

NEW SOLUTIONS

A Journal of Environmental and Occupational Health Policy

Controlling Health Hazards to Hospital Workers

Theresa Gorman
Jonathan Dropkin
Jacob Kamen
Somashekhar Nimbalkar
Norman Zuckerman
Thomas Lowe
Jaime Szeinuk
Debra Milek
George Piligian
Alice Freund



A Reference Guide

On the Cover



Lost workdays due to employee injuries were reduced 96% after Methodist Rehabilitation Center installed ceiling lifts to transfer patients.

**Credit: Methodist Rehabilitation Center
Mississippi, U.S.**



Radiation Safety Technician at Mount Sinai Hospital checks for contamination after inpatient therapy procedure.

Credit: Mount Sinai Hospital Radiation Safety Department, New York, U.S.



A microbiologist at Shree Krishna Hospital uses a biological safety cabinet to prevent her exposure to harmful bacteria.

Credit: Shree Krishna Hospital, Gujarat, India

CONTROLLING HEALTH HAZARDS TO HOSPITAL WORKERS: A Reference Guide

*Theresa Gorman, Jonathan Dropkin,
Jacob Kamen, Somashekhar Nimbalkar,
Norman Zuckerman, Thomas Lowe,
Jaime Szeinuk, Debra Milek,
George Piligian, Alice Freund*

PREFACE

PREFACE

Hospitals have many unique hazards that can potentially affect the health of employees. These hazards include biological and chemical hazards, ergonomic hazards, hazardous drugs, ionizing and non-ionizing radiation, shift work, stress, and violence. They can be eliminated or reduced by a variety of exposure control methods, including design elimination, substitution, engineering controls, administrative controls, and personal protective equipment, in order of preference. Controls for more than 30 hazards, primarily focusing on engineering controls, are identified based on published studies, guidelines, and hospital walk-throughs. More than 150 engineering controls are identified to eliminate or reduce health hazards in the hospital setting. Internet-based resources are identified to obtain more detailed information. Published studies of control effectiveness are summarized in tabular form.

TABLE OF CONTENTS

TABLE OF CONTENTS

| | |
|---|----|
| PREFACE | 2 |
| INTRODUCTION | 6 |
| Research Sources | 7 |
| Organization of Content | 7 |
| Limitations | 8 |
| GENERAL INFORMATION FOR CONTROLLING | |
| EXPOSURES | 9 |
| Hierarchy of Controls | 9 |
| Ventilation | 10 |
| Setting Priorities | 13 |
| Worker Input | 13 |
| New Purchases and Donated or Borrowed Equipment | 14 |
| Renovations and Construction | 15 |
| CONTROLS FOR SPECIFIC HAZARDS | 16 |
| Section 1. Biological Hazards | 16 |
| Bloodborne Pathogens | 16 |
| Latex (Natural Latex Rubber) | 19 |
| Medical Waste | 22 |
| Methicillin-Resistant <i>Staphylococcus aureus</i> (MRSA) | 25 |
| Tuberculosis and Other Airborne Diseases | 27 |
| Section 2. Chemical Hazards | 37 |
| Cleaning Agents | 37 |
| Ethylene Oxide | 39 |
| Formaldehyde | 41 |
| Glutaraldehyde | 42 |
| Mercury | 43 |
| Methyl Methacrylate and Other Bonding Materials (Glues) | 46 |
| Surgical Smoke | 48 |

TABLE OF CONTENTS

| | |
|--|-----|
| Section 3. Ergonomic Hazards | 59 |
| Health Effects and Regulations | 59 |
| Computer Workstations | 61 |
| Hand Held Devices | 63 |
| Laboratory | 64 |
| Laparoscopy | 65 |
| Patient Handling | 65 |
| Radiology | 67 |
| Slips, Trips, and Falls | 69 |
| Sonography | 71 |
| Section 4. Hazardous Drugs | 83 |
| Aerosolized Medications | 83 |
| Anesthetic Gases | 86 |
| Antineoplastic and Other Hazardous Drugs | 88 |
| Nitric Oxide | 90 |
| Pentamidine | 91 |
| Ribavirin | 93 |
| Section 5. Radiation | 98 |
| Ionizing Radiation and General Controls | 98 |
| Radionuclides: Nuclear Medicine and Diagnostic Medical Imaging | 101 |
| Radionuclides: Radiation Therapy | 104 |
| X-Rays | 108 |
| Non-Ionizing Radiation | 110 |
| Section 6. Shift Work, Stress, and Violence | 126 |
| Shift work | 126 |
| Stress | 129 |
| Violence | 131 |
| DISCUSSION AND ADDITIONAL RESOURCES | 137 |
| CONCLUSIONS | 141 |
| ACKNOWLEDGMENTS | 141 |
| INDEX | 141 |
| REFERENCES | 142 |
| CONTRIBUTORS' BIOGRAPHIES | 165 |

