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Effect of Power Crisis Caused By Earthquake on Operating Room Environment

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Abstract

The Great East Japan Earthquake in 2011 caused unprecedented damage to Japan and blasted the myth of safety at nuclear power plants. Electric power in Japan has yet to be completely restored. The suspension of air conditioning in operating rooms stemming from power blackouts hampers the ability to adjust room temperature and humidity levels and suspends ventilation through air cleaning filters. In this work, we used simulations to investigate the effect of changes in an operating room environment as a result of air conditioning suspension. We prepared two rooms, one equipped with an LED shadowless lamp and the other with a xenon gas lamp, suspended the air conditioning, and measured the changes in temperature, humidity, and air cleanliness on operating tables and in the entire rooms. The physical impressions of four staff members working in each room were also collected. Results showed that, after suspension of the air conditioning, the temperature on the operating table increased by 11.8°C in the LED room and by 26.2°C in the xenon gas room. The overall temperature in both rooms increased by 2-3°C. Although the humidity on the operating table in both rooms decreased, it increased in the entire room by 10-12% in both rooms. As for the physical impressions of the staff, in the LED room, half complained of the heat while working, and in the xenon gas room, all complained of damp heat affecting their work. Air cleanliness surpassed the designated level within 8 and 22 minutes of suspension of air conditioning in the LED and xenon gas rooms, respectively. After that, particles continued to increase and surpassed 35,000/ft^3 in both rooms. These results demonstrate that the suspension of air conditioning in operating rooms rapidly degrades the working environment, thus increasing the risk of surgical site infection.

Keywords: Operating room environment; Power blackout; Air conditioning; Air cleanliness; Surgical site infection, Earthquake, Nuclear accident

Introduction

On March 11, 2011 a massive magnitude 9.0 earthquake struck Japan and the subsequent tsunami inflicted serious damage on the whole eastern side of the country, particularly the Pacific coastal areas of Tohoku and Kanto. To date, the number of missing and dead attributed to this disaster has surpassed 18,000, and more than 400,000 buildings were fully or partially destroyed [1].

This unprecedented earthquake was also characterized by the grave nuclear power disaster that occurred directly afterward at the Fukushima Daiichi nuclear power plant located in Okuma-cho, Futaba-gun, Fukushima Prefecture and operated by the Tokyo Electric Power Company (TEPCO). When the power supply of the cooling equipment of the nuclear reactor was lost due to damage from the tsunami, meltdown and the leakage of a huge amount of radioactive materials resulted. Radioactive contamination of the soil prolonged the evacuation of the surrounding residents and is still continuing today.

At the time of the disaster, life lines in the affected areas were cut off and many power plants, substations, and transmission facilities throughout Tohoku and Kanto in addition to the Fukushima plants were suspended. Scheduled blackouts[1] were conducted in regions situated far from the affected areas. Also, due to anxiety over the safety of nuclear power plants in the wake of the Fukushima accident, restarting plants in Japan following the required safety reviews has not met with the popular approval. Moreover, the nationwide power shortages have not been reduced, even today after three years have passed since the earthquake occurred.

Generally, emergency power supplies in medical facilities are used only in emergency blackouts. Therefore, if scheduled blackouts occur frequently within a short period of time, there will only be a limited number of facilities that can allow normal medical care to continue. In facilities where air conditioning is centrally controlled, it may take time to switch to emergency power and provide air conditioning in operating rooms after electric power has been restored. Because operating rooms are typically closed spaces, once an air conditioning system is stopped, adjusting the temperature and humidity becomes impossible. The resulting suspension of ventilation through air cleaning filters worsens the working environment of the staff members and reduces air cleanliness.

[1]Scheduled blackout: If there is any risk of electric power demands reaching the limit of the amount of supply, the power company suspends power transmission for each area to avoid a large-scale blackout due to system overflow caused by excessive load. This is called a rolling blackout and is commonly practiced in developing countries where the number of power plants and power supply networks is insufficient and power generation capacity is inadequate. Though it is rare for rolling blackouts to be carried out in developed countries, after the earthquake and tsunami, they were performed in Japan for the first time in response to the power crisis resulting from damage to power equipment. This is called a scheduled or planned blackout. Scheduled blackouts were initiated in the Tokyo metropolitan area from March 14 to 28, 2011 immediately after the earthquake.

