</tr>
</tbody>
</table>

### Table 3. Interaction of Sleep and Consultant Age: Effect on Mortality and/or 10 Major Complications

<table>
<thead>
<tr>
<th>Consultant Age, y</th>
<th>Sleep, h</th>
<th>Mortality or Other Complications, No./Total (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;45</td>
<td>0-6</td>
<td>206/1393 (14.8)</td>
</tr>
<tr>
<td>&gt;6</td>
<td>264/1515 (17.4)</td>
<td></td>
</tr>
<tr>
<td>&gt;50</td>
<td>0-6</td>
<td>53/285 (18.6)</td>
</tr>
<tr>
<td>&gt;6</td>
<td>140/854 (16.4)</td>
<td></td>
</tr>
</tbody>
</table>

*Logistic regression results; consultant age (<45 vs >50 years), P = .33; sleep (0-6 vs >6 hours), P = .39, interaction, P = .09.*

### Abbreviations:
- IABP: intra-aortic balloon pump
- ICU: intensive care unit
- MI: myocardial infarction

*See references for operational definitions of the patient outcome variables.*
The investigators did not find any association between resultant high risk of misclassification bias. Nonetheless, most attending combat the effects of sleep deprivation. Most attending well-developed compensatory mechanisms must exist to work-hour limitations.

gest reassessment of this belief when contemplating trainee mon tenet used to justify maximum-work-hour legisla-

tion (ACGME) in the United States imposed national accations in restricting current trainee work hours when educations in restricting current trainee work hours when future practice may demand optimal performance during sleep-deprived conditions. It is now almost 7 years since the Accreditation Council for Graduate Medical Edu-
cation (ACGME) in the United States imposed national work-hour limits for postgraduate medical trainees. However, the effects of the ACGME work-hours mandate on patient mortality and educational opportunities have been equivocal. Similarly in Europe, more aggressive work-hour restrictions have been implemented that have improved trainee lifestyle satisfaction; however, again, there are few data demonstrating any reduction in medical errors or improved patient safety. An analysis of the sleep characteristics of 180 attending physicians from varied specialties found that reduced sleep, not hours worked, was associated with increased sleepiness, highlighting the weak link between work hours and quantity of sleep. This finding undermines the intuitive belief that reduced work hours improves daytime fatigue, trainee performance, and, hence, patient safety, which was a common tenet used to justify maximum-work-hour legis-

ation. Regardless, the findings of our study might suggest reassessment of this belief when contemplating trainee work-hour limitations.

Given the results of our study, we hypothesize that well-developed compensatory mechanisms must exist to combat the effects of sleep deprivation. Most attending cardiac surgeons could have developed physiologic ad-

aptation to chronic sleep deprivation and, through condi-
tional learning, practiced enough to reduce errors under these conditions. With development of expertise, the complex decision making and manual dexterity required for cardiac surgical procedures has likely become more routine for attending surgeons, thus likely requiring less of the sleep-dependent, higher executive cognitive functions. Most importantly, cardiac surgery is a “team sport” that involves multiple levels of trainee, surgical, and nursing staff who collectively could potentially compensate for a consultant surgeon’s fatigue-related impairment. Simple countermeasures that have been recommended, such as continuous social interaction and brightly lit operating rooms, can also protect against fatigue-related error. Caffeine may mitigate the effects of sleep deprivation by improving cognitive function and has been the standard “postcall meal” for genera-

tions of surgeons.

There is a burgeoning body of literature on the potential influence of personality traits on the manifestations of sleep deprivation, especially the effect of introversion-extraversion traits and how individual differences in emotional intelligence determine the response to frustration following sleep loss. There is also emerging evidence that differential vulnerability to the effects of acute sleep de-

privation is a stable, traitlike characteristic that may be mediated by specific polymorphisms in the PER gene. Future studies should consider administering validated personality inventories to participating health care practi-

tioners to explore a possible interaction between personality traits, observed behaviors during acute sleep deprivation, and patient outcomes.

The strengths of our study include the accurate, prospective ascertainment of surgeon sleep hours in a rela-
tively large patient cohort and the fact that our group of participating consultant surgeons were of different sexes and ages. Limitations of our study included the relatively small number of patients (ie, 83 [2.1%]) who were operated on by consultant surgeons with severe sleep deprivation (<3 hours’ sleep). Nonetheless, 1595 patients in this cohort (39.4%) were operated on by surgeons who had at least moderate acute sleep deprivation (3–6 hours’ sleep). Another shortcoming of our study may be the limited generalizability of the results of 6 consultant surgeons (4 aged <45 years and 2 aged >50 years) in a single academic center, with none older than 55 years and in their last decade of practice. Conclusions of the interaction between surgeon age, sleep hours, and postoperative outcomes must therefore be made with caution. Furthermore, the generalizability of our study findings is limited by the fact that the clinical setting was a busy academic cardiac surgical unit with a strong cardiac surgery residency training program. Whether our study results and conclusions would be the same in a nonacademic setting without postgraduate trainees as potential mitigating agents remains uncertain.

