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Operating room noise in a tertiary care hospital in China: a cross-sectional study

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Operating room noise in a tertiary care hospital in China: a cross-sectional study

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2950 words in the main text.

Abstract

Objectives: We aimed to provide a comprehensive description of noise levels in ORs in a tertiary care hospital in China, examine the deviation in noise levels from international and internal standards and examine the differences in noise levels by category of surgery and during weekdays.

Methods: We monitored noise levels in 23 different ORs between August 2015 and March 2016 in a tertiary care hospital in China. Dosimeters were used to determine the noise levels. The noise data collected in the dosimeter were downloaded to an IBM computer for subsequent analysis. One way ANOVA and t tests were used to examine the differences in noise levels.

Results: The noise levels in the ORs ranged between 59.2 and 72.3 dB (A), with 100% of the measurements exceeding the recommended hospital noise standards. There was a great deal of similarity in noise levels from Monday to Friday ($F=1.404$, $p=0.234$), with a range between 63.7 and 64.5 dB (A). The differences in noise levels by category of surgery was significant ($F=3.381$, $p<0.001$). The post hoc analysis suggested ophthalmic surgery had significantly higher noise levels than otolaryngological surgery and general surgery.

Conclusions: Ophthalmic surgery had significantly higher noise levels than otolaryngological surgery and general surgery. Similarly high noise levels were detected in all evaluated ORs during weekdays, with noise levels in the evaluated ORs consistently exceeding the currently accepted standards. This finding warrants further investigation to determine the harmful effects of noise on both patients and staff in ORs.

Keywords: noise; operating room; hospital

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Article summary

Strengths and limitations of this study:

Strengths:

1. This is the first time dosimeters have been used to monitor noise levels in the OR. The dosimeters have real-time monitoring metrics, thereby providing more precise measurements of noise levels than the tools used in previous studies.
2. This study used dosimeters to measure noise over a long period in a wide range of procedures. The readings can be saved, and the distribution of noise levels can be identified, including the examination of noise levels versus time, location and category of surgery.

Limitation:

A limitation of this study was that specific events, such as the use of noisy tools, could not be directly linked to the recorded noise levels.

INTRODUCTION

Noise represents a known health hazard, a finding that has been demonstrated in hospitals and especially operating rooms (ORs). Excessive noise may have a negative effect on patient care and safety. Noise in the OR can also affect the health and performance of staff. The World Health Organization (WHO), the Environmental Protection Agency (EPA), and China have established guidelines and standards describing safe noise levels in hospitals and ORs. The WHO recommends that noise levels should not exceed 35 dB (A) ^[1]. The EPA document states that noise levels should not exceed 45 dB (A) ^[2]. In China, regulations assert that noise levels in ORs should not exceed 50 dB (A) ^[3]. These standards stress that OR noise should be maintained at levels that are as low as possible.

Notwithstanding these standards or guidelines, hospitals are never quiet places. Busch-Vishniac IJ and colleagues conducted a review of the studies that have previously examined noise levels in hospitals, and found noise measurements to consistently exceed the recommended levels by, on average, 20-40 dB (A) ^[4]. A corresponding significant linear increase in hospital noise levels has been observed since 1960, with increases averaging 0.38 dB per year during the day and 0.42 dB per year at night. Within hospitals, researchers are specifically concerned about noise in ORs, where the mean noise level ranges between 51 and 75 dB (A) ^[5]. Prior studies have measured noise levels produced by tools used primarily during conventional surgeries ^[6-10]. Several studies have reported the sound pressure levels for a particular surgery or specific surgeries ^[11-16].

However, it is difficult to characterize noise in the OR based on these published articles. Because previous studies were limited to surgical tools and particular surgeries, it is not

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surprising that we cannot characterize typical patterns in sound pressure levels over the course of a workday within an operating room. In addition, based on these data, the distribution of noise levels cannot be identified, including noise levels versus time and category of surgery. In this study, we measured noise levels in 23 different ORs according to different types of surgery performed, aiming to provide a comprehensive description of noise levels in ORs in a tertiary care hospital. We aimed to compare the deviation in noise levels from the currently accepted standards and compare the differences in noise levels across day of the week and type of surgery.

METHODS

overview

The cross-sectional study was approved by the Institutional Review Board (IRB) of our hospital. The requirement for written informed consent was waived by the IRB because patient and staff data were not collected. We obtained permission from the hospital administration to place noise monitoring equipment in the ORs. All personnel were unaware of the ongoing noise monitoring, and no changes were made that would control noise levels or disturb staff routines throughout the study. This manuscript adheres to the applicable Equator guidelines. This cross-sectional study was conducted in a tertiary care hospital located in a densely populated district in the city of Beijing, China. The study was conducted between August 2015 and March 2016. During the first period, noise levels were monitored in seventeen operating rooms in the surgical building. All types of surgeries except ophthalmology and otolaryngology surgeries were included. During the second period, we measured noise levels in seven rooms in the Ophthalmology and Otorhinolaryngology Department.

instrument

Personal noise dosimeters (Aihua, Model AWA5610B, Hangzhou, China) were used to determine noise levels. The dosimeter meets the International Electrotechnical Commission Standard (IEC) 61672-2002 class 2 and Chinese National Standards (GB) GB/T15952-1995 class 2. Noise is measured in decibels on a logarithmic scale. What may seem to be a relatively small increase in noise levels is actually a significant ascension. The A-weighted

scale, dB (A), was used in this study to measure noise levels. This scale is used frequently in clinical practice, as it filters out the very low and very high frequencies to which humans are insensitive. The dosimeter provided a direct sound pressure reading and could detect sound levels ranging from 45 to 140 dB (A) with an accuracy of less than ± 1 dB (A) over a temperature range of 0-40°C. Before any measurements were taken, each dosimeter was calibrated using a Model AWA6221A Sound Level Calibrator (Aihua Instruments) that complied with IEC 60942-2004 class 1 in a controlled environment at a 94.0-dB sound pressure level from a single point source with a 1 kHz frequency.

procedure

Measurements were made during weekdays to ensure that surgical action would occur within the rooms. Before any measurements were taken, the dosimeters were fully charged and calibrated. The noise levels were measured and monitored automatically within our study setting. Often, noise measurement commenced on the investigator's way to the OR at, on average, 06:50 to 07:30. In addition, the instruments were placed in the ORs under study before staff entered the ORs for operation preparation at 08:00. The staff were generally unaware of the instrument placement and noise monitoring to ensure that they would work as they always did. No behavior changes were made, including controlling conversation or abstaining from the playing of music.

The instrument was placed inside each room throughout the full-shift period, from before 08:00 to the anesthesia emergence and transportation of the last patient out of the operating room at, on average, 17:00. In each room, the instrument was positioned so that it did not interfere with the surgical schedule and was outside of the sterile field. The instrument was

placed within two meters of the anesthesia machine at a height of 1.5 meters from the floor. The noise data collected in the dosimeter were downloaded to an IBM computer for subsequent analysis.

The sample interval was two seconds, which meant that two seconds of A-weighted equivalent continuous sound levels ($L_{Aeq, 2s}$) was collected every two seconds. The $L_{Aeq, 2s}$ measurements were plotted against time using time series plots to facilitating their graphical summarization. An A-weighted equivalent sound pressure level in dB, as measured over the noise assessment period T ($L_{Aeq, T}$), was calculated for each room. The $L_{Aeq, T}$ was calculated as follows^[17]:

$$L_{Aeq, T} = 10 \log \left(\frac{1}{T} \sum_{i=1}^n 2 \times 10^{0.1 L_{Aeq, 2s}} \right)$$

where T is the whole noise assessment period and n is the total readings that occurred over the period, e.g., the noise measurement in an OR from 08:00 to 17:00 allowed for the collection of 16200 $L_{Aeq, 2s}$ readings; therefore, T equaled 32400 seconds and n equals 16200.

We obtained permission to view the surgical logs to identify operations occurring within the measurement period. The surgery log provides a detailed description of the nature of each procedure and the division of surgery under which it falls. Generally, the same type of surgeries were performed in the same room on a same day. Using the data obtained from the dosimeters and logs, the noise levels in each OR were calculated.

statistical analysis

Data were exported from the dosimeters using their proprietary software and then analyzed using MATLAB 7.7 (R2008b) and SPSS for Windows, Version 20.0 (SPSS, Chicago,

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IL, USA). The distribution of $L_{Aeq, T}$ across all ORs was summarized graphically using a histogram. One sample t test was applied to examine the deviation in noise levels from international and internal standards. One way ANOVA was applied to examine the differences in noise levels among groups for categorical parameters (days of the week and category of surgery). The post hoc analysis used Bonferroni methods. All reported p values were two tailed, and $p < 0.05$ was established as the level of significance.

RESULTS

The study area was a surgical building in a tertiary care hospital in which annual operations number in the tens of thousands. According to the available data, 56000 surgeries were performed in this hospital in 2015. In addition, under the assumption that a year comprises 250 weekdays, 225 operations were performed each day. Divided this number by the 48 operating rooms, it can be estimated that nearly five consecutive surgeries belonging to the same category (e.g., neurology, gynecology, etc.) were conducted in a given room per day. Consecutive surgeries was defined as conditions in which once a surgery was completed, the next operation on the operating list was initiated.

Based on our observations, we found that the ORs varied in size from 10 to 20 square meters. All of the rooms have hard surfaces and furnishings with no material added for sound absorption. Noise sources included the functioning laminar airflow system, surgical trolleys, equipment and instruments, vacuum suction, power drills, anesthetic monitors, alarms, power tools, preparing for the operation, moving and dropping metal tools, telephones ringing, doors opening and slamming, background music, and conversations among staff that was not related to the procedure.

