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# Noise in hospital intensive care units—a critical review of a critical topic

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Hospital;
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**Abstract**

**Purpose:** The aims of the study were to examine the studies related to hospital noise in intensive care units (ICUs) to understand the sources and effects of noise and to describe best practices and common problems in the varying methods commonly applied to reduce the noise level.

**Materials and Methods:** The ISI Web of Knowledge and PubMed were used to search original research articles to obtain articles related to hospital ICU noise analysis.

**Result:** This review article analyzes the 29 extant studies related to noise in ICUs.

**Conclusion:** Significant opportunities exist to improve methodologies to study noise levels to reduce noise in hospital ICUs. Many previous studies have used inconsistent methodologies with poorly defined parameters that make it difficult to compare results. Our work points out common pitfalls in the recording and sharing of hospital acoustic parameters and also points to the paucity of important economic considerations in extant studies. These results can be helpful for future research in this area. Many past salutary interventions—including educational noise reduction programs, behavioral modification using sound detection equipment, and low- as well as high-cost environmental alterations—do not generally appear to be adequate to minimize noise to levels for hospital rooms specified by international agencies. But a potentially important clue for future work involves the finding that as the number of patients and staff of the ICU increases, noise levels appear to also increase.


## 1. Introduction

A hospital intensive care unit (ICU) is designed to treat critically ill patients who need special care and treatment, sometimes at nearly the same extreme level required in an operating room. Thus, although ICUs may be less complex than an operating room, they have become quite sophisticated, with a panoply of medical devices that support an array of physician-specialists, nurses, technicians, and other staff. Noise in ICUs has increased dramatically as a consequence of these changes, and the effect of noise on patients and staff has become an important issue. After all, excessive noise is not only annoying, but can also interfere with the proper performance of medical care. Studies have shown that noise has cardiovascular and physiologic effects that can also affect mental health. Moreover, noise causes sleep disturbances for patients who are vitally in need of sleep; it can also have long-term effects on hearing [1].

A recent review by Choiniere [2], "The Effects of Hospital Noise," affirms these findings, noting that "research

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has indicated that there is a positive correlation between hospital noise and physiological responses experienced by patients, the most significant being an increased risk of hypertension and ischemic heart disease." Another important review by Morrison et al [3] concluded that noise is potentially a significant contributor to higher heart rates, tachycardia, stress, and annoyance in nurses.

It is helpful at this point to take a step back and see what sound levels are thought to be appropriate in a hospital setting. Three key organizations—the World Health Organization (WHO), the International Noise Council, and the Environmental Protection Agency (EPA)—have set standards in this area. Unfortunately, as shown in Table 1, the 3 have established different standards as far as what they recommend for maximum allowable noise for hospital patient room settings [1,4,5]. To make sense of the varying nature of the limits recommended by differing agencies and to learn whether and how hospitals might reach those recommended limits, we conducted a literature review of extant research involving noise in hospital ICU environments, as described below. The main thrust of this review is to better understand the different sources of noise in ICU settings and the most effective methods to reduce such noise.

As Table 2 indicates, a noise level of 40 dBA may cause interruption in activities that need concentration. This is a key limiting factor. Nurses must be able to concentrate during their patient caregiving activities, yet if they are working where noise levels are above 40 dBA, there is a higher potential for error. Supporting this concept is the "Levels Document" by the EPA, which states that "the highest noise level that permits relaxed conversation with 100% sentence intelligibility throughout the room is 45 dBA. People tend to raise their voices when the background noise exceeds 45-50 dBA" [7]. Moreover, the "Guidelines for Community Noise" by the WHO, published some quarter century after the EPA standards, states that "for complete sentence intelligibility in listeners with normal hearing, the signal-to-noise ratio (i.e. the difference between the speech level and the sound pressure level of the interfering noise) should be 15–18 dBA. Thus, with a speech level of 50 dBA, (at 1 m distance this level corresponds to a casual speech level of both women and men), the sound pressure level of interfering noise should not exceed 35 dBA" [1]. These are the primary reasons that noise levels must be kept to those recommended by the WHO, the EPA, or the International Noise Council.