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Materials and Methods

The purpose of this research is to determine the effect of air conditioning suspension on the operating room environment. We simulated the suspension of air conditioning in operating rooms and then measured the changes in room temperature, humidity, and air cleanliness. The physical impressions of staff members working in the rooms were also collected.

We used the operating rooms of the facility to which we, the authors of this paper, belong. The operating room environment features a one footwear system and air cleaning with a HEPA filter is adopted for the air conditioning. We arranged 24-h ventilation by vertical laminar flow, a ventilation frequency of 30 times/hr, and the introduction of outside air 3 times/hr. The designated level of air cleanliness in the room was set at class[2] 10,000 for the entire room and at class 100 on the top of the operating table. Because the calorific value of lighting equipment for surgery (shadowless lamp) is high, the effect on room temperature is considered significant. The simulation was performed using two rooms, one installed with LED shadowless lamps ("the LED room") and the other with xenon gas shadowless lamps ("the xenon gas room"). The specifications of each room are listed in Table 1.

In both rooms, the air conditioning temperature was set at 24.0°C while air volume and air direction were set to automatic by in-room operation (no setting for humidity). The fluorescent lamps, shadowless lamps, a device for general anesthesia, biological information monitors, hospital information system terminals, and an electrosurgical knife were placed in the rooms. The temperature, humidity, and air cleanliness on the operating tables (center of the room, directly below the shadowless lamps) and in the entire rooms (mean of two points on the wall approximately 3 meters from center of the room) were then measured. A polymer resistance change-type SK-L200TH thermistor manufactured by Sato Keiryoki Manufacturing Co., Ltd. was used to log temperature and humidity data and a portable air particle counter AEROTRACK 9310 manufactured by Nitta Corporation was used as the cleanliness-maintaining indicator.

After closing the doors to the operating rooms, data were measured for 120 minutes as control values and confirmed as stable. The air conditioning suspension was set to last 120 minutes and the changes in temperature, humidity, and air cleanliness were recorded over time while the air conditioning was being suspended. Air conditioning in the hallways outside the rooms was operated continuously. Four staff members-a surgeon, an anesthesiologist, a nurse in charge of handling machines, and a nurse in charge of rounds-were assigned to each room and their physical impressions of the heat, humidity, and effect on their work were collected.

LED room (operating room with LED shadowless lamps)
Floor area: 53.0 m^2 Air- conditioning capacity: 5.6 kw×4 units Air volume in circulation: 3.963/4.680 m^3/hr (actual measurements/ specifications)
Xenon gas room (operating room with xenon gas shadowless lamps)
Floor area: 62.0 m^2 Air- conditioning capacity: 5.6 kw×5 units Air volume in circulation: 5.298/5.760 m^3/hr (actual measurements/ specifications)

Table 1: Size and air conditioning capacity of LED room and xenon gas room.

[2]Cleanliness classes: U.S. Federal Specifications and Standards (Fed-Std-209D. Federal Standard Airborne Particulate Cleanliness Classes in Clean Rooms and Clean Zone. June 15, 1988): Particles ≥ 05. μm per 1ft^3 (28.3 L)=number of dust particles.

Results

Measuring environment

Measurements were taken on June 26, 2011. Outside air temperature was 22°C and humidity was 92%.

Temperature

The mean control value was 25.1°C in the LED room and 24.5°C in the xenon gas room. The temperature on the operating table began to rise 5 minutes after suspension of the air conditioning in the LED room and 35 minutes after suspension in the xenon gas room. After about 100 minutes had elapsed, the temperature reached a maximum of 36.9°C in the LED room and 50.7°C in the xenon gas room. In the entire room, the temperature rose to 27.1°C in the LED room and to 27.7°C in the xenon gas room (Figures 1 and 2).

Humidity

The mean control value was 44.4% in the LED room and 44.7% in the xenon gas room. After suspension of the air conditioning, the humidity on the operating table dropped to 29.8% in the LED room and to 20.9% in the xenon gas room as a result of the increased temperature. In the entire room, the humidity rose to 54.6% in the LED room and to 57.1% in the xenon gas room (Figures 3 and 4).

