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Case Studies

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Carbon Dioxide Exposures to Medical Personnel as a Result of Wearing Surgical Isolation Suits

Dawn Tharr, Column Editor

Reported by Alan Echt, G.E. Burroughs, Marc H. Rubman, and Donald E. Booher

Introduction

The National Institute for Occupational Safety and Health (NIOSH) received a management request for a health hazard evaluation (HHE) from a physician from a sports medicine and orthopedic center. Technical assistance was requested in evaluating carbon dioxide exposures among surgeons, nurses, and other operating room personnel performing or assisting with surgical procedures while wearing surgical isolation suits. Operating room personnel had complained about headaches, irritability, discomfort, and sweating while using the suits. NIOSH investigators, working in collaboration with physicians at the center, measured carbon dioxide concentrations inside suit helmets (also known as surgical helmets) during an experimental exercise routine. The exercise protocol was designed to simulate the effort required during orthopedic surgery. A simulation was performed because the surgeons were concerned that testing the helmet atmosphere during surgical procedures might prolong the operations, thus increasing the patients' risk of infection.

Background

Surgical isolation suits were introduced in orthopedic surgery to prevent the infection of patients by operating room personnel.[1] One study showed a 750-fold reduction in the average airborne concentration of bacterial particles during total hip implants when total body exhaust clothing was used in conjunction with a vertical laminar flow ventilation system in an operating room.[2] However, further studies have shown that the use of ultraviolet (UV)-C (100 to 280 nm) light and occlusive clothing resulted in a further reduction in the airborne bacteria concentration compared with the use of surgical isolation suits, and that UV-C is less expensive than the use of isolation suits.[3,4] Concerns about the potential transmission of bloodborne pathogens from infected patients to healthcare providers through the inhalation of aerosols, especially during orthopedic procedures (where surgical hand and power tools, including drills, hammers, chisels, reamers, bone saws, and electrocautery are used) have re-emphasized the need for contamination control.[5,6] These concerns were heightened when the human immunodeficiency virus was demonstrated to remain viable in cool aerosols generated by certain surgical power tools.[7] According to the HHE requester, these concerns have resulted in the widespread use of surgical isolation suits during total joint replacement surgery.

The surgical helmet typically consists of a helmet frame with disposable cover, a window that may or may not be an integral part of the cover, air filters for inhaled and exhaled air, and one or more fans. A consultant to a surgical helmet manufacturer measured carbon dioxide concentrations inside a surgical helmet that approached the Occupational Safety and Health Administration's (OSHA's) permissible exposure limit (PEL) of 5000 parts per million (ppm) while test subjects stood still. The PEL for carbon dioxide was exceeded when the subjects exercised.

Surgical helmets resemble powered air-purifying respirators (PAPRs), but none have been tested and approved by NIOSH. To provide a comparison, carbon dioxide concentrations were measured in two NIOSH-approved PAPRs during this study. The respirators evaluated were selected because of their potential for use by healthcare providers.

Methods

Exercise Protocol

A brief questionnaire was administered to all study participants to assess the potential for risk to their health from participating in the exercise protocol. A "yes" response to any of the questions resulted in further investigation by a NIOSH physician to determine whether the individual should participate in the study.

Test subjects were asked to perform light exercise (<4 kcal/min), approximating the effort of total joint replacement, while standing at an upper extremity ergometer (Figure 1).[8,9] The ergometer was set at a work load of 20 W, and the subjects were asked to maintain an exercise rate of 60 revolutions per minute (rpm) on the ergometer's hand cranks. This exercise level was intended to be no more demanding than the work of orthopedic surgery, which may involve the use of hand or power tools (e.g., hammers, chisels) during operations such as hip or knee joint replacement. Subjects wore typical surgical clothing (i.e., a surgical gown) with (1) no helmet, (2) each of the four surgical helmets available to this medical practice, or (3) two NIOSH-approved PAPRs with high efficiency particulate air (HEPA) filters. An exercise test would have been halted if a measured carbon dioxide concentration reached the NIOSH short-term exposure limit (STEL) of 30,000 ppm, or if the carbon dioxide in the helmet reached a steady state for 5 minutes. A trial was halted if a carbon dioxide concentration in a helmet did not reach the NIOSH STEL or a steady state after 15 minutes. Subjects rested between exercise periods until their heart rate, blood oxygen saturation, and oral temperature returned to baseline values, or for as long as the duration of the exercise period which preceded the rest period—whichever was longer.