**Table 1** The recommended sound level limits for hospital patient rooms as defined by different organizations

| | WHO [1], dBA | International Noise Council [4], dBA | EPA [5], dBA |
|---|---|---|---|
| Day | 35 | 45 | 45 |
| Evening | – | 40 | – |
| Night | 30 | 20 | 35 |

Note that decibel is the usual logarithmic unit of sound pressure level. "A" is a weighted filter that makes a dosimeter (sound-capturing device) respond in the same way a human ear hears; the result is denoted "dBA."

**Table 2** Example of sound sources with their sound pressure levels in dBA

| | Sound pressure level in dBA |
|---|---|
| Sound source examples with distance | |
| Two-stroke chainsaw at a 10-m distance; loud toilet flush at a 1-m distance | 85 |
| Passing car at a 7.5-m distance | 75 |
| Noisy lawn mower at a 10-m distance | 60 |
| Low volume of radio or television at a 1-m distance; noisy vacuum cleaner at a 10-m distance | 55 |
| Noise of normal living; talking, or radio in the background | 45 |
| Learning or concentration is possible, but distraction occurs | 40 |
| Very quiet room fan at low speed at a 1-m distance | 35 |
| Sound of breathing at a 1-m distance | 25 |
| Auditory threshold | 0 |

Adapted from reference [6].

## 2. Methods

A systematic literature search was done on PubMed and ISI Web of Knowledge during the study to obtain English-language research articles related to the characterization of noise levels in hospital ICUs through mid May 2011. The following keywords were used: *ICU*, *noise* and *hospital*, *noise*. Abstracts of the original research articles were searched, and only those related to ICU noise analysis were selected for this study. Research articles with the purpose of studying the sources of noise levels, current noise levels in the ICU, and methods applied to reduce the noise level were included in inclusion criteria. Studies related to noise level measured in general hospital wards or overall hospital noise were excluded from this review.

## 3. Results

The literature search found 29 articles related to noise in ICUs. These studies had 3 different foci:

1. studies that simply measured noise amplitude in decibels (15 studies) [2,3,8-20];
2. more complex studies that measured noise amplitude using frequency analysis (4 studies) [21-24]; and
3. studies that first measured noise levels, then performed a subsequent salutary intervention and, finally, again measured noise levels (10 studies) [4,5,25-32].

Because most researchers' ultimate concern is to understand the best ways to ameliorate sound in an ICU, for this review, we focused on the 10 studies of item 3. Table 3 provides detailed information about these studies.

### 3.1. Noise levels in the ICU

One relatively recent study [21] indicated that, in the half century since 1960, average daytime noise in hospitals has increased from 57 dBA in 1960 to 72 dBA by 2005, whereas average nighttime noise has increased from 42 dBA in 1960 to 60 dBA by 2005. On average, then, hospital noise levels have increased by 0.38 dB/y during the day and 0.42 dB/y at night. These levels appear to still be increasing linearly. Lawson et al [13] found that although the mean sound pressure level in a patient's room was below 45 dBA, the peak levels were greater than 85 dBC.[1] These types of results emphasize the importance of measuring not only mean, but also peak sound levels.

Finally, the recent study, "Variation of NICU [Neonatal ICU] Sound by Location and Time of Day" (Matook et al [11]), concluded that day shifts are noisier than the night shifts and that sound levels were significantly higher during weekdays than on weekends. In this study, the average sound level varied from 49.5 to 89.5 dBA, with a mean of 85.15 dBA. The peak sound ($L_{peak}$) ranged from 66.4 to 138.9 dBC with a mean of 134.45 dBC. Clearly, then, the neonatal ICU was very noisy.

### 3.2. Noise sources

A study by Krueger et al [31] classified the sources of sound in NICUs as being either operational or structural. Specifically,

1. operational sounds are those generated by the staff or equipment in the NICU, and
2. structural sounds are those generated by the building, as for example, sounds generated by ventilation, air-conditioning systems, and doors.

In general, the same classification scheme could be applied to all hospital noises.

