

# SOUND INTENSITY AND NOISE EVALUATION IN A CRITICAL CARE UNIT

By Nancy Lawson, AS, RRT, Kim Thompson, RN, BSN, Gabrielle Saunders, PhD, Jaya Saiz, RN, MN, Jeannette Richardson, RN, MS, Deborah Brown, RN, BSN, Naomi Ince, RN, BSN, Marc Caldwell, AuD, and Diana Pope, RN, PhD

**CE** 1.25 Hours

## Notice to CE enrollees:

A closed-book, multiple-choice examination following this article tests your understanding of the following objectives:

1. Describe the different ways sound and noise can be measured with relation to patient care and disruption of healing.
2. Discuss the World Health Organization guidelines for noise levels in hospitals and for sound events during the night.
3. Identify at least 5 different ways sound and noise can be measured.

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**Background** Sound levels in intensive care units can be high. Unfortunately, high levels of sound tend to result in poor sleep quality, which leads to slower healing, poorer immune response, and decreased cognitive function.

**Objectives** To measure sound levels to which patients in intensive care units are typically exposed.

**Methods** Peak sound pressure levels of alarms on medical devices set at different output levels were measured. Additionally, ambient sound pressure levels for durations of 10 to 24 hours were measured on 12 occasions in patients' rooms in the intensive care unit.

**Results** Peak levels of equipment alarms measured inside a patient's room were high, and increased as the setting of the alarm level increased. The levels of these alarms when measured in an adjacent room did not increase with alarm output level. Mean sound levels inside the patient's room were generally less than 45 dB(A), but peak levels were often greater than 85 dB(C). Closing the door of the adjacent room did not decrease these peak levels. Peak and mean levels did not differ systematically during 24 hours of measurement.

**Conclusions** High-intensity equipment alarms disturb patients' sleep but are critical in a medical emergency. However, nurses should not assume that raising the alarm output level will ensure that the alarm is audible from an adjacent room. Ambient noise measurements indicate high peak levels during both day and night. (*American Journal of Critical Care*. 2010;19:e88-e99)

**S**leep disruption in intensive care units (ICUs) is common<sup>1</sup> and is detrimental to patients' health and recovery.<sup>2</sup> Causes of the disruptions include necessary medical interventions, such as measurement of vital signs and checking of equipment<sup>3</sup>; disruptions due to pain, medications, and stress<sup>4,5</sup>; staff interactions with other patients and one another<sup>6,7</sup>; environmental light<sup>8</sup>; and noise.<sup>9-11</sup> In a review of the literature, Xie et al<sup>12</sup> reported that between 17% and 57.6% of arousals and awakenings are due to noise. Aaron et al<sup>13</sup> found a significant correlation between sound peaks and electroencephalographic evidence of arousals from sleep and a significant difference between the number of arousals that occurred during noisy periods and those that occurred during quiet periods.

Sound is measured as a sound pressure level (SPL), in units of decibels, with a sound level meter (SLM). A decibel is a ratio between a measured level and a reference level. The dB scale is logarithmic and therefore is nonlinear. Furthermore, the human ear is differentially sensitive across frequencies. Specifically, the human ear requires much higher SPLs to detect low-frequency signals (eg, those <100 Hz) than it does to detect signals between 500 Hz and 8000 Hz; at greater than 8000 Hz, sensitivity decreases again. For these reasons, sound can be relatively complex to quantify and define.

Sound can be quantified in many different ways, and because of the differential sensitivity of the human ear, a system of weighting networks has been developed to take sensitivity into account. In our study, we used 2 weighting networks: the A-weighting network or dB(A) scale and the C-weighting network or dB(C) scale. The dB(A) scale gives more importance to frequencies to which the human ear is most sensitive and thus gives less weight to low-frequency sounds than it does to mid- to high-frequency sounds. In contrast, the dB(C) scale is almost linear; it gives almost equal weighting to sounds of all frequencies. In this study, we used 2 different ways to quantify sound: the mean sound level over a period of time

and the peak level within that period. We measured the mean level by using a metric known as the equivalent continuous SPL (Leq) and the peak level by using a metric known as the peak SPL (Lpk). A technical definition of the Leq is the steady SPL that during a given time has the same total energy as the fluctuating noise. A technical definition of the Lpk is the highest instantaneous SPL detected during the time of observation. Traditionally, and for this study, the Leq is measured by using the A-weighting or dB(A) scale (ie, LAeq). The Lpk is measured by using the C-weighting or dB(C) scale (ie, LCpk). For more information about sound and its measurement, see *Introduction to Sound: Acoustics for the Hearing and Speech Sciences*.<sup>14</sup>

Both patients and members of critical care health teams generally acknowledge that noise levels in the ICU seem high, and studies confirm this notion.<sup>7,15,16</sup> More specifically, the World Health Organization guidelines<sup>17</sup> for noise levels in hospitals specify that the maximum level of sound events during the night should not exceed 40 dB indoors and that sound levels in rooms in the hospital should be 30 dB LAeq, with a maximum level of 40 dB during the night. In addition, because patients have decreased ability to cope with stress, LAeq SPLs should not exceed 35 dB in most rooms in which patients are being treated or observed. Studies have indicated that sound levels in ICUs are generally much greater than these recommended levels. For instance, in a study by Petterson,<sup>18</sup> nighttime levels were greater than 50 dB(A) and peak levels were between 80 and 86 dB(A). Freedman et al<sup>9</sup> found mean levels of 59.1 dB(A) during the day and 56.8 dB(A) during the night; corresponding peak levels were 85.9 and 82.8 dB(A). As a reference, 60 dB(A) is about the

As many as 57% of intensive care unit (ICU) patient arousals and awakenings are due to noise.

#### About the Authors

**Nancy Lawson** is a respiratory therapist, **Kim Thompson**, **Deborah Brown**, and **Naomi Ince** are registered nurses, **Gabrielle Saunders** is a research scientist and deputy director of the National Center for Rehabilitative Auditory Research, **Jaya Saiz** is a student nurse technician, **Jeannette Richardson** is a clinical nurse specialist, and **Diana Pope** is acting director of nursing research at Portland VA Medical Center, Portland, Oregon. **Marc Caldwell** is an audiologist at the Seattle VA Medical Center, Seattle, Washington.

