The Effect of Sunlight on Postoperative Analgesic Medication Use: A Prospective Study of Patients Undergoing Spinal Surgery

JEFFREY M. WALCH, BSA, BRUCE S. RABIN, MD, PHD, RICHARD DAY, PHD, JESSICA N. WILLIAMS, BS, KRISSY CHOI, BS, AND JAMES D. KANG, MD

Objective: Exposure to natural sunlight has been associated with improvement in mood, reduced mortality among patients with cancer, and reduced length of hospitalization for patients who have experienced myocardial infarction. Our aim was to evaluate whether the amount of sunlight in a hospital room modifies a patient's psychosocial health, the quantity of analgesic medication used, and the pain medication cost. **Methods:** A prospective study of pain medication use was conducted in 89 patients undergoing elective cervical and lumbar spinal surgery where they were housed on either the "bright" or "dim" side of the same hospital unit. Analgesic medication was converted to standard morphine equivalents for interpatient comparison. The intensity of sunlight in each hospital room was measured daily and psychologic questionnaires were administered on the day after surgery and at discharge. **Results:** Patients staying on the bright side of the hospital unit were exposed to 46% higher-intensity sunlight on average ($p = .005$). Patients exposed to an increased intensity of sunlight experienced less perceived stress ($p = .035$), marginally less pain ($p = .058$), took 22% less analgesic medication per hour ($p = .047$), and had 21% less pain medication costs ($p = .047$). Age quartile was the only other variable found to be a predictor of analgesic use, with a significant negative correlation ($p < .001$). However, patients housed on the bright side of the hospital consistently used less analgesic medications in all age quartiles. **Conclusion:** The exposure postoperatively of patients who have undergone spinal surgery to increased amounts of natural sunlight during their hospital recovery period may result in decreased stress, pain, analgesic medication use, and pain medication costs. **Key words:** analgesic medication, sunlight, morphine, stress, opioid.

ACCF = anterior cervical corpectomy and fusion; **ACDF** = anterior cervical discectomy and fusion; **AEDET** = Achieving Excellence Design Evaluation Toolkit; **CES-D** = Center for Epidemiological Studies–Depression Scale; **CNS** = central nervous system; **DS** = degenerative spondylolisthesis; **LOS** = length of stay; **LOT-R** = Life Orientation Test-Revised; **LS** = lumbar stenosis; **MPQ** = McGill Pain Questionnaire; **OR** = operating room; **PACU** = post-anesthesia care unit; **PCA** = patient-controlled analgesia; **PFI** = Private Finance Initiative; **POMS** = Reduced POMS–Anxiety Scale; **PRN** = as needed; **PSS** = Perceived Stress Scale; **SAD** = seasonal affective disorder; **TCAs** = tricyclic antidepressants; **UK** = United Kingdom.

INTRODUCTION

Exposure to artificial high-intensity light (phototherapy) or natural light has been shown to positively affect feelings and emotions (1,2). Phototherapy has been successfully used to treat patients with depression and seasonal affective disorder (SAD) (3,4). Studies examining the effects of natural sunlight on the recovery of patients with refractory, bipolar, and SAD have demonstrated a decreased length of stay (LOS) among patients exposed to increased light intensity (5–7). Exposure to natural sunlight or artificial high-intensity light has been associated with reduced depression for pregnant women (8); reduced mortality from ovarian, breast, and colon cancer (9,10); as well as reduced hospital mortality and LOS in patients experiencing myocardial infarction (11).

The average annual rate of increase for prescription drug expenditures was 15% per year from 1995 to 2001 (12). This increase was higher than for any other type of healthcare expenditure measured by the Consumer Price Index (12). The use of analgesic medication to relieve pain can produce side effects that include constipation, drowsiness, urinary problems, nausea, and vomiting (13). Therefore, modalities that can decrease analgesic medication use may reduce associated side effects and prescription drug expenditures.

The activity of serotonin n-acetyltransferase, which catalyzes the conversion of serotonin into melatonin, is reduced after exposure to light (14). This research indicates that light increases the concentration of serotonin. Serotonin acts as an inhibitor of pain pathways in the central nervous system (15). Therefore, based on this reported relationship, we evaluated the effect of sunlight on the postoperative analgesic medication requirement of a uniform patient population.

A multitude of studies have examined the effect of sunlight and artificial high-intensity light on hospitalized patients (5–11). However, to our knowledge, no prior investigations have studied the effects of exposure to natural sunlight or artificial high-intensity light on the use of analgesic medications by hospitalized patients. In this article, we report the results of the first prospective study to determine the effects of natural sunlight on the use of opioid-equivalent medications among a group of 89 postoperative patients who had undergone spinal surgery.

METHODS

Subject Recruitment

Consecutive patients undergoing elective cervical and lumbar spinal surgeries were assessed for eligibility when admitted postoperatively onto the patient unit. Patients were excluded if they were being discharged on the day after their surgery or if there was any history of major depression or the use of antidepressant medications. Patients admitted into single-occupancy rooms on the hospital unit between March 12, 2003, and August 7, 2003, were asked to participate in this study. One hundred forty-seven patients were approached; 46 (31.3%) declined to participate and 12 (8.2%) were excluded because they failed to meet all inclusion criteria. Eighty-nine patients participated in the study. The University of Pittsburgh's Institutional Review Board approved the study protocol and all participating patients signed approved

From the Departments of Pathology (J.M.W., B.S.R.), Biostatistics (R.D.), and Orthopedics (J.D.K.), University of Pittsburgh, Pittsburgh, Pennsylvania; and Carnegie Mellon University, Pittsburgh, Pennsylvania (J.N.W., K.C.).

