Original article

Scand J Work Environ Health 1992;18(2):106-109

Study design for the characterization of aerosols during surgical procedures.

by Smith J, Yeh HC, Muggenburg B, Guilmette R, Martin LS, Strine PW

Affiliation: Division of Physical Sciences and Engineering, National Institute for Occupational Safety and Health, Centers for Disease Control, Cincinnati, OH 45237.

This article in PubMed: www.ncbi.nlm.nih.gov/pubmed/1514063

Scand J Work Environ Health 1992;18 Suppl 2:106—9

Study design for the characterization of aerosols during surgical procedures[1]

by Jerome Smith, PhD,[2] Hsu-Chi Yeh, PhD,[3] Bruce Muggenburg, DVM,[3] Raymond Guilmette, PhD,[3] Linda S Martin, PhD,[4] Phillip W Strine, BA[4]

Concern about the transmission of infectious diseases from patients to workers in the health care professions is increasing. There have been documented cases of health care workers becoming infected with human immunodeficiency virus (HIV) through injuries with sharp objects and through exposures to mucous membranes and nonintact skin (1, 2). Another area of concern is the possibility of the transmission of HIV or other bloodborne pathogens through aerosols produced by various surgical procedures (3). In many such procedures, several types of surgical tools are used. Two types of surgical tools are of special interest, those that impart thermal energy to tissue, such as surgical lasers and electrocautery, and those that impart mechanical energy to tissues, such as bone saws, reamers, and drills. A variety of surgical lasers is used in differing configurations with a wide range of power levels. They are known to produce aerosols with a small particle size (4). Electrocautery is also used in several modes for a variety of procedures and can produce aerosols with a range of particle sizes. Power tools, such as drills and saws, and handtools, such as reamers, are used frequently in orthopedic procedures (5). These tools are known to produce large blood droplets (ie, spatter) that coat surgical garments and protective equipment such as face shields. They have also been shown to produce aerosol particles in the respirable size range (5).

An important question to be answered is whether operating personnel can be infected by a blood aerosol containing a bloodborne pathogen such as HIV. No documented cases of human infection have occurred through this route. Some experiments have demonstrated that an uninfected cell culture can be infected with HIV from aerosols produced by either surgical lasers or power tools used on cell cultures infected with HIV (6, 7).

In the absence of direct evidence documenting human infection from HIV in aerosols generated by lasers or power tools, the question of whether surgical personnel can become infected by such aerosols can be broken down into two parts, (i) what types and amounts of aerosols are produced and (ii) are these aerosols infectious to health care workers? The present study was undertaken to answer the first question. In it the aerosol produced by various surgical tools was measured during simulated and actual human surgical procedures. The hip replacement procedure was chosen for study. It was used because it employs power tools, handtools, and electrocautery and, therefore, has a high probability for aerosol production from a variety of surgical devices. It is also a commonly used surgical procedure performed in many hospitals.

Methods

Aerosol measurements. Several aerosol collection and measurement instruments were used to characterize the aerosols produced during simulated and actual hip replacement procedures (table 1). One type of sample was collected with Marple personal impactors to measure the personal exposure of surgical personnel to blood containing aerosols produced during the surgical procedure. Marple personal impactors (Anderson Instruments, Inc) are small cascade impactors that were worn in the breathing zone of the persons performing or observing the surgery to determine the size distribution and concentration of the aerosol produced during the surgery.

A second type of measurement assessed the production of aerosols from different surgical tools and procedures. This measurement was done with a quartz crystal microbalance (model PC—2 Air Particle Analyzer®, California Measurements, Inc) which is capable of measuring the size distribution of the aerosol produced in real time. It uses the principle of impaction to deposit aerosol particles of a given size range in each stage. The amount of mass deposited at

[1] Disclaimer: Mention of commercial names or products does not constitute endorsement by the National Institute for Occupational Safety and Health.

[2] Division of Physical Sciences and Engineering, National Institute for Occupational Safety and Health, Centers for Disease Control, Public Health Service, US Department of Health and Human Services, Cincinnati, Ohio, United States.

[3] Lovelace Biomedical and Environmental Research Institute, Inc, Albuquerque, New Mexico, United States.

[4] HIV/AIDS Activity, National Institute for Occupational Safety and Health, Centers for Disease Control, Public Health Service, US Department of Health and Human Services, Atlanta, Georgia, United States.

Correspondence to: Dr J Smith, Division of Physical Sciences and Engineering, National Institute for Occupational Safety and Health, Cincinnati, Ohio 45237, USA.

each stage is measured by the frequency change of a crystal onto which the aerosol fraction is collected. The sample for the quartz crystal microbalance was drawn through an aerosol probe located near the surgical site and into a chamber at a flow rate higher than the sampling rate of the quartz crystal microbalance. This procedure minimized sampling delays and particle loss. The samples taken from the chamber with the quartz crystal microbalance and the excess flow was drawn through a filter so that the air could be sampled.