The plot for $L_{Aeq, 2s}$ versus time (07:30~17:30) within an operating room during the performance of gynecological surgeries is shown in Figure 1. Figure 1 shows a typical trace of $L_{Aeq, 2s}$ versus time for an operating room. With the passage of time, considerable variation

in noise levels was identified. The noise level was below 50 dB (A) when the operating room was unoccupied and then increases incrementally with the entry of staff and patients, with a range of L_{eq} from 50 to 85 dB (A). We identified the performance of four different surgeries during the measurement period, with a very short nonsurgical interval between adjacent operations. The first surgery was performed from 07:55 to 11:44, the second was performed from 11:55 to 14:10, the third was performed from 14:25 to 15:40 and the fourth was performed from 15:55 to 17:15. At the beginning of each surgery, noise levels were relatively high, ranging from 55 to 75 dB (A), then gradually decreased, ranging from 50 to 70 dB (A) at the end of the surgery.

Noise data were collected in 23 ORs, with multiple measurements taken in each OR, thus generating 225 $L_{Aeq, T}$ data points, the distribution of which is shown in Figure 2. The horizontal axis represents the $L_{Aeq, T}$ measurements, and the actual measured frequencies lie on the vertical axis. The results revealed a noise level ranging between 59.2 and 72.3 dB (A). None of the measured $L_{Aeq, T}$ values complied with the WHO, EPA or Chinese guidelines, with 100% of the measurements exceeding these standards. The mean noise level was 64.2 (± 2.1) dB (A), which was 29.2 dB (A) higher than the WHO standard ($t=211.3$, $p<0.001$), 19.2 dB (A) louder than the 45 dB (A) recommended by the EPA ($t=138.9$, $p<0.001$) and 14.2 dB (A) higher than the Chinese standards ($t=102.7$, $p<0.001$). This result certainly suggests there was excessive noise in the ORs surveyed.

In addition to the overall distribution of $L_{Aeq, T}$, the average noise levels across the different ORs ranged from 61.8 to 66.7 dB (A). The averages were calculated by averaging the multiple measurements for each OR. The observed narrow variation fits with the staff's

perception of noise. Based on these data, it was clear that there was no discernable pattern that distinguished the noisiest from the least noisy OR.

The operating rooms were occupied on weekdays and noise data were collected during these periods. As shown in Table 1, each result was represented as an average over multiple measurements that were typically obtained in more than one OR. There was a great deal of similarity in noise levels from Monday to Friday ($F=1.404$, $p=0.234$), with a range between 63.7 and 64.5 dB (A) identified.

Table 1 Operating room noise levels on weekdays

Weekday	Mean±SD dB(A)	Range dB(A)	Number of Measurements	F	p
Monday	63.7±2.0	59.8~68.4	45	1.404	0.234
Tuesday	64.4±2.0	60.6~69.5	47		
Wednesday	64.7±1.5	61.4~68.8	43		
Thursday	64.0±1.8	59.9~68.9	40		
Friday	64.2±2.7	59.2~72.3	50		
Total	64.2±2.1	59.2~72.3	225		

Table 2 Operating room noise levels by category of surgery

Division	Mean±SD dB(A)	Range dB(A)	Number of Measurements	F	p
Thoracic	63.2±1.3	61.6~65.1	11	3.381	<0.001
Otolaryngology*	63.3±1.5	59.9~65.8	39		
General Surgery*	63.5±2.4	59.2~72.3	33		
Sports Medicine	64.1±1.5	61.4~66.3	10		
Urology	64.2±2.0	61.8~68.1	20		
Neurosurgery	64.2±1.8	59.8~66.7	16		
Gynecology	64.4±2.0	61.3~68.9	15		
Cardiology	64.5±2.3	61.1~68.4	11		
Orthopedic	64.8±2.6	60.9~72.0	29		
Ophthalmology	65.4±1.6	62.5~71.1	41		
Total	64.2±2.1	59.2~72.3	225		

*lower noise levels than Ophthalmology.

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Table 2 summarizes the noise level measurements by category of surgery (e.g., neurology, gynecology, etc.). Overall, the noise levels ranged from 59.2 to 72.3 dB (A), as indicated by their $L_{Aeq, T}$ values, and the average noise levels by category of surgery ranged from 63.2 to 65.4 dB (A). The differences in noise levels detected in the ORs by category of surgery was significant ($F=3.381$, $p<0.001$). The post hoc analysis suggested ophthalmic surgery (65.4 dB (A)) had higher noise levels than otolaryngological surgery (63.3dB (A)) and general surgery (63.4 dB (A)).

DISCUSSION

The results revealed a noise level ranging between 59.2 and 72.3 dB (A), which was much louder than guidelines recommended by China, the WHO and the EPA. The noise levels recorded here (64.2 ± 2.1 dB (A)) show that ORs are noisy environments, a finding which is in line with other studies that have previously established noise levels in the OR (51 to 75 dB (A))^[5,11-16]. No previously published results have shown noise levels in ORs that complies with the WHO guidelines or other standards for hospital noise. Thus, the problem of excessive noise in the OR appears to be universal regardless of the type of hospital or geographic location^[4]. These findings certainly raise questions regarding the significance of these guidelines, as these data imply that the current standards for hospital noise does not apply in the OR. The establishment of guideline values for sound pressure levels in the OR warrants future research.

The results suggested that ophthalmic surgery had significantly higher noise levels than otolaryngological surgery and general surgery. Because we do not have sound recordings, we cannot identify the causes of the difference. Based on our observations, there was music playing in the ophthalmic surgery, which might accounted for the higher noise levels. It would be necessary to replicate this study using data acquired from operating rooms in other hospitals.

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Additionally, no discernable patterns that distinguished the noisiest from the least noisy OR were identified. In addition, there was a great deal of similarity in noise levels detected from Monday to Friday. This similarity may be largely attributed to the similarity in noise sources. In addition to the functioning laminar airflow system, equipment and instruments, anesthetic monitors, alarms and vacuum suction comprised these noisy environments. Because of their continuous presence in the room and the stability of the levels they produce, these sources contributed to the sustained similar noise levels detected in the evaluated ORs. This issue warrants further study and research.

Excessive noise can be a threat to patient comfort and safety. Evidence has been presented suggesting that more than one-third of patients perceived ORs as noisy and 16% of patients actually felt stressed by the noise in this environment ^[18]. The stapedius muscle can be weakened by anesthetic drugs, which normally contracts and protects the cochlea when exposed to loud sounds ^[19]. Thus, we are concerned that the hearing of patients might be at risk when the natural reflex mechanism was abolished.

Excessive noise can also have detrimental effect on staff health. Evidence has been presented suggesting that high noise levels (over 55 dB (A)) were associated with adverse events such as hypertension, fatigue, annoyance, burn-out, stress and headaches ^[1]. All the $L_{Aeq, T}$ values measured in the present study were above 55 dB (A), which suggests that excessive noise may pose a potential health risk to OR staff. Previous studies have suggested that anesthetists are especially susceptible to the hazards associated with excess noise ^[14] because of their continuous presence in the room, their close proximity to noisy equipment and the fact that noise in the OR is louder during the critical anesthesia components of care,

such as induction and emergence, than other critical points. Particular attention should be given to the mental and physical health of anesthetists.

Noise in the OR can also interfere with work progression. Surgeons, nurses, and anesthetists are engaged in complex mental activities that require a high degree of concentration. The staff, especially anesthetists, might be at risk of being disturbed by noise. In one study, 84% of anesthetists complained that noise levels in the OR negatively affected their work ^[14]. In addition, a significant worsening in mental efficiency and short-term memory test results were observed in anesthetists after exposure to pre-recorded operating room noise ^[20]. Operating room noise might cause a decrease in auditory processing function ^[21]. Researchers also reported that noise had a negative effect on the ability of resident anesthesiologists to detect changes in oxygen saturation with pulse oximetry ^[22]. However, these studies were conducted in controlled settings, and future work is needed to consider the impact of noise on anesthetists under real working conditions.

In the OR, it is vital to ensure effective and high quality communication between surgeons, nurses, and anesthetists; however, conversational ability may be often hindered by high levels of noise. To ensure speech communication, the signal-to-noise ratio should be at least 15 dB ^[1]. With noise levels ranging between 59.2 and 72.3 dB (A) in the OR, the staff need to speak at 74.2–87.3 dB (A), which is well above the normal speaking levels of 55–65 dB (A). Thus, medical staff might raise their voice to ensure good communication, thereby creating more noise. This noisy environment pose a potential risk of miscommunication, which can lead to unacceptable medical errors.

This is the first time dosimeters have been used to monitor noise levels in the OR. The

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dosimeters have real-time monitoring metrics, thereby providing more precise measurements of noise levels than the tools used in previous studies. The readings can be saved, and the distribution of noise levels can be identified, including the examination of noise levels versus time, location and category of surgery.

A limitation of this study was that specific events, such as the use of noisy tools, could not be directly linked to the recorded noise levels. In later work, we intend to document these events, including their time and duration. Through the use of qualitative records and time series plots examining changes in $L_{Aeq, 2s}$ over time, it may be able to identify noisy processes. The measurements described in this study were limited to ORs in a tertiary care hospital in China, and further work is needed to establish noise levels in ORs in other hospitals.

Contributorship statement

Xiaoxiao Wang collected noise data and analyzed data; Lin Zeng designed the study and provided interpretive analysis; Gang Li and Mao Xu commented on the study plan and provided critical revision. Bin Wei and Yan Li collected surgery logs and provided critical revision on the discussion. Nan Li, Liyuan Tao and Hua Zhang discussed the results and provided critical revision. Xiangyang Guo and Yiming Zhao put forward the conception of the work, organized and coordinated the study and commented on the manuscript. All authors participated in the review, drafting, and final approval of the manuscript. All authors declare no other conflict of interest. The project described was not supported by any organizations.

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For peer review only

Competing interests: There are no competing interests.

Funding: The project described was not supported by any organizations.

Data sharing statement: No additional unpublished data are available.