Address correspondence and reprint requests to Jeffrey M. Walch, BSA, Clinical Immunopathology Lab-CLSI Suite 5725, UPMC-CHMT, 200 Lothrop Street, Pittsburgh PA 15213-2582. E-mail: walchjm@upmc.edu.

Received for publication April 7, 2004; revision received July 7, 2004.

This work was funded by the UPMC Healthy Lifestyle Program and through a grant from Carnegie Mellon University's Undergraduate Research Initiative.

DOI: 10.1097/01.psy.0000149258.42508.70

0033-3174/05/6701-0156

consent forms before study admittance. The study used the intent-to-treat model and no patients were dropped after signing the consent.

Patient Rooms

The patient rooms, all of the same size and configuration, were located on the east and west side of a corridor of Montefiore Hospital. An adjacent building, located approximately 25 meters away, blocked sunlight exposure to patient rooms on the east side of the patient unit. Therefore, the patient rooms on the east side were designated "dim" and rooms on the west side were designated "bright."

Patient Assignment

The 89 patients who agreed to participate in the study were assigned to the bright ($n = 44$) or the dim ($n = 45$) side of the corridor after discharge from the postanesthesia care unit (PACU). Patients were held in the PACU and then discharged when a room on the unit became available. The unit director followed normal hospital protocol and assigned patients to either side of the unit depending on room availability. There were no patient characteristics (age, sex, procedure, and so on) used by the unit director to determine assignment of patients to the bright or dim side of the unit. Room availability was the only variable that determined patient assignment to the bright or dim side of the unit. The study personnel were not involved in randomizing the patients into bright or dim rooms. Patients were blind to the study's intervention as well as whether their room was located on the bright or dim side of the unit. Recruitment into this study ended on August 7, 2003, as a result of the relocation of the spinal surgery unit to another location in the hospital.

Measurement of Sunlight Intensity

Beginning on the afternoon of postoperative day 1 and continuing throughout hospitalization, light intensity (lux) was measured twice daily in the rooms of all study participants at approximately 9:30 AM and 3:30 PM. Before measurement, the door to the room was closed, all artificial sources of light were extinguished, and the window blinds were opened to permit maximum sunlight to enter the room. Three measurements were taken to estimate *direct*, *reflective,* and *ambient* sunlight.

The *direct* measurement recorded the intensity of sunlight at the point that it entered the patient's hospital room. The light meter (L-508Cine Zoom Master; Sekonic Corp., Tokyo, Japan) was placed at the center of the windowsill and the sensor was pressed against the window. The *reflective* measurement recorded the intensity of sunlight reflected off the patient. Study personnel stood at the foot of the bed with the light meter directed at the patient's eye level. The *ambient* measurement recorded the intensity of sunlight reflected off interior surfaces. The light meter was placed next to the patient's head and positioned toward the hospital room window. Each measurement was taken 5 times at every AM and PM visit and then averaged to obtain a reliable estimate of the *direct*, *reflective,* and *ambient* sunlight intensity. These reliable *direct*, *reflective,* and *ambient* estimates were then averaged together to obtain the overall AM and PM sunlight intensities. The resulting AM lux measurement and PM lux measurement was then multiplied by the number of AM (sunrise to noon) and PM (noon to sunset) exposure hours occurring on each day, respectively. The resulting 2 numbers were then summed to determine the cumulative daily sunlight exposure in lux-hours.

Quantifying Analgesic Use

The primary outcomes of this prospective study were analgesic medication use per hour and pain medication cost per hour. During the patient's stay in the operating room (OR) and the PACU, analgesic medications were prescribed and administered by the medical staff. When the patient left the PACU to stay on the bright or dim side of the hospital unit, all analgesic medication was administered as needed (PRN). Furthermore, all of the patients self-administered analgesic medication through a patient-controlled analgesia (PCA) during the first 24 hours of their stay on the unit.

A registered nurse, who was blind to patient group assignment, abstracted the daily use of all opioid and opioid-equivalent medications from the patient's medical records. The analgesic medications were then converted to an oral morphine-equivalent (mg) using a standard method (16). The amount of oral morphine-equivalent pain medication used each day on the hospital unit was divided by 24 hours to find the average analgesic medication use per hour (mg/hr) for each day of the patient's hospitalization. Then, the total amount of morphine equivalent pain medication, used after the OR and PACU, was divided by the patient's LOS to find the average analgesic medication use per hour (mg/hr) for the entire length of stay. In addition to recording the amount of pain medication prescribed in the OR and PACU, each patient was also assessed for 1) the hospital record of analgesic pain medication usage before admission and 2) use of nonanalgesic medications while at the hospital that might have reduced analgesic pain medication needs.

A hospital administrator, who was blind to patient group assignment, determined the total pain medication cost for each study patient from the hospital billing system. The pain medication cost for patients was divided by their LOS to obtain an estimate of analgesic cost per hour.

Psychologic and Pain Measures

The secondary outcomes for this prospective study were derived from 4 questionnaires that were administered to both bright and dim side patients on 2 occasions: postoperative day 1 and discharge day. First, the McGill Pain Questionnaire (MPQ) was given to measure subjective pain (17). The Center for Epidemiological Studies Depression Scale (CES-D) measures depressive symptomatology and has a reliability alpha of 0.84 (18). The Perceived Stress Scale (PSS) determines the degree that people perceive their lives as stressful (19). The reliability alpha is 0.78 and the measure correlates in a predicted way with other measures of stress. Finally, the Profile of Mood States (POMS) anxiety scale was used to assess positive and negative affect (20). The reliability of the alphas for the anxiety scale is 0.916.