**Corresponding author:** Gabrielle Saunders, PhD, National Center for Rehabilitative Auditory Research, Portland VA Medical Center, 3710 SW US Veteran's Hospital Rd, Portland, OR 97239 (e-mail: Gabrielle.saunders@va.gov).

level of ongoing conversational speech, and 85 dB(A) is close to the level of a shout.<sup>19</sup>

Noise in the ICU has many sources, including heating and cooling systems, overhead fluorescent lights, computer monitors, noise-generating beds, ventilators and other medical equipment, high-intensity alarms to signal medical emergencies, staff and patient conversations, television sound, doors opening and closing, housekeeping and linen carts rolling on linoleum floors, overhead paging, telephones ringing, sink faucets running, and items being dropped.<sup>16,20</sup> Some specific levels include staff conversations, 59 to 90 dB(A)<sup>20</sup>;

ventilator sounds, 76 dB(A); cardiac monitors, 72 to 77 dB(A)<sup>15</sup>; and infusion pumps, 73 to 78 dB(A).<sup>21</sup> Of these, staff conversations and equipment alarms are often cited as the most disturbing to patients.<sup>12</sup> For instance, Christensen<sup>22</sup> found a strong positive correlation between noise level and the number of staff present, and about 25% of the human noise produced on the unit was from the nurses' station. Similarly Kahn et al<sup>23</sup> reported that 26% of noise in the ICU was due to talking, and Southwell and Wisotow<sup>24</sup> found that staff conversations accounted for 18% of all sources of disturbance reported by patients.

Few studies on the spectral content of hospital noise have been published. Busch-Vishniac et al<sup>25</sup> assessed the spectral content of noise at various locations around Johns Hopkins Hospital, Baltimore, Maryland. In all the locations they examined, the sound spectrum was flat between 63 and 1000 Hz, with a gradual roll-off at higher frequencies. These investigators postulated that the majority of low-frequency noise was due to heating, ventilation, and air conditioning systems; the high-frequency

content was most likely due to alarms and mobile medical equipment. Ryherd et al<sup>26</sup> conducted a similar analysis of noise in a neurological ICU and reported a similar pattern. In their data, a dip in the sound level occurred at 160 Hz, a change they assumed was the result of a mode in the room. That is, the

dimensions of the room were such that the peaks and troughs of the 160-Hz sinusoidal waves at the point of measurement canceled each another out, resulting in the dip at 160 Hz.

Evidence suggests that continuous levels of noise, even those as low as 60 dB(A), have physiological effects on blood pressure<sup>27,28</sup> and salivary cortisol levels.<sup>29</sup> In the ICU, the primary health effect of noise

is disturbed sleep,<sup>9,10</sup> which can lead to problems such as slower healing,<sup>5,30</sup> a poorer immune response,<sup>31</sup> and decreased cognitive function.<sup>8</sup> A lack of sleep has also been associated with, but is not necessarily the cause of, ICU delirium.<sup>32</sup> Recently, Bartick et al<sup>33</sup> reported that decreasing sleep disruptions by lowering lighting levels, having nurses avoid waking patients for measurement of vital signs, and instituting a "quiet time" resulted in decreased use of sedatives among patients.

Compared with noise in other locations in the hospital, noise in the ICU is perhaps a greater concern, but it is also more difficult to control, because of the need for ventilators and cardiac monitors that generate ongoing noise and have alarms that sound in a medical emergency. These alarms must be heard by nurses and other staff members and thus must have a frequency and sufficient intensity to be heard above other hospital sounds. In fact, a recent Veterans Health Administration safety alert<sup>34</sup> stated that alarms on bedside physiological monitors should be set to physiologically reasonable limits for specific patients; that alarms should not be set below minimal levels or be disabled; and that the importance of correct alarm settings, audible volume settings, and alarm responses must be conveyed to staff to prevent close calls and adverse events leading to patients' deaths. The alert is unequivocal in setting priorities related to providing a therapeutic acoustic environment: "Consideration for not disturbing the sleep of patients in the vicinity is not sufficient rationale to set the audible limits [of monitors] low."

Nurses and respiratory therapists in the ICU at the Portland VA Medical Center, Portland, Oregon, were concerned about the noise levels in the unit arising from equipment and communication among staff members. Specifically, the concern was that noise levels would detrimentally affect recovery of extremely ill patients. We therefore conducted a study in which we measured (1) the SPLs of alarms from medical equipment in a patient room with alarm outputs set at different volumes to determine the range of SPLs, (2) SPLs of equipment alarms in an adjacent room to determine whether patients in the ICU are likely to be disturbed by alarms in other patients' rooms, and (3) the ambient SPLs in the ICU over time to assess mean and peak levels in the ICU during the day and night.

## Methods

The overall aim of the study was to measure sound levels to which patients in the ICU are typically exposed. Measurements were made in 3 phases.

**Staff conversations and equipment alarms are the most disturbing to patients.**

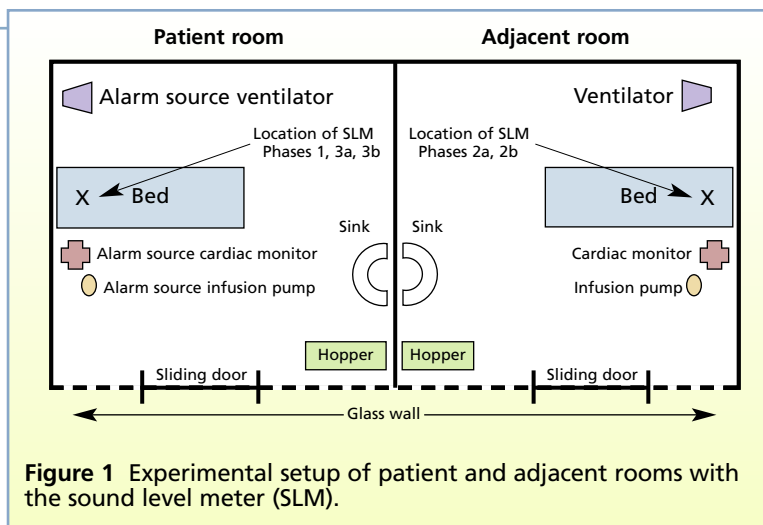
**Even low levels of continuous noise have physiological effects on BP and salivary cortisol.**

In phase 1, the SPLs of alarms from a bedside cardiac monitor, a ventilator system, and an infusion pump were measured inside a patient room. Measurements were made with the alarm outputs at maximum, minimum, and interim settings to determine the range of sound levels to which a patient could be exposed within his or her own room. In phase 2, the SPLs of the same alarms were measured from an adjacent room to assess the SPLs that patients in rooms near the alarms experience. In phase 3, the ambient noise in the ICU was measured during several 10- to 24-hour periods to determine daily noise levels and whether or not noise levels vary systematically throughout the day and night.

