Noise Levels in Surgical ICUs Are Consistently Above Recommended Standards

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Objective: The equipment, monitor alarms, and acuity of patients in ICUs make it one of the loudest patient care areas in a hospital. Increased sound levels may contribute to worsened outcomes in these particularly vulnerable patients. Our objective was to determine whether ambient sound levels in surgical ICUs comply with recommendations established by the World Health Organization and Environmental Protection Agency, and whether implementation of an overnight "quiet time" intervention is associated with lower ambient sound levels.

Design: Prospective, observational cohort study.

Setting: Two comparable 18-bed, surgical ICUs in a large, teaching hospital. Only one ICU had a formal overnight quiet time policy at the start of the study period.

Measurements and Main Results: Sound levels were measured in 30-second blocks at preselected locations during the day and night over a period of 6 weeks using a simple, hand-held sound meter. All sound measurements in both units at all times exceeded recommended standards. Median minimum sound levels were lower at night in both units (50.8 and 50.3 vs 53.1 and 51.0 dB, $p = 0.0003$ and $p = 0.009$) and were similar between the two units ($p = 0.52$). The maximum overnight sound levels were statistically lower in the unit with the quiet time intervention implemented (62.5 vs 59.6 dB; $p = 0.0040$) and decreased overnight immediately after implementation of quiet time in the other unit (62.5 vs 56.1 dB; $p < 0.0001$). Maximum sound levels were lower inside patient rooms (52.2 vs 55.3 dB; $p = 0.004$), but minimum sound levels were similar (49.1 vs 49.2 dB; $p = 0.23$). Linear regression analysis showed that ICU census did not significantly influence sound levels.

Conclusions: Ambient sound levels in the surgical ICUs were consistently above levels recommended by the World Health Organization and Environmental Protection Agency at all times. The use of a formal quiet time intervention was associated with a significant, but clinically irrelevant reduction in the median maximum sound level at night. Our results suggest that excessive ambient noise in the ICU is largely attributable to environmental factors, and behavior modifications are unlikely to have a meaningful impact. Future investigations, as well as hospital designs, should target interventions toward ubiquitous noise sources such as ventilation systems, which may not traditionally be associated with patient care. (*Crit Care Med* 2016; 44:147–152)

Key Words: critical care; environmental; intensive care unit; noise; quiet; sound

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Modern ICUs are a cacophony of raucous devices (1). In addition to the noise (alarms and mechanical "hum") produced by monitors and devices (ventilators, hemodynamic assist devices, and infusion pumps), conversations between staff, patients, and visitors, as well as sounds emanating from the patients, contribute to background noise. For ICU patients, high levels of ambient sound may be associated with sleep disturbance and the risk of delirium (2). Furthermore, healthcare providers exposed to elevated noise levels may be at risk for hearing damage and unintended distractions that may lead to increased cognitive errors (3).

The Environmental Protection Agency (EPA) recommends a sound level of 35–45 A-weighted decibels (dB(A), abbreviated here as dB, unless otherwise specified) for sleeping environments

(4), and the Occupational Safety and Health Administration recommends that occupational sound exposure not exceed 90 dB (continuously) for a total time of exposure of 8 hours (5). The World Health Organization (WHO) recommends that background noise should not exceed 30 dB in sleeping environments, with individual noise events not exceeding 45 dB. Specifically for hospitals, the WHO recommends baseline levels below 30 dB, with sound events not exceeding 40 dB (6). Existing data suggest that ambient sound levels in the hospital environment consistently exceed these recommendations (7–9).

Recent data suggest that over 50% of noise in the ICU may be generated by speech and human activities (10, 11). Because a reduction in ambient noise may influence the health of patients and providers, the use of behavioral modification interventions such as mandatory quiet times has been suggested as an effective measure to reduce noise levels (12, 13). Evidence to support the effectiveness of such interventions in the ICU is limited and contradictory (14). The primary aim of our study was to determine baseline noise levels in the surgical ICU and to assess whether a formal quiet time intervention was associated with reductions in ambient noise level.

METHODS

We conducted a prospective, observational cohort study involving two comparable surgical ICUs at the Massachusetts General Hospital (MGH) in Boston, MA. This subsequently incorporated a secondary quasi-experimental (before/after) study. The study was approved by the Partners Human Research Committee (institutional review board). The medical and nursing directors of both ICUs were aware of the exempt status of the research protocol and were supportive of sound recordings being performed inconspicuously by the study investigators, all of whom regularly provide care for patients in both ICUs. MGH is 1052-bed teaching hospital, which is a level 1 trauma center and serves as a primary and tertiary care hospital for patients throughout the world.