Patients housed on the bright and dim sides also completed 2 baseline questionnaires to assure that there were no differences in these parameters: 1) a 10-cm pain scale was administered when the patient left the PACU to obtain an initial pain score and 2) the Life Orientation Test Revised (LOT-R) that measures dispositional optimism was administered on post-operative day 1 to assess optimism as a personality trait (21). The reliability of the whole sample alpha is 0.78 with test–retest reliability at 28 months of 0.79.

Statistical Methods

Data analyses were carried out using the Minitab statistical software program. Univariate hypotheses were tested using parametric (*t* test for independent samples) or nonparametric equivalents (Mann-Whitney test or chi-squared) depending on the distribution (normal vs. nonnormal) and format (continuous vs. categorical) of the variable being tested. Also, multivariate analysis of variance was carried out using the Minitab generalized linear model procedure, which permits balanced and unbalanced designs with fixed and random variables. Critical levels of significance were set at 0.05. All *p* values were 2-sided, and no missing value procedures were used.

No-Interaction Group

One of every 5 patients ($N = 17$) admitted into the study were randomized into a no-interaction group (bright side = 10, dim side = 7). The no-interaction patients did not receive any psychologic or pain questionnaires but were administered the 10-cm pain scale by the nurses on discharge from the PACU. Sunlight intensity, pain medication use, and analgesic cost were recorded for the no-interaction group.

The no-interaction group was included to measure possible effects of research staff contact with the patients. The main outcome measure, pain medication use, was compared between the no-interaction and the other patients to determine whether contact with the research staff affected the study results.

RESULTS

Patient Characteristics

Table 1 shows that the patients assigned to the bright and the dim sides of the unit did not differ with regard to: 1) demographic and clinical characteristics, 2) patient's clinical diagnosis or surgical procedure, 3) baseline pain and optimism

TABLE 1. Demographic and Clinical Characteristics of Patients Having Undergone Spinal Fusion on Bright and Dim Sides of the Hospital Unit

Variables	Percent (No.)* or Mean ± SD			
	Bright Side (N = 44)	Dim Side (N = 45)	All (N = 89)	p Value†
Demographic characteristics				
Sex				
Female	43.2% (19)	60.0% (27)	51.7% (46)	
Male	56.8% (25)	40.0% (18)	48.3% (43)	.112
Race/ethnicity				
White	95.5% (42)	88.9% (40)	92.1% (82)	
Other	4.5% (2)	11.1% (5)	7.9% (7)	.250
Education				
Less than high school	2.3% (1)	6.7% (3)	4.5% (4)	
High school diploma	41.0% (18)	33.3% (15)	37.1% (33)	
More than high school diploma	56.8% (25)	60.0% (27)	58.4% (52)	.512
Income				
≤20,000	29.4% (10)	19.4% (6)	18.0% (16)	
20,001–50,000	50.0% (17)	41.9% (13)	33.7% (30)	
50,001–80,000	8.8% (3)	25.8% (8)	12.4% (11)	
≥80,000	11.8% (4)	12.9% (4)	9.0% (8)	
No answer	22.7% (10)	31.1% (14)	27.0% (24)	.347
Age at interview (y),				
Mean ± SD	60.1 ± 13.7	57.6 ± 13.4	58.9 ± 13.5	.384
Clinical characteristics				
Prior analgesic medication use				
Yes	77.3% (34)	77.8% (35)	77.5% (69)	
No	22.7% (10)	22.2% (10)	22.5% (20)	.954
Diagnosis				
LS and DS	50.0% (22)	40.0% (18)	44.9% (40)	
Lumbar other	27.3% (12)	24.4% (11)	25.8% (23)	
Cervical	22.7% (10)	35.6% (16)	29.2% (26)	.403
Procedure				
Laminectomy	52.3% (23)	40.0% (18)	46.1% (41)	
Revision	25.0% (11)	24.4% (11)	24.7% (22)	
Cervical	22.7% (10)	35.6% (16)	29.2% (26)	.371
Surgical complications				
Dural tear	18.2% (8)	6.7% (3)	12.4% (11)	
None	81.8% (36)	93.3% (42)	87.6% (78)	.099
Systolic bood pressure (mm Hg)	140.0 ± 24.3	141.3 ± 16.5	140.7 ± 20.6	.762
Diastolic blood pressure (mm Hg)	77.6 ± 12.5	78.1 ± 11.3	78.2 ± 11.8	.684
Heart rate (beats/min)	75.0 ± 12.1	76.2 ± 13.6	75.6 ± 12.8	.667
Body mass index	28.9 ± 5.8	29.9 ± 5.4	29.4 ± 5.6	.419
No. of levels fused	1.6 ± 1.6	2.0 ± 1.6	1.8 ± 1.6	.226
OR morphine (mg/hr)	15.4 ± 6.4	17.7 ± 8.2	16.6 ± 7.4	.132
PACU morphine (mg/hr)‡	9.8 ± 10.2	14.0 ± 11.4	12.2 ± 11.0	.242
Pain rating at PACU discharge (cm)	3.1 ± 2.8	2.9 ± 2.8	3.0 ± 2.8	.826
Optimism level on postoperative day 1	16.9 ± 4.3	16.9 ± 4.8	16.9 ± 4.5	.959