Biological Monitoring

Heart rate and blood oxygen saturation were measured with a pulse oximeter. This gauged the effect of the different surgical helmets on the cardiovascular system at equal levels of physical exertion. The probe was attached to the test subject's left index finger. Because a sub-

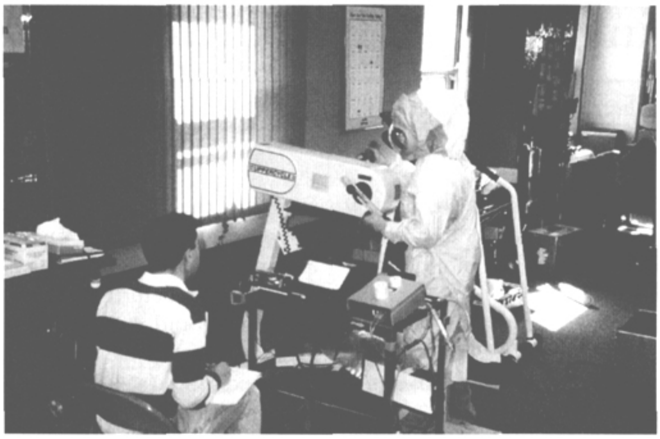

FIGURE 1. Test subject using ergometer.

ject's arm motion affected the instrument's performance, subjects held their left hand up every 2 minutes while continuing to exercise with their right arm, and kept it up until a stable reading was attained. Body temperature was measured before and after each trial with an oral thermometer. Measuring oral temperature indicated whether wearing a surgical helmet or PAPR placed an individual at increased risk of heat stress compared with the exercise protocol alone. The "no helmet" condition was always the first test performed by a subject, but the order of helmets tested was varied.

Study Participants

The study participants were two orthopedic surgeons and two NIOSH investigators. Participation in this study was voluntary, and a signed informed consent form was obtained from each subject. Participants had access to information about the study via an information sheet distributed prior to the study.

Environmental Monitoring

Carbon dioxide measurements were made using a Gastech model RI-411A portable infrared (IR) indicator. This instrument is battery powered, weighs approximately 2.6 kg, and is 23 cm wide, 19 cm high, and 11 cm deep. It is a chopped, single-beam, nondispersive IR analyzer which monitors absorbance of carbon dioxide in a selected (unspecified) narrow frequency range. An internal pump continuously draws sample air through the detection chamber where absorbance is measured, compared with a background signal, and converted to an output signal used to show carbon dioxide concentration on an LCD display. The output signal can also be sent to an analog data collection device for storage. Normal instrument range is 0 to 4975 ppm carbon dioxide in air, with the instrument reading in 25-ppm increments.

For the purposes of this study, the sample air stream was diluted by drawing the total sample from two legs of a "T" as shown in Figure 2. Two Hastings model CPR-4SA mass flow controllers were used to adjust the flow of the contaminant air stream drawn from the sample site and the diluent stream drawn from ambient air. Ambient air was drawn through a scrubber containing Ascarite II to remove carbon dioxide. Scrubbed air was then mixed with the contaminant stream coming from the surgical helmet system being tested before being drawn into the carbon dioxide indicator.