For peer review only

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4	What this paper adds
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6	1. Noise represents a known health hazard, a finding that has been demonstrated in hospitals
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8	and especially operating rooms (ORs).
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13	2. Very little reliable information exists regarding the characteristics of operating room noise
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15	and the distribution of noise levels cannot be identified, including noise levels versus time and
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24	3. This study used dosimeters to measure noise over a long period in a wide range of
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26	procedures and illustrated typical patterns in sound pressure levels over the course of a
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34	4. This study compared noise levels by category of surgery and found that ophthalmic surgery
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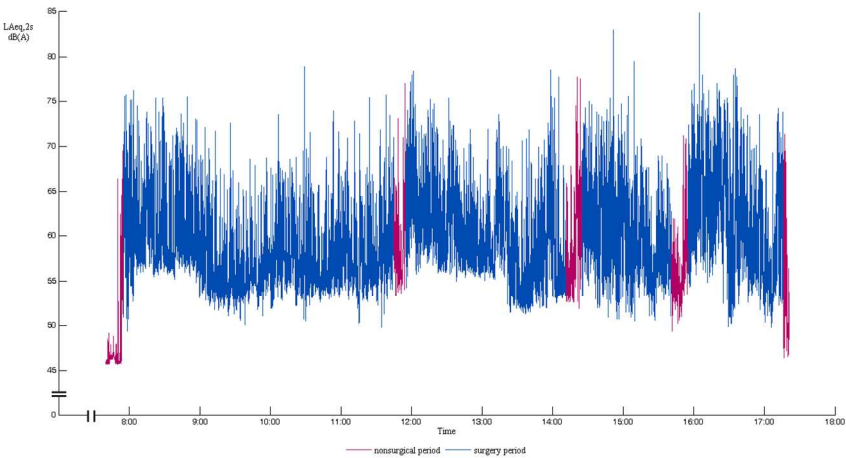
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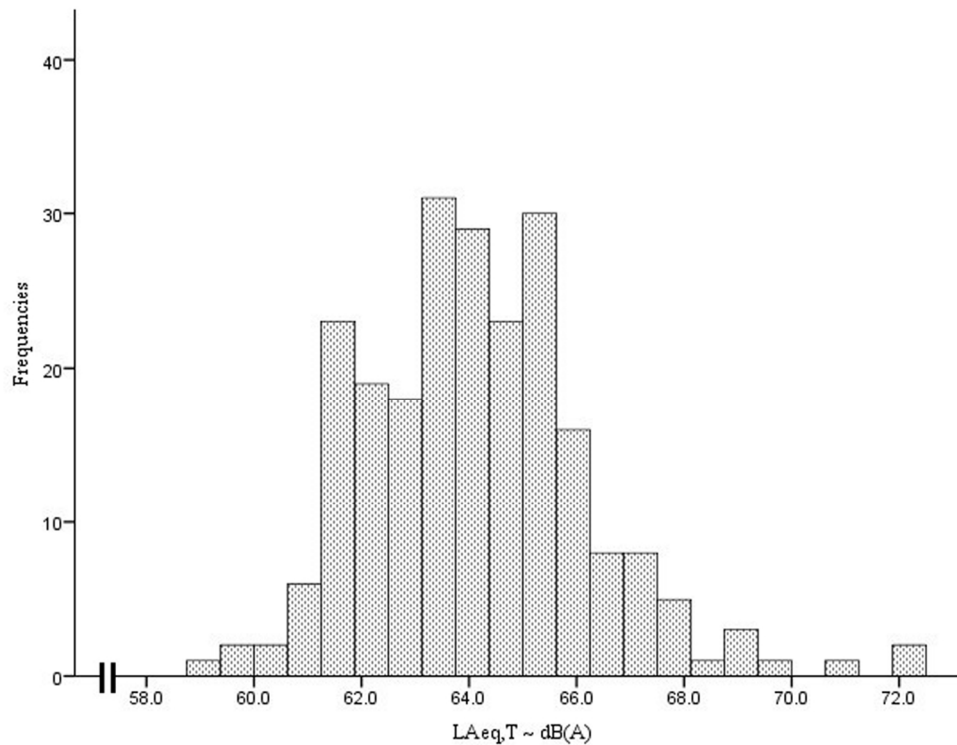


Figure 2 The distribution of A-weighted equivalent sound pressure level measured in all ORs

165x137mm (200 x 200 DPI)

STROBE Statement—Checklist of items that should be included in reports of *cross-sectional studies*

	Item No	Recommendation
Title and abstract	1	(a) Indicate the study’s design with a commonly used term in the title or the abstract Page 1
		(b) Provide in the abstract an informative and balanced summary of what was done and what was found Page 2
Introduction		
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported Page 4
Objectives	3	State specific objectives, including any prespecified hypotheses Page 5
Methods		
Study design	4	Present key elements of study design early in the paper Page 6
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection Page 6
Participants	6	(a) Give the eligibility criteria, and the sources and methods of selection of participants Not applicable
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable Not applicable
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group Page 7
Bias	9	Describe any efforts to address potential sources of bias Page 6
Study size	10	Explain how the study size was arrived at Not applicable
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why Not applicable
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding Page 8
		(b) Describe any methods used to examine subgroups and interactions Not applicable
		(c) Explain how missing data were addressed Not applicable
		(d) If applicable, describe analytical methods taking account of sampling strategy Not applicable
		(e) Describe any sensitivity analyses Not applicable
Results		
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed Not applicable
		(b) Give reasons for non-participation at each stage Not applicable
		(c) Consider use of a flow diagram Not applicable
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders Page 10
		(b) Indicate number of participants with missing data for each variable of interest Not applicable
Outcome data	15*	Report numbers of outcome events or summary measures Not applicable
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were

		adjusted for and why they were included Not applicable
		(b) Report category boundaries when continuous variables were categorized Page 12
		(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period Not applicable
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses Not applicable
Discussion		
Key results	18	Summarise key results with reference to study objectives Page 14
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias Page 16
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence Page 17
Generalisability	21	Discuss the generalisability (external validity) of the study results Page 17
Other information		
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based Page 19

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is available at www.strobe-statement.org.

BMJ Open

A cross-sectional study in a tertiary care hospital in China: What do we know about operating room noise?

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1 A cross-sectional study in a tertiary care hospital in China:

2 What do we know about operating room noise?

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20 3050 words in the main text

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Abstract

Objectives: We aimed to provide a comprehensive description of noise levels in operating rooms (ORs) in a tertiary care hospital in China and to examine the deviation in noise levels from international and internal standards as well as the differences in noise levels by the category of surgery and day of week.

Methods: We monitored noise levels in 23 different ORs between August 2015 and March 2016 in a tertiary care hospital in China. Dosimeters were used to determine noise levels. The noise data collected in the dosimeter were downloaded to an IBM computer for subsequent analysis. One-way ANOVA and t tests were used to examine the differences in noise levels.

Results: The Noise levels in the ORs ranged between 59.2 and 72.3 dB (A), with 100% of the measurements exceeding the recommended hospital noise standards. There was substantial similarity in noise levels from Monday to Friday ($F=1.404$, $p=0.234$), with a range between 63.7 and 64.5 dB (A). The differences in noise levels by the category of surgery was significant ($F=3.381$, $p<0.001$). The results of the post hoc analysis suggested that ophthalmic surgery had significantly higher noise levels than otolaryngological surgery or general surgery.

Conclusions: Ophthalmic surgery had significantly higher noise levels than otolaryngological or general surgeries. Similarly, high noise levels were identified in all evaluated ORs during weekdays, and these levels consistently exceeded the currently accepted standards. These findings warrant further investigation to determine the harmful effects of noise on both patients and staff in ORs.

Strengths and limitations of this study:

Strengths:

1. This investigation is the first time dosimeters have been used to monitor noise levels in ORs. The dosimeters have real-time monitoring metrics, which thus provide more precise measurements of noise levels than the tools used in previous studies.

2. This study used dosimeters to measure noise over an extended period in a wide range of surgical procedures. The readings can be saved, and the noise level distribution can be identified, including the examination of noise levels versus the surgical time, location and category.

Limitations:

One limitation of this study was that specific events, such as the use of noisy tools, could not be directly linked to the recorded noise levels.

INTRODUCTION

Noise represents an established health hazard, a finding that has been demonstrated in hospitals and particularly operating rooms (ORs). Excessive noise may have negative effects on patient care and safety. Noise in the OR may also affect the health and performance of staff. The World Health Organization (WHO), the Environmental Protection Agency (EPA), and China have established guidelines and standards that describe safe noise levels in hospitals and ORs. The WHO recommends that noise levels should not exceed 35 dB (A) ^[1]. The EPA guidelines state that noise levels should not exceed 45 dB (A) ^[2]. In China, regulations assert that noise levels in ORs should not exceed 50 dB (A) ^[3]. These standards stress that OR noise should be maintained at levels that are as low as possible.

Notwithstanding these standards or guidelines, hospitals are never quiet places. Busch-Vishniac IJ and colleagues conducted a review of previous studies that have examined noise levels in hospitals and determined noise measurements consistently exceeded the recommended levels by an average of 20-40 dB (A) ^[4]. A corresponding significant linear increase in hospital noise levels has been identified since 1960, with increases averaging 0.38 dB per year during the day and 0.42 dB per year at night. Within hospitals, researchers are specifically concerned with noise in ORs, in which the mean noise level ranges between 51 and 75 dB (A) ^[5]. Previous studies have measured noise levels produced by tools used primarily during conventional surgeries ^[6-10]. Several studies have reported the sound pressure levels for a particular surgery or specific surgeries ^[11-16].

However, it is difficult to characterize noise in the OR based on these published articles. Previous studies were limited to surgical tools and specific surgeries; thus, it is not surprising

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1 that the typical patterns in sound pressure levels over the course of a workday within an
2 operating room cannot be characterized. In addition, based on these data, the distribution of
3 noise levels cannot be identified, including noise levels versus time and category of surgery.
4 In this study, we measured noise levels in 23 different ORs according to the different types of
5 surgery performed, with the aim to provide a comprehensive description of noise levels in
6 ORs in a tertiary care hospital. We aimed to compare the deviation in noise levels from the
7 currently accepted standards and compare the differences in noise levels across the day of the
8 week and type of surgery.