An additional methodological issue in this and most other sleep-deprivation studies in the literature is the failure to control for potential confounding variables that may have had an effect on the observed clinical results. These include the possible concomitant influ-
ence of chronic partial sleep restriction,15,17,30 the effect of differing personality traits on vulnerability to sleep deprivation,26-28 and the failure to control for stimulant use.23-25 Although surgeons may subjectively adapt to restricted sleep,17 objective measures of performance continued to worsen during conditions of chronically reduced sleep hours.17,18,31,32 The accurate measurement of chronic partial sleep deprivation could not be accomplished in our study given the variability in operating room and vacation schedules of participating surgeons during the 6 years that patient outcome data were recorded.

In summary, our 6-year prospective study showed no evidence that consultant surgeon sleep hours had an adverse effect on postoperative outcomes, even in patients with a high predicted risk. Future studies should explore the compensatory mechanisms that individual health care practitioners and surgical teams use to maintain good patient outcomes when key members of the team are sleep deprived.

Accepted for Publication: February 22, 2011.

Published Online: May 16, 2011. doi:10.1001/archsurg.2011.121

Correspondence: Michael W. A. Chu, MD, FRCSC, B6-106 University Hospital, London Health Sciences Centre, 339 Windermere Rd, PO Box 5339, London, ON N6A 5A5, Canada (michael.chu@lhsc.on.ca).

Author Contributions: Study concept and design: Chu, Fox, and Novick. Acquisition of data: Chu, Fox, Kiai, Quantz, Myers, Hewitt, and Novick. Analysis and interpretation of data: Chu, Stitt, Fox, Guo, and Novick. Drafting of the manuscript: Chu and Novick. Critical revision of the manuscript for important intellectual content: Chu, Stitt, Fox, Kiai, Quantz, Guo, Myers, Hewitt, and Novick. Statistical analysis: Stitt. Administrative, technical, and material support: Chu, Fox, Kiai, Quantz, Guo, Myers, Hewitt, and Novick. Study supervision: Novick.

Financial Disclosure: None reported.

Funding/Sponsor: This study was supported by internal research funds from the Division of Cardiac Surgery, University of Western Ontario.

Disclaimer: Internal research funds of the Division of Cardiac Surgery at the University of Western Ontario covered the salaries of the clinical research associates who run our clinical database as well as biostatistical consultation fees. All data collection, analysis, and interpretation as well as the writing of this report were performed by the study authors, without the involvement of any outside party.

Additional Contributions: Elizabeth Millar assisted in manuscript preparation and Vladimir Hachinski, CM, MD, FRCPC, DSc, reviewed an earlier version of the manuscript.

REFERENCES

Academic traditionalists in the cardiac surgical community are presently going through the 5 Kubler-Ross stages of grief in dealing with the residency work-hour restrictions imposed by the ACGME. Because this patient safety measure is largely based on the notion that tired and sleep-deprived physicians and surgeons are more prone to error, this study represents an excellent attempt at determining whether fatigue compromises the technical performance and patient outcomes in the demanding discipline of cardiothoracic surgery. The authors cogently hypothesize that the maintenance of good outcomes under these circumstances might be attributed to the “team sport” character of cardiac surgery and “burned-in” cognitive and technical skills and physiologic conditioning of consultant surgeons.

However, the results of this study, while reassuring, may not be reflected in future generations of cardiac surgeons. At least some, if not all, of the consultant surgeons who participated in this study did not train under work-hour restrictions and enjoy the purported benefits of comparatively long hours, including physiologic and mental conditioning and following the course of an acute disease process from beginning to end. The concern many traditional academic surgeons have lies in the ability of the new generation of cardiac surgeons to sufficiently adapt to long hours and fatigue in their own practices without the work-hour protections afforded by the ACGME. Will patient safety be paradoxically compromised by young practicing cardiac surgeons who can more easily convince themselves that delaying the coronary revascularization of an ischemic patient or repair of an acute ascending aortic dissection for a few hours of extra sleep will actually improve their technical or cognitive performance and therefore serve the best interests of the patient?

It is unlikely that the debate between proponents and detractors of work-hour restrictions will end any time soon, simply because the consequences of these measures or lack thereof will be evaluated for many years to come.

David D. Yuh, MD

Published Online: May 16, 2011. doi:10.1001/archsurg.2011.120

Author Affiliation: Division of Cardiac Surgery, Johns Hopkins Hospital, Baltimore, Maryland.

Correspondence: Dr Yuh, Division of Cardiac Surgery, Johns Hopkins Hospital, 600 N Wolfe St, Blalock 618, Baltimore, MD 21287-4618 (dyuh@jhmi.edu).

Financial Disclosure: None reported.