The major sources of ICU sound that the studies of this review have identified or referred to are

- conversations between the ICU staff, medical professionals, and visitors;
- medical equipment alarms;
- caregiving activities such as hand washing, opening disposable equipment packages, and storage drawers;
- telephones, pagers, and televisions; and
- closing doors and falling objects.

One group studying noise levels and sources in acute care hospital wards concluded that "34% of noise sources appear to be totally avoidable and 28% of noise sources are partially avoidable" [20]. More detailed information about ICU noise sources and techniques commonly used to reduce them, as described in the 10 extant studies involving sound mitigation, is tabulated in Table 3.

### 3.3. Effect on staff performance

Our literature survey revealed only 2 studies that investigated the effect of noise on ICU staff. A study conducted by Morrison et al [3] investigated the correlation between noise and nursing stress through use of a questionnaire and by measuring salivary amylase and heart rate. This study concluded that "noise is potentially a significant contributor to higher heart rates, and tachycardia among nurses, as well as nurses' stress and annoyance." The second study, by Ryherd et al [22], used a questionnaire to parse nurses' perception of noisy environments. Of the surveyed nurses, 91% felt that noise could negatively affect them in their routine work environment. The study also found that 66% of nurses felt irritation and fatigue, 43% had concentration problems, and 40% experienced tension headaches as an effect of noisy work environments. No study was found that quantified any relation between noise and work performance.

### 3.4. Patient's perception of noise

Two studies surveyed patients to learn their perceptions of noise levels [25,29]. Dube et al [25] surveyed patients to identify the noisiest time of the day—patients were also asked to list the noises that they felt were annoying. Morning (7 AM to noon) was found to be the most annoying time—the most annoying noise source was people talking. Connor and Ortiz [29] conducted a survey asking the patients to rate the noise level before and after the staff education program. Patients' rating of the noise from staff improved, with fewer *poor* ratings and more *good* and *very good* ratings after the staff education.

## 4. Discussion

No study found that the noise level in the ICU was within the recommended levels by the WHO and/or the EPA. In fact, 1 perceptive study, "How Noisy is Intensive Care?" notes that "background sounds levels were measured in four units and found to be comparable to the hospital

[1] Note that decibel C is used to measure the true peak sound pressure level. "C" weighting provides a flat frequency response with slight attenuation for the high and low frequencies. The WHO guidelines for peak sound pressure level for children are not more than 120 dBC and for adults are not more than 140 dBC [1]. These guidelines are for impulse sounds from toys, fireworks, and firearms—there are no specific guidelines for hospital environment.