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METHODS

overview

This cross-sectional study was approved by the Institutional Review Board (IRB) of our hospital. The requirement for written informed consent was waived by the IRB because patient and staff data were not collected. We obtained permission from the hospital administration to place noise monitoring equipment in the ORs. All personnel were unaware of the ongoing noise monitoring, and no changes were made that would control noise levels or disturb staff routines throughout the study. This manuscript adheres to the applicable Equator guidelines. This cross-sectional study was conducted in a tertiary care hospital located in a densely populated district in the city of Beijing, China. The study was conducted between August 2015 and March 2016. During the first period, noise levels were monitored in seventeen ORs in the surgical building. All types of surgeries with the exception of ophthalmology and otolaryngology surgeries were included. During the second period, we measured noise levels in seven rooms in the Ophthalmology and Otorhinolaryngology Departments.

instrument

Personal noise dosimeters (Aihua, Model AWA5610B, Hangzhou, China) were used to determine noise levels. The dosimeter meets the International Electrotechnical Commission Standard (IEC) 61672-2002 class 2 and Chinese National Standards (GB) GB/T15952-1995 class 2. Noise is measured in decibels on a logarithmic scale. A change that may appear to be a relatively small increase in noise levels can actually be a significant ascension. The A-weighted scale, dB (A), was used in this study to measure noise levels. This scale is

1 frequently used in clinical practice because it filters out the very low and very high
2 frequencies to which humans are insensitive. The dosimeter provided a direct sound pressure
3 reading and detected sound levels that ranged from 45 to 140 dB (A) with an accuracy of less
4 than ± 1 dB (A) over a temperature range of 0-40°C. Before measurements were obtained,
5 each dosimeter was calibrated using a Model AWA6221A Sound Level Calibrator (Aihua
6 Instruments), which complied with IEC 60942-2004 class 1 in a controlled environment at a
7 94.0-dB sound pressure level from a single point source with a 1 kHz frequency.

8 **procedure**

9 Measurements were obtained during weekdays to ensure that surgical action would occur
10 within the rooms. Before measurements were obtained, the dosimeters were fully charged and
11 calibrated. Noise levels were automatically measured and monitored in our study setting. In
12 general, noise measurement commenced on the investigator's way to the OR at, on average,
13 06:50 to 07:30. In addition, the instruments were placed in the ORs under study before the
14 staff entered the ORs for operation preparation at 08:00. In general, the staff were unaware of
15 the instrument placement and noise monitoring to ensure that they would work as usual. No
16 behavior changes were made, including controlling conversation or abstaining from the
17 playing of music.

18 The instrument was placed inside each room throughout the full-shift period from before
19 08:00 to the anesthesia emergence and transportation of the last patient out of the operating
20 room at, on average, 17:00. In each room, the instrument was positioned so that it did not
21 interfere with the surgical schedule and was outside of the sterile field. The instrument was
22 placed within two meters of the anesthesia machine at a height of 1.5 meters from the floor.

1 The noise data collected in the dosimeter were downloaded to an IBM computer for
2 subsequent analysis.

3 The sample interval was two seconds, which indicated that two seconds of A-weighted
4 equivalent continuous sound levels ($L_{Aeq, 2s}$) were collected every two seconds. The $L_{Aeq, 2s}$
5 measurements were plotted against time using time series plots to facilitate their graphical
6 summarization. An A-weighted equivalent sound pressure level in dB, as measured over the
7 noise assessment period T ($L_{Aeq, T}$), was calculated for each room. The $L_{Aeq, T}$ was calculated
8 as follows ^[17]:

$$L_{Aeq, T} = 10 \log \left(\frac{1}{T} \sum_{i=1}^n 2 \times 10^{0.1 L_{Aeq, 2s}} \right)$$

10 where T represents the entire noise assessment period, and n represents the total readings
11 that occurred over the period, e.g., the noise measurement in an OR from 08:00 to 17:00
12 allowed for the collection of 16,200 $L_{Aeq, 2s}$ readings; therefore, T equaled 32,400 seconds,
13 and n equaled 16,200.

14 We obtained permission to view the surgical logs to identify operations that occurred
15 within the measurement period. The surgery log provides a detailed description of the nature
16 of each procedure and the division of surgery. In general, the same type of surgeries were
17 performed in the same room on the same day. Using the data obtained from the dosimeters
18 and logs, noise levels in each OR were calculated.

19 **statistical analysis**

20 Data were exported from the dosimeters using their proprietary software and were
21 subsequently analyzed using MATLAB 7.7 (R2008b) and SPSS for Windows, Version 20.0
22 (SPSS, Chicago, IL, USA). The distribution of $L_{Aeq, T}$ across all ORs was graphically

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1 summarized using a histogram. One sample t test was applied to examine the deviation in
2 noise levels from international and internal standards. One-way ANOVA was applied to
3 examine the differences in noise levels among groups for categorical parameters (days of the
4 week and category of surgery). The post hoc analysis used Bonferroni methods. All reported p
5 values were two tailed, and $p < 0.05$ was established as the level of significance.

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RESULTS

The study area was a surgical building in a tertiary care hospital in which annual operations number in the tens of thousands. According to the available data, 56,000 surgeries were performed in this hospital in 2015. In addition, under the assumption that one year comprises 250 weekdays, 225 operations were performed each day. When this number was divided by the 48 ORs, it was estimated that nearly five consecutive surgeries that belong to the same category (e.g., neurology and gynecology) were conducted in a given room per day. Consecutive surgeries were defined as conditions in which the completion of one surgery resulted in the initiation of the next operation on the operating list.

Based on our observations, the ORs varied in size from 10 to 20 square meters. All rooms had hard surfaces and furnishings with no material added for sound absorption. Noise originated from both equipment and staff. The functioning laminar airflow system generated steady noise over the period. The equipment for anesthesia (e.g., anesthetic monitors) generated many distracting alarms and alerts (on average 1~2 alarms within several minutes). The equipment and instruments for surgery (e.g., power drills, power tools, or vacuum suction) generated instantaneous, sudden, and distinct noise with a duration of several seconds. The total time of instrument use varied depending on the operating time. Staff-related activities (e.g., preparing for the operation, activities regarding patient care, moving and dropping metal tools, telephones ringing, doors opening and slamming, or moving surgical trolleys) were a major component of the operating room noise. Noise sources also included background music and conversations among staff members. Most staff-related sources were sudden and

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1 unpredictable.

2 The plot for the $L_{Aeq, 2 s}$ versus time (07:30~17:30) within an operating room during the
3 performance of gynecological surgeries is shown in Figure 1. Figure 1 presents a typical trace
4 of the $L_{Aeq, 2 s}$ versus time for an operating room. With the passage of time, considerable
5 variation in noise levels was identified. The noise level was below 50 dB (A) when the
6 operating room was unoccupied and incrementally increased with the entry of staff and
7 patients, with a range of L_{eq} from 50 to 85 dB (A). We identified the performance of four
8 different surgeries during the measurement period, with a very short nonsurgical interval
9 between adjacent operations. The first surgery was performed from 07:55 to 11:44, the second
10 surgery was performed from 11:55 to 14:10, the third surgery was performed from 14:25 to
11 15:40, and the fourth surgery was performed from 15:55 to 17:15. At the beginning of each
12 surgery, noise levels were relatively high, with a range from 55 to 75 dB (A), and then the
13 levels gradually decreased, with a range from 50 to 70 dB (A) at the end of the surgery.

14 Noise data were collected in 23 ORs, with multiple measurements obtained in each OR,
15 which thus generated 225 $L_{Aeq, T}$ data points; the distribution of the data is shown in Figure 2.
16 The horizontal axis represents the $L_{Aeq, T}$ measurements, and the actual measured frequencies
17 are presented on the vertical axis. The results indicated a noise level that ranged between 59.2
18 and 72.3 dB (A). None of the measured $L_{Aeq, T}$ values complied with the WHO, EPA or
19 Chinese guidelines, with 100% of the measurements exceeding these standards. The mean
20 noise level was 64.2 (± 2.1) dB (A), which was 29.2 dB (A) higher than the WHO standard
21 ($t=211.3$, $p<0.001$), 19.2 dB (A) louder than the 45 dB (A) recommended by the EPA ($t=138.9$,
22 $p<0.001$) and 14.2 dB (A) higher than the Chinese standards ($t=102.7$, $p<0.001$). In addition

to the overall distribution of the $L_{Aeq, T}$, the average noise levels across the different ORs ranged from 61.8 to 66.7 dB (A). The averages were calculated by averaging the multiple measurements for each OR.

The ORs were occupied on weekdays, and noise data were collected during these periods. As shown in Table 1, each result was represented as an average over multiple measurements that were typically obtained in more than one OR. There was substantial similarity in noise levels from Monday to Friday ($p=0.234$).

Table 1 Operating room noise levels on weekdays

Weekday	Mean±SD dB(A)	Range dB(A)	Number of Measurements	F	p
Monday	63.7±2.0	59.8~68.4	45	1.404	0.234
Tuesday	64.4±2.0	60.6~69.5	47		
Wednesday	64.7±1.5	61.4~68.8	43		
Thursday	64.0±1.8	59.9~68.9	40		
Friday	64.2±2.7	59.2~72.3	50		
Total	64.2±2.1	59.2~72.3	225		

Table 2 Operating room noise levels by category of surgery

Division	Mean±SD dB(A)	Range dB(A)	Number of Measurements	F	p
Thoracic	63.2±1.3	61.6~65.1	11	3.381	<0.001
Otolaryngology*	63.3±1.5	59.9~65.8	39		
General Surgery*	63.5±2.4	59.2~72.3	33		
Sports Medicine	64.1±1.5	61.4~66.3	10		
Urology	64.2±2.0	61.8~68.1	20		
Neurosurgery	64.2±1.8	59.8~66.7	16		
Gynecology	64.4±2.0	61.3~68.9	15		
Cardiology	64.5±2.3	61.1~68.4	11		
Orthopedic	64.8±2.6	60.9~72.0	29		
Ophthalmology	65.4±1.6	62.5~71.1	41		
Total	64.2±2.1	59.2~72.3	225		

*lower noise levels than the Ophthalmology Department.