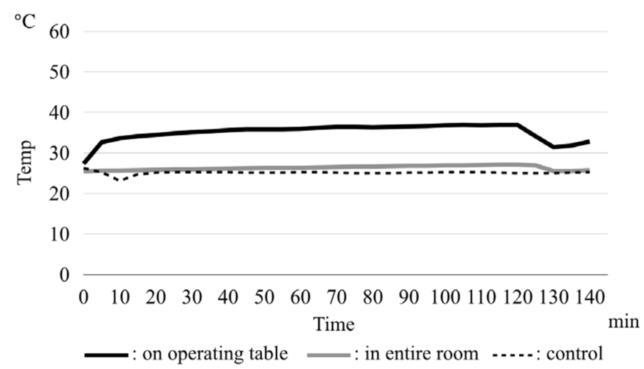

Figure 1: Temperature in LED room. Temperature increased by 11.8°C (5 min after suspension of air conditioning) on the operating table and by 2.0°C in entire room.

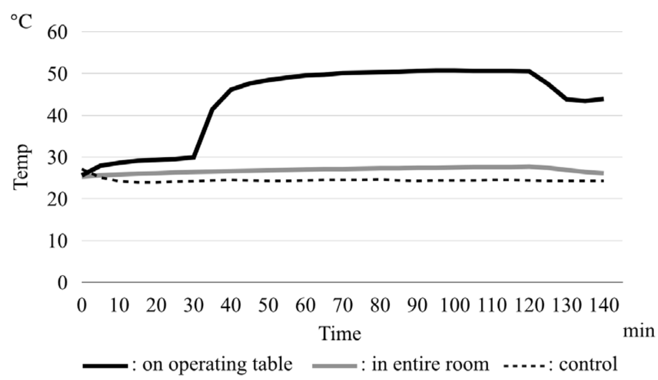

Figure 2: Temperature in xenon gas room. Temperature increased by 26.2°C (35 min after suspension of air conditioning) on the operating table and by 3.2°C in entire room.

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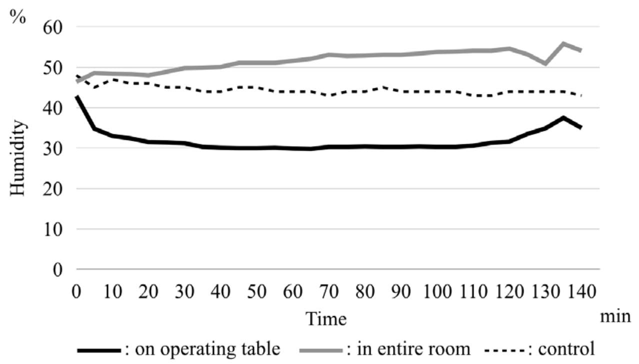

Figure 3: Humidity in LED room. While humidity on operating table dropped as a result of increased temperature, humidity in the entire room increased by 10.2%.

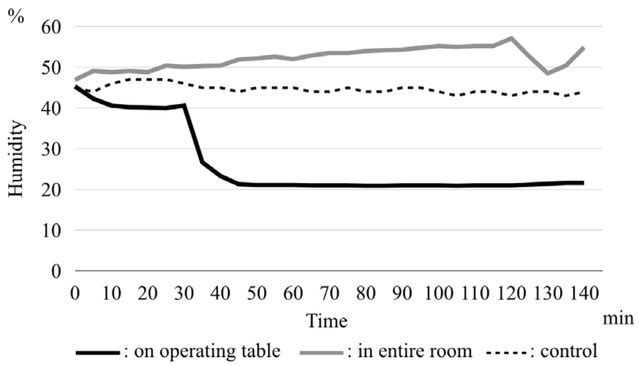

Figure 4: Humidity in xenon gas room. While humidity on operating table dropped as a result of increased temperature, humidity in the entire room increased by 12.4%.

Physical impressions

In the LED room, 2 of the 4 staff members began to feel hot and uncomfortable 35 minutes after suspension of air conditioning. In the xenon room, 3 of the 4 staff members began to feel it was humid 20 minutes later while all 4 felt hot and uncomfortable after 35 minutes. Nobody in either room said that the heat and/or humidity interfered with their work or that they could not continue working (Figures 5 and 6).