Data were collected in the ICU of the Portland VA Medical Center, a 152-bed university-based teaching hospital. The research and development committee at the medical center approved the study, and the institutional review board granted an exemption.

The ICU in the medical center is a rectangular 28-bed facility that serves a mix of acutely ill medical and surgical patients. Each room in the unit has 3 solid walls and a sliding glass door that faces the hallway. The glass door can be covered with a retractable privacy curtain. The floors of the unit are tiled throughout, and the ceilings are constructed with hanging acoustic tiles. The unit has 3 nursing stations, located in the north, south, and east areas. The nursing stations are equipped with telephones, intercoms, computers, and visual patient-monitoring systems. Cardiac monitors are located in the south, north, and east hall areas. Nutrition rooms, supplied with microwaves, sinks, refrigerators, and ice machines, are located near the south and north nursing stations. During the study, the ICU census was 16 to 26 patients.

Measurements were made in rooms measuring approximately 4.8 m by 3.3 m (16 ft by 11 ft). All rooms used in the study had the same furnishings. In phases 2 and 3, measurements were made with the doors to the rooms both open and closed. Figure 1 shows the configuration of the rooms used, and Table 1 describes the various locations of the SLM and the door status during all 3 phases. Although ICU staff members were aware that the study was taking place, they were asked to conduct care as usual. Vacant rooms rather than occupied rooms were used for 2 reasons: to ensure the investigation did not in any way interfere with patient care and to avoid the need to obtain informed consent from critically ill patients. Although the rooms used for the measurements were vacant, the surrounding rooms were occupied.



**Figure 1** Experimental setup of patient and adjacent rooms with the sound level meter (SLM).

**Table 1**  
Locations of the sound level meter and door status during each study phase

Phase	Location of alarms being measured	Location of sound level meter	Door to patient room	Door to adjacent room
1	Patient room	Patient room	Open	Not applicable
2a	Patient room	Adjacent room	Open	Open
2b	Patient room	Adjacent room	Open	Closed
3a	Not applicable	Patient room	Open	Not applicable
3b	Not applicable	Patient room	Closed	Not applicable

### SPL Measurements

Two models of SLM from Brüel and Kjaer North America Inc, Norcross, Georgia, were used during the study: a 2250 Light for measurement of alarm output levels in phases 1 and 2, and a 2260 Investigator with programmable storage capacity for the 24-hour measurements of phase 3. Both SLMs were used with a 1/2 in (1.3-cm) free-field microphone. For phases 1 and 2, the LCpk for a 10-second recording period for each alarm and output setting was measured. The SLM automatically recorded the peak sound level in each 10-second period and displayed that value on the screen. Within that 10-second period, the SLM can detect a peak that is only microseconds long. LCpk values were manually recorded in a notebook. The SLM used in phase 3 has software that computes and stores the LAeq and the LCpk for a user-chosen time period. In phase 3, the LAeq and the LCpk were measured for each 15-minute period during the recording time. The data were then downloaded to a spreadsheet for analysis. In all 3 phases of the study, the microphone of the SLM was suspended from the ceiling of a vacant patient room, with the

The study aim was to measure sound levels to which patients in the ICU are typically exposed

diaphragm hanging 15.2 cm (6 in) above the bed pillow to simulate the position of a patient's head while the patient was lying in bed. Before each recording session, the SLM was calibrated by using a Brüel and Kjaer 4231 Sound Level Calibrator.

### Procedures

In phase 1, the sound levels of equipment alarms experienced by patients in their rooms were simulated. The microphone of the SLM was suspended from the ceiling of the room by using an infusion stand.

Each equipment alarm was manually switched on for 10 seconds, and the LCpk value for that period was recorded. This process was repeated 3 times in a single session for each alarm setting and item of equipment. The whole procedure was then repeated 4 weeks later.

The cardiac monitor system has 3 alarms that differ in signal frequency and/or temporal information to indicate the severity of an emergency. The least urgent alarm consists of a repeating low-frequency tonal signal and is accompanied by a green light. The second most urgent alarm is acoustically identical to the least urgent alarm but is accompanied by a yellow light. The most urgent alarm consists of a mid-frequency tonal signal that repeats at the same rate as the other previous alarms and is accompanied by a red light. Each alarm was set to 4 different output levels (minimum, one-third, two-thirds, and maximum).

The ventilator system has 3 alarms that indicate different clinical conditions such as low pressure, apnea, and an open tubing circuit. The low-pressure alarm consists of a repeating high-frequency tonal signal followed by a low-frequency tonal signal (eg, 1-2-1-2). The apnea indicator consists of 3 repeating low-frequency tonal signals (eg, 1-1-1), and the open tubing circuit alarm consists of 4 tonal signals rising in pitch with a fifth tone being a repeat of the fourth (1-2-3-4-4). The LCpk of each alarm was measured at its minimum and maximum setting.

The infusion pump alarm is a single high-frequency repeating tonal signal (1-1-1). The alarm was set to 5 different output levels, minimum, one-fourth, one-half, three-fourths, and maximum, and the LCpk was measured for each level.

Sound with meaningful content (speech), is more disturbing than sound that is not meaningful (machinery).

Phase 2 was conducted to determine whether patients are likely to be disturbed by alarms from other rooms. The procedure described for phase 1 was used, but the SLM was located in an adjacent room (room B). Measurements were made with the door to the adjacent room open and then with the door closed. The door to the first room (room A) was always open. As in phase 1, the procedure was repeated 4 weeks later.

In phase 3, measurement of ambient noise levels, the microphone of the SLM was suspended from the ceiling of the patient room with the diaphragm 15.2 cm above the bed pillow. The SLM was switched on and left to record the LAeq and LCpk every 15 minutes during the 10- to 24-hour recording period. Recordings were made on 12 occasions; the door to the room was open for 8 and closed for 4.

### Statistical Analysis

Analyses were conducted with SPSS, version 17.0 (SPSS Inc, Chicago, Illinois). Geometric means rather than arithmetic means were computed because decibels are recorded on a logarithmic scale.