Study Population

Both surgical ICUs (labeled SICU 1 and SICU 2 here for convenience) are staffed by the same group of faculty intensivists, residents, and fellows from the Department of Anesthesia, Critical Care and Pain Medicine, as well as the Department of Surgery at MGH. SICU 1 and SICU 2 are general surgical and trauma units that also serve as overflow units from the medical, neurosciences, cardiac, and burn ICUs (**Table 1**). In general, admission destination is determined by bed availability.

Quiet Time Definition

A formal quiet time intervention program had been in effect for approximately 12 months in SICU 2 before the start of this project. The intervention consisted of turning down hallway lights and encouraging staff to minimize unnecessary noise by the use of multiple visual cues, including posters and simulated traffic light signals indicating the desired sound level, as well as in-person reminders by administrative personnel. Alarm limits and volumes were not altered. Quiet time hours in SICU 2 were officially between 11 PM and 5 AM. Data recorded from SICU 1 during the same hours, but without the designated quiet time, are referred to as "overnight."

Data Collection

Observational measurements were obtained prospectively over a 6-week period at four comparable locations on both ICUs. Locations were selected to include the perceived "noisiest" (next to the refrigerator) and "quietest" areas (at the end of the hallway), as well as in two "midrange" areas. Data were recorded by a critical care fellow who was inconspicuous on the unit, but not actively providing patient care during the data collection.

At each location, the highest and lowest sound levels were recorded for two consecutive 30-second intervals. This process was then immediately repeated on the complementary unit to provide comparable data. The order of which ICU was measured first was distributed roughly evenly based on sampling convenience, and paired samples were not always possible due to patient care needs. Sampling times were selected based on availability of a data collector and distributed between quiet time/overnight hours and standard working hours to provide a control sample. All noise levels were measured using an Extech 407730 digital sound meter with a 0.5″ (12.7 mm) electric condenser microphone (Extech Instruments, Nashua, New Hampshire). The device includes a windscreen to minimize artifact and has a measurement range from 40 to 130 dB, with 0.1 dB resolution and an accuracy of ± 2 dB. A 1-second refresh rate was used.

ICU census was also assessed during the observation times. Additionally, paired data were collected in each ICU to determine whether there was a difference between sound levels measured in the common areas (hallways) versus inside the patient rooms. After initial data collection was complete (6-wk study period), SICU 1 introduced an overnight quiet time, similar to that already in place in SICU 2. To take advantage of this natural before-and-after opportunity, we also collected data from SICU 1 after implementation of a quiet time intervention.

Statistical Analysis

A pilot sample was obtained during rounds, which is typically the noisiest time of the day, in each ICU (n = 20 observations) approximately 60 days before the start of the study. The median peak sound level was approximately 90 ± 10 dB. We assumed that median peak sound levels would drop to 60 dB in SICU 1 and 50 dB in SICU 2 during overnight and quiet time hours, respectively (based on a few sample measurements). To detect this change, assuming a common standard deviation of 10 dB, with α set at 0.01, and β of 0.9, would require a minimum of 60 observations in each ICU during overnight/quiet time and during regular working hours (minimum of 240 observations in total). The decision to use an α of 0.01 was based on a Bonferroni correction because of the multiple recordings obtained at four different locations on each unit (0.05/4 = 0.0125). Therefore, a p value of less than 0.01 was considered significant.

Data analysis was performed using STATA 13 (StataCorp, College Station, TX). Normality was assessed with the Shapiro-Wilk test, and it was determined that the data were not normally

TABLE 1. Baseline Demographics

	SICU 1	SICU 2
SICU characteristics		
No. of ICU beds	20	18
Census (total)	1,436	1,288
Census (range)	7–20	8–18
Census, mean ± SD	15.6±2.7	15±2.3
Census, median (IQR)	16.0 (15.0–17.0)	15 (12.5–16.0)
Patient characteristics		
Acute Physiology and Chronic Health Evaluation 2 (median)	15.0	15.0
Age (yr), mean	64.0	64.0
Gender: female (%)	35.0	34.0

SICU = surgical ICU, IQR = interquartile range.

distributed (likely due to the logarithmic nature of the decibel measurements). Statistical significance for continuous variables was therefore analyzed using the Wilcoxon rank-sum test.

To investigate the association of unit census with ambient sound levels, linear regression analysis was performed with the ICU (SICU 1 vs SICU 2) as the control variable.