Air cleanliness

In the LED room, the mean control values for dust count were 200/ft³ on the operating table and 6,400/ft³ in the entire room. In the xenon gas room, the mean control values for dust count were 80/ft³ on the operating table and 3,000/ft³ in the entire room. In both rooms, the dust count on the operating table increased to a level equivalent to that in the entire room immediately after the air conditioning was suspended. The dust count surpassed 10,000/ft³, the designated level for the entire room, 8 minutes after the suspension in the LED room and 22 minutes after suspension in the xenon gas room. The dust count in both rooms continued to increase while the air conditioning was suspended and reached approximately 40,000/ft³ in the LED room and approximately 27,000/ft³ in the xenon gas room after 120 minutes had elapsed. The maximum value in the dust count was 45,707/ft³ (after 93 minutes) in the LED room and 37,602/ft³ (after 94 minutes) in the xenon gas room (Figures 7 and 8).

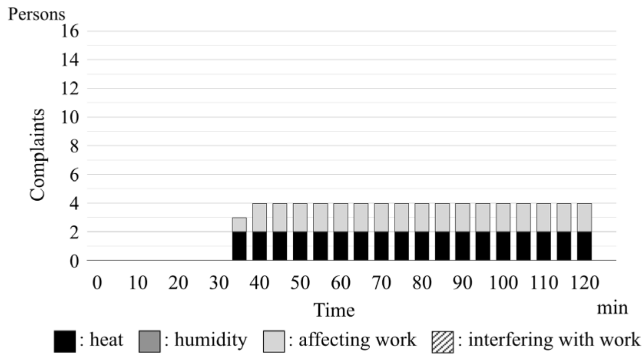

Figure 5: Physical impressions of staff members in LED room. 2 of 4 complained of heat affecting their work.

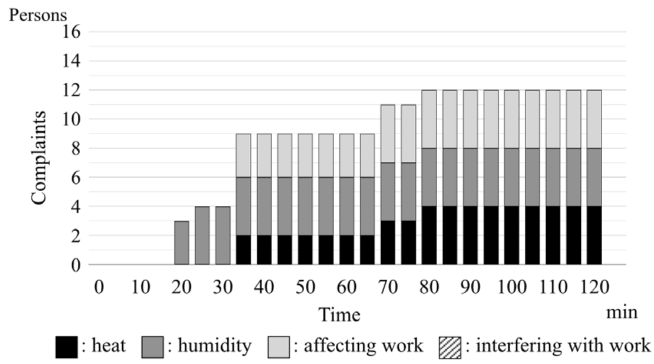

Figure 6: Physical impressions of staff members in xenon gas room. 3 of 4 complained of humidity and all 4 complained of heat affecting their work.

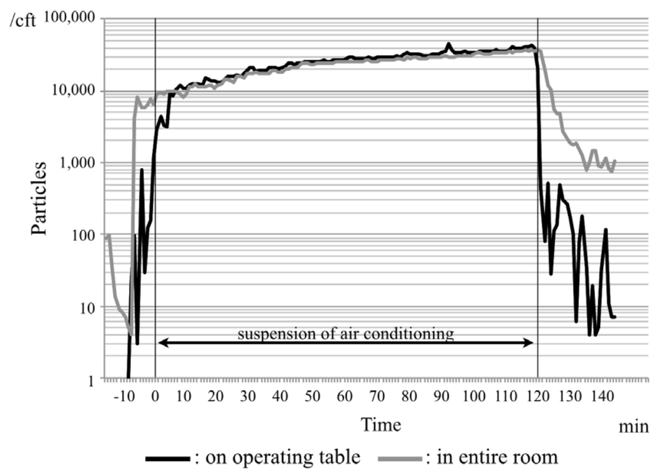

Figure 7: Air cleanliness in LED room. Immediately after suspension of air conditioning, no difference was observed in air cleanliness on the operating table and in entire room. Air cleanliness surpassed the designated level 8 min after suspension and eventually reached approximately 45,000/ft³.