In phases 1 and 2, a total of 3 LCpk values were recorded for each alarm setting at each of 2 recording sessions. Unexpectedly, some variability occurred in the LCpk measured. Because levels of alarms for a particular output setting are static, the variability most likely was due to extraneous sounds, such as voices, telephones ringing, and so on. The lowest of the 3 LCpk values recorded was used in the analyses on the assumption that this value was least contaminated by extraneous sounds.

An analysis of variance (ANOVA) was conducted for each piece of equipment separately to determine whether the alarm output levels in the patient room and the adjacent room differed and whether opening and closing the door to the adjacent room affected alarm levels in that room.

### Results Cardiac Monitoring System

The LCpk values for the alarms of the cardiac monitoring system were 73.3 dB(C) for the least urgent setting, 73.1 dB(C) for the middle setting, and 73.3 dB(C) for the most urgent setting. ANOVA indicated that the 3 sound outputs did not differ significantly ( $F=0.003$ ;  $P=.96$ ); therefore the data from each setting were averaged in the remaining analyses.

Figure 2 shows the LCpk values of the cardiac monitor alarms for each output setting in the 3 test configurations. Univariate ANOVA, with the 4 alarm settings and test configurations as fixed factors,

confirmed that the alarm levels were higher when the SLM was in the patient room than when it was in the adjacent room ( $F=228.2$ ;  $P<.001$ ). The mean value of the alarms was 86.5 dB(C) when the SLM was in the patient room, 67.5 dB(C) when it was in the adjacent room with the door closed, and 69.4 dB(C) when it was in the adjacent room with the door open. The LCpk values for the adjacent room with the door open and the door closed did not differ significantly from each other ( $t=1.47$ ;  $P=.18$ ).

Figure 2 also suggests that the alarm output settings resulted in different LCpk values when the SLM was in the patient room but not when it was in the adjacent room. Univariate ANOVA confirmed that a significant interaction was indeed present ( $F=24.8$ ;  $P<.001$ ). The different alarm settings resulted in different output levels when the SLM was in the patient room ( $F=52.6$ ;  $P<.001$ ), but not when it was in the adjacent room ( $F=3.92$ ;  $P=.06$ ).

### Ventilator System

Figure 3 shows the LCpks of each alarm for the ventilator system. Univariate ANOVA, with the alarms and test configurations as fixed factors, confirmed that LCpk values were highest when the SLM was in the patient room, lower when it was in the adjacent room with the door open, and lowest when it was in the adjacent room with the door closed; the differences in LCpk values for the test configurations were significant ( $F=38.9$ ;  $P<.001$ ). Post hoc testing confirmed that the level was highest in the patient room (86.0 dB), significantly lower in the adjacent room with the door open (71.5 dB), and significantly lower still in the adjacent room with the door closed (65.8 dB).

### Infusion Pump

Figure 4 shows the LCpk values of the alarms of the infusion pump at the each output setting for which data are available. Univariate ANOVA, with the alarm settings and test configurations as fixed factors, confirmed that the LCpk values were higher when the SLM was in the patient room than when it was in the adjacent room ( $F=71.9$ ;  $P<.001$ ). ANOVA also indicated that the output settings resulted in levels that differed significantly from each other when the SLM was in the patient room but not when it was in the adjacent room ( $F=6.1$ ;  $P<.009$ ). This analysis was limited to measurements from the patient room and from the adjacent room with the door open because data were missing for the adjacent room with the door closed. The mean LCpks were 83.8 dB(C) in the patient room and 67.9 dB(C) in the adjacent room with the door open.

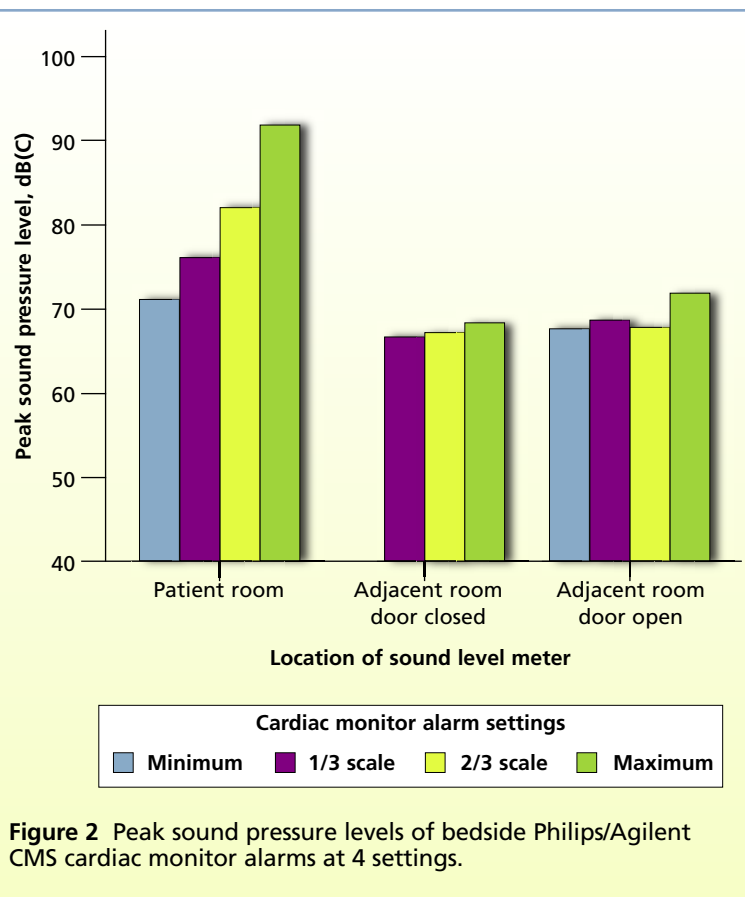


Figure 2 Peak sound pressure levels of bedside Philips/Agilent CMS cardiac monitor alarms at 4 settings.