**Table 3** Summary of the studies fully analyzed in this review, organized by date of study ICU, NICU, MICU, and RICU

| Reference and ICU type | Primary purpose | Sample size | Economic considerations | Primary noise sources (according to respective study authors) | Methods applied to reduce noise | Study conclusions | Study limitations |
|---|---|---|---|---|---|---|---|
| Elander and Hellström [4], NICU | To investigate the effectiveness of educational intervention on reduction of noise level in the ICU | 10-min interval recordings over a total of 24 consecutive hours at the pillow level of 2 infants—one in the incubator and other on a bed | 1-h total training for unspecified no. of people | This study did not specifically investigate noise sources, but staff laughter, conversation, careless closing of doors, and incubator ports were mentioned | Educational information sessions, including a video tape of an infant's response to various sounds, instruction detailing the decibel values of different activities, and a discussion related to sound mitigation methods | This method had a significant effect on the noise resulting from the nurses' activities; it reduced minimum average noise intensity from 52 to 38 dB and the maximum average intensity from 70 to 60 dB | It was not possible to compare similar days (eg, 2 Mondays) for the pre- and posttest measurements. This may have had some influence on differences in measurements. It would be better to collect the data over several days. |
| Kahn et al [5], MICU and RICU | To identify the sources of noise producing peaks ≥80 dBA and apply a behavioral modification program to reduce the no. of those peaks | The mean peak noise level was recorded for a 1-min interval consecutively over 24 h for 2 d | Training hours and no. of staff involved in the training were not noted in the study. | Air-conditioners, ventilators, alarms (infusion pumps, monitor, ventilator, and oximeter), televisions, telephones, nebulizers, intercoms, beepers, and voices | 3-wk behavior modification educational program that included a discussion of noise pollution and its impact on patients and work environment. The duration of each session was not mentioned in the report. | The total no. of peaks ≥80 dBA reduced from 1363 (baseline) to 976. These data indicate that behavior modification is effective in reducing noise levels in ICU settings. | Limited data acquisition period (2 d). The life of the effect of the behavior modification is unknown. Usually peaks are measured in dBC, but in this study, peaks were noted in dBA. This indicates that peaks ($L_{peak}$) were confused with maximum sound pressure ($L_{max}$). |
| Johnson [30], NICU | To develop a protocol to reduce noise levels and maintain the reduction over an extended period | 2 sets of sound measurement of 2-h duration each over each shift on Mondays and Thursdays for 1 wk for the baseline study. After the educational training, measurements were taken each week for 6 wk then reduced to 1 wk/mo, continuing for 14 mo. | The educational session's hours and no. of staff involved in the sessions were not noted in the study. | The most important factors were door closing, pulse oximeter alarms, portable x-ray examinations, and high-volume personnel and visitor traffic. Noise sources also included caregiving activities such as hand washing, opening disposable equipment packages and storage drawers, and opening doors. | Educational program for staff to make them aware of sources of environmental noise and caregiving behaviors that contribute to noise. | Over the 14-mo period of the study, the average noise level was reduced from 64 to 56.29 dB. The educational program was thus shown to be effective, but the final noise level measured at the end of the study was still above the recommended level of 45 dBA. (The authors appeared to use decibel and dBA interchangeably, which made it difficult to track outcomes.) | This exceptionally large NICU had 70 beds. Thus, there were more staff and visitors as compared with a small 10- or 20-bed NICU. This made it difficult to control human traffic and interaction between people. Moreover, frequent addition of new staff and other factors made it very difficult to apply effective noise reduction techniques. |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Krueger et al [31], NICU | To study sound levels before and after structural reconstruction | 8 h of continuous recording were made for 9 d before reconstruction. After reconstruction, comparison data were collected for 2 d. | The cost of reconstruction was not noted in the study. | Staff and equipment-generated sounds and structural sounds—that is, sounds generated by the building itself, such as air-conditioners and heating systems | The structure of the NICU was modified while maintaining the same bed capacity—ceilings were lowered, facility space was increased, heating and air-conditioning systems were reconfigured with attenuation material, and ceiling tiles with a high sound absorption rating were placed throughout the NICU. | The average noise level decreased from 60.44 to 56.4 dBA, but the $L_{max}$ increased from 78.39 to 90.6 dBA. Thus, these efforts did not reduce the noise level below the recommended 45 dBA. | The shape of the NICU changed because of reconstruction. The no. of patients varied in the before and after situations. These changes may have thrown off true comparisons. |
| Taylor-Ford et al [26], medical surgical unit | To quantify noise level and evaluate impact of the noise reduction program | 6 readings per hour were recorded for 6 d. The duration of the recording interval was not noted. | Behavioral modification using sound detection equipment was carried out for 1 mo. | People, television, telephones, paging systems, falling objects, and opening and closing doors | 1. Educational noise reduction program, one 15-min presentation daily for 2 wk<br>2. Behavioral modification using sound-detection equipment<br>3. Low-cost environmental alterations | There was no significant reduction in the noise level with the educational noise reduction or behavioral modification programs. Therefore, the authors recommend use of sound-absorbing tiles to reduce noise levels. | Sound-detection equipment was manipulated by the staff, who increased the triggering level and occasionally, disabled the device by unplugging it. This resulted in data loss. The nursing staff may also have ignored the warning sign shown by the sound detector. |
| Dube et al [25], patient care unit | To identify noise sources as reported by the patients and nursing staff and implement noise reduction methods | 24 h of continuous data recording for 1 d. Patient and staff perception of noise level by survey | The cost involved in the interventions was not stated in the study. | Voices, carts traveling in the hall, foot traffic in the hall, cardiac monitor alarms, overhead pages, and pulse oximeter alarms | Closing of doors to patient rooms, dimming of lights at night, lowering speaking voices, ringers on telephones turned down, quiet signs posted, and alarms turned down as far as safely possible. | Morning was the noisiest period of the day. Noise intervention techniques significantly reduced noise as perceived by patients and staff. | The noise level was measured by surveys reported by the patients and staff. This provides only a qualitative measurement. The quantitative measurement of study was not clearly discussed in article. |
| Ramesh et al [27], level III NICU | To examine the effectiveness and cost of implementing a noise reduction protocol | Hourly noise level was recorded for 15-d period before and after implementation of protocol. Length of each recording period not noted in study. | Cost involved for modifying the environment was Rs.3884 (cost is in Indian currency as of Jan 2008) | Not mentioned | Behavioral modification (time duration of the program was not mentioned) and low-cost environmental modification | The average noise levels reduced from 68.96 to 59.38 dBA in the ventilator room, with similar reductions in other rooms. Final noise levels were still above recommended limit. | Behavioral modification and low-cost environmental modifications were not adequate to reduce noise level below the maximum recommended limit of 45 dBA by EPA. |