Discussion

In operating rooms, it is essential to not only control the temperature and humidity via air conditioning but also to guarantee the cleanliness

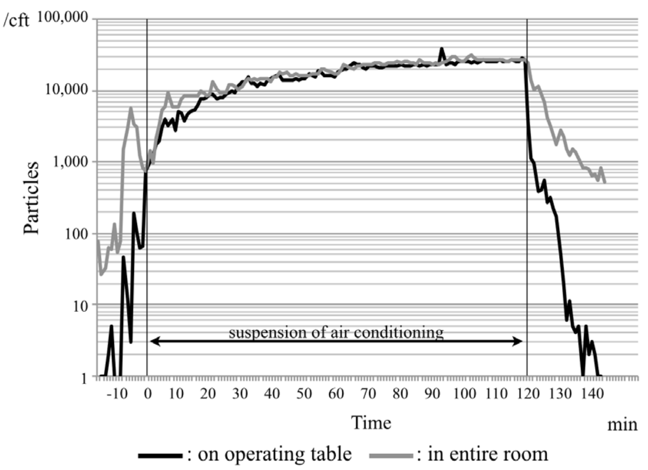

Figure 8: Air cleanliness in xenon gas room. Immediately after suspension of air conditioning, no difference was observed in air cleanliness on the operating table and in entire room. Air cleanliness surpassed the designated level 22 min after suspension and eventually reached 37,000/ft³.

of surgical equipment to prevent surgical site infection [2]. This is done by taking measures against dust, floating microorganisms, and odor by controlling atmospheric pressure and airflow and by purifying the air through filter ventilation and the introduction of outside air. Periodic maintenance and inspection are therefore key components of proper air conditioning facility operation. In Japan, however, there are currently no legal regulations included in the Medical Service Act, the Hospital Act, the Building Standards Act, or elsewhere that specify rules for air conditioning in hospitals. Nor do the conditions for reimbursement of medical fees or criteria for facilities specified by the Ministry of Health, Labor and Welfare specify the level of air cleanliness in operating rooms.

Furthermore, although air conditioning systems require electricity for their operation, there are no clear standards required for the use of electric power supplies in medical institutions in Japan. The Fire Service Act and the Hospital Act require the installment of an emergency power supply when constructing a hospital, but the output volume, operational time, etc. of the generator are not specified. In a survey administered to 1,948 medical facilities on the use status of emergency medical devices etc. in the case of a scheduled blackout implemented after the earthquake (355 valid responses), although 90.5% of the medical facilities had privately owned electrical power facilities, the mean limit time for use was 7.0 hours [3].

Scheduled blackouts were implemented in limited areas after the earthquake, but because the time from the announcement (grouping, time zones) to implementation was so short, a lot of confusion due to lack of awareness occurred. The affected companies and local governments were compelled to make quick responses and, because scheduled blackouts were often cancelled at the last minute after a supply of electricity was secured, social activities in general were disrupted amid conflicting reports. While medical institutions were exempted from blackouts in a phased manner, the criteria for their exclusion were not clear and actions taken by electric power companies in response to demands by the government also differed. Several days after the earthquake, the Japanese government finally gave notice that medical institutions were exempt from scheduled blackouts as a special exception even in times of tight electrical power needs [4]. The Ministry of Health, Labor and Welfare, the Ministry of Education, Culture, Sports, Science and Technology, the Agency for Natural Resources and Energy, and the Ministry of Economy, Trade and Industry officially announced that 501 facilities in the Kanto and Tohoku areas were excluded from scheduled blackouts. These facilities included emergency medical care centers, university hospitals, prenatal medical centers, disaster base hospitals, national sanatoriums, the National Research Center for Advanced and Specialized Medical Care, other national hospital organizations, Rosai hospitals, social insurance hospitals, Japan community healthcare organizations, hospitals established by local governments, and regional medical care support hospitals.

Our facility, which functions as the core medical institution in our area, was initially subject to scheduled blackouts and experienced a total of three blackouts until it was exempted. At the time of the earthquake, just five years had passed since the construction of a new hospital building, so our facility was relatively new. We had an emergency power supply that could supply electricity for 72 hours continuously at maximum operation. However, when we considered the stockpile of fuel needed for the generator and the nationwide difficulty in receiving various medical materials and drugs, we had no choice but to greatly restrict medical care operations. This was also due to the fact that, immediately after the earthquake, we had no clear information as to the condition of the power supply.