Table 2 summarizes the noise level measurements by category of surgery (e.g.,

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1 neurology and gynecology). The differences in noise levels detected in the ORs by category
2 of surgery was significant ($p<0.001$). The post hoc analysis suggested ophthalmic surgery
3 (65.4 dB (A)) had higher noise levels than otolaryngological surgery (63.3 dB (A)) and
4 general surgery (63.4 dB (A)).

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DISCUSSION

The results indicated a noise level that ranged between 59.2 and 72.3 dB (A), which was substantially louder than the guidelines recommended by China, the WHO and the EPA. Noise levels recorded here (64.2 ± 2.1 dB (A)) indicated that ORs are noisy environments, a finding which is in line with other studies that have previously established noise levels in ORs (51 to 75 dB (A))^[5,11-16]. No previously published results have shown noise levels in ORs that comply with the WHO guidelines or other standards for hospital noise. Thus, the problem of excessive noise in the OR appears to be universal regardless of the type of hospital or geographic location^[4]. These findings clearly raise questions regarding the significance of these guidelines, as these data imply that the current standards for hospital noise do not apply in the OR. The establishment of guideline values for sound pressure levels in the OR warrants future research.

The results suggested that ophthalmic surgery had significantly higher noise levels than otolaryngological surgery and general surgery. We did not obtain sound recordings; thus, we cannot identify the causes of the difference. Based on our observations, there was music playing in the ophthalmic surgery room, which may have accounted for the higher noise levels. This assumption warrants further investigation.

The observed narrow variation across the different ORs is consistent with the staff's perception of noise. Based on these data, it was clear that there was no discernable pattern that distinguished the noisiest OR from the least noisy OR. In addition, there was substantial

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1 similarity in noise levels detected from Monday to Friday. This similarity may be largely
2 attributed to the similarity in noise sources. Further research is necessary to determine decibel
3 measurements of various noise sources from within ORs and subsequently estimate the degree
4 of contribution to noise levels.

5 Excessive noise may be a threat to patient comfort and safety. Evidence suggests that
6 more than one-third of patients perceived ORs as noisy, and 16% of patients felt stressed by
7 the noise in this environment ^[18]. The stapedius muscle may be weakened by anesthetic drugs,
8 which normally contracts and protects the cochlea when exposed to loud sounds ^[19]. Thus, we
9 are concerned that patient hearing may be at risk when the natural reflex mechanism is
10 abolished.

11 Excessive noise may also have detrimental effects on staff health. Evidence suggests that
12 high noise levels (greater than 55 dB (A)) were associated with adverse events, such as
13 hypertension, fatigue, annoyance, burn-out, stress and headaches ^[1]. All $L_{Aeq, T}$ values
14 measured in the present study were greater than 55 dB (A), which suggests that excessive
15 noise may pose a potential health risk to OR staff. Previous studies have suggested that
16 anesthetists are particularly susceptible to the hazards associated with excess noise ^[14]
17 because of their continuous presence in the room, their close proximity to noisy equipment
18 and the finding that noise in the OR is louder during the critical anesthesia components of
19 care, such as induction and emergence, than at other critical points. Particular attention should
20 be given to the mental and physical health of anesthetists.

21 Noise in the OR may also interfere with work progression. Surgeons, nurses, and
22 anesthetists are engaged in complex mental activities that require a high degree of

1 concentration. The staff, particularly anesthetists, may be at risk of being disturbed by noise.
2 In one study, 84% of anesthetists complained that noise levels in the OR negatively affected
3 their work ^[14]. In addition, a significant worsening in mental efficiency and short-term
4 memory test results have been identified in anesthetists after exposure to pre-recorded
5 operating room noise ^[20]. Operating room noise may cause a decrease in auditory processing
6 function ^[21]. Researchers have also reported that noise had a negative effect on the ability of
7 resident anesthesiologists to detect changes in oxygen saturation with pulse oximetry ^[22].
8 However, these studies were conducted in controlled settings, and future work is necessary to
9 consider the impact of noise on anesthetists under real working conditions.

10 In the OR, it is vital to ensure effective and high-quality communication between
11 surgeons, nurses, and anesthetists; however, the conversational ability may often be hindered
12 by high levels of noise. To ensure speech communication, the signal-to-noise ratio should be
13 at least 15 dB ^[1]. With noise levels that range between 59.2 and 72.3 dB (A) in the OR, the
14 staff need to speak at 74.2–87.3 dB (A), which is well above the normal speaking levels of
15 55–65 dB (A). Thus, medical staff may raise their voice to ensure good communication,
16 thereby creating more noise. This noisy environment poses a potential risk of
17 miscommunication, which may lead to unacceptable medical errors.

18 The adverse effects of noise within ORs may be ameliorated by the implementation of
19 measures to minimize noise levels. The oversized return air inlet and poor design of the air
20 exhaust contributed to noise levels. Specific attention should be given to noise when decisions
21 are made concerning air supplies and operating room design. Consideration should be given
22 to determine the minimum volume on the premise that surgeons and anesthetists perceived

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1 auditory changes in equipment, and staff would subsequently adjust the volume to appropriate
2 decibels. Efforts should be directed toward establishing systems for interpersonal
3 communications and educating staff regarding noise to reduce staff-related noise. Further
4 research is required to demonstrate the impact by monitoring noise levels before and after the
5 use of these measures.

6 This investigation is the first time dosimeters have been used to monitor noise levels in
7 ORs. The dosimeters have real-time monitoring metrics, which thus provide more precise
8 measurements of noise levels than the tools used in previous studies. The readings can be
9 saved, and the distribution of noise levels can be identified, including the examination of
10 noise levels versus the surgical time, location and category.

11 One limitation of this study was that specific events, such as the use of noisy tools, could
12 not be directly linked to the recorded noise levels. In subsequent work, we intend to document
13 these events, including their time and duration. Thus, it may be possible to identify noisy
14 processes using qualitative records and time series plots that examine changes in the $L_{Aeq, 2 s}$
15 over time. The measurements described in this study were limited to ORs in a tertiary care
16 hospital in China, and further work is required to establish noise levels in ORs in other
17 hospitals.

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Figure legends

Figure 1. A-weighted equivalent sound pressure level measured in an operating room for gynecological surgeries over a 10 h period. The red line indicates nonsurgical period and the blue line indicates surgery period.

Figure 2. The distribution of A-weighted equivalent sound pressure level measured in all operating rooms. The horizontal axis represents the $L_{Aeq, T}$ measurements, and the actual measured frequencies are presented on the vertical axis.

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Contributorship Statement

Xiaoxiao Wang collected and analyzed noise data. Lin Zeng designed the study and provided interpretive analysis. Gang Li and Mao Xu commented on the study plan and provided critical revision. Bin Wei and Yan Li collected surgery logs and provided critical revision on the discussion. Nan Li, Liyuan Tao and Hua Zhang discussed the results and provided critical revision. Xiangyang Guo and Yiming Zhao conceived the work, organized and coordinated the study and commented on the manuscript. All authors participated in the review, drafting, and final approval of the manuscript. All authors declare no other conflict of interest. The project described was not supported by an organization.

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5 1-R01-OH-002317 from the National Institute for Occupational Safety and Health in the
6 United States.

7 **Data sharing statement:** No additional unpublished data are available.

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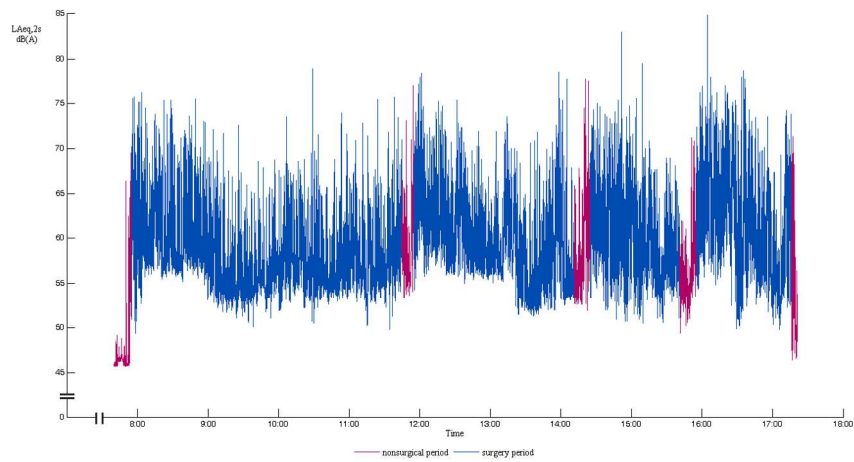


Figure 1. A-weighted equivalent sound pressure level measured in an operating room for gynecological surgeries over a 10 h period.

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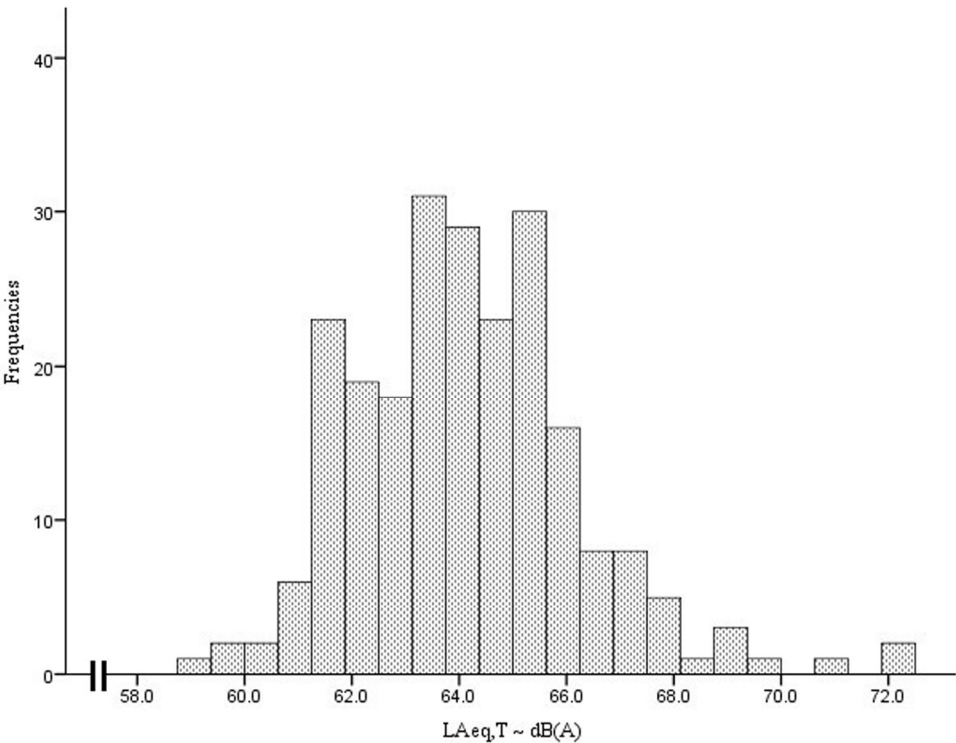