(*continued on next page*)

**Table 3** (*continued*)

| Reference and ICU type | Primary purpose | Sample size | Economic considerations | Primary noise sources (according to respective study authors) | Methods applied to reduce noise | Study conclusions | Study limitations |
|---|---|---|---|---|---|---|---|
| Connor and Ortiz [29], neuroscience unit | To minimize the noise level and obtain satisfactory feedback from patients. | 6 readings per day at a predefined time were measured for 3 wks immediately before and after the staff education program and again after 6 mo. The duration of each recording was not stated in the study. | Training hours and no. of staff involved in the training not noted. | Beeping machines, closing of doors, staff conversation, call bells, hallway traffic, and monitors | Educational program to teach nursing and other staff about the effects of noise and importance of reduction of noise for patient healing | Before staff education program, average noise level was 65 dB; it was reduced to 61.3 dB after staff education. 6 mo after the education program, average noise level was further reduced to 56.1 dB. Ultimately, final noise levels still above recommended limit of 45 dBA—although, confusingly, measurements were made only in decibels, not in dBA. | The feedback survey obtained from patients might not have provided accurate information. Only 6 measurements were taken per day at predefined times; this method does not provide adequate data. |
| Milette [28] NICU | To quantify noise level and evaluate impact of the noise awareness program | Average noise levels recorded for 5 consecutive minutes per hour, 24 h/d, for 13 consecutive days for both pre- and postinterventions. | Daily 1-h training program for the staff of each shift was conducted for 2 wks. Total no. of staff involved not noted. | Standard hospital equipment within ICU, no. of staff members present (health care professionals were found to be the chief noise makers), and work-related activities | Noise awareness educational program. A daily teaching program (1 h each, for day- and night-shift staff ) for staff was conducted for 2 wks; posters related to noise awareness week were placed at entrance of ICU. | Because of increase in the no. of nurses and patients after the educational program, the noise level increased significantly; thus, the intervention program was deemed ineffective. | Peaks and baselines of the noise levels were not recorded, resulting in inability to analyze key data points. |
| Dennis et al [32] Neuro-ICU | To implement a QT protocol to reduce noise levels | Noise levels were recorded 6 times a day for a period of 5 s before, during, and after QT. The measured noise parameter and the no. of days for data collection were not clearly described. | Staff education was provided on one-to-one interaction basis, but the total no. of staff involved was not recorded. | Telephones, pagers, monitor alarms, and staff conversation | QT protocol was implemented during which everyone remained silent and lights were turned off or dimmed. | Noise level during QT level decreased. However, the noise level was never below the recommended levels of 45 dB. | Because of the frequent assessment activities of the patients, it was very difficult to maintain effective QTs—thus, noise level was not controlled effectively. |

MICU indicates medical ICU; RICU, respiratory ICU; QT, quiet time.