Dilution of the contaminant air stream in a 1:9 ratio with scrubbed ambient air enabled the analytical range of the assembled instrumentation package to be extended from 4950 to 49,500 ppm, measured in 250-ppm increments; no measurements or calibrations were made above 20,000 ppm. A multipoint calibration of the assembled analytical instrumentation was conducted in the laboratory and validated on site using standards prepared by injecting known volumes of pure carbon dioxide into known volumes of room air using 50-ml and 1-L syringes. A zero setting was accomplished by adding a second carbon dioxide scrubber to the contaminant stream inlet to eliminate carbon dioxide from both the contaminant and diluent legs of the T. Combined data from on site, precalibration and postcalibration produced a correlation coefficient of 0.971 for 110 data points.

The carbon dioxide concentration in room air was monitored continuously during all testing using a second, nondiluted carbon dioxide analyzer. This second monitor was calibrated using a commercial span gas. Continuous voltage output (corresponding to carbon dioxide concentration) from both analyzers was sent to Metrosonics model DL3200 dataloggers for data storage. These data were subsequently downloaded to a personal computer. The helmet carbon dioxide

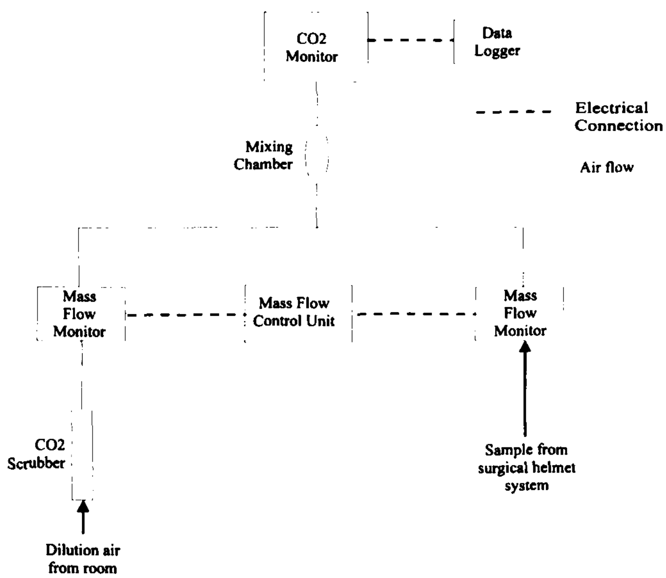

FIGURE 2. Block diagram of monitoring instruments.

concentration was recorded every 2 minutes during the exercise trials, and the room carbon dioxide concentration was recorded by an investigator before and after each trial.

Evaluation Criteria

Carbon dioxide is a simple asphyxiant and a potent stimulus to respiration. It is both a depressant and an excitant of the central nervous system.[10] Carbon dioxide is a normal constituent of air at a concentration of about 300 ppm.[11] As the concentration of carbon dioxide in inspired air increases, the alveolar to capillary ratio of carbon dioxide decreases, rendering normal diffusion of carbon dioxide from the blood less favorable.[12] The body compensates by an increase in respiratory depth and rate and an accompanying increase in cardiac output.[12]

After several hours of exposure to carbon dioxide at a concentration of 20,000 ppm, exposed subjects develop headache and shortness of breath on mild exertion.[10] Headaches become progressively more severe at 30,000 ppm, diffuse sweating occurs, and shortness of breath will exist even at rest.[12] Chronic exposures to increased carbon dioxide concentrations produce widespread physiologic alterations, including acidosis and adrenal cortical exhaustion following prolonged, continuous exposures to 10,000 to 20,000 ppm.[12] However, adaptation to levels ranging from 15,000 to 30,000 ppm has occurred with chronic exposure.[10] The NIOSH recommended exposure limit for carbon dioxide is 5000 ppm as a time-weighed average (TWA) for up to a 10-hour workday, with a STEL of 30,000 ppm.[13] The OSHA PEL is 5000 ppm, 8-hour TWA.[14] The American Conference of Governmental Industrial Hygienists threshold limit value is 5000 ppm as an 8-hour TWA, with a STEL of 30,000 ppm.[15]