RESULTS

During the entire study period, 408 observations were assessed. For the initial sampling period, 168 observations were made in SICU 1 and 160 observations in SICU 2. In SICU 1, 80 measurements were taken during overnight hours (matched according to quiet time hours in SICU 2) and 88 measurements during daytime hours (matched according to nonquiet time in SICU 2). In SICU 2, 72 measurements were taken during overnight (quiet time) hours and 88 measurements were taken during daytime (nonquiet time) hours. In addition, 80 observations were made after the implementation of a quiet time intervention in SICU 1, which included sets of data taken from both inside and outside patients' rooms. During this postimplementation phase, all of the 80 measurements were taken during quiet time hours.

Sound Levels Comparing SICU 1 Versus SICU 2

Sound levels observed on the two units were similar (**Table 2** and **Fig. 1**). There was a statistically significantly higher median maximum sound level in SICU 1 than in SICU 2, both overnight and during the daytime. Minimum sound levels did not show a significant difference.

Sound Levels Comparing Daytime Versus Overnight

The median minimum sound level overnight was lower than the daytime level on both units, regardless of the presence of the quiet time intervention (**Table 3**). However, the median maximum volume during daytime was similar to the overnight maximum on both units.

Sound Levels in SICU 1 Before and After Implementation of Quiet Time

After implementation of quiet time in SICU 1, the minimum sound level did not change, but the maximum volume decreased (**Table 4**). The difference between the minimum and the maximum value also reflected a difference. The unit census was lower after the implementation.

Sound Levels Inside and Outside Patients' Rooms (During Quiet Time)

The minimum sound level inside the rooms was similar to the minimum sound level outside the room (**Table 5**). However, the maximum sound levels inside the patient rooms were

TABLE 2. Sound Levels, Surgical ICU 1 Versus Surgical ICU 2, Median (Interquartile Range)

SICU 1		SICU 2			With Regression
Overnight (no quiet time), 80 observations		Overnight quiet time, 72 observations		*p*	*p*
Min (dB)	50.8 (49–53)	Min (dB)	50.3 (47–54.5)	0.52	0.45
Max (dB)	62.5 (58.9–77.7)	Max (dB)	59.6 (56.7–63.7)	**0.0040**	**0.005**
Difference (dB)	12.4 (7.7–24.1)	Difference (dB)	8.55 (4.7–16.9)	**0.0115**	**0.022**
Census (% bed occupancy)	88 (85–90)	Census (% bed occupancy)	88.9 (83.3–94)	0.90	
Daytime 88 observations		Daytime, 88 observations			
Min (dB)	53.1 (51.3–55.3)	Min (dB)	51 (50.1–55.4)	0.0621	0.472
Max (dB)	63.3 (61.6–77.4)	Max (dB)	61.2 (57.8–66.5)	**0.0001**	**< 0.001**
Difference (dB)	11.1 (7.68–24.1)	Difference (dB)	8.1 (6.2–12)	**0.0005**	**< 0.001**
Census (% bed occupancy)	90 (80–94)	Census (% bed occupancy)	83.3 (83.3–94.4)	0.85	

SICU = surgical ICU.
Bold values are any value less than 0.01, which we considered statistically significant.