cafeteria at noon and only somewhat less noisy than a boiler room" [17]. There was also no consistency in the measurement of noise levels in hospitals with respect to the parameters measured and the duration for which these parameters measured [21]. Moreover, there were important discrepancies and points of confusion between studies. For example, peak levels were often confused with maximum sound levels ($L_{max}$). (The $L_{peak}$ is the true peak of sound pressure wave measured in dBC, whereas the $L_{max}$ is the highest time-weighted sound level measured in dBA.) In some studies, the noise levels were recorded in decibel without clearly specifying whether A-weighting or C-weighting was being used [29]. This creates confusion in understanding the results and analysis of such data. Also troublesome is that some studies collected data for only 1 day or over a small period, thus providing insufficient data for drawing rigorous conclusions.

*Best practices*

- *Educational noise reduction programs to the ICU staff commonly appeared to be the most helpful and inexpensive mechanism for reducing sound.*
- *Public indicators that provide a light or beacon when sounds exceed specified levels are also helpful reminders for ICU staff and visitors about sound levels.*
- *A "quiet time" protocol may be helpful to institute a culture change for the staff. Even if it only runs for an hour during the afternoon, such a protocol serves as a useful reminder for everyone of the importance of quiet.*
- *Low-cost environmental alterations such as fixing the noisy doors and wheelchairs can have a small but noticeable effect on the sound levels within the ICU.*

*Common pitfalls*

- *Lack of clear definitions of the units used to measure the sound levels of decibel, dBA, and dBC.*
- *Peak levels and $L_{max}$ are often not clearly distinguished.*
- *In many of the studies, the duration and number of staff involved in the behavior modification program were not discussed, which means that there is no record for other researchers of the economics involved in program.*
- *Some of the studies had very short data collection periods, making it difficult to generalize the findings.*

In this literature review, we found that 4 studies concentrated their measurements not only on varying sound pressure level, but also on the frequency analysis of noise. The frequency analysis is useful in understanding which frequencies are louder so that better methods can be brought to bear to reduce the noise level of those frequencies. In a previous study by Busch-Vishniac et al [21], octave band filters revealed that the frequencies between 63 and 1000 Hz (the speech band) had almost constant (medium) sound intensity level, whereas the higher frequencies (>1000 Hz) had low sound intensity, and low frequencies (<63 Hz) had high sound intensity. The sources for low-frequency noise were heating, ventilating, and air-conditioning systems. The sources for high-frequency noise were thought to be alarms and sounds from mobile medical equipment [21].

Ryherd et al [22], however, using one-third octave band filters, came to a very different conclusion: that the ICU is dominated by high-frequency noise. Yet another study by Kellam and Bhatia, specifically designed to collect data on sources of high-frequency sound in an NICU, came to similar conclusions, noting "the ambient environment of the intensive care nurseries is filled with high-frequency sound" [23]. Kellam and Bhatia also suggested that the assessment of high-frequency sound should become mandatory for tertiary-level NICUs. And yet another study—this one conducted to better understand the spectral qualities of equipment and activity noise in a level 3 NICU—also found that higher frequencies dominated in high noise levels, with the highest noise levels observed in the 1- to 8-kHz frequency range. Ventilators with alarms, vacuum cleaners, and dropping of trays were found to generate maximum noise [24].

In sum, then, there are differences of opinion as to whether high- or low-frequency noise dominates in the ICU environment, although a preponderance of studies lends credence to the idea that higher frequencies dominate.

Because noise sources in the ICU are many and varied, there can be no single solution to reduce noise levels. The 10 different research studies in Table 3 have applied various noise reduction techniques to reduce the noise levels in the ICU, including behavior modification, quiet-time protocol, reconstruction of the unit, low-cost modifications of doors, and reducing the volume of televisions, telephones, pagers, and overhead speakers.

The study by Krueger et al [31], which compared sound levels before and after the structural reconstruction of an NICU, found that average noise level decreased from 60.44 to 56.4 dBA because of the reconstruction. This is a significant reduction in noise level, but ultimately, noise levels were still above recommended limits. In a different approach by Dennis et al [32], a quiet-time protocol was used to reduce the noise levels. Noise levels were found to be reduced during quiet time as compared with before and after quiet time, but noise levels were still above recommended levels [32].