Continuous variables are reported as mean ± SD. Categorical variables are listed as columnwise percentage (N).
*Percent (no.) is based on the total participants with available data for each variable. Percentages may not equal 100 as a result of rounding.
†p value is determined by a chi-squared test for categorical variables, and by an independent samples t test between bright and dim sides for continuous variables.
‡ N = 17 for bright side, N = 23 for dim side, N = 40 for all.
SD = standard deviation; LS = lumbar stenosis; DS = degenerative spondylolisthesis; OR = operating room; PACU = postanesthesia care unit.

ratings, and 4) the use of analgesic pain medications before hospitalization, in the OR or in the PACU. Table 2 lists the specific clinical diagnosis and the type of elective surgery performed for all 89 patients.

Sunlight Intensity

Patients on the bright side of the unit received an average of 46% (p = .005) more natural sunlight per day (73,537 vs. 50,410 lux-hrs) than patients on the dim side of the unit when factoring in both the AM and PM sunlight intensities. All patients in the experiment wore identical hospital gowns throughout their patient stay and every hospital room was painted with the same colors. Therefore, patient clothing and room interior were not considered to be confounding factors in determining the daily sunlight intensity. Patient skin color was also excluded as a possible confounding factor because there was no significant statistical difference in the racial composite of either the bright

TABLE 2. Diagnosis and Procedure of Patients Having Undergone Spinal Fusion on Bright and Dim Sides of the Hospital Unit

	Percent (No.)*		
Variable	Bright Side (N = 44)	Dim Side (N = 45)	All (N = 89)
Diagnosis			
LS and DS	50.0% (22)	40.0% (18)	44.9% (40)
Lumbar other			
Herniated disc	2.3% (1)	2.2% (1)	2.2% (2)
Lumbar stenosis	15.9% (7)	8.9% (4)	12.4% (11)
Isthmic spondylolisthesis	6.8% (3)	4.4% (2)	5.6% (5)
Degenerative disc disease	0.0% (0)	2.2% (1)	1.1% (1)
Lumbar infection	0.0% (0)	2.2% (1)	1.1% (1)
Nonunion of previous fusion	2.3% (1)	4.4% (2)	3.4% (3)
Cervical			
Stenosis and radiculopathy	9.1% (4)	13.3% (6)	11.2% (10)
Stenosis and myeloradiculardy	9.1% (4)	20.0% (9)	14.6% (13)
Stenosis and myelopathy	4.5% (2)	0.0% (0)	2.2% (2)
Nonunion of previous fusion	0.0% (0)	2.2% (1)	1.1% (1)
Procedure			
Laminectomy			
Laminectomy	11.4% (5)	4.4% (2)	7.9% (7)
Laminectomy/fusion (1 level)	25.0% (11)	8.9% (4)	16.9% (15)
Laminectomy/fusion (2 levels)	6.8% (3)	20.0% (9)	13.5% (12)
Laminectomy/fusion (>2 levels)	9.1 (4)	6.7% (3)	7.9% (7)
Revision			
Revision laminectomy	2.3% (1)	4.4% (2)	3.4% (3)
Revision laminectomy/fusion (1 level)	9.1% (4)	13.3% (6)	11.2% (10)
Revision laminectomy/fusion (2 levels)	11.4% (5)	2.2% (1)	6.7% (6)
Revision laminectomy/fusion (>2 levels)	2.3% (1)	4.4% (2)	3.4% (3)
Cervical			
ACDF (1 level)	2.3% (1)	6.7% (3)	4.5% (4)
ACDF (2 levels)	6.8% (3)	8.9% (4)	7.9% (7)
ACCF (2 levels)	2.3% (1)	11.1% (5)	6.7% (6)
ACCF (3 levels)	4.5% (2)	6.7% (3)	5.6% (5)
Laminoplasty	4.5% (2)	0.0% (0)	2.2% (2)
Laminoplasty/fusion	2.3% (1)	0.0% (0)	1.1% (1)
Postfusion	0.0% (0)	2.2% (1)	1.1% (1)

*Percent (no.) is based on the total participants with available data for each variable. Percentages may not equal 100 as a result of rounding.
LS = lumbar stenosis; DS = degenerative spondylolisthesis; ACDF = anterior cervical discectomy and fusion; ACCF = anterior cervical corpectomy and fusion.

or dim side of the hospital unit (Table 1). Ninety-two percent of the study population was white.

Analgesic Use

The average analgesic medication use per hour (mg/hr) for patients on the bright and dim side was compared for each day of their hospital stay as well as for their entire length of stay (Table 3). The spinal surgery patients on the dim side of the unit averaged 28.3% (p = .047) more opioid-equivalent analgesic medications per hour, over the entire length of stay, than the patients on the bright side (Table 3). The patients on the dim side of the hospital consistently required more analgesic medication on each day of their stay than the patients on the bright side. Postoperative day 1 was the only 24-hour period of the patients' hospital stay in which there was a statistically significant difference between the 2 study groups (+38.1%, p = .036). Table 3 includes the daily postoperative average analgesic medication use for patients on both the bright and dim side of the hospital unit.

