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Airborne Exposure of Methyl Methacrylate During Simulated Total Hip Arthroplasty and Fabrication of Antibiotic Beads

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ABSTRACT

As the use of cement remains prevalent in orthopedic surgery, so do concerns over the safety of its active ingredient, methyl methacrylate (MMA). The Occupational Health and Safety Agency (OSHA) limits the airborne exposure to 100 parts per million (ppm) averaged over an 8 hour period. We measured MMA exposure to operating room personnel during simulated total hip arthroplasty (THA), antibiotic bead fabrication and simulated spill of MMA. Cumulative and peak exposures during simulated THA and antibiotic bead fabrication did not exceed OSHA limits of 100 ppm. Vacuum mixing and greater distance from the vapor source reduced measured MMA exposure. Spilled MMA led to prolonged and elevated MMA levels. MMA levels returned to a negligible level in all scenarios by 20 minutes after mixing.

The use of poly methyl methacrylate (PMMA) cement in orthopedics began in the 1960's and is a well-established practice in hip and knee arthroplasty [1]. Applications for PMMA have expanded to include its use as a bone void filler for defects and for localized elution of antibiotics in musculoskeletal wounds and infections. PMMA is formed by polymerization of its monomer, methyl methacrylate (MMA), which has well described negative health effects on fertility, the cardiopulmonary system, liver, kidneys, and even mortality, in animal models [2–6].

The Occupational Safety and Health Agency (OSHA) recommends a maximum airborne exposure of 100 ppm averaged over eight hours [2]. The American Conference of Governmental Industrial Hygienists (ACGIH) suggests a limit of 50 ppm averaged over eight hours and 100 ppm as a peak exposure level [7]. In spite of the widespread use of MMA there is a paucity of literature addressing airborne exposure to orthopedic personnel [8,9]. Peak and duration of MMA exposure during common orthopedic applications such as total hip arthroplasty or creation of antibiotic beads remain undefined. Characteristics of MMA exposure may be of particular interest for women in orthopedic operating rooms. Previous studies have suggested workplace exposure to anesthetic gases is associated with increased rates of miscarriage and teratogenic effects [10,11]. Animal studies have linked MMA vapor exposure to low birth weight and skeletal abnormalities among offspring [5].

The purpose of this study was to determine MMA exposure to operating room personnel during simulated total hip arthroplasty and fabrication of antibiotic beads. We sought to measure peak and cumulative exposure levels, and determine how long it took for operating room levels to return to a negligible value. The impact of the sterile surgical helmet system and vacuum mixing was also evaluated. We hypothesized that MMA exposures would be directly related to proximity to the source of vapors with most operating room personnel receiving minimal exposure. We also hypothesized that vacuum mixing and sterile surgical helmet systems would significantly reduce vapor exposures.

Methods/Materials

All simulations were performed within a single operating room routinely used for total hip arthroplasty (THA) within our institution. The operating room measured 433 cubic feet and had positive pressure ventilation with 15.9 air exchanges per hour in accordance with standards given by National Institute of Occupational Safety and Health (NIOSH), American Society of Heating, Refrigerating and Air-Conditioning engineers (ASHRAE), Centers for Disease Control and Prevention (CDC), and American Institute of Architects (AIA). Room temperature averaged 33.5 °F. Relative humidity averaged 33.5%. Vapor monitoring stations were placed in four locations to simulate the position of scrub technician, surgeon, circulating nurse and a control position outside the operating room door. See Fig. 1 for a pictorial representation of room set up. Two separate vapor monitoring systems were used at these stations to measure and record exposure in real time. Dosimeter badges were also placed at each station and left in place for four consecutive simulations to reflect cumulative exposure.

Equipment employed for vapor detection included Sensor Safety dosimeter badges (Sensors™ Safety Products, Raleigh, NC), MIRAN® portable ambient air analyzer (Thermo Fisher Scientific Inc., Waltham, MA), and GrayWolf Direct Sense IQ-610 probe® (GrayWolf Sensing Solutions LLC, Shelton, CT). Vapor detection technique included use of gas chromatography as approved by OSHA Method 94.

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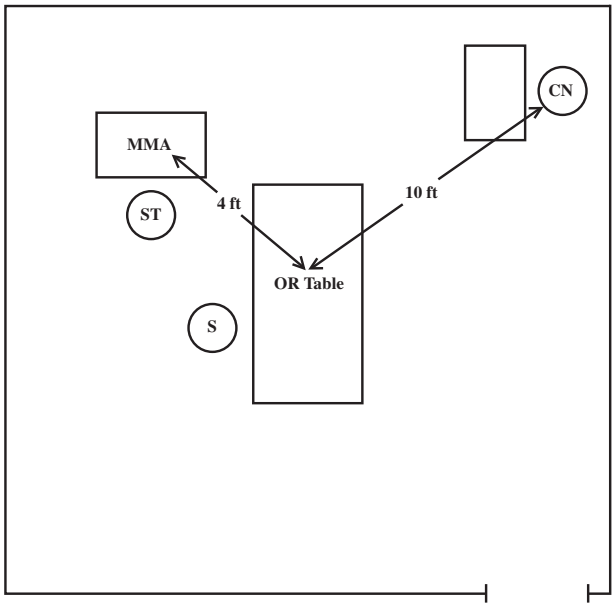

Fig. 1. Operating room set-up. Vapor monitoring stations were established in four separate locations, representing the position of the scrub technician, surgeon, circulating nurse, and a control position immediately outside the operating room door. A scrub table for mixing cement was fashioned four feet from the operating room table. The station representing the circulating nurse was positioned ten feet from the operating room table. CN = circulating nurse, MMA = methyl methacrylate, NA = nurse anesthetist, OR = operating room, S = surgeon, ST = scrub technician.