The most commonly applied low-cost method for reducing noise was behavior modification, with educational sessions that provided information related to noise pollution, the effects of noise on patients and work environment, and methods to reduce the noise levels in the ICU. Of the 10 primary studies analyzed in this review, 7 applied behavior modification programs. Of those 7 studies, 5 concluded that behavior modification programs reduced noise levels—but the reduction was still not enough for noise levels to reach recommended levels for ICUs. Of the 7 studies, 2 noted no significant reduction in average noise level. One study (Milette [28]) found that the noise level increased because of an increase in the number of nurses and patients between pre- and postsituations. This latter study is the only one to discuss the effect of change in the number of staff and patients on variation of the noise levels as compared with pre- and postinterventional situations. Of the 10 studies, one (Dennis et al [32]) applied a quiet-time protocol and found that the noise level decreased before and after the quiet-time period. In many of the studies, the duration of the staff education program and the number of staff involved were not clearly stated—this meant that it was not possible to assess the economics of the proposed sound mitigation solutions. Only 1 study provided the information on the cost of the intervention methods applied.

A potentially important clue for future work in this area involves the finding of Milette [28] that the noise level increased in relation to an increase in the number of nurses and patients between pre- and post-situations. Future work in sound mitigation in hospital ICU settings might thus profitably focus on artificial methods to mimic less crowded or perhaps physically smaller ICUs. This may provide a way around the limitations indicated by current studies, where the many differing methods proposed and used by different researchers to reduce noise levels, including educational noise reduction programs, behavioral modification using sound detection equipment, and low- and high-cost environmental alterations, often do not appear to be effective in bringing ICU sound levels to within recommended limits. Moreover, the many previous studies in this area do not examine the critical tradeoffs between noise reduction of medical device alarms and compromising of patient safety.

"Best practices" in these types of studies include educating the nursing staff on noise reduction techniques, behavior modification through sound detection equipments, implementing quiet-time protocols, and posting signboards to help ensure silence. "Common pitfalls" include lack of clear definition for sound measurements: the various decibel forms—decibel, dBA, and dBC, for example—were often unclearly specified, and peak levels were often confused with $L_{max}$.

Reduction of sound levels in hospital ICUs to the recommended level of 45 dBA is clearly an important goal. Just as clearly, as this review reveals, a great deal of work remains to be done to make significant progress in this area.

Lastly, many of the studies applied administrative control methods such as behavior modification, but there is a need to carry out research on how to reduce the noise generated by medical devices alarms without compromising patient safety issues. Thus, a better combination of administrative and engineering controls may reduce the noise levels below the recommended level while simultaneously ensuring patient safety.