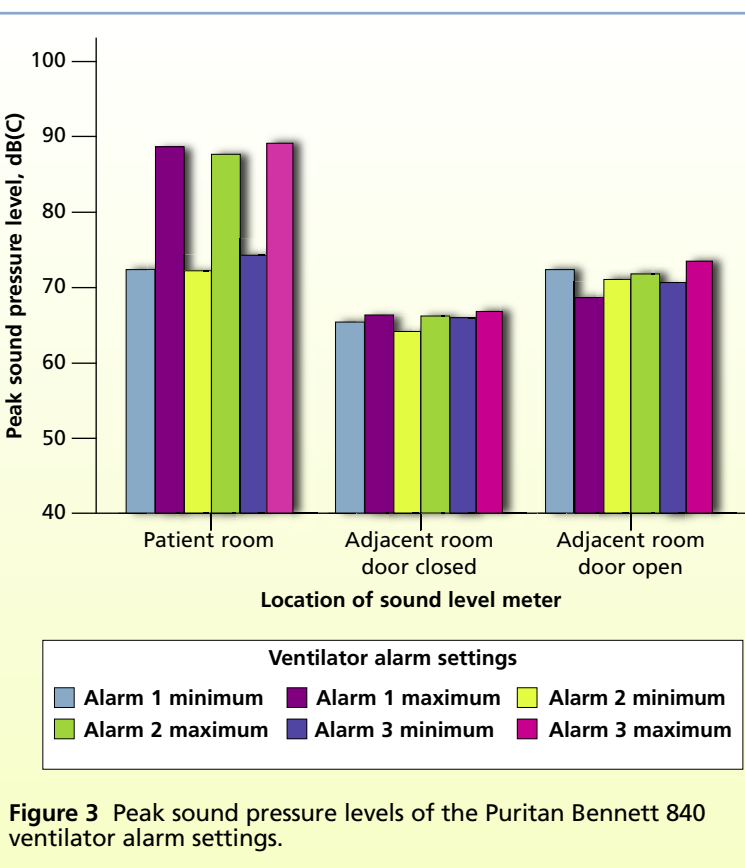
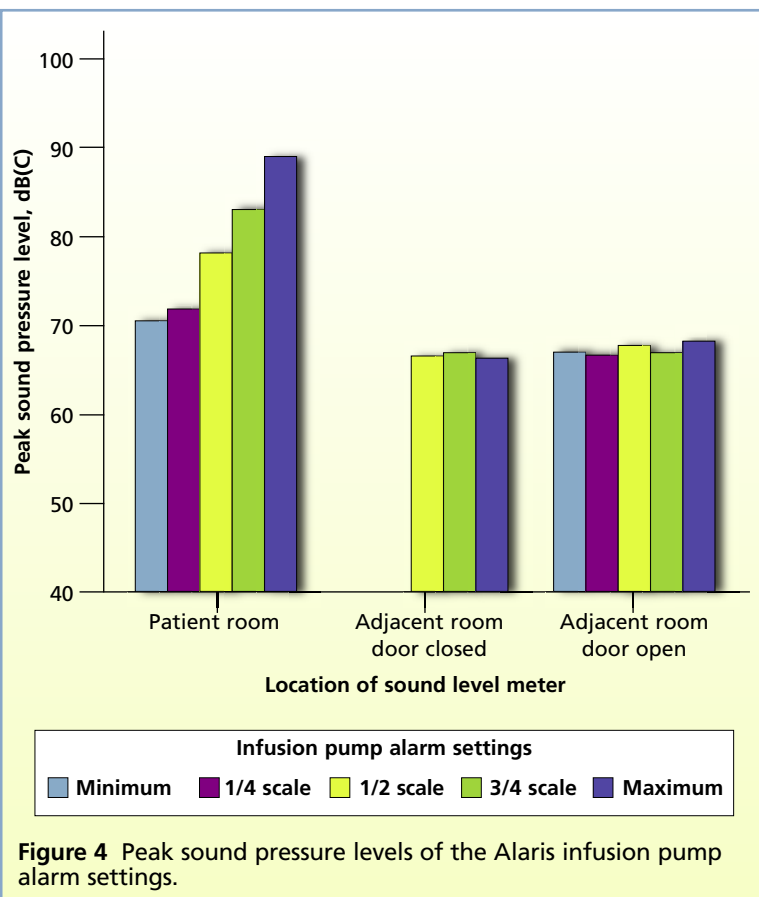
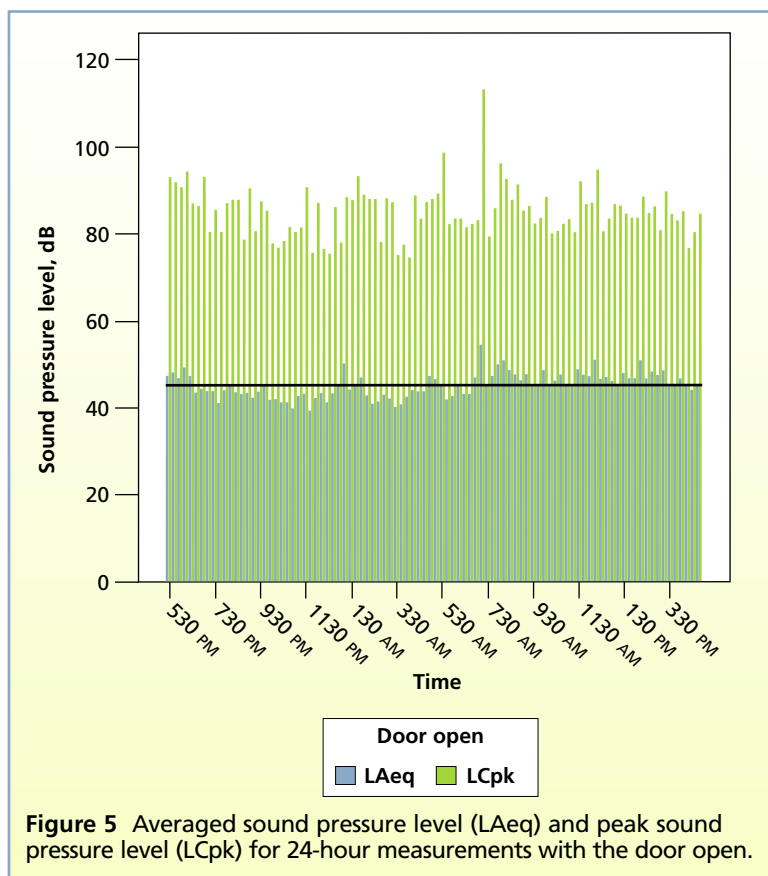


Figure 3 Peak sound pressure levels of the Puritan Bennett 840 ventilator alarm settings.