Equal numbers of patients on both sides of the hospital unit: 1) had a history of analgesic medication usage, before hospital admission; and 2) were administered nonanalgesic medications during their hospital stay that may have affected the amount of analgesic medication they used (Table 1). Before admission onto the bright or dim side of the hospital unit, there was no significant statistical difference between the patients with regard to: 1) the quantity of analgesic medication prescribed in the OR, 2) the quantity of analgesia prescribed in the PACU; and 3) the patients' pain rating at PACU discharge (Table 1). In the OR and PACU, the quantity of pain medication prescribed to patients who were assigned to rooms on both sides of the unit were equal. Therefore, any possible "hangover" effects of the OR and PACU analgesics on pain medication use while on the unit will be equal for patients staying on both sides. No confounding factors were identified that may lead to a difference in analgesic medication requirement among patients admitted to the bright or dim side of the hospital unit.

A number of covariates, including age, sex, day of discharge, and history of analgesic medication use, were investigated to determine whether they also affected postoperative

TABLE 3. Clinical Results of Patients Having Undergone Spinal Fusion on Bright and Dim Sides of the Hospital Unit*

Variables	Bright Side		Dim Side		All		*p* Value†
	N	Percent (No.) or Mean ± SD	N	Percent (No.) or Mean ± SD	N	Percent (No.) or Mean ± SD	
Discharge day							
Postoperative day 2	44	20.5% (9)	45	26.7% (12)	89	23.6% (21)	
Postoperative day 3	44	29.5% (13)	45	31.1% (14)	89	30.3% (27)	
Postoperative day 4	44	31.8% (14)	45	26.7% (12)	89	29.2% (26)	
Postoperative day 5+	44	18.2% (8)	45	15.6% (7)	89	16.9% (15)	.879
Other medications‡							
Yes	44	40.9% (18)	45	40.0% (18)	89	40.4% (36)	
No	44	59.1% (26)	45	60.0% (27)	89	59.6% (53)	.930
Mean oral morphine consumption (mg/hr)							
Surgery day§	44	5.3 ± 4.5	44	6.9 ± 6.4	88	6.1 ± 5.5	.166
Postoperative day 1	44	3.7 ± 2.1	45	5.1 ± 3.8	89	4.4 ± 3.2	.036
Postoperative day 2	44	3.2 ± 2.2	45	3.3 ± 2.0	89	3.3 ± 2.1	.785
Postoperative day 3	35	2.5 ± 2.2	33	3.2 ± 2.0	68	2.9 ± 2.1	.162
Postoperative day 4	22	2.5 ± 1.9	20	4.3 ± 7.0	42	3.4 ± 5.0	.259
Postoperative day 5	8	1.1 ± 1.4	8	3.4 ± 3.0	16	2.2 ± 2.5	.064
Entire stay on bright/dim side	44	3.2 ± 1.9	45	4.1 ± 2.4	89	3.7 ± 2.2	.047
Pain medication cost per hour ($/hr)‖	44	0.23 ± 0.12	45	0.29 ± 0.16	89	0.26 ± 0.14	.047
Length of stay (days)	44	3.6 ± 1.6	45	3.4 ± 1.5	89	3.5 ± 1.5	.508

*Percent (no.) is based on the total participants with available data for each variable. Percentages may not equal 100 as a result of rounding.
†*p* value is determined by a chi-squared test for categorical variables and by an independent samples *t* test between bright and dim sides for continuous variables.
‡Other medications taken during stay that may have affected pain perception.
§Surgery day includes medication used on bright/dim side after surgery and post-anesthesia care unit stay.
‖Pain medication cost reported per hour to control for length of stay as a confounding factor.
SD = standard deviation.

analgesic use. Age quartile was the only variable found to be a predictor of analgesic use, with a significant negative correlation ($p < .001$). When age quartile was placed in a general linear model with the unit side (bright/dim), both variables were found to have significant main effects on analgesic use. Age was the more significant of the 2 variables and there was no-interaction effect ($p = .69$). Figure 1 plots the results of this multivariate analysis. Figure 1 shows that patients on the bright side of the unit consistently used less analgesic medications in all age quartiles and that the largest statistically different effect was in the youngest age group.

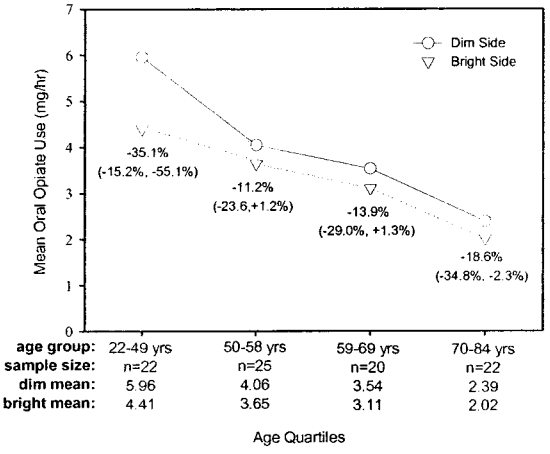

Figure 1. Mean oral opiate use in each age quartile, by side of hall, with percent difference and 95% confidence interval.

A general linear model was also used to investigate whether the patients' reported experience of stress and pain mediated the effects of unit side on medication requirement. When the change scores for stress and/or pain were placed together with unit side in a statistical model, neither one showed significant main effects on medication use. Plots of these analyses (not shown) clearly indicate that there is no monotonic linear relationship between the severity of these psychologic change scores and the increased use of analgesic medications within each side of the unit.

Pain Medication Cost

Postoperative patients who had undergone spinal surgery who were staying on the bright side had an average 21% ($p = .047$) reduction in analgesic medication cost compared with patients on the dim side (Table 3).