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## References

[1] Berglund B, Lindvall T, Schwela DH. Guidelines for community noise. http://www.who.int/docstore/peh/noise/guidelines2.html (accessed Mar/16/ 2011).
[2] Choiniere D. The effects of hospital noise. Nurs Adm Q 2010;34(4): 327-33.
[3] Morrison WE, Haas EC, Shaffner DH, et al. Noise, stress, and annoyance in a pediatric intensive care unit. Crit Care Med 2003;31(1): 113-9.
[4] Elander G, Hellström G. Reduction of noise levels in intensive care units for infants: evaluation of an intervention program. Heart Lung: J Acute Crit Care 1995;24(5):376-9.
[5] Kahn DM, Cook TE, Carlisle CC, et al. Identification and modification of environmental noise in an ICU setting. Chest 1998;114(2):535-40.
[6] Sengpiel E. Typical dBA levels—how loud is dangerousf? http://www.sengpielaudio.com/TableOfSoundPressureLevels.htm (accessed 03/20 2011).
[7] EPA 550/9-74-004, 1974, U.S. Environmental Protection Agency. (The Noise Pollution Clearing House (NPC) Online Library.). Condensed version of EPA levels document. http://www.nonoise.org/library/levels/levels.htm (accessed 05/24 /2011).
[8] Christensen M. Noise levels in a general intensive care unit: a descriptive study. Nurs Crit Care 2007;12(4):188-97.
[9] Darcy AE, Hancock LE, Ware EJ. A descriptive study of noise in the neonatal intensive care unit: Ambient levels and perceptions of contributing factors. Adv Neonatal Care 2008;8(5):S16-26.
[10] Tsiou C, Eftymiatos D, Theodossopoulou E, et al. Noise sources and levels in the Evgenidion hospital intensive care unit. Intensive Care Med 1998;24(8):845-7.
[11] Matook SA, Sullivan MC, Salisbury A, et al. Variations of NICU sound by location and time of day. Neonatal Netw: J Neonatal Nurs 2010;29(2):87-95.
[12] Allaouchiche B, Duflo F, Debon R, et al. Noise in the postanaesthesia care unit. Br J Anaesth 2002;88(3):369-73.
[13] Lawson N, Thompson K, Saunders G, et al. Sound intensity and noise evaluation in a critical care unit. Am J Crit Care 2010;19(6):E88-99.
[14] Elliott RM, McKinley SM, Eager D. A pilot study of sound levels in an Australian adult general intensive care unit. Noise Health 2010;12(46): 26-36.
[15] Macedo ISC, Mateus DC, Costa EDMGC, et al. Noise assessment in intensive care units. Braz J Otorhinolaryngol 2009;75(6):844-6.
[16] Balogh D, Kittinger E, Benzer A, et al. Noise in the ICU. Intensive Care Med 1993;19(6):343-6.
[17] Redding JS, Hargest TS, Minsky SH. How noisy is intensive care? Crit Care Med 1977;5(6):275-6.
[18] Meyer TJ, Eveloff SE, Bauer MS, et al. Adverse environmental conditions in the respiratory and medical ICU settings. Chest 1994;105(4):1211-6.
[19] Pope D. Decibel levels and noise generators on four medical/surgical nursing units. J Clin Nurs 2010;19(17 18):2463-70.
[20] MacKenzie D, Galbrun L. Noise levels and noise sources in acute care hospital wards. Building Serv Eng Res Technol 2007;28(2):117-31.
[21] Busch-Vishniac IJ, West JE, Barnhill C, et al. Noise levels in Johns Hopkins Hospital. J Acoust Soc Am 2005;118:3629-45.
[22] Ryherd EE, Waye KP, Ljungkvist L. Characterizing noise and perceived work environment in a neurological intensive care unit. J Acoust Soc Am 2008;123:747-56.
[23] Kellam B, Bhatia J. Sound spectral analysis in the intensive care nursery: measuring high-frequency sound. J Pediatr Nurs 2008;23(4):317-23.
[24] Livera M, Priya B, Ramesh A, et al. Spectral analysis of noise in the neonatal intensive care unit. Indian J Pediatr 2008;75(3):217-22.
[25] Dube JAO, Barth MM, Cmiel CA, et al. Environmental noise sources and interventions to minimize them: A tale of 2 hospitals. J Nurs Care Qual 2008;23(3):216-24.
[26] Taylor-Ford R, Catlin A, LaPlante M, et al. Effect of a noise reduction program on a medical-surgical unit. Clin Nurs Res 2008;17(2):74-88.

[27] Ramesh A, Suman Rao P, Sandeep G, et al. Efficacy of a low cost protocol in reducing noise levels in the neonatal intensive care unit. Indian J Pediatr 2009;76(5):475-8.
[28] Milette I. Decreasing noise level in our NICU: the impact of a noise awareness educational program. Adv Neonatal Care 2010;10(6):343-51.
[29] Connor A, Ortiz E. Staff solutions for noise reduction in the workplace. Permanente J 2009;13(4):23-7.
[30] Johnson AN. Adapting the neonatal intensive care environment to decrease noise. J Perinat Neonatal Nurs 2003;17(4):280-8.
[31] Krueger C, Schue S, Parker L. Neonatal intensive care unit sound levels before and after structural reconstruction. MCN Am J Matern Child Nurs 2007;32(6):358-62.
[32] Dennis CM, Lee R, Woodard EK, et al. Benefits of quiet time for neuro-intensive care patients. J Neurosci Nurs 2010;42(4):217-24.