Experiment 1: Total Hip Arthroplasty – 2 Bags of Cement, Hood, Vacuum Mixing

The surgeon and scrub technician wore sterile surgical helmet systems with vapor monitoring probes placed within the helmets to continuously monitor MMA levels. A sawbones femur model (Johnson & Johnson, New Brunswick, NJ) was prepared with a femoral neck cut and broaching to accommodate a standard femoral implant. The scrub technician mixed two bags of Simplex P Bone Cement® (Stryker Orthopaedics Inc., Mahwah, NJ) using a Zimmer Compact Vacuum Cement Mixing System® (Zimmer Orthopaedic Surgical Products Inc., Dover, OH) for two minutes at the sterile scrub table. The cement was placed into a cement gun and handed to the surgeon standing at the operating table. The cement was allowed to cure until reaching appropriate consistency for THA implantation. The length of time was determined by the surgeon and varied between 30 and 60 seconds. The Sawbones femur was filled with cement using a standard retrograde filling technique with pressurization.

The excess cement was expressed out of the gun and formed into a ball to determine when curing occurred. Along with the empty cement gun, the excess cement was placed back on the scrub table. Once the cement had cured, the Sawbones femur was placed into a sealed bag to simulate closure of the soft tissues. The remaining cement and mixing devices were left on the scrub table as is standard practice at our institution. Once the levels of MMA had returned to baseline the simulation was over. The simulation was repeated four times.

Experiment 2: Total Hip Arthroplasty – 2 Bags of Cement, No Hood, Vacuum Mixing

In this experiment sterile surgical helmet systems were not utilized by surgeon or scrub technician. The set up and methodology for this simulation were otherwise identical to experiment 1.

Levels of MMA vapor were monitored continuously at the surgeon, scrub and the circulator stations. Once the levels of MMA had returned to baseline levels, the simulation was over. The simulation was repeated four times.

Experiment 3: Antibiotic Bead Simulation – 1 Bag of Cement, No Hood, Hand Mixing

In this simulation, both the surgeon and the scrub technician remained at the scrub table station. Real time vapor probes were placed within the breathing field of surgeon/scrub technician and circulator. As is common practice at our institution, the scrub technician mixed the cement and the surgeon prepared the antibiotic beads on the back table.

A scrub technician without a sterile surgical helmet system mixed one bag of Simplex P Bone Cement® (Stryker Orthopaedics Inc., Mahwah, NJ) for two minutes using a Zimmer Compact Cement Mixing System® (Zimmer Orthopaedic Surgical Products Inc., Dover, OH) at the sterile scrub table without the use of vacuum. After two minutes the lid was opened and the surgeon periodically assessed the cement until it reached the optimum consistency for creating antibiotic beads. Beads with an approximate diameter of one centimeter were fashioned until all cement was utilized. After the beads cured they were placed in a sealed bag to simulate closure of the soft tissues. The remaining cement and mixing devices were left on the scrub table.

Levels of MMA vapor were monitored continuously at the scrub/surgeon station and the circulator station. Once the levels of MMA had returned to baseline, the simulation was over. The simulation was repeated four times.

Experiment 4: Spill Simulation – 1 Vial of MMA Monomer Component, No Hoods

A spill was simulated by directly pouring the liquid MMA onto the sterile drapes over the scrub table. No attempt was made to re-drape or remove the liquid. No cement was mixed during this simulation. Levels of MMA vapor were monitored continuously at the scrub table and the circulator station. This simulation was only performed once.

Exposure (total exposure, peak exposure, and time to return to negligible level) was compared between experiments 1 and 2 to assess the impact of sterile surgical helmet systems on exposure for the surgeon and scrub. Exposure was also compared between experiments 2 and 3 to assess the impact of vacuum mixing on exposure. Student-t or non-parametric rank-sum testing was used, where appropriate, to compare mean values between the groups, with $P < 0.05$ considered significant. All statistical analysis was performed using SAS 9.3 software (SAS, Cary, NC).

Source of Funding

Materials employed during this study, including sawbones femurs, cement, and cement mixing bowls were supplied by Synthes®, Stryker®, and Zimmer® respectively.

Results

Experiment 1: Total Hip Arthroplasty – 2 Bags of Cement, Hood, Vacuum Mixing

The results of a representative simulation from this experiment are shown in Fig. 2. For the surgeon, the peak exposure mean by continuous monitoring was 6.4 ppm. The time for exposure to return to baseline levels of <1 ppm was a mean of 8.4 minutes. The area under the curve, which indicates total exposure for a single simulation, was 18.4 ppm-min. Over all four simulations this was 73.6 ppm-min; equivalent to 0.15 ppm averaged over 8 hours. The total exposure over four simulations recorded by the Sensor Safety dosimeter badge and weighted for 8 hours was 0.14 ppm.