Psychologic and Pain Measures

Table 4 summarizes the mean baseline scores and the change from baseline scores at the time of discharge for all of the psychologic and pain measures used in this study. There were no statistical differences between the 2 study groups in any of the baseline measures. At discharge, however, patients on the bright side reported significantly greater decreases in stress (PSS, $p = .035$) and a marginal decrease in pain (MPQ, $p = .058$) than the patients on the dim side. Change from baseline scores for depression and anxiety were similar in the 2 study groups.

TABLE 4. Psychologic Measures of Patients Having Undergone Spinal Fusion on Bright and Dim Sides of the Hospital Unit

Variables	Bright Side		Dim Side		All		*p* Value†
	N*	Mean ± SD	N*	Mean ± SD	N*	Mean ± SD	
Stress							
Day 1	33	15.6 ± 6.6	34	16.5 ± 8.3	67	16.1 ± 7.4	.615
Change‡	29	-2.9 ± 5.2	30	0.5 ± 6.6	59	-1.2 ± 6.2	.035
Depression							
Day 1	32	8.8 ± 5.8	34	11.1 ± 7.6	66	10.0 ± 6.8	.187
Change‡	29	0.6 ± 5.0	30	0.0 ± 5.0	59	0.3 ± 5.0	.617
Anxiety							
Day 1	33	5.5 ± 3.6	34	6.8 ± 3.6	67	6.1 ± 3.6	.138
Change‡	29	0.0 ± 2.8	30	-0.8 ± 2.5	59	-0.4 ± 2.6	.246
Severity of pain							
Day 1	32	5.9 ± 2.4	34	6.0 ± 2.4	66	5.9 ± 2.4	.958
Change‡	29	-2.1 ± 2.6	30	-0.8 ± 2.4	59	-1.4 ± 2.6	.058

*Reduced sample size as a result of the no-interaction group patients (bright = 10, dim = 7) who did not receive questionnaires.
†*p* values are determined by an independent samples *t* test between bright and dim sides.
‡Change measures last day observation - first day observation.
SD = standard deviation.

No-Interaction Group

There was no significant difference ($p = .901$) in analgesic medication use per hour between patients randomized into the no-interaction group (3.62 ± 1.47 mg/hr) and the other patients (3.69 ± 1.47 mg/hr) in the study. Therefore, researcher interaction with the patients did not affect the primary outcome of the study.

CONCLUSIONS

This prospective study consisted of consecutive patients undergoing elective spinal surgery who were assigned postoperatively to rooms on either the bright or dim side of the hospital unit. The patients staying on the bright side received 46% more natural sunlight and required 22% less opioid-equivalent analgesic medications during their hospitalization. The patients staying on the bright side also experienced a 21% reduction in analgesic medication cost compared with patients on the dim side. This study is the first analysis of sunlight's effect on postoperative analgesic medication use and, therefore, should be replicated to confirm the presented results. Specific limitations of this research include the following: 1) First, our study population was restricted to patients who had undergone spinal surgery as well as a small sample size. Future studies should include an increased sample size with a wider range of surgical patients. Positive results among a variety of surgical patients with a larger sample would indicate greater validity of sunlight's ability to reduce analgesic use. 2) The measurement of sunlight intensity occurred twice daily at 9:30 AM and 3:30 PM. This methodology of sunlight measurement could not account for individuals who may have adjusted their blinds, overhead lighting, or other variables that could affect the exposure intensity. However, even if a few patients on the bright side closed their blinds or reduced their amount of sunlight exposure, their data were still included in our results because we followed the intent-to-treat model. The entire bright side population was analyzed even if a few patients may have closed their blinds and did not experience a decrease in analgesic use.

For future research, it would be preferable to use more sophisticated equipment that has the ability to continuously monitor sunlight intensity inpatient rooms. Light-frequency sensors, which measure the intensity of both sunlight and fluorescent light at short time intervals, could be situated in the interior of patient rooms. Such equipment could accurately measure the quantity of natural sunlight and manufactured light that a patient is exposed to while they are in their hospital room. 3) Another limitation of this research is that no biologic samples were collected from the patient population. Subsequent studies should measure a variety of biologic parameters (eg, serotonin) to investigate potential mechanisms of sunlight action on psychosocial and analgesic medication outcomes. 4) Subjects were admitted into this study after they were assigned to hospital rooms on either the bright or dim side of the unit. The unit director assigned patients to either side based only on room availability and without consideration of biographic characteristics (eg, age, sex, surgical procedure). Although statistical analysis revealed no significant differences between the characteristics of patients on both sides of the unit, a formal randomization procedure would be preferable. 5) Finally, age was determined to be a confounding factor that correlated significantly with a decrease in analgesic medication use. Although patients on the bright side consistently used less analgesic medications in all age groups, future studies could remove age as a possible confounding variable by stratifying patients before room assignment. The ideal replication would admit patients into the study before having surgery, then stratify based on age, and use a formal randomization procedure to assign patients to hospital rooms. This methodology, although it may not be feasible in a hospital setting, would qualify as a randomized, controlled trial.

The pioneering work of Roger Ulrich (22) first established the potential influence of the hospital room environment on

the course of hospitalization. Our data extends the influence of the environment to the amount of sunlight present in a hospital room. The demonstrated effect of sunlight exposure on analgesic medication use could have implications for architects, scientists, physicians, and hospital administrators.

