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Original Article

Carbon Dioxide Exposure Resulting From Hood Protective Equipment Used in Joint Arthroplasty Surgery

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ABSTRACT

Background: To protect both the surgeon and patient during procedures, hooded protection shields are used during joint arthroplasty procedures. Headache, malaise, and dizziness, consistent with increased carbon dioxide (CO_2) exposure, have been anecdotally reported by surgeons using hoods. We hypothesized that increased CO_2 concentrations were causing reported symptoms.
Methods: Six healthy subjects (4 men) donned hooded protection, fan at the highest setting. Arm cycle ergometry at workloads of 12 and 25 watts (W) simulated workloads encountered during arthroplasty. Inspired O_2 and CO_2 concentrations at the nares were continuously measured at rest, 12 W, and 25 W. At each activity level, the fan was deactivated and the times for CO_2 to reach 0.5% and 1.0% were measured.
Results: At rest, inspired CO_2 was 0.14% ± 0.04%. Exercise had significant effect on CO_2 compared with rest (0.26% ± 0.08% at 12 W, $P = .04$; 0.31% ± 0.05% at 25 W, $P = .003$). Inspired CO_2 concentration increased rapidly with fan deactivation, with the time for CO_2 to increase to 0.5% and 1.0% after fan deactivation being rapid but variable (0.5%, 12 ± 9 seconds; 1%, 26 ± 15 seconds). Time for CO_2 to return below 0.5% after fan reactivation was 20 ± 37 seconds.
Conclusion: During simulated joint arthroplasty, CO_2 remained within Occupational Safety and Health Administration (OSHA) standards with the fan at the highest setting. With fan deactivation, CO_2 concentration rapidly exceeds OSHA standards.

Orthopedic surgery results in hazards to the patient because of dangers of infection and hazards to physicians and surgical team members because of fragments of bone, blood, and other tissues. Hooded protection shields are designed to protect both the surgeon and patient during procedures such as total joint arthroplasty. Currently, no independent studies in the literature demonstrate the safety of hood use. One consequence of the hooded protection shields is the potential for the buildup of carbon dioxide (CO_2) within them due to inadequate ventilation. Many joint arthroplasty procedures require a degree of exertion on the part of the surgeon, a hood system that is adequate at rest may not provide adequate clearance of CO_2 during exertion. Anecdotal reports of symptoms associated with hood usage exist, such as headache, malaise, dizziness, discomfort, especially with prolonged use during long and physically taxing procedures. Prior studies evaluated comfort of body exhaust suits vs hooded systems with notable comfort issues with both; however, clear comfort advantages of hooded systems over body exhaust systems were reported [1].

CO_2 is a potent ventilatory stimulant. Even modest increases in inspired CO_2 will result in substantial increases in ventilation in most people [2,3]. Occupational exposures to CO_2 often occur in persons who are required to work in confined spaces where ventilation is inadequate or who wear protective breathing equipment, especially in the face of exercise requirements

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(eg, firefighters). Such increases in ventilation are often perceived as uncomfortable or distracting, factors that are undesirable in a surgical setting. Prolonged exposure to elevated CO_2 (over periods of hours or longer) is seen in crews on submarines and in spaceflight. In the latter case, inspired CO_2 levels above 3.5 mm Hg (0.5%) are associated with increased reports of headache from crew on board the International Space Station [4].

Because some joint arthroplasty procedures cover many hours, we hypothesized that the anecdotal reports of headache and other forms of discomfort might be related to exposure to elevated CO_2 within the hood systems. The purpose of this study was to investigate the CO_2 levels within a standard hooded protection shield during activities designed to mimic the workloads encountered during arthroplasty procedures.

Methods

Overall Study Design

Inspired O_2 and CO_2 concentrations were monitored in subjects wearing protective equipment typically used for joint arthroplasty surgical procedures to reduce infection risk. The protective equipment consisted of a helmet with an incorporated fan (Stryker T5 Personal Protection System; Stryker, Kalamazoo, MI), a plastic face shield (Stryker Sterishield; Stryker, Kalamazoo, MI), a surgical “toga” gown (Stryker, Kalamazoo, MI), and standard disposable nitrile gloves. To simulate workloads that might be encountered in the operating room, data were collected at rest and at 2 levels of moderate upper body exercise using one-hand cranking of a cycle ergometer (Lode Excalibur Sport; Lode B.V., Groningen, Netherlands) with a fixed workload set at 12 and 25 W. The 25 W level was chosen as an appropriate estimate of work performed during a joint arthroplasty, as assessed by an orthopedic surgeon after trials of work rates of up to 50 W and comparing these with the perceived level of exertion achieved during a procedure.