**Figure 4** Peak sound pressure levels of the Alaris infusion pump alarm settings.



**Figure 5** Averaged sound pressure level (LAeq) and peak sound pressure level (LCpk) for 24-hour measurements with the door open.

### Summary of Phases 1 and 2

In summary, the results of phases 1 and 2 indicated that the LCpk values of alarms measured in the patient room were higher than the values in the adjacent room for all equipment alarms investigated and that closing the door to the adjacent room further decreased the LCpk measured for the ventilator system but not for the cardiac monitoring system. Data were not available to make this comparison for the infusion pump. Of interest, for all equipment, changing alarm output settings altered the LCpk levels measured in the patient room but not in the adjacent room.

### Ambient Noise

In phase 3, data were collected for 24 hours. Because of variations in ICU census, the duration of recording time and the start and end of recording times varied across recording sessions, and equal sets of data for the door open and the door closed could not be obtained. Specifically, 8 sets of data for the door open and 4 sets for the door closed were available. For the analyses, all data for the door open were averaged, as were all data for the door closed.

Figures 5 and 6 show LAeq and LCpk levels measured over time with the door open and the door closed, respectively. Table 2 gives the mean LAeq and LCpk levels and the results of ANOVA comparing the two. The minimum value shown on these figures (and in Figure 7) is 39 dB(A). During data collection with the door open, the SLM was inadvertently set incorrectly such that any LAeq less than 40 dB(A) was stored as 39 dB(A). In order to make comparisons across the door-open and door-closed conditions, all LAeq readings less than 40 dB(A) were coded as 39 dB(A).

LAeq values were higher when the door to the patient room was open, but LCpk levels were similar whether the door was open or closed. In other words, closing the door to a patient room decreases the mean noise level in that room but not the peak noise level.

Figure 7 shows a histogram of the LAeq values measured throughout the 24-hour surveillance period, and Figure 8 shows the LCpk data. Analyses indicated that 83% of LAeq values were less than 45 dB(A). LCpk values were considerably higher; 6% with the door closed and 9% with the door open were greater than 90 dB(C).

### Discussion

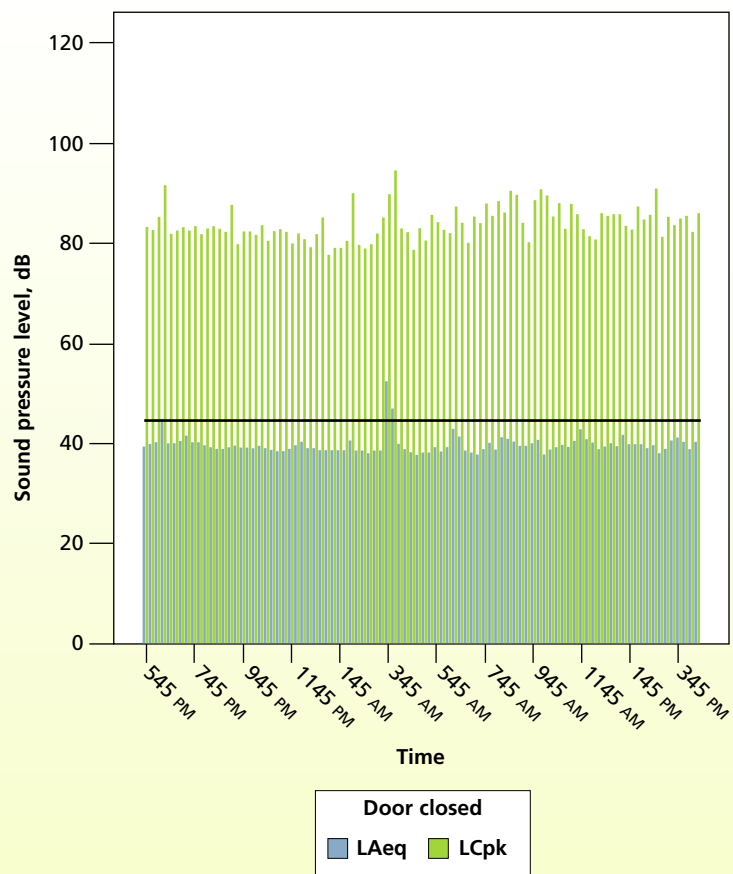
The mean SPLs over time were less than 40 dB(A) when the door to the patient room was closed and

less than 45 dB(A) when the door to the room was open. These values differ significantly from each other; thus closing the door to a patient's room when trying to minimize noise levels would appear to have some value. The levels are acceptably close to the criteria specified by the World Health Organization<sup>17</sup> of 30 dB LAeq, with a maximum level of 40 dB during the night, and are lower than those typically measured in other studies<sup>13,18,22,35,36</sup> of noise in the ICU. However, the extent to which ambient sound is disturbing depends on attributes such as frequency, predictability, content, emotional implications, and temporal characteristics. More specifically, a high-pitch squeak tends to be more disturbing than a low-pitch hum; an unpredictable noise will cause a startle response, whereas a predictable noise will not; sound with meaningful content, such as speech, is more disturbing than sound that is not meaningful, such as machinery; a sound with an unpleasant connotation, such as a cry of pain, is more disturbing than a sound with a pleasant connotation, such as a child laughing; and a sudden impulse noise is more disturbing than an ongoing steady noise.<sup>37</sup> Thus, a study of the sources of ambient sounds would provide important information about the extent to which sounds are likely to be disturbing to patients.

On average, peak SPLs were about 83 dB(C), but levels of 90 dB(C) and greater were measured. Such high levels of sound inevitably disrupt patients' rest and disturb nurses' focus. However, because the sounds are of short duration, they are not likely to cause damage to the auditory system. Closing the door to the patient room did not decrease peak values measured. This finding suggests that either the peak levels occurred within the patient room itself or that the sounds registering as peaks were outside the patient room but were not attenuated or absorbed by the walls and door. Without an analysis of the specific sound sources, we cannot know which interpretation is correct.

The fluctuations in SPLs during the 24-hour measurement periods did not vary systematically over the day. This finding differs from the results of some studies<sup>16,22,23,38,39</sup> in which sound levels in the ICU were lower at night than during the day. Our finding is similar, however, to the results of Christensen,<sup>7</sup> who found random fluctuations during each 24-hour period measured. Most likely, noise in our ICU is not associated with routine housekeeping, meal times, a regular sleep schedule, shift changes, or visiting hours. The ICU is an emergency unit, so a lack of routine is perhaps not surprising.