Figure 2 The distribution of A-weighted equivalent sound pressure level measured in all ORs

165x137mm (300 x 300 DPI)

STROBE Statement—Checklist of items that should be included in reports of *cross-sectional studies*

	Item No	Recommendation
Title and abstract	1	(a) Indicate the study’s design with a commonly used term in the title or the abstract Page 1
		(b) Provide in the abstract an informative and balanced summary of what was done and what was found Page 2
Introduction		
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported Page 4
Objectives	3	State specific objectives, including any prespecified hypotheses Page 5
Methods		
Study design	4	Present key elements of study design early in the paper Page 6
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection Page 6
Participants	6	(a) Give the eligibility criteria, and the sources and methods of selection of participants Not applicable
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable Not applicable
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group Page 7
Bias	9	Describe any efforts to address potential sources of bias Page 6
Study size	10	Explain how the study size was arrived at Not applicable
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why Not applicable
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding Page 8
		(b) Describe any methods used to examine subgroups and interactions Not applicable
		(c) Explain how missing data were addressed Not applicable
		(d) If applicable, describe analytical methods taking account of sampling strategy Not applicable
		(e) Describe any sensitivity analyses Not applicable
Results		
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed Not applicable
		(b) Give reasons for non-participation at each stage Not applicable
		(c) Consider use of a flow diagram Not applicable
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders Page 10
		(b) Indicate number of participants with missing data for each variable of interest Not applicable
Outcome data	15*	Report numbers of outcome events or summary measures Not applicable
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were

		adjusted for and why they were included	Not applicable
		(b) Report category boundaries when continuous variables were categorized	Page 12
		(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	Not applicable
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	Not applicable
Discussion			
Key results	18	Summarise key results with reference to study objectives	Page 14
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	Page 16
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	Page 17
Generalisability	21	Discuss the generalisability (external validity) of the study results	Page 17
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	Page 19

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is available at www.strobe-statement.org.

BMJ Open

A cross-sectional study in a tertiary care hospital in China: Noise or silence in the operating room

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Secondary Subject Heading:	Epidemiology, Surgery, Public health
Keywords:	noise, operating room, hospital

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1 A cross-sectional study in a tertiary care hospital in China:

2 Noise or silence in the operating room

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Abstract

Objectives: This study aims to provide a comprehensive description of noise levels in operating rooms (ORs) in a tertiary care hospital in China. Additionally, the study aims to examine the deviation in noise levels from international and internal standards as well as the differences in noise levels by category of surgery and day of the week.

Methods: We monitored noise levels in 23 ORs in a tertiary care hospital in China between August 2015 and March 2016. Dosimeters were used to determine noise levels. The noise data collected in the dosimeter were downloaded to an IBM computer for subsequent analysis. One-way ANOVA and t tests were used to examine the differences in noise levels.

Results: The noise level in the ORs ranged between 59.2 and 72.3 dB (A), with 100% of the measurements exceeding the recommended hospital noise standards. There was substantial similarity in noise levels from Monday to Friday ($F=1.404$, $p=0.234$), with a range between 63.7 and 64.5 dB (A). The difference in noise levels by category of surgery was significant ($F=3.381$, $p<0.001$). The results of the post hoc analysis suggested that ophthalmic surgery had significantly higher noise levels than otolaryngological surgery or general surgery.

Conclusions: Ophthalmic surgery had significantly higher noise levels than otolaryngological or general surgeries. High noise levels were identified in all evaluated ORs during weekdays, and these levels consistently exceeded the currently accepted standards. These findings warrant further investigation to determine the harmful effects of noise on both patients and staff in ORs.

Keywords: noise; operating room; hospital

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Article summary

Strengths and limitations of this study:

Strengths:

1. This investigation is the first time dosimeters have been used to monitor noise levels in ORs. Dosimeters have real-time monitoring metrics that provide more precise measurements of noise levels than the tools used in previous studies.

2. This study used dosimeters to measure noise over an extended period during a wide range of surgical procedures. This approach allows the readings to be saved and the noise level distribution to be identified, including the examination of noise levels versus surgical time, location and category.

Limitations:

One limitation of this study was that specific events, such as the use of noisy tools, could not be directly linked to the recorded noise levels.

INTRODUCTION

The finding that noise represents an established health hazard has been demonstrated in hospitals and particularly in operating rooms (ORs). Excessive noise may have negative effects on patient care and safety. Noise in the OR may also affect the health and performance of staff. The World Health Organization (WHO), the Environmental Protection Agency (EPA), and the country of China have established guidelines and standards for safe noise levels in hospitals and ORs. The WHO recommends that noise levels should not exceed 35 dB (A)^[1]. The EPA guidelines state that noise levels should not exceed 45 dB (A)^[2]. In China, regulations assert that noise levels in ORs should not exceed 50 dB (A)^[3]. These standards stress that OR noise should be maintained at levels that are as low as possible.

Notwithstanding these standards or guidelines, hospitals are never quiet places. Busch-Vishniac IJ and colleagues conducted a review of previous studies that examined noise levels in hospitals and determined that noise measurements consistently exceeded the recommended levels by an average of 20-40 dB (A)^[4]. A corresponding significant linear increase in hospital noise levels has been identified since 1960, with increases averaging 0.38 dB per year during the day and 0.42 dB per year at night. Within hospitals, researchers are specifically concerned with noise in ORs, in which the mean noise level ranges between 51 and 75 dB (A)^[5]. Previous studies have measured noise levels produced by tools used primarily during conventional surgeries^[6-10]. Several studies have reported the sound pressure levels for a particular surgery or specific surgeries^[11-16].

However, it is difficult to characterize noise in the OR based on these published articles. Previous studies were limited to surgical tools and specific surgeries; thus, it is not surprising

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1 that the typical patterns in sound pressure levels over the course of a workday within an
2 operating room cannot be characterized. In addition, based on these data, the distribution of
3 noise levels cannot be identified, including noise levels versus time and category of surgery.
4 In this study, we measured noise levels in 23 ORs according to the types of surgery performed
5 with the aim of providing a comprehensive description of noise levels in ORs in a tertiary care
6 hospital. We aimed to compare the deviation in noise levels from the currently accepted
7 standards and compare the differences in noise levels across the day of the week and type of
8 surgery.

METHODS

overview

This cross-sectional study was approved by the Institutional Review Board (IRB) of our hospital. The requirement for written informed consent was waived by the IRB because patient and staff data were not collected. We obtained permission from the hospital administration to place noise monitoring equipment in the ORs. The investigator conducted non-documented observations to identify sources of noise originating from personnel, equipment, etc. All personnel were unaware of the ongoing noise monitoring, and no changes were made that would control noise levels or disturb staff routines throughout the study. This manuscript adheres to the applicable Equator guidelines. This cross-sectional study was conducted in a tertiary care hospital located in a densely populated district in the city of Beijing, China. The study was conducted between August 2015 and March 2016. During the first period, noise levels were monitored in seventeen ORs in the surgical building. All types of surgeries with the exception of ophthalmology and otolaryngology surgeries were included. During the second period, noise levels were measured in seven rooms in the Ophthalmology and Otorhinolaryngology Departments. Decibel measurements of various noise sources were not undertaken due to the lack of an instrument to identify specific sources of noise.

instrument

Personal noise dosimeters (Aihua, Model AWA5610B, Hangzhou, China) were used to determine noise levels. The dosimeter meets the International Electrotechnical Commission Standard (IEC) 61672-2002 class 2 and Chinese National Standards (GB) GB/T15952-1995 class 2. The A-weighted scale, dB (A), was used in this study to measure noise levels. This

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1 scale is frequently used in clinical practice because it filters out the very low and very high
2 frequencies to which humans are insensitive. The dosimeter provided a direct sound pressure
3 reading and detected sound levels that ranged from 45 to 140 dB (A) with an accuracy of less
4 than ± 1 dB (A) over a temperature range of 0-40°C. Before measurements were obtained,
5 each dosimeter was calibrated using a Model AWA6221A Sound Level Calibrator (Aihua
6 Instruments), which complied with IEC 60942-2004 class 1 in a controlled environment at a
7 94.0-dB sound pressure level from a single-point source with a 1 kHz frequency.

8 **procedure**

9 Measurements were obtained during weekdays to ensure that surgical action would occur
10 within the rooms. Before measurements were obtained, the dosimeters were fully charged and
11 calibrated. Noise levels were automatically measured and monitored in our study setting. In
12 general, noise measurement commenced on the investigator's way to the OR at, on average,
13 06:50 to 07:30. The instruments were placed in the ORs under study before the staff entered
14 the ORs for operation preparation at 08:00. In general, the staff were unaware of the
15 instrument placement and noise monitoring to ensure that they would work as usual. No
16 behavioural changes were made, including controlling conversation or abstaining from the
17 playing of music.

18 The instrument was placed inside each room throughout the full-shift period from before
19 08:00 to anaesthesia emergence and transportation of the last patient out of the operating
20 room at, on average, 17:00. In each room, the instrument was positioned so that it did not
21 interfere with the surgical schedule and was outside of the sterile field. The instrument was
22 placed within two meters of the anaesthesia machine at a height of 1.5 meters from the floor.