The third type of sample comprised area samples used to assess the spread of blood-containing aerosol to various areas within the surgical room. These samples were taken with total filters to estimate the aerosol concentration or rate of aerosol production in various parts of the room. A Lovelace multijet impactor was also used for the same purpose. The tissue source of the aerosol could also be determined from the samples. An electrostatic precipitator was used mainly for obtaining samples for electron microscopy in order that the morphology of the aerosol particles could be evaluated. These samples could be used to evaluate the tissue source of the particles.

The concentration and composition of the aerosol could be estimated in three ways. The first was by mass measurement, during which the impactor substrates and filters were weighed before and after the aerosol collection. In the experiments using a dog as a model, the red blood cells were radiolabeled to allow a sensitive measurement of the amount of blood in the aerosol. The third procedure involved the measurement of hemoglobin with CHEMSTRIP 9® (Boehringer Mannheim Corporation), a commercially available clinical chemistry device that provides a simple and sensitive method for evaluating the amount of hemoglobin present.

Hip replacement procedure. For the purpose of studying aerosol formation the hip replacement procedure was divided into five steps (table 2). The first step was the skin incision and exposure of the hip joint. This procedure involved skin incision, separation of the muscles, and opening of the joint capsule. Electrocautery was used to control bleeding during this part of the procedure, and it presented the greatest potential to produce aerosols. In the second step, the head of the femur was cut off, the femoral bone cavity was reamed for the prosthesis, and the acetabulum was enlarged and fitted with the acetabular prosthesis. According to previous studies, several tools have the potential to produce aerosols, including power saws, drills, and reamers, during this procedure. The third step was the cleaning of the surgical site and final installation of the prosthesis. Some hammering was performed during this step, but the most likely source of aerosols involved the use of pulsed irrigation. At the completion of this step the wound was closed. The fifth and final step was the cleaning of the room after the surgery. Surgical drapes and other equipment were contaminated with blood and other tissue fragments, and they were removed during this step.

Simulated human hip replacement with the dog as a model. The use of a simulated human procedure performed in the laboratory allowed better control over variables that affect aerosol production, and better techniques for aerosol collection and measurement could then be employed. The techniques that can be employed during actual human surgery are much more limited than those used in the laboratory because of considerations of infection control, equipment placement, and interference with surgical personnel.

The dog was chosen as the surgical surrogate for human surgery since the dog has sufficient size in its hip to mimic hip replacement in a human. In addition, a limited number of hip replacement prostheses for dogs are available that are very similar to those used in human hip replacement surgery.

The aerosol produced during the laboratory surgery was collected and measured by the aerosol collection instruments described earlier. One unique feature of the simulated procedure was the radiolabeling of the red blood cells of the dog with ^{51}chromium. This procedure allowed a more sensitive measurement of the amount of blood in the aerosol since ^{51}chromium

Table 1. Aerosol sampling and measuring instruments used in the study.

Instrument	Purpose
Marple personal impactors	Measurement of personal exposure and size distribution
Quartz crystal microbalance	Real-time assessment of emissions from different tools or processes and size distribution
Total filters	Measurement of total aerosol mass
Lovelace multijet impactor	Measurement of total aerosol mass and size distribution
Electrostatic precipitator	Samples for electron microscopy

Table 2. Steps and tools used in the total hip replacement.

Step	Tools used	Potential[a]	Type and size[b]
Skin incision and opening	Electrocautery	High	Peripheral blood, muscle — small size
Femur cutting, acetabulum forming	Bone drill, saw	High	Bone and bone marrow — large size
Fitting and placement of prosthesis	Reamers, hammer pulse irrigation	High	Bone marrow, blood, saline — large size
Closure	None	Low	
Room clean-up	Unknown	Unknown fragments	Blood, bone

[a] The potential for aerosol production.
[b] The type and size of the aerosol likely to be produced.

selectively labels red blood cells and can be measured with great sensitivity. An assessment of the amount of blood-containing aerosol produced could be made from the radiolabel measurements.

Figure 1 shows a diagram of the surgery room and the sampling instruments used during the hip replacement procedure in dogs. All of the personnel wore a Marple personal impactor to evaluate breathing zone exposure and to collect samples for size distribution and the average concentration for the duration of the surgery. A quartz crystal microbalance probe was held (by AS1 in figure 1) about 3—15 cm from the surgical site to obtain an air sample with a filter and the real-time size distribution of the aerosol produced by a given surgical instrument for a procedure. Two or three area filters and an overhead Lovelace multijet impactor were used to obtain information about the spread of the aerosol produced throughout the surgery room.

Human total hip replacement surgery. The aerosol measurement procedures during human total hip replacement were similar to those used for the simulated surgery. The hip replacement surgical procedure was performed in a normal fashion in an operating room commonly used for this type of surgery. However, there was less freedom in the placement of aerosol sampling instruments, and there was no control over the procedure in order to collect aerosol samples from certain parts of the procedure. There was no radiolabeling of blood, and therefore only mass measurements and hemoglobin analysis could be done on the samples collected from this surgery.