Equipment alarm levels measured from inside the patient room (room A) ranged from less than



**Figure 6** Averaged sound pressure level (LAeq) and peak sound pressure level (LCpk) for 24-hour measurements with the door closed.

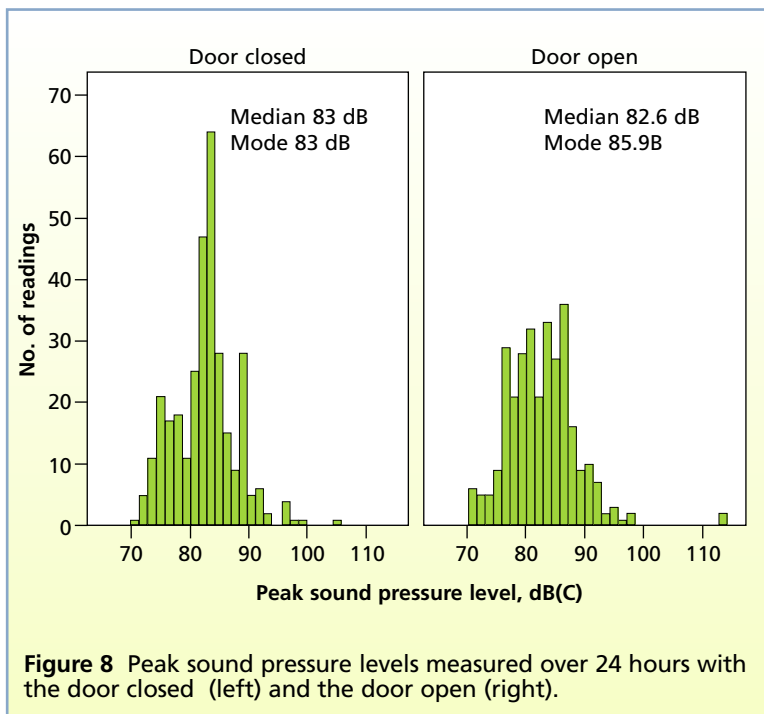
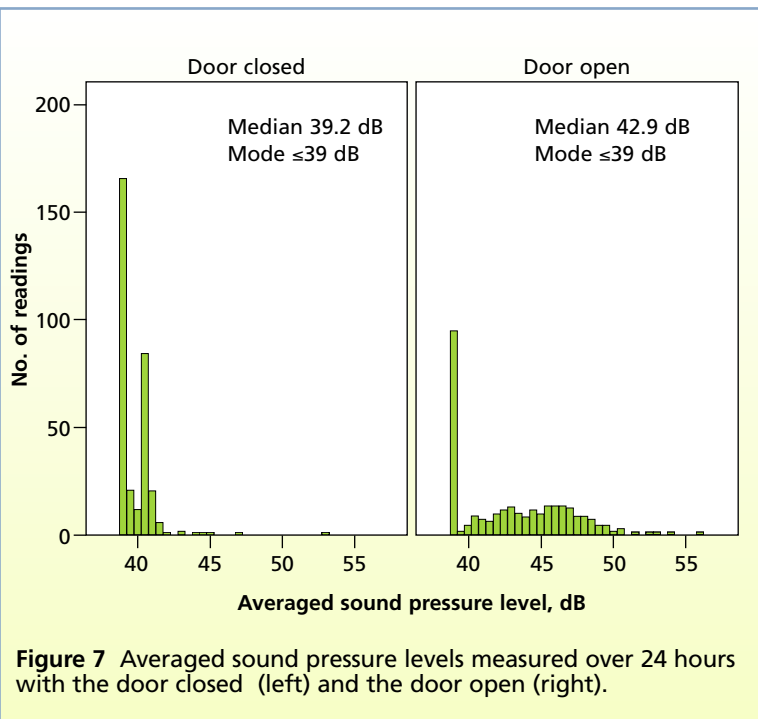
**Table 2**

**Mean LAeq and LCpk levels for recordings made with the door to the patient's room open and closed during 24-hour surveillance conditions and results of analysis of variance of values for door open and door closed**

Variable/analysis	LAeq, dB	LCpk, dB(C)
Door closed, mean (SD)	39.8 (1.3)	82.7 (5.2)
Door open, mean (SD)	43.2 (3.8)	82.6 (5.8)
Analysis of variance		
F	225.3	0.03
P	<.001	.85
Abbreviations: LAeq, averaged sound pressure level; LCpk, peak sound pressure level.		

70 dB(C)—the lowest settings on the cardiac monitors and infusion pumps—to more than 90 dB(C)—the highest settings on the cardiac monitors and infusion pumps. When these same alarms were measured in an adjacent room (room B), the alarm levels were considerably attenuated. Specifically, when the door to the adjacent room was left open, values ranged from 65 to 79 dB(C). When the door to the adjacent room was closed, the levels ranged





from 64 to 69 dB(C). These findings can be explained by 2 factors: the relative energy of low- vs high-frequency signals and the directionality of low- vs high-frequency signals. Specifically, low-frequency signals have more energy than do high-frequency signals, and low-frequency signals, because of their longer wavelength, are less directional than are high-frequency signals. Thus, when the door to the adjacent room was closed, the low-energy, high-frequency

components of the alarms were most likely dissipated before they reached the room, so the signal levels measured were those of the remaining low-frequency components. On the other hand, when the door to the adjacent room was open, the low-frequency components of the signals traveled around the doorway in the adjacent room, and thus measured levels were higher. Examination of Figures 3 and 4 supports this interpretation; the low-frequency alarms of the ventilator system had greater differences between the door-open and door-closed conditions than did the high-frequency alarms of the infusion pump system.

The overall alarm SPLs we detected are similar to those measured in other studies.<sup>15,21</sup> Presumably, the purpose of an alarm is to alert staff to a medical emergency. This purpose most likely explains why alarm output levels can be so high. However, Figures 2, 3, and 4 suggest that increasing the output level does not necessarily provide a better alert. Specifically, if a member of the medical team is in a sick patient's room, an SPL of 70 dB(C), the lowest output level of the alarms we measured, is of sufficient intensity to be heard by a normal-hearing person or by a moderately hearing-impaired person who is using hearing aids. Increasing the alarm level will do little more than stress a sick patient and is almost certain to arouse the patient from sleep. On the other hand, if a member of the medical team is in a room adjacent to a sick patient's room, alarm levels are so attenuated that increasing the alarm output level will not result in better detection of the alarm. These findings are of particular concern if medical team members rely on the false assumption that increasing an alarm's output level will make detection of the alarm easier in an adjacent room. We realize that these findings might be specific to the architecture and engineering of the ICU at the Portland medical center, but nonetheless we think that awareness of this issue is beneficial. To this end, staff should be encouraged to experiment with alarm output levels to optimize audibility while minimizing disturbance of patients.