1 The noise data collected in the dosimeter were downloaded to an IBM computer for
2 subsequent analysis.

3 The sample interval was two seconds; that is, two seconds of A-weighted equivalent
4 continuous sound levels ($L_{Aeq, 2s}$) were collected every two seconds. The $L_{Aeq, 2s}$
5 measurements were plotted against time using time series plots to facilitate their graphical
6 summarization. An A-weighted equivalent sound pressure level in dB, as measured over the
7 noise assessment period T ($L_{Aeq, T}$), was calculated for each room. The $L_{Aeq, T}$ was calculated
8 as follows ^[17]:

$$L_{Aeq, T} = 10 \log \left(\frac{1}{T} \sum_{i=1}^n 2 \times 10^{0.1 L_{Aeq, 2s}} \right),$$

10 where T represents the entire noise assessment period and n represents the total readings that
11 occurred over the period. The noise measurement in an OR from 08:00 to 17:00 allowed for
12 the collection of 16,200 $L_{Aeq, 2s}$ readings; therefore, T equaled 32,400 seconds, and n equalled
13 16,200.

14 We obtained permission to view the surgical logs to identify operations that occurred
15 within the measurement period. The surgery log provides a detailed description of the nature
16 of each procedure and the division of surgery. In general, the same types of surgeries were
17 performed in the same room on the same day. Using the data obtained from the dosimeters
18 and logs, noise levels in each OR were calculated.

19 **statistical analysis**

20 Data were exported from the dosimeters using their proprietary software and were
21 subsequently analysed using MATLAB 7.7 (R2008b) and SPSS for Windows, Version 20.0
22 (SPSS, Chicago, IL, USA). The distribution of $L_{Aeq, T}$ across all ORs was graphically

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1 summarized using a histogram. One sample t test was applied to examine the deviation in
2 noise levels from international and internal standards. One-way ANOVA was applied to
3 examine the differences in noise levels among groups for categorical parameters (days of the
4 week and category of surgery). The post hoc analysis used Bonferroni methods. All reported p
5 values were two tailed, and $p < 0.05$ was established as the level of significance.

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RESULTS

The study area was a surgical building in a tertiary care hospital in which annual operations number in the tens of thousands. According to the available data, 56,000 surgeries were performed in this hospital in 2015. Under the assumption that one year comprises 250 weekdays, 225 operations were performed each day. When this number was divided by the 48 ORs, it was estimated that nearly five consecutive surgeries belonging to the same category (e.g., neurology and gynaecology) were conducted in a given room per day. Consecutive surgeries were defined as conditions in which the completion of one surgery resulted in the initiation of the next operation on the operating list. Based on our observations, the ORs varied in size from 10 to 20 square meters. All rooms had hard surfaces and furnishings with no material added for sound absorption.

The plot for the $L_{Aeq, 2s}$ versus time (07:30~17:30) within an operating room during the performance of gynaecological surgeries is shown in Figure 1. Figure 1 presents a typical trace of the $L_{Aeq, 2s}$ versus time for an operating room. With the passage of time, considerable variation in noise levels was identified. The noise level was below 50 dB (A) when the operating room was unoccupied. The noise level incrementally increased with the entry of staff and patients, with a range of L_{eq} from 50 to 85 dB (A). We identified the performance of four different surgeries during the measurement period, with a very short nonsurgical interval between adjacent operations. The first surgery was performed from 07:55 to 11:44, the second

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surgery was performed from 11:55 to 14:10, the third surgery was performed from 14:25 to 15:40, and the fourth surgery was performed from 15:55 to 17:15. At the beginning of each surgery, noise levels were relatively high, with a range from 55 to 75 dB (A). The noise level gradually decreased, with a range from 50 to 70 dB (A) at the end of the surgery.

Noise data were collected in 23 ORs, with multiple measurements obtained in each OR, generating 225 $L_{Aeq, T}$ data points. The distribution of the data is shown in Figure 2. The horizontal axis represents the $L_{Aeq, T}$ measurements, and the actual measured frequencies are presented on the vertical axis. The results indicated a noise level that ranged between 59.2 and 72.3 dB (A). None of the measured $L_{Aeq, T}$ values complied with the WHO, EPA or Chinese guidelines, with 100% of the measurements exceeding these standards. The mean noise level was 64.2 (± 2.1) dB (A), which was 29.2 dB (A) higher than the WHO standard ($t=211.3$, $p<0.001$), 19.2 dB (A) louder than the 45 dB (A) recommended by the EPA ($t=138.9$, $p<0.001$) and 14.2 dB (A) higher than the Chinese standards ($t=102.7$, $p<0.001$). In addition to the overall distribution of the $L_{Aeq, T}$, the average noise levels across the different ORs ranged from 61.8 to 66.7 dB (A). The averages were calculated by averaging the multiple measurements for each OR.

The ORs were occupied on weekdays, and noise data were collected during these periods. As shown in Table 1, each result was represented as an average over multiple measurements that were typically obtained in more than one OR. There was substantial similarity in noise levels from Monday to Friday ($p=0.234$).

Table 1 Operating room noise levels on weekdays

Weekday	Mean \pm SD dB(A)	Range dB(A)	Number of Measurements	F	p
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Monday	63.7±2.0	59.8~68.4	45	1.404	0.234
Tuesday	64.4±2.0	60.6~69.5	47		
Wednesday	64.7±1.5	61.4~68.8	43		
Thursday	64.0±1.8	59.9~68.9	40		
Friday	64.2±2.7	59.2~72.3	50		
Total	64.2±2.1	59.2~72.3	225		

Table 2 Operating room noise levels by category of surgery

Division	Mean±SD dB(A)	Range dB(A)	Number of Measurements	F	p
Thoracic	63.2±1.3	61.6~65.1	11	3.381	<0.001
Otolaryngology*	63.3±1.5	59.9~65.8	39		
General Surgery*	63.5±2.4	59.2~72.3	33		
Sports Medicine	64.1±1.5	61.4~66.3	10		
Urology	64.2±2.0	61.8~68.1	20		
Neurosurgery	64.2±1.8	59.8~66.7	16		
Gynaecology	64.4±2.0	61.3~68.9	15		
Cardiology	64.5±2.3	61.1~68.4	11		
Orthopaedic	64.8±2.6	60.9~72.0	29		
Ophthalmology	65.4±1.6	62.5~71.1	41		
Total	64.2±2.1	59.2~72.3	225		

*lower noise levels than the Ophthalmology Department.

Table 2 summarizes the noise level measurements by category of surgery (e.g., neurology and gynaecology). The difference in noise levels detected in the ORs by category of surgery was significant ($p<0.001$). The post hoc analysis suggested that ophthalmic surgery (65.4 dB (A)) had higher noise levels than otolaryngological surgery (63.3 dB (A)) and general surgery (63.4 dB (A)).

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DISCUSSION

The results indicated a noise level that ranged between 59.2 and 72.3 dB (A), which was substantially louder than the guidelines recommended by China, the WHO and the EPA. The recorded noise levels (64.2±2.1 dB (A)) indicated that ORs are noisy environments, a finding that is in line with other studies that have examined noise levels in ORs (51 to 75 dB (A))^[5, 11-16]. No previously published results have shown noise levels in ORs that comply with the WHO guidelines or other standards for hospital noise. Thus, the problem of excessive noise in the OR appears to be universal regardless of the type of hospital or geographic location^[4]. These findings clearly raise questions regarding the significance of these guidelines because the data imply that the current standards for hospital noise do not apply in the OR. The establishment of guideline values for sound pressure levels in the OR warrants future research.

The results suggested that ophthalmic surgery had significantly higher noise levels than otolaryngological surgery and general surgery. We did not obtain sound recordings; thus, we cannot identify the causes of the difference. Based on our observations, there was music playing in the ophthalmic surgery room, which may have accounted for the higher noise levels. This assumption warrants further investigation.

These data indicated that there was no discernible pattern that distinguished the noisiest

1 OR from the least noisy OR. Based on our discussion with operating room staff, their
2 perception of noise is consistent with the observed narrow variation across the ORs. This
3 warrants further study to investigate the staff's perception of noise with a questionnaire or
4 qualitative interviews.

5 In addition, there was substantial similarity in noise levels detected from Monday to
6 Friday. This similarity may be largely attributed to the similarity in noise sources. Based on
7 our observation, noise originated from both staff and equipment. Staff-related activities and
8 conversations were a major component of operating room noise. The functioning laminar
9 airflow system generated steady noise over the period. The anaesthetic monitors generated
10 many distracting alarms and alerts (on average, 1~2 alarms within several minutes). The
11 surgical instruments (e.g., power drills) generated instantaneous, sudden, and distinct noise
12 with a duration of several seconds. Further research is necessary to determine the decibel
13 measurements of various noise sources within ORs and to estimate the degree of contribution
14 of these sources to noise levels.

15 Excessive noise may be a threat to patient comfort and safety. Evidence suggests that
16 more than one-third of patients perceive ORs as noisy, and 16% of patients feel stressed by
17 the noise in this environment ^[18]. The stapedius muscle, which normally contracts and
18 protects the cochlea when exposed to loud sounds, may be weakened by anaesthetic drugs ^[19].
19 Thus, we are concerned that patient hearing may be at risk when this natural reflex
20 mechanism is abolished.

21 Excessive noise may also have detrimental effects on staff health. Evidence suggests that
22 high noise levels (greater than 55 dB (A)) are associated with adverse events, such as

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1 hypertension, fatigue, annoyance, burn-out, stress and headaches ^[1]. All $L_{Aeq, T}$ values
2 measured in the present study were greater than 55 dB (A), which suggests that excessive
3 noise may pose a potential health risk to OR staff. Previous studies have suggested that
4 anaesthetists are particularly susceptible to the hazards associated with excess noise ^[14]
5 because of their continuous presence in the room, their close proximity to noisy equipment
6 and the finding that noise in the OR is louder during the critical anaesthesia components of
7 care, such as induction and emergence, than at other critical points. Particular attention should
8 be paid to the mental and physical health of anaesthetists.