TABLE OF CONTENTS

List of Tables

| | |
|---|-----|
| Table 1: Dilution Ventilation Requirements in Air Changes Per Hour (AC/H) and Pressure Relations for Select Rooms in Hospitals and Dental Operations | 11 |
| Table 2: Alternative Treatments for Medical Waste | 23 |
| Table 3: Strategies to Reduce Antimicrobial Resistance in a Hospital | 27 |
| Table 4: Studies of Controls for Biological Hazards | 32 |
| Table 5: Main Chemical Components of Cleaning Products | 38 |
| Table 6: Studies of Controls for Chemical Hazards | 52 |
| Table 7: Studies of Controls for Ergonomic Hazards | 73 |
| Table 8: Studies of Controls for Hazardous Drugs | 95 |
| Table 9: Maximum Permissible Dose (MPD) Limits for Ionizing Radiation | 99 |
| Table 10: Non-Ionizing Radiation Exposures from Various Types of Medical Equipment | 111 |
| Table 11: Health Effects and Symptoms of Non-Ionizing Radiation | 113 |
| Table 12: Guidelines for Non-Ionizing Radiation | 115 |
| Table 13: Studies of Controls for Radiation | 120 |
| Table 14: Studies of Controls for Shift Work and Violence | 135 |
| Table 15: Resources for Hazards Not Covered Elsewhere | 138 |
| Table 16: General Internet Resources for Hospital Hazards | 140 |

INTRODUCTION

INTRODUCTION

Theresa Gorman

Hospitals have many unique hazards that can potentially affect the health of employees. Exposures to occupational hazards throughout hospital departments are highly variable. Chemical exposures can occur from sterilants, disinfectants, cleaning compounds, hazardous drugs, mercury, and anesthetic gases. Biological hazards include viruses and bacteria, which cause hepatitis B and C, HIV, and tuberculosis, as well as latex allergy. Physical hazards include ionizing and non-ionizing radiation and ergonomic injuries from patient lifting and handling, lifting heavy equipment, and static postures. Finally psychological and work organization stressors include shift work, burnout, and the threat of workplace violence. Controlling and minimizing workplace hazards for healthcare personnel (HCP) in hospitals present a unique challenge because the health and wellbeing of hospital patients must also be considered. Industrial hygienists and safety professionals must work to control occupational exposures in a way that does not interfere with safe patient care.

There have been previous research, articles, and literature reviews on the potential acute and chronic health effects of various hazardous agents within hospitals [1-4]. They often characterize different types of hazards and identify exposed populations [5, 6]. Information about exposure controls can be found through a variety of resources, such as reference texts [2, 7, 8]; through government agency recommendations and regulations, such as the National Institute for Occupational Safety and Health (NIOSH), the Occupational Safety and Health Administration (OSHA), and the National Council on Radiation Protection and Measurements (NCRP), in the United States (U.S.); and the International Commission on Radiological Protection (ICRP), and the European Commission [9], or through case studies and published reports in the literature [10-12].

The goal of this guide is to briefly summarize the various hazards faced by hospital workers and effective control methods for these hazards; and to present the information in a way that it is easily accessible to hospital employees and healthcare safety professionals. This information is supplemented with a list of internet resources for further information for the reader. To accomplish this

INTRODUCTION

goal we have reviewed the published research, focusing primarily on engineering control methods for hospital health hazards. The nature of some hazards necessitates methods other than engineering controls. We explain the hierarchy of controls and other general considerations for controlling all workplace health hazards.

RESEARCH SOURCES

Hand and computer-assisted searches were conducted of journal articles in PubMed, the Web of Science, and Google Scholar to identify key resources for inclusion in this report. Searches were restricted to articles published in English after 1985. Key words used included “occupational hazards to healthcare workers,” “hospital hazards,” “industrial hygiene control measures hospitals,” as well as specific well-known hospital hazards such as ethylene oxide, glutaraldehyde, antineoplastic drugs, needlestick injuries, ionizing radiation, and safe patient handling. NIOSH, OSHA, and the Environmental Protection Agency (EPA) recommendations and guidelines were consulted for a particular hazard, when applicable (i.e., the OSHA Bloodborne Pathogen Standard and the NIOSH Alert on Antineoplastic Drugs). Articles that reported on specific control measures for hospital hazards were tallied and summarized. We made an effort to find and cite articles from many countries. Textbooks and other reference books on hazards of hospital workers also were consulted for recommendations on controlling exposures. Site visits to three New York City hospitals were conducted to view examples of various control measures.