Results and Discussion

Four types of surgical helmets were evaluated from among those manufactured by three companies: the Stackhouse Freedom Mark, the Stackhouse Freedom-Aire, the Stryker Steri-shield, and the DePuy Sterile View. The two PAPRs evaluated were the Racal Air-Mate HEPA 10 (TC-21C-635) and the 3M Belt-Mounted PAPR Snapcap Hood System with HEPA filter (TC-21C-671). The surgical helmet systems were categorized by design (self-contained unit with internal fans or helmet with belt-mounted fans and hoses) and by ventilation pattern (inflow alone or inflow with exhaust). The surgical helmet systems could all be modified by changing the external fan direction, fan speed, or number of hoses connected to the fans. Each system tested was classified by these modifications. The Freedom Mark system with belt-mounted fans was classified as either "shark" or "ram" (because of its appearance) based on the number of hoses connected to each fan and the pattern of hose placement on the helmet (top or bottom ports on both left and right front of the helmet). The 11 surgical helmet configurations tested were based on recommendations to the center's physicians by sales representatives, manufacturers' literature, or operating room personnel. No other modifications or alterations were made to any system. Surgical helmets tested were selected from operating room inventory or provided by sales representatives.

The results of the tests are presented in Table 1. For each of the 11 surgical helmet systems and two PAPRs tested, the means in the table resulted from averaging the means of four tests. The maximum and minimum values reported represent the maximum and minimum of all four tests for that particular surgical helmet configuration or PAPR. Mean carbon dioxide concentrations ranged from 5500 to 11,700 ppm. These results indicate that if these surgical helmets and PAPRs are used during operations lasting 8 hours or more, the users will be exposed to carbon dioxide levels exceeding the 8-hour TWA exposure limits. For the highest mean carbon dioxide concentration measured (11,700 ppm), a user would be overexposed if a procedure lasted for 3.5 hours or longer. Three of the four subjects reported headaches following several hours of trials.

The concentration of carbon dioxide in room air ranged from 375 to 575 ppm, with a mean of 450 ppm. The mean difference between pre- and post-test oral temperatures was 0.2°C. In 12 of 56 instances, the oral temperature dropped during the trial. The maximum decrease was 0.9°C. In three cases, oral temperature rose more than 1°C. In one case, this increase was 2°C (from 35° to 37°C). However, the oral temperature did not exceed 38°C in any of the trials. Therefore, no heat strain was noted as a result of using either the surgical helmets or PAPRs. The difficulty encountered in the use of the pulse oximeter on a hand in motion in the beginning of this study precludes the report of the measurements obtained with it.

Conclusions

Air sampling inside surgical helmets and two NIOSH-approved air-purifying respirators showed a buildup of carbon dioxide levels during light exercise. However, none of the carbon dioxide concentrations measured during any of the 15-minute tests exceeded the STEL of 30,000 ppm. The results of this study indicate that wearing a surgical helmet or NIOSH-approved PAPR during orthopedic surgical procedures may result in a user being overexposed to carbon dioxide, depending on the duration of surgery. The results of this study agree with the results of a previous laboratory study of the performance of positive pressure powered respirators.[16]

While the carbon dioxide concentrations noted in this study have not been associated previously with adverse health effects, they may explain the symptoms reported by the employees at the center and experienced by three of the test subjects. The effects of these exposures in combination with other airborne contaminants in operating rooms, such as waste anesthetic gases, vapors from adhesives used in joint replacement, and fumes from electrocautery are unknown.

Recommendations

The following recommendations may help reduce symptoms of headache, discomfort, irritability, and sweating when wearing surgical helmets:

1. The most comfortable helmet should be selected among those configurations which result in the lowest mean carbon dioxide concentration. OSHA regulations require the use of NIOSH-approved respirators when they are available. None of the surgical helmets tested have been submitted for NIOSH approval.
2. The manufacturers of the non-NIOSH-approved devices used in this evaluation should submit their surgical helmets to NIOSH approval testing. Once approved by NIOSH, these systems could then be used with confidence that the helmets' components met the minimum requirements for

safe and effective protection from infectious agents.