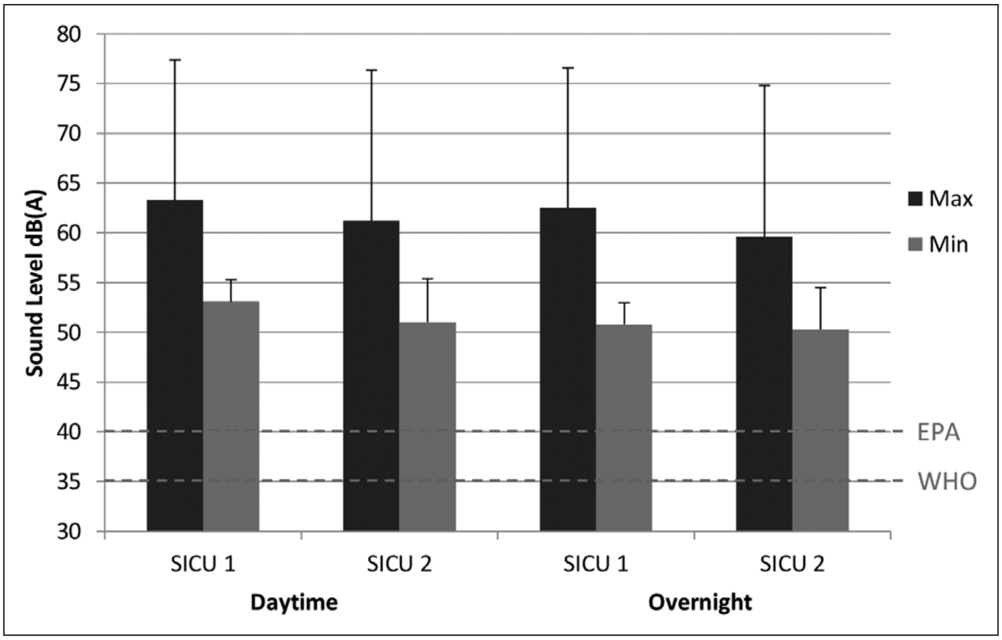

Figure 1. Median sound levels during the daytime vs overnight in the two surgical ICUs (SICUs). SICU 2 overnight had the quiet time intervention (error bars represent interquartile range, Environmental Protection Agency [EPA], and World Health Organization [WHO] recommendations in *dotted lines*).

was primarily attributable to the ventilation system (50–55 dB) and the refrigerator (60–65 dB).

Sound Levels Stratified by Census

To investigate the association of unit census with ambient sound levels, we performed linear regression analyses while controlling for type of ICU (SICU 1 vs SICU 2). During the daytime, census was not associated with mean minimum or maximum sound level (β = 4.04; 95% CI, –6.53 to 14.61; p = 0.452 and β = –0.72; 95% CI, –17.08 to 15.64; p = 0.931, respectively). In this model, type of SICU was not independently associated with mean minimum sound level (β = 0.55; 95% CI, –0.96 to 2.07; p = 0.472); however, SICU 2 was found to have lower mean maximum sound levels during the day (β = –4.43; 95% CI, –2.08 to –6.78; p < 0.001). Overnight, census was not independently associated with mean minimum or maximum sound levels (β = 12.5; 95% CI, 0.81 to 24.20; p = 0.036 and β = –17.5; 95% CI, 2.61 to –37.60; p = 0.088, respectively). Although the presence of a quiet time protocol was not associated with mean minimum sound level (β = –0.67; 95% CI, 1.07 to –2.40; p = 0.450), it was inversely associated with mean maximum sound level (β = –4.43; 95% CI, –1.34 to –7.32; p = 0.005).

We also performed linear regression to investigate the association of census with ambient overnight sound levels, while

lower. The difference between the minimum and the maximum value also reflected a difference. Unit census was identical during these measurements.

Sources of Noise

Although data regarding the provenance of noise events were not identified as an outcome a priori, the data recorder noticed repetitive events associated with noise peaks. These peaks occurred with doors opening/closing (55–82 dB), monitor alarms (55–68 dB), pneumatic tube system (65–75 dB), conversations between staff (50–80 dB), and nursing call bells (60–65 dB). Background noise

TABLE 3. Sound Levels, Daytime Versus Overnight, Median (Interquartile Range)

Daytime		Overnight			With Regression
SICU 1, 88 observations		No quiet time, 80 observations		*p*	*p*
Min (dB)	53.1 (51.3–55.3)	Min (dB)	50.8 (49–53)	**0.0003**	**0.001**
Max (dB)	63.3 (61.6–77.4)	Max (dB)	62.5 (58.9–77.7)	0.19	0.32
Difference (dB)	11.1 (7.68–24.1)	Difference (dB)	12.4 (7.7–24.1)	0.69	0.69
Census (% bed occupancy)	90 (80–94)	Census (% bed occupancy)	88 (85–90)	0.47	
SICU 2, 88 observations		Quiet time, 72 observations			
Min (dB)	51.0 (50.1–55.4)	Min (dB)	50.3 (47–54.5)	**0.009**	**0.002**
Max (dB)	61.2 (57.8–66.5)	Max (dB)	59.6 (56.7–63.7)	0.09	0.367
Difference (dB)	8.1 (6.2–12)	Difference (dB)	8.55 (4.7–16.9)	0.45	0.121
Census (% bed occupancy)	83.3 (83.3–94.4)	Census (% bed occupancy)	88.9 (83.3–94)	0.91	

SICU = surgical ICU.
Bold values are any value less than 0.01, which we considered statistically significant.