OSHA Permissible Exposure Limits (PELs) and the American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLVs) booklet were both used to describe mandatory and recommended occupational exposure limits [13]. They were supplemented with NIOSH’s Recommended Exposure Limits (RELs) or ICRP’s guidelines when there were no OSHA or ACGIH limits or when NIOSH RELs or ICRP limits were more stringent.

This report primarily addresses hazards that are unique to hospitals or are relevant to most departments. Hazards not covered are listed at the end of the report (see [Discussion](#)) with a table of resources where the reader can find additional links to internet resources.

ORGANIZATION OF CONTENT

Information on controlling all hazards is presented in the beginning of this guide. Specific hazards are addressed in six sections, in alphabetical order, under the following headings. Within the sections, topics are listed in alphabetical order. The beginning of each section describes how HCP are exposed to the hazard, the health effects, and occupational exposure limits. It is followed by a section on controls and on internet resources for each topic. At the end of each

INTRODUCTION

of the six sections is a table summarizing the engineering control studies on the hazards covered in that section:

Section 1. Biological hazards: bloodborne pathogens, latex, medical waste management, methicillin-resistant *staphylococcus aureus* (MRSA), tuberculosis, and other airborne pathogens;

Section 2. Chemical hazards: cleaning agents, ethylene oxide, formaldehyde, glutaraldehyde, mercury, methyl methacrylate, surgical smoke;

Section 3. Ergonomic hazards: computer workstations, hand-held devices, laboratory, laparoscopy, radiology, safe patient handling, slips, trips, and falls, sonography;

Section 4. Hazardous drugs: aerosolized medication, anesthetic gases, anti-neoplastic drugs, nitric oxide, pentamidine, ribavirin;

Section 5. Radiation: ionizing radiation (radionuclides in nuclear medicine and diagnostic imaging, radionuclides in radiation therapy, X-rays), and non-ionizing radiation (magnetic resonance imaging, lasers, ultraviolet lights);

Section 6. Shift work, stress, and violence.

LIMITATIONS

Best available technology is constantly changing. Guidelines and research accessed in this report may soon be outdated by more currently available technology and information, not all of which can be evaluated by independent scientific or standard-setting agencies. Readers are therefore encouraged to scrutinize current technology to see if it has been independently evaluated if it is not contained in the latest recommendations of independent agencies.

This guide lists specific types of equipment for some control methods. They are only one component of an integrated hazard management plan. Such products or instruments change over time and evaluating technical specifications and actual performance under real life conditions in specific healthcare settings is beyond the scope of this report. Hence, independent evaluation is needed before purchase and during use to ensure that the desired efficacy is obtained in protecting those at risk.

The links to websites are here to help readers expand their resources. Although we have attempted to find websites and resources with useful information, we do not vouch for the accuracy or current availability of the information on these websites.

GENERAL CONTROLS: Hierarchy of Controls

GENERAL INFORMATION FOR CONTROLLING EXPOSURES

Alice Freund

HIERARCHY OF CONTROLS

A traditional concept, called the “hierarchy of controls,” is that exposure controls are most effective at the source and least effective at the worker. Controls are therefore often listed in order of effectiveness (from most to least) in this hierarchy: elimination, substitution, engineering, administrative, and personal protective equipment (PPE). The best controls of all are eliminating the hazard altogether or substituting a less hazardous chemical or process. Engineering controls, including enclosure, redesign, automation, ventilation, or robotics, are also effective and reliable methods of eliminating worker exposure to hazards [14].

When engineering controls are not feasible, the focus shifts from control of the hazard to risk reduction or risk avoidance strategies. Administrative controls, such as limiting exposure time, training, changing work practices, and operational and maintenance procedures, can reduce exposure to the hazard. Adequate staffing is important for controlling hazards in a number of ways, including limiting the amount of exposure to hazards like lifting, patient handling, violence, and stress. Adequate staffing also is necessary for cleaning and maintenance activities that reduce hazards. Adequate time must be allotted to the job to prevent incidents caused by overuse, rushing, or taking short cuts.

The least desirable type of control is PPE, which includes respirators, gloves, clothing, hearing protection, and other personal gear. The use of PPE usually requires special expertise in selecting the appropriate equipment or clothing based on the type and degree of the assessed hazard, selecting the proper size for each worker, and assuring proper fit (often with special testing equipment). A professional must also assure that the worker is trained to select the correct device in a particular circumstance; assure that the worker is trained to put on, wear, and take off the device; assure that the worker is medically fit to withstand

GENERAL CONTROLS: Ventilation

the physiological stress of extra gear; and maintain the devices. PPE is considered the last resort in protection because of a number of factors including unreliability, inability to fit certain individuals, lack of protection for some chemicals, the level of training necessary for some PPE, lack of compliance due to discomfort and unfamiliarity, and interference with other aspects of work. Most importantly, PPE is the last line of defense; if it fails, the worker has direct exposure to the hazard. Therefore, if it is used at all, it should be to supplement, rather than replace, other types of controls. For these reasons, we have focused primarily on elimination, substitution, and engineering controls. When other controls are critical, we have also mentioned them.