The United Kingdom recently established a Private Finance Initiative (PFI) to redevelop 25% of all healthcare buildings within 10 years, incurring a cost of over $2.1 billion to date (23). The British government's National Health Service proposed an Achieving Excellence Design Evaluation Toolkit (AEDET) to assess current healthcare buildings and provide design specifications for new PFI hospitals (24). One major element of the AEDET assessment is whether the hospital design provides a therapeutic environment for patients (23,24). The beneficial outcomes presented in this study may encourage architects to consider the level of sunlight exposure for patients. An optimal therapeutic hospital design may maximize sunlight exposure for patients with high use of analgesic medication. This research may also inspire architects and researchers to conduct similar studies that examine the effect of other hospital room design elements on the healing process.

Patients on the bright side in our study reported a significantly greater decrease in perceived stress at the time of discharge; however, this was not statistically associated with lower mean levels of analgesic use. These findings suggest that different mechanisms may mediate the effects of sunlight on psychosocial factors and analgesic use. Possible mechanisms may involve hormonal alteration in response to light. One particular neurotransmitter is serotonin, the concentration of which increases after light exposure. The activity of serotonin n-acetyltransferase, which catalyzes the conversion of serotonin into melatonin, is reduced after exposure to light (14). The serotonin metabolite concentration in the cerebrospinal fluid peaks during the summer months (25). This occurs during a time of higher-intensity sunlight and a longer period of daylight compared with the winter months that have the lowest concentration of hypothalamic serotonin (26). Research has shown that high-intensity light (phototherapy) increases platelet imipramine-binding sites (27), which are an indicator of serotonin uptake.

Serotonin is secreted by nuclei that originate in the brainstem (15). It then acts as an inhibitor of pain pathways in the spinal cord and other areas of the central nervous system (15). The role of serotonin in nociceptive processes is well documented (28), along with studies that correlate low serum serotonin concentrations and a high level of tenderness for patients with temporomandibular disorders (29).

Data from over 40 controlled trials indicates that tricyclic antidepressants (TCAs) reduce a patient's pain perception (30). TCAs block the removal of serotonin from the synaptic cleft and thus prolong and increase the time that serotonin remains active in the body (31). This is analogous to having an increase serotonin concentration in the central nervous system (CNS) during time periods of exposure to higher-intensity sunlight (25). Therefore, our hypothesis is that exposure to sunlight may reduce a patient's perception of pain and their need for analgesic medication.

Side effects from opioid use are common among postoperative patients. One survey reported that 82% of patients taking opioid medications had at least 1 side effect from that medication (13). The incidence of common side effects such as nausea and vomiting increases with an increase in the opioid dose (32). A reduction in opioid use among postoperative patients who are exposed to increased sunlight may cause a reduction in the occurrence of specific dose-dependent side effects. The potential health benefits of patient exposure to sunlight may cause physicians to encourage their patients to leave the blinds open in their hospital room.

Analgesic medication use in this patient population was the most in the youngest age group (22–49 year-olds). This is consistent with prior research demonstrating that the duration of pain relief after a single dose of an opioid increases with age (33). Sunlight had the most significant effect on analgesic use among the youngest age group and also on the first day after surgery, when the most pain medication was used. This study demonstrated that hospital patients who use the highest amount of analgesia received the most benefit from sunlight exposure. These results may encourage hospital administrators to relocate patient populations with high-analgesic requirements to units with higher-intensity sunlight.

The influence of the hospital environment on the healing process may contribute to a significant reduction of healthcare costs. This is of great importance during the present time because inpatient healthcare expenditures in the United States rose 6.2% from January 2002 to June 2002 (34), with pharmacy departments representing the third largest component of hospital costs (35). In our study, pain medication costs for patients on the bright side were reduced by 21%. These findings suggest that the exposure of surgical patients to increased amounts of natural sunlight during their hospital recovery period not only has important medical benefits for the patient, but also has significant cost saving benefits for health systems.

The authors thank all the patients who took part in this study. The authors also acknowledge the work of Nicole Daver and Michelle Webb as senior research assistants; and the assistance of Stephen Blank and Treacy Silverstein in data analysis. The authors also thank Gregory Bascug, Reneeta Basu, Steven Buslovich, Colleen Carroll, Caroline Chen, Melissa Frisby, Salome Ho, Meng Lu, Tara Marsh, Sara Rankin, Ken Shurin, Usmeet Singh, Zach Svigals, Derek Tang, and Georgia Thomas for their help with data collection. The authors thank Colleen Dunwoody, Michelle Hughes, Dr. Amy Burkert, Dr. William Brown, and Irene Kane for their administrative assistance. Finally, this research would not have been possible without the cooperation of Mary Beth, Joanna, and all of the nurses of Montefiore 8 South, who cared for this patient population.

REFERENCES

1. Partonen T, Lönnqvist J. Bright light improves vitality and alleviates distress in healthy people. J Affect Disord 2000;57:55–61.
2. Yamada N, Martin-Iverson MT, Daimon K, Tsujimoto T, Takahashi S.