Subjects

The protocol was reviewed and approved by the local Human Research Protection Program, and subjects provided written informed consent following a description of the study. Subjects were recruited from the pool of orthopedic surgeons and medical colleagues from other specialties from 2 institutions. The target age group was 30-60 years to reflect the age of the population of orthopedic surgeons. Subjects completed a Physical Activity Readiness Questionnaire to assess potential for cardiovascular disease. Subjects that answered “yes” to any of the first 7 questions regarding risk factors to perform physical activity were excluded, as were those who were pregnant.

Study Details

Subjects donned a Stryker T5 Personal Protection System with a standard single-use surgical gown. Nitrile gloves were worn and a pulse oximeter probe was attached to the index finger of the hand that was not used for exercise with the nitrile glove placed over the probe. The pulse oximeter (Nellcor N-395, Medtronic, Minneapolis, MN) was used to monitor heart rate and oxygen saturation during the experiment. Termination of the trial occurred if the subject's oxygen saturation fell below 90%. A cycling glove was provided for the hand performing the exercise to minimize discomfort.

In each condition, we measured inspired gas concentrations (O_2 and CO_2) with the fan operating normally at the highest air flow setting, with the fan off for a period of 5 minutes (simulating a fan failure, battery pack disconnection, or battery discharge) and after reactivation of the fan. This design was chosen to cover the events considered most likely to be encountered in the operating room. The sampling capillary of a mass spectrometer (Perkin Elmer MGA-1100, Perkin Elmer, Waltham, MA) was secured with tape to the subject between the nostrils and the upper lip to obtain measurements of inspired O_2 and CO_2 representative of the gas inspired during either mouth or nose breathing.

The fan helmet had variable airflow settings; the highest flow rate was used for all subjects for all conditions when the fan was in use. The rest condition was measured first for all subjects. Exercise conditions of 12 and 25 W were then performed in a balanced order between subjects. For the rest condition, inspired O_2 and CO_2 were measured while the subject stood for 5 minutes with the fan on, then the fan was turned off by unplugging the battery pack and further 5 minutes of data were collected. The fan was then turned back on and data were recorded until a plateau was seen in the inspired concentrations of O_2 and CO_2, assessed by observing a real-time display of the mass spectrometer output.

Each exercise condition started with the fan on and data were collected at rest until a steady state was seen. The subject then commenced exercise at the assigned level for a 5-minute period with the fan on. The fan was then turned off and the subject continued exercising until an increase in CO_2 to a maximum inspired concentration of 5% or until a new steady state was reached. The fan was then switched back on while the subject continued exercise until a plateau was seen in the CO_2 concentration, providing data on the removal of CO_2 by the system. The study ended with a period of rest, with data recording ending when a steady level of CO_2 was seen.

Data were collected using AcqKnowledge software and a Biopac M-100 data acquisition system (Biopac Systems, Inc, Goleta, CA) at a data rate of 1000 Hz. A 2-point calibration was performed before each session of data collection using ambient air and a gas mix of 5% CO_2 with 15% O_2 in nitrogen. Results were analyzed using LabChart Reader (AD Instruments, Dunedin, New Zealand), taking the end-inspiratory value seen at each breath to obtain inspired O_2 and CO_2 measurements. Means for each condition (rest, exercise fan on, exercise fan off, exercise fan on recovery, recovery) for each subject and workload were calculated from this.

A repeated measure analysis of variance was performed on the obtained data to assess changes in concentrations of CO_2 and O_2 between different exercise intensities and fan state (on/off). In cases in which an overall significant F-ratio in the analysis of variance occurred, Fisher's protected least significant difference was applied to the data to identify any pairwise differences between conditions, with a significance level of 5% 2-tailed.

Results

Six subjects with no cardiovascular disease, as indicated by the Physical Activity Readiness Questionnaire completed the study (4 men, 2 women, mean age 38 ± 7 years). No subjects were disqualified from those recruited. Initial inspired CO_2 levels in the hood (before fan deactivation and before the start of exercise) were not significantly different between runs at different subsequent exercise levels (Table 1).

Compared with rest, 12 W exercise with the fan on resulted in an increase in CO_2 concentration from 0.14% ± 0.02% to 0.26% ± 0.08% ($P =$ .0109). Similarly, a significant increase in CO_2 was also seen between rest and 25 W exercise with the fan on, from 0.15% ± 0.05% to 0.31% ± 0.05% ($P =$ .0002). A significant increase in the CO_2 concentration in the hood (with corresponding drop in O_2) was seen in all conditions when the fan was deactivated (Table 1). At rest, CO_2 increased from 0.13% ± 0.04% to 1.09% ± 0.33% ($P <$ .001). During exercise at 12 W, the increase in CO_2 concentration was from 0.26% ± 0.08% to 1.51% ± 0.83% ($P <$ .001). At 25 W, CO_2 rose from 0.31% ± 0.05% to 1.81% ± 0.47% ($P <$ .001).