Engineering controls often need to be accompanied by administrative controls, such as training and policies, to make them effective. In addition, there are other administrative controls that should be applied across the board to many hazards. Rather than repeat them for each hazard we list them here:

- Eating and drinking must be prohibited where hazardous materials are handled.
- Policies, including written operating and maintenance procedures, are required to implement new processes or engineering controls.
- Labeling and warning signs are necessary to alert users of hazards.
- Regular inspection and maintenance of engineering controls, equipment, and the physical plant are critical.
- Workers need training in engineering controls, new processes, and equipment in order to understand their purpose and how to implement or operate them correctly.
- The effectiveness of controls, including engineering controls, policy, and training, needs to be regularly evaluated and updated.

Much of this report emphasizes engineering controls. It is assumed, however, that operating procedures, maintenance, training, and policies will be needed to effectively implement and enforce the use of these controls.

VENTILATION

One of the most common types of engineering controls is ventilation. Most ventilation systems fall into two main categories: local exhaust ventilation (LEV) and general ventilation. LEV is designed to remove air contaminants at the point where they are generated. These systems can be built into a facility or may be portable. They are designed to capture particles or vapors, eliminate them by some type of mechanical filtration or chemical treatment, and discharge them to the outdoors or back into the work area. An example would be a chemical fume hood in a laboratory or a smoke evacuator used for laser surgery. When purchasing LEV systems, users must be aware of the maintenance requirements for the units, including frequency of filter changes.

GENERAL CONTROLS: Ventilation

General ventilation is used to dilute air contaminants in a room by adding natural or mechanically supplied outdoor or treated air. These contaminants could be chemicals, infectious agents, or odors, for example. General ventilation is not considered suitable when contaminants are highly toxic (such as organic liquids with threshold limit values below 100 parts per million); when amounts generated are too great to feasibly dilute; when workers are very close to the source; or when contaminant generation is not uniform [15].

In the U.S., there are ventilation guidelines written by the American Society of Heating, Refrigerating and Air-Conditioning Engineering (ASHRAE) and the American Society for Healthcare Engineering (ASHE) for hospital construction which are sometimes adopted by the states as regulations [16]. Some of the design parameters, including air changes per hour (AC/H), in the ASHRAE guidelines are included in [Table 1](#), below. For a more complete list, including when exceptions can be made, temperature and humidity requirements, and how air can be recirculated, the reader should consult the referenced guidelines and the

Table 1. Dilution Ventilation Requirements in Air Changes per Hour (AC/H) and Pressure Relations for Select Rooms in Hospitals and Dental Operations [16, 19]

| Space | Minimum outdoor AC/H | Minimum total AC/H | Pressure relative to adjacent areas (if noted, must be exhausted directly to the outdoors) |
|--|----------------------|--------------------|--|
| Delivery rooms, surgical cytosopic rooms, and operating rooms that use general anesthetics* | 4 | 20 | Positive |
| Procedure rooms that use local anesthetics | 3 | 15 | Positive |
| Positively pressured rooms for immunocompromised patients | 2 | 12 | Positive |
| Newborn intensive care | 2 | 6 | Positive |
| Trauma room (crisis or shock); X-ray (surgery, critical care, and catheterization) (see below for X-ray diagnosis and treatment) | 3 | 15 | Positive |
| Endoscopy | 2 | 15 | Positive |
| Gastrointestinal endoscopy procedure room | 2 | 6 | Positive |

GENERAL CONTROLS: Ventilation

Table 1. (Cont'd.)

| Space | Minimum outdoor AC/H | Minimum total AC/H | Pressure relative to adjacent areas (if noted, must be exhausted directly to the outdoors) |
|---|----------------------|--------------------|--|
| Pharmacy | 2 | 4 | Positive |
| Patient rooms; newborn nursery; labor, delivery recovery, and postpartum; surgery recovery area; X-ray diagnosis and treatment; dialysis treatment area; most examination and treatment rooms (other than those that include bronchoscopy and anesthetic gases); critical and intensive care; burn unit | 2 | 6 | No requirement |
| Nuclear medicine treatment room; soiled or decontamination room in central supply; and most areas of the laboratory (excluding glass washing