TABLE 4. Overnight Versus Quiet Time Intervention in Surgical ICU 1, Median (Interquartile Range)

Overnight Without Quiet Time, 80 Observations		Overnight With Quiet Time, 48 Observations			With Regression
				p	*p*
Min (dB)	50.8 (49–53)	Min (dB)	49.5 (48.1–52.9)	**0.08**	0.905
Max (dB)	62.5 (58.9–77.7)	Max (dB)	56.1 (53–60.2)	**< 0.0001**	0.005
Difference (dB)	12.4 (7.7–24.1)	Difference (dB)	5.65 (2.65–9.0)	**< 0.0001**	0.006
Census (% bed occupancy)	88.0 (85–90)	Census (% bed occupancy)	65 (60–75)	**0.0001**	

Bold values are any value less than 0.01, which we considered statistically significant.

controlling for the before and after quiet time implementation periods in SICU 1. In this model, census was not associated with mean minimum or maximum sound level (β = 3.207; 95% CI, –2.991 to 9.404; *p* = 0.308 and β = 11.06; 95% CI, –2.592 to 24.72; *p* = 0.111, respectively). Although there was no difference in the pre- and postimplementation periods regarding mean minimum sound level (β = –0.1174; 95% CI, –2.067 to 1.832; *p* = 0.905), the postimplementation period was associated with lower mean maximum sound level (β = 6.161; 95% CI, 1.865 to 10.46; *p* = 0.005).

DISCUSSION

Sound levels in the SICU are suboptimal. Our study demonstrates that ambient sound levels at our institution were above both WHO and EPA recommendations at all times. We also found that a multipronged quiet time intervention was not effective in helping to meet these recommendations.

Sound reduction as part of a bundle has previously been shown to reduce delirium in a general ICU (15). It is notable, however, that the sound levels reported in that study (68.8 ± 4.2 dB before vs 61.8 ± 9.1 dB after; *p* = 0.002) also exceed the recommended standards. In addition to potentially deleterious effects on patients, the effects of environmental noise on providers should be considered. In an era of increasing concern for adverse events attributable to alarm fatigue and environmental distractions leading to cognitive errors (16), our study provides additional support to limiting the number and severity of alarms occurring during patient care.

Surprisingly, unit census did not correlate with a significant effect on sound levels. Increased patient volume, increased staffing, and an overall increased activity level during a higher patient census would be expected to raise the ambient sound levels, as well as increase the intensity of noise events, but this did not have a meaningful effect. Although linear regression analysis demonstrated a small association between census and peak noise levels, this is unlikely to have a clinically important effect as the minimum noise levels were still far above the recommended standards. This further reinforces the notion that the prevailing sources of ambient sound are not related to patients and staff and are attributable to consistently present sources such as the ventilation system, refrigerator, and pneumatic tube system.

Although maximum sound levels were higher outside patient rooms, minimum levels remained similar. This suggests that much of the cause of background noise (e.g., ventilation system) is present inside patient rooms, whereas causes of significant noise events (doors slamming, conversations between staff, etc.) occur in the common areas. Therefore, to decrease background noise, it may be more prudent to target interventions toward ubiquitous noise sources such as ventilation systems, not traditionally associated with patient care.

The device used had a lower threshold of 40 dB, potentially limiting the accuracy of the low-end measurements, and overestimating sound levels. However, the low end of the recording

TABLE 5. Inside Versus Outside Patient Rooms, Median (Interquartile Range)

Inside, 40 Observations		Outside, 40 Observations			With Regression
				p	*p*
Min (dB)	49.1 (47.4–50.1)	Min (dB)	49.2 (48.1–51.1)	0.23	0.061
Max (dB)	52.2 (50.1–54)	Max (dB)	55.3 (52.2–58)	**0.004**	**0.001**
Difference (dB)	3 (1.8–4.4)	Difference (dB)	5.4 (2.35–6.8)	**0.0099**	**0.009**
Census (% bed occupancy)	65 (60–65)	Census (% bed occupancy)	65 (60–65)	1.00	

Bold values are any value less than 0.01, which we considered statistically significant.

spectrum was only reached in a minority of measurements (28/408). In addition, median values were used for analysis, which were not affected by this range limit, so the impact should be negligible.

Our study was performed at a single institution and limited to only the two SICUs. As a result, our results may not be applicable to other types of ICUs, inpatient units, or other institutions. However, we believe that the general setup and equipment in most ICUs is fairly consistent and contain many of the same sound-generating devices. Similarly, many of the environmental sources of noise are present throughout all patient care areas of the hospital, not just ICUs. Interventions targeted at influencing these devices (ventilation system, monitor alarms, etc.) require further investigation.

CONCLUSIONS

Ambient noise in both surgical ICUs was consistently above levels recommended by both the WHO and the EPA at all times. Even after implementation of a quiet time intervention, noise levels were higher than recommended standards. An intervention to reduce noise by staff at our institution was found to be not clinically meaningful and failed to meet recommended standards. Our results suggests that the design of the physical environment may play a much larger role in noise control than what was previously appreciated, and environmental sources of noise should be carefully considered in future designs of ICUs.

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