Our study has a number of limitations. First, limited data were collected during shift changes at 5 PM and 5 AM because the monitoring equipment was set up and removed at these times. Second, a full 24-hour monitoring period could not be completed during 10 of 12 recording sessions because of the high number of patients and new admissions into the ICU. As a result, monitoring had to be stopped prematurely on these occasions. Measurement periods ranged from a minimum of 10 hours to a maximum of 24 hours. Third, as mentioned earlier, the SLM range was inadvertently set incorrectly

during the door-open recordings, limiting readings to a minimum of 39 dB(A). We could argue that sound levels less than 39 dB(A) are so low that they are inconsequential; that is, patients will not be disturbed by such low ambient noise levels. However, for completeness, recording of values less than 39 dB(A) would have been preferable. Fourth, during the measurement of ambient noise levels in phase 3, the patient rooms were unoccupied. This situation may have resulted in an underestimation of ambient noise levels. Finally, we did not measure the spectral content of the sound. This information could have provided data on the extent to which alarms might be annoying or stressful to patients. It might also have shed light on why during phase 3 the peak values were the same in the patient room and the adjacent room even though the mean levels differed.

## Conclusions

Even though our data indicated that LAeq values in the ICU were generally satisfactory, staff members are developing a sleep protocol to decrease noise levels and improve sleep in the ICU. Previous studies indicated that initiating quiet times was successful in decreasing noise levels<sup>20,23</sup> and in improving patients' sleep quality.<sup>2,33</sup> Further, as mentioned earlier, low mean SPLs should not be interpreted as an indication that disturbing sounds are not present. In future, an analysis to determine the sources of the peak SPLs should be conducted, as should interviews with patients to determine which sounds they find most disturbing, so that measures can be taken to decrease the sources of those specific sounds.

## ACKNOWLEDGMENTS

This research was performed at Portland VA Medical Center. We extend our appreciation to all the participating administrators and staff at the center.

## FINANCIAL DISCLOSURES

This study was supported in part by grant 4844C from the Department of Veterans Affairs, Veterans Health Administration Rehabilitation Research and Development.

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## SEE ALSO

For more about ICU environmental factors, visit the *Critical Care Nurse* Web site, [www.ccnonline.org](http://www.ccnonline.org), and read the article by Dunn et al, "Nighttime Lighting in Intensive Care Units" (June 2010).

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**CE Test** Test ID A1019064: **Sound Intensity and Noise Evaluation in a Critical Care Unit** *Learning objectives:* 1. Describe the different ways sound and noise can be measured with relation to patient care and disruption of healing. 2. Discuss the World Health Organization guidelines for noise levels in hospitals and for sound events during the night. 3. Identify at least 5 different ways sound and noise can be measured.

**1. Which of the following best describes sleep disruption in the intensive care unit (ICU)?**

- a. It is uncommon in female patients.
- b. It is common and detrimental to patients' health and recovery.
- c. It is uncommon in male patients.
- d. It is common and does not affect patients' health or recovery.

**2. High levels of sound result in poor sleep quality that leads to which of the following?**

- a. Slower healing, poorer immune response, and decreased cognitive function
- b. A need to have multiple opportunities to sleep for at least 1 hour
- c. Increased irritability and decreased cooperation of patients and families
- d. Increased skin breakdown and increased falls

**3. Which of the following explains why the World Health Organization guidelines for noise levels in hospitals specify that the sound levels in rooms where patients are being treated or observed should not exceed 35dB?**

- a. Patients probably want to hear the television and radio to promote healing
- b. Patients have decreased ability to cope with stress
- c. Families of patients will find noise levels too high when visiting
- d. Medical staff must be able to communicate easily with patients

**4. Which of the following is often cited as the source of noise that is most disturbing for ICU patients?**

- a. Movement of housekeeping and linen carts
- b. Repeated door opening and closings
- c. Overhead paging and phones ringing
- d. Staff conversations and equipment alarms

**5. Evidence suggests that continuous levels of noise, even those as low as 60 dB(A), have physiological effects on salivary cortisol levels and which of the following?**

- a. Blood pressure
- b. Pulse oximetry
- c. Respiratory rate
- d. Heart rate

**6. Bartick et al reported that decreasing sleep disruptions by lowering lighting levels, having nurses avoid waking patients for measurement of vital signs, and investigating a "quiet time" resulted in which of the following?**

- a. Decreased blood pressure and respirations
- b. Decreased use of sedatives among patients
- c. Increased cognitive impairment among patients
- d. Increased immune response in patients

**7. The Veterans Health Administration safety alert stated that alarms on bedside physiological monitors should be set to physiologically reasonable limits for specific patients. They also indicated the following?**

- a. Alarms should not be set below minimal levels or disabled
- b. Alarms can be set low if they disrupt rest or sleep
- c. Setting an inaudible alarm is acceptable with a physician's order
- d. The frequency of alarms can be adjusted to promote rest

**8. Christensen found a strong, positive correlation between noise level and which of the following?**

- a. Patient acuity in the unit
- b. Number of staff present
- c. Number of visitors present
- d. Number of ventilated patients

**9. Christensen also noted that about 25% of human noise produced on the unit was from which of the following?**

- a. The patient's room
- b. Conversations in the hall
- c. The nurses' station
- d. The visitors lounge

**10. Which of the following has been successful in decreasing noise levels and in improving patients' quality of sleep?**

- a. A limit on the alarm tone
- b. Specific visiting times
- c. Initiating quiet times
- d. Different tones for lethal alarms

**11. Southwell and Wistow found that 18% of all sources of disturbance reported by patients was produced by the following?**

- a. Visitors' lounge
- b. Staff conversations
- c. Equipment movement
- d. Patient alarms

**12. In a review of the literature, Xie et al reported that between 17% and 57% of arousals and awakenings are due to which of the following?**

- a. Diet
- b. Stress
- c. Medications
- d. Noise

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