Clinical and chronobiological effects of light therapy on nonseasonal affective disorders. Biol Psychiatry 1995;37:866–73.
3. Blehar MC, Rosenthal N, Terman M, Wehr T. Identification, assessment, and treatment of seasonality in mood disorders. Psychopharmacol Bull 1990;26:3–11.
4. Eastman CI, Young MA, Fogg LF, Liu L, Meaden PM. Bright light treatment of winter depression: a placebo-controlled trial. Arch Gen Psychiatry 1998;55:883–9.
5. Benedetti F, Colombo C, Barbini B, Campori D, Smeraldi E. Morning sunlight reduces length of hospitalization in bipolar depression. J Affect Disord 2001;62:221–3.
6. Beauchemin KM, Hays P. Sunny hospital rooms expedite recovery from severe and refractory depressions. J Affect Disord 1996;40:49–51.
7. Wirz-Justice A, Graw P, Krauchi K, Sarrafzadeh A, English J, Arendt J, Sand L. 'Natural' light treatment of seasonal affective disorder. J Affect Disord 1996;37:109–29.
8. Oren DA, Wisner KL, Spinelli M, Epperson CN, Peindl KS, Terman JS, Terman M. An open trial of morning light therapy for treatment of antepartum depression. Am J Psychiatry 2002;159:666–9.
9. Lefkowitz ES, Garland CF. Sunlight, vitamin D, and ovarian cancer mortality rates in US women. Int J Epidemiol 1994;23:1133–6.
10. Freedman DM, Dosemeci M, McGlynn K. Sunlight and mortality from breast, ovarian, colon, prostate, and non-melanoma skin cancer: a composite death certificate based case–control study. Occup Environ Med 2002;59:257–62.
11. Beauchemin KM, Hays P. Dying in the dark: sunshine, gender, and outcomes in myocardial infarction. J R Soc Med 1998;91:352–4.
12. Freid VM, Prager K, MacKay AP, Xia H. Chartbook on Trends in the Health of Americans. Health, United States 2003. Hyattsville, MD: National Center for Health Statistics; 2003:10.
13. Chronic pain in America: roadblocks to relief. American Pain Society; 1999. Available at: http://ampainsoc.org/whatsnew/summary4_road.htm. Accessed September 18, 1999.
14. Deguchi T, Axelford J. Control of circadian change of serotonin n-acetyltransferase activity in the pineal organ by the beta-adrenergic receptor. Proc Natl Acad Sci USA 1972;69:2547–50.
15. Guyton AC, Hall JE. Textbook of Medical Physiology, 10th ed. Philadelphia: WB Saunders Co; 2000.
16. McCaffery M, Pasero C. Pain: Clinical Manual. 1999:241–43.
17. Melzack R. The short-form McGill Pain Questionnaire. Pain 1987;30: 191–7.
18. Radloff LS. The CES-D scale: a self-report depression scale for research in general population. Applied Psychological Measurement 1977;1: 385–401.
19. Cohen S, Williamson GM. Perceived stress in a probability sample of the United States. The Social Psychology of Health 1988.
20. Usala PD, Hertzog C. Measurement of affective states in adults. Res Aging 1989;11:403–426.
21. Scheier MF, Carver CS, Bridges MW. Distinguishing optimism from neuroticism (and trait anxiety, self-mastery, and self-esteem): a re-evaluation of the Life Orientation Test. J Pers Soc Psychol 1994;67: 1063–78.
22. Ulrich R. View through a window may influence recovery from surgery. Science 1984;224:420–1.
23. Gesler W, Bell M, Curtis S, Hubbard P, Francis S. Therapy by design: evaluating the UK hospital building program. Health Place 2004;10: 117–28.
24. NHS Estates, 2001. Achieving Excellence Design Evaluation Toolkit. A toolkit for evaluating the design of healthcare buildings from initial proposals through to post project evaluation: Instructions. NHS Estates. Available at: http://195.92.246.148/nhsestates/chad/chad_content/publications_guidance/introduction.asp#sub_3.
25. Brewerton T, Berrettini W, Nurnberger J, Linnoila M. Analysis of seasonal fluctuations of CSF monoamine metabolites and neuropeptides in normal controls: findings with 5HIAA and HVA. Psychiatry Res 1988; 23:257–65.
26. Carlsson A, Svennerhom L, Winblad B. Seasonal and circadian monoamine variations in human brain examined post mortem. Acta Psychiatr Scand Suppl 1980;280:75–83.
27. Szádóczky E, Falus A, Arató M, Németh A, Teszéri G, Moussong-Kovács E. Phototherapy increases platelet 3H-imipramine binding in patients with winter depression. J Affect Disord 1989;16:121–5.
28. Beitz A. The anatomy of ascending serotonergic pathways possibly involved in pain modulation. In: Besson, ed. Serotonin and Pain. Elsevier Science Publishers; 1990:31–46.
29. Ernberg M, Hedenberg-Magnusson B, Alstergren P, Lundeberg T, Kopp S. Pain, allodynia, and serum serotonin level in orofacial pain of muscular origin. J Orofac Pain 1999;13:56–62.
30. Lynch ME. Antidepressants as analgesics: a review of randomized controlled trials. Psychopharmacol Pain 2001;26:30–6.
31. Fields HL. Neurophysiology of pain and pain modulation. Am J Med 1984;2–8.
32. Cepeda MS, Farrar JT, Baumgarten M, Boston R, Carr DB, Strom BL. Side effects of opioids during short-term administration: effect of age, gender, and race. Clin Pharmacol Ther 2003;74:102–12.
33. Bellville JW, Forrest WH, Miller E, Brown BW. Influence of age on pain relief from analgesics: a study of postoperative patients. JAMA 1971; 217:1835–41.
34. Strunk BC, Ginsberg PB, Gabel JR. Tracking health care costs: growth accelerates again in 2001. Health Aff 2002;W299–W310.
35. Data trends—direct expense percentage by department. Healthc Financ Manage 2001;55–84.