Figure 2 shows a diagram of the operating room where the human surgery was conducted. Again, selected individuals wore a Marple personal impactor to collect samples for size distribution and the average concentration for the duration of the whole period of the surgery. The probe of the quartz crystal microbalance was held about 5—20 cm from the surgical site to obtain the quartz crystal microbalance sample, a filter sample, and a sample for the electrostatic precipitator. Two or three area samples were taken with filters and an overhead Lovelace multijet impactor to monitor the spread of the aerosols throughout the room.

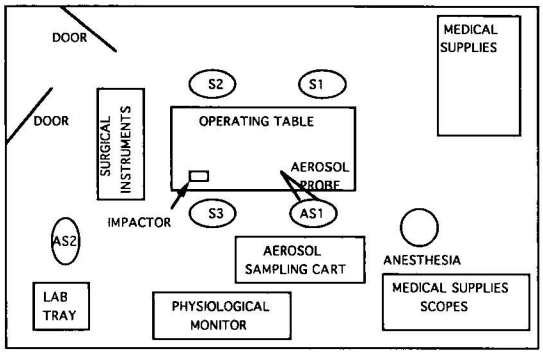

Figure 1. Operating room for dog surgery. (S1, S2, and S3 = surgeons; AS1 and AS2 = aerosol science personnel)

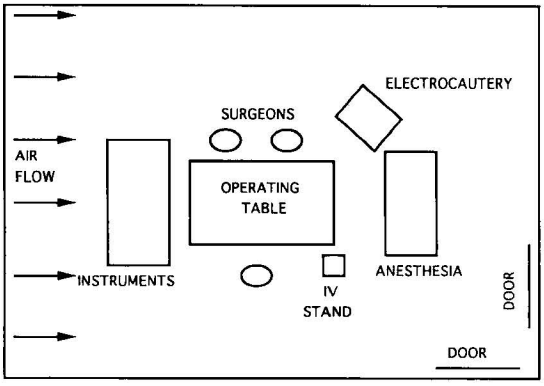

Figure 2. Operating room for human surgery.

Results

Aerosol samples were collected in several experiments using the hip replacement procedure in the dog. The data have not been analyzed to any great extent, and several further experiments are needed before a complete characterization of the aerosol produced can be obtained. The preliminary experiments showed that relatively low concentrations of aerosol were produced and that a large fraction of the aerosol was in the respirable size range. There was high variability in exposure among the personnel present. The quartz crystal microbalance was used to measure the size distribution of the aerosol produced at various times by different tools during the surgery. The aerosol had a multimodal size distribution with each mode attributable to the use of a given surgical tool. As expected, electrocautery was found to produce an aerosol with a relatively small particle size (< 1 μm). However, with the limited data obtained to date, it is difficult to separate aerosol particles produced by a given surgical tool from aerosols produced by another surgical tool. The measurement of hemoglobin with the CHEMSTRIP 9® was found to be a sensitive means of determining the amount of blood in the aerosol (5). In one preliminary experiment using a dog with radiolabeled blood, the CHEMSTRIP 9® showed the presence of hemoglobin in samples, whereas measurement of the radiolabel did not.

Future work

From measurements made during the simulated human hip replacement surgery performed in the laboratory and the actual hip replacement surgery performed in an operating room, an assessment of the ability of various surgical tools and procedures to produce aerosols will be made. This assessment will allow the ex-

posure of various surgical personnel to be assessed. After an assessment of the exposure, techniques for limiting exposure can be evaluated. These techniques might include the use of personal protective equipment or methods to control the aerosol at its point of production. Knowledge of the size distribution of the aerosol will be important in determining which of these control methods might be applicable. The aerosol measurements should be completed and analyzed by October 1992.

References

1. Marcus R. Surveillance of healthcare workers exposed to blood from patients infected with human immunodeficiency virus. N Engl J Med 1988;319:1118—23.
2. National Institute for Occupational Safety and Health. Guidelines for prevention of transmission of human immunodeficiency virus and hepatitis B virus to health-care and public safety workers, a response to public law 100—607, The Health Omnibus Programs Extension Act of 1988. US Department of Health and Human Services, 1989:37.
3. Day L. Perils of orthopedic surgery [letter]. Can Med Assoc J 1988;139:1035—6.
4. Moon KC, Niniger RC. Surgical laser smoke characteristics and applicable filtration system [abstract 1P.22]. American Association for Aerosol Research Meeting, 1989.
5. Heinsohn P, Jewett DL, Balzer L, Bennett CH, Seipel P, Rosen A. Aerosols created by some power tools: size distribution and qualitative hemoglobin content. App Occup Environ Hyg 1991;6:773—6.
6. Johnson GK, Robinson WS. Human immunodeficiency virus (HIV-1) in vapors of surgical power instruments. J Med Virol 1991;33:47—50.
7. Baggish M, Poiesz BJ, Joret D, Williamson P, Refai A. Presence of human immunodeficiency virus DNA in laser smoke. Lasers Surg Med 1991;11:197—203.