Our central operating room was in good condition and it was possible to operate almost all medical devices using the emergency power supply. For safety purposes, the number of planned surgeries was limited to 70 to 80% of the normal capacity and additional staff members were secured to prepare for unforeseeable circumstances. Various schedules were also adjusted in order to circumvent problems related to transporting patients resulting from shutdown of hospital elevators (excluding emergency elevators) or problems with the administration of anesthesia. When we switch to the emergency power supply, it takes time to resume operation of the hospital information system, laboratory test equipment, and autoclave sterilizers because they are not equipped with batteries or connected to the uninterruptible power supply (UPS). In addition, they enter a waiting mode immediately after power has been interrupted.

Currently, most medical facilities in Japan use the emergency power supply for air conditioning in all operating rooms if the volume of the emergency generator is 60% or more of the presumed maximum demand power. However, in many facilities in the days after the earthquake, the emergency power supply was used for air conditioning only in some rooms to enable use of the operating rooms during emergency operation even if the power supply facilities were being maintained or inspected. Although our facility is designed so that air conditioning can be operated with the emergency power supply in 3 of the 21 central operating rooms, because of its nature as a regional core hospital, performing more than 10,000 surgeries per year, it is difficult to deal with all planned surgeries in 3 operating rooms alone. We therefore had to schedule some surgeries in rooms where the air conditioning did not work during the scheduled blackout period.

In addition, when actual blackouts were occurring, the air conditioning did not restart in all rooms after the switch to emergency power supply or after the restoration of power following the completion of the blackout. This uncontrollable condition continued for 30 to 60 minutes in the operating rooms. Subsequent investigation revealed that this system error occurred due to overlapping control of the air conditioning from three areas: the central monitoring room that controls the air conditioning for the entire facility, the control room that operates ON/OFF air conditioning modes in each area of the central operating rooms, and the operation of air conditioning in each room. After determining this, we were able to solve the problem by coordinating the operating procedures and communication among divisions.

In our current study, the results of simulated suspension of air conditioning in the operating rooms suggest that blackouts worsen the working environment and reduce the level of air cleanliness. We also found that especially radiant heat from the shadowless lamp source is propagated to just below the operating table. Because the calorific value of the LED shadowless lamp, which has become widespread in recent years, is small, the impact of this lamp on patients in terms of increased temperature decreased humidity, as well as the impact on surgeons and their work, is smaller than that of the conventional xenon gas shadowless lamp. Depending on the scale, equipment, and/or content of the operations of each facility, greater environmental changes than those measured in this research may occur from an earlier stage. For example, the size of the operating room, the type and number of shadowless lamps, and the calorific value of the devices used during the operation (ultrasonically activated scalpel, X-ray fluoroscope, endoscope, surgical microscope, operation support robot, etc.) can all have a different effect on the temperature. Regarding the level of air cleanliness, factors such as air conditioning performance, the number of persons in the operating room, the coming and going of individuals (opening and closing of doors), and the movement of people can increase the dust count, which in turn increases the number of floating microorganisms [5-8]. Since there is a positive correlation between the number of people in a room and the dust count [9], if a large number of people need to be in a room (e.g., at a medical educational institution), the level of air cleanliness may significantly decrease and careful attention should be paid to the onset of surgical site infection [10].

Conclusion

The damage caused by the Great East Japan Earthquake in 2011 was immense, and the worsening electric power condition triggered by the accident at the Fukushima Daiichi nuclear plant continues to affect the country in various ways. In this work, we investigated changes in operating room environments and the effect of blackouts by measuring the temperature, humidity, and air cleanliness during simulations of suspended air conditioning. The physical impressions of the staff members working in these rooms were also collected. The results showed that suspension of air conditioning worsens the operating environment within a short period of time and increases the risk of surgical site infection. These findings are of especial use to anesthesiologists, who need not only to ensure safe medical care in operating rooms but also to understand how the various pieces of medical equipment are affected in an emergency and then take the appropriate actions to mitigate any increased risks that may occur in emergency situations.

Acknowledgment

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