9 Noise in the OR may also interfere with work progression. Surgeons, nurses, and
10 anaesthetists are engaged in complex mental activities that require a high degree of
11 concentration. Staff members, particularly anaesthetists, may be at risk of being disturbed by
12 noise. In one study, 84% of anaesthetists complained that noise levels in the OR negatively
13 affected their work ^[14]. In addition, significant worsening in mental efficiency and short-term
14 memory test results have been identified in anaesthetists after exposure to pre-recorded
15 operating room noise ^[20]. Operating room noise may cause a decrease in auditory processing
16 function ^[21]. Researchers have also reported that noise has a negative effect on the ability of
17 resident anaesthetists to detect changes in oxygen saturation with pulse oximetry ^[22].
18 However, these studies were conducted in controlled settings. Future work is necessary to
19 consider the impact of noise on anaesthetists under real working conditions.

20 In the OR, it is vital to ensure effective and high-quality communication among surgeons,
21 nurses, and anaesthetists. However, conversational ability may often be hindered by high
22 levels of noise. To ensure speech communication, the signal-to-noise ratio should be at least

1 15 dB^[1]. With a normal voice level of 50 dBA, the background level should not exceed 35
2 dBA. The noise level in the OR ranged between 59.2 and 72.3 dB (A), staff members need to
3 raise their voices to ensure good communication, thereby creating more noise. This noisy
4 environment poses a potential risk of miscommunication, which may lead to unacceptable
5 medical errors.

6 The adverse effects of noise within ORs may be ameliorated by the implementation of
7 measures to minimize noise levels. The oversized return air inlet and poor design of the air
8 exhaust contributed to noise levels. Specific attention should be paid to factors related to
9 noise when decisions are made concerning air supplies and operating room design.
10 Consideration should be given to determine the minimum volume on the premise that
11 surgeons and anaesthetists perceive auditory changes in equipment, and staff members
12 subsequently adjust the volume to appropriate decibels. Efforts should be directed toward
13 establishing systems for interpersonal communications and educating staff to reduce
14 staff-related noise. Further research is required to demonstrate the impact of these measures
15 by monitoring noise levels before and after their implementation.

16 This investigation is the first time dosimeters have been used to monitor noise levels in
17 ORs. Dosimeters have real-time monitoring metrics, which provide more precise
18 measurements of noise levels than the tools used in previous studies. The readings can be
19 saved and the distribution of noise levels can be identified, including the examination of noise
20 levels versus surgical time, location and category.

21 One limitation of this study was that specific events, such as the use of noisy tools, could
22 not be directly linked to the recorded noise levels. In subsequent work, we intend to document

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these events, including their time and duration. Thus, it may be possible to identify noisy processes using qualitative records and time series plots that examine changes in the $L_{Aeq, 2 s}$ over time. The measurements described in this study were limited to ORs in a tertiary care hospital in China. Further work is required to determine noise levels in ORs in other hospitals.

Figure legends

Figure 1. A-weighted equivalent sound pressure level measured in an operating room for gynaecological surgeries over a 10 h period. The red line indicates the nonsurgical period, and the blue line indicates the surgery period.

Figure 2. The distribution of A-weighted equivalent sound pressure level measured in all operating rooms. The horizontal axis represents the $L_{Aeq, T}$ measurements, and the actual measured frequencies are presented on the vertical axis.

Contributorship Statement

Xiaoxiao Wang collected and analysed noise data. Lin Zeng designed the study and provided interpretive analysis. Gang Li and Mao Xu commented on the study plan and provided critical revision. Bin Wei and Yan Li collected surgery logs and provided critical revision on the discussion. Nan Li, Liyuan Tao and Hua Zhang discussed the results and provided critical revision. Xiangyang Guo and Yiming Zhao conceived the work, organized and coordinated the study and commented on the manuscript. All authors participated in the review, drafting, and final approval of the manuscript. All authors declare no other conflicts of interest. The project was not supported by an organization.

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1 **Competing interests:** There are no competing interests.

2 **Funding:** The project was not supported by an organization. The noise meters were purchased
3 during the process of a cooperative programme with the State University of New York at
4 Plattsburgh. The project was completed in 2011 and supported by Grant No.
5 1-R01-OH-002317 from the National Institute for Occupational Safety and Health in the
6 United States.

7 **Data sharing statement:** No additional unpublished data are available.

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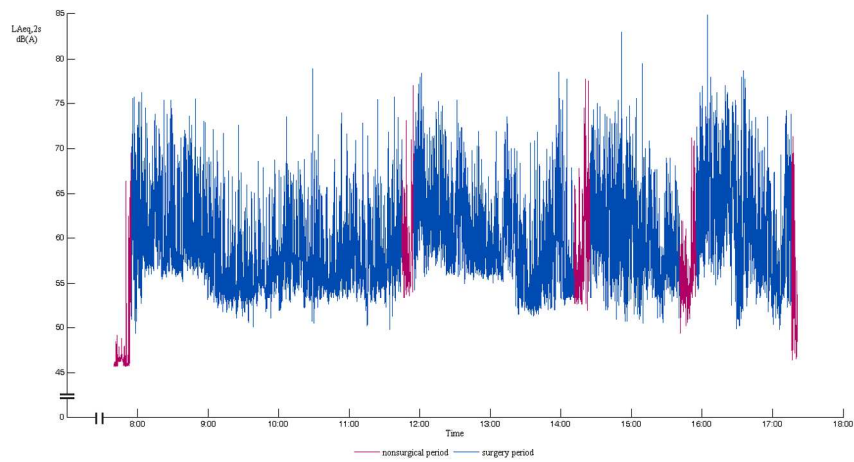


Figure 1. A-weighted equivalent sound pressure level measured in an operating room for gynecological surgeries over a 10 h period.

418x207mm (300 x 300 DPI)

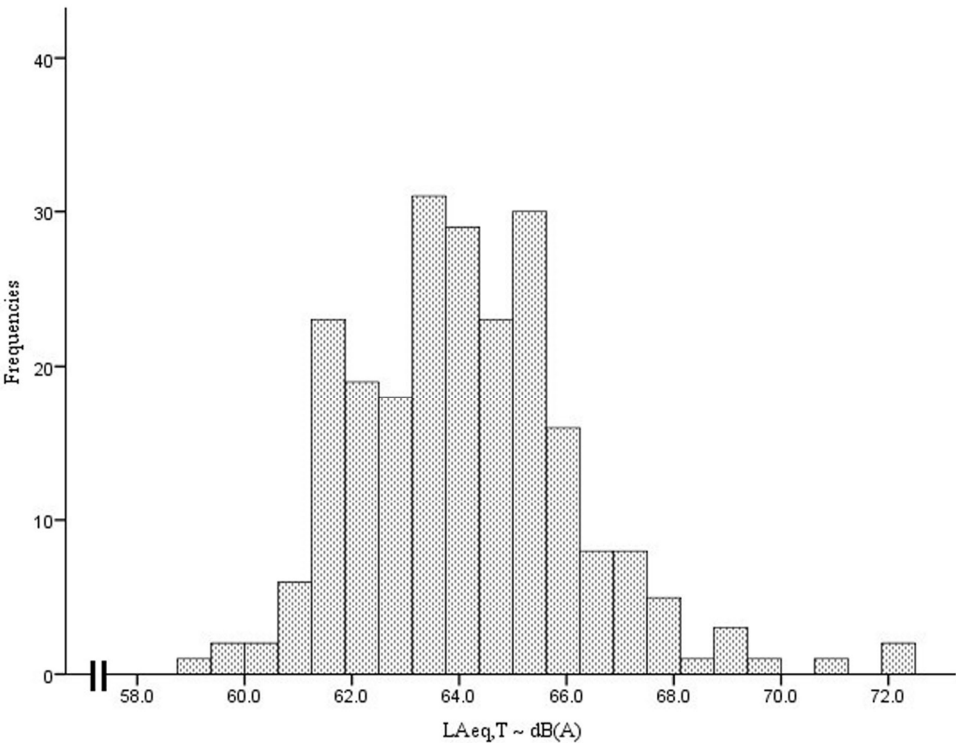


Figure 2 The distribution of A-weighted equivalent sound pressure level measured in all ORs

165x137mm (300 x 300 DPI)

STROBE Statement—Checklist of items that should be included in reports of *cross-sectional studies*

	Item No	Recommendation
Title and abstract	1	(a) Indicate the study’s design with a commonly used term in the title or the abstract <u>Page 1</u> (b) Provide in the abstract an informative and balanced summary of what was done and what was found <u>Page 2</u>
Introduction		
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported <u>Page 4</u>
Objectives	3	State specific objectives, including any prespecified hypotheses <u>Page 5</u>
Methods		
Study design	4	Present key elements of study design early in the paper <u>Page 6</u>
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection <u>Page 6</u>
Participants	6	(a) Give the eligibility criteria, and the sources and methods of selection of participants <u>Not applicable</u>
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable <u>Not applicable</u>
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group <u>Page 7</u>
Bias	9	Describe any efforts to address potential sources of bias <u>Page 6-7</u>
Study size	10	Explain how the study size was arrived at <u>Not applicable</u>
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why <u>Not applicable</u>
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding <u>Page 8-9</u>
		(b) Describe any methods used to examine subgroups and interactions <u>Not applicable</u>
		(c) Explain how missing data were addressed <u>Not applicable</u>
		(d) If applicable, describe analytical methods taking account of sampling strategy <u>Not applicable</u>
		(e) Describe any sensitivity analyses <u>Not applicable</u>
Results		
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed <u>Not applicable</u>
		(b) Give reasons for non-participation at each stage <u>Not applicable</u>
		(c) Consider use of a flow diagram <u>Not applicable</u>
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders <u>Page 10</u>
		(b) Indicate number of participants with missing data for each variable of interest <u>Not applicable</u>
Outcome data	15*	Report numbers of outcome events or summary measures <u>Not applicable</u>
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were

		adjusted for and why they were included	Not applicable
		(b) Report category boundaries when continuous variables were categorized	Page 11-12
		(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	Not applicable
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	Not applicable
Discussion			
Key results	18	Summarise key results with reference to study objectives	Page 13
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	Page 16
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	Page 16
Generalisability	21	Discuss the generalisability (external validity) of the study results	Page 16
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	Page 19

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is available at www.strobe-statement.org.