3. Respirator manufacturers should work with physicians to develop respirators that meet the needs of orthopedic surgeons for comfort, visual and auditory acuity, and ease of use. Other healthcare professionals who use surgical helmets should also take part in the development of these products.
4. Additional studies should be conducted to evaluate carbon dioxide exposures that occur during actual orthopedic procedures. These studies should also evaluate exposures to other air contaminants present during surgery (e.g., waste anesthetic gases, vapors from adhesives).
5. Additional studies should be performed to measure carbon dioxide exposures in NIOSH-approved PAPRs, especially during the performance of physically demanding tasks, such as asbestos removal.

References

1. Charnley, J.: Clean Air in the Operating Room. Cleveland Clinic Quarterly 40: 99–114 (1973).
2. Whyte, W.; Vesley, D.; Hodgson, R.: Bacterial Dispersion in Relation to Operating Room Clothing. J. Hyg. 76:367–378 (1976).
3. Berg, M.; Bergman, B.R.; Hoborn, J.: Ultraviolet Radiation Compared to an Ultra-clean Air Enclosure. The Journal of Bone and Joint Surgery 73-B:811–815 (1991).
4. Berg-Périer, M.; Cederblad, A.; Persson, U.: Ultraviolet Radiation and Ultra-clean Air Enclosures in Operating Rooms. The Journal of Arthroplasty 7:457–463 (1992).
5. Yeh, H.C.; et al.: Characterization of Aerosols Produced During Surgical Procedures in Hospitals. Aerosol Science and Technology 22:151–161 (1995).
6. Hester, R.A.; Nelson, C.L.; Harrison, S.: Control of Contamination of the Operating Team in Total Joint Arthroplasty. The Journal of Arthroplasty 7:267–269 (1992).
7. Johnson, G.K.; Robinson, W.S.: Human Immunodeficiency virus-1 (HIV-1) in the Vapors of Surgical Power Instruments. NIOSHTIC Reference No. 00207426. Stanford University School of Medicine, Stanford, CA.
8. Pate, R.R., et al,: Physical Activity and Public Health, JAMA 273:402–407 (1995).
9. McCormick E.J.; Sanders, M.S.: Human Factors in Engineering and Design, 5th ed. McGraw-Hill Book Company, New York (1982).
10. Hathaway, G.J.; Proctor, N.H.; Hughes, J.P.: Proctor and Hughes' Chemical Hazards of the Workplace, 4th ed. Van Nostrand Reinhold, New York (1996).
11. National Institute for Occupational Safety and Health: Pocket Guide to Chemical Hazards. DHHS (NIOSH) Pub. No. 94-116. NIOSH, Cincinnati, OH (1994).
12. Schulte, J.H.: Sealed Environments in Relation to Health and Disease. Arch. Environ. Health 8:438–452 (1964).
13. National Institute for Occupational Safety and Health: Recommendations for Occupational Safety and Health: Compendium of Policy Documents and Statements. DHHS (NIOSH) Pub. No. 92-100. NIOSH, Cincinnati, OH (1992).
14. Code of Federal Regulations 29 CFR 1910.1000. U.S. Government Printing Office, Washington, DC (1993).
15. American Conference of Governmental Industrial Hygienists: 1997 Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices. ACGIH, Cincinnati, OH (1997).
16. Bostock, G.J.: An Investigation into the Performance of Positive Pressure Powered Dust Hoods and Blouses at Low Flow Rates. Ann. Occup. Hyg. 29:415–420 (1985). Editorial Note: Alan Echt is with the Hazard Evaluation and Technical Assistance Branch, G.E. Burroughs is with the Methods Research Branch, and Donald Booher is with the Industrywide Studies Branch of NIOSH. Marc H. Rubman is with the Northern New Jersey Orthopedic Specialists, Madison, New Jersey. More detailed information on this investigation is contained in Health Hazard Evaluation Report No. 96-0060-2632, available through NIOSH, Hazard Evaluations and Technical Assistance Branch, 4676 Columbia Parkway, Cincinnati, Ohio 45226; telephone (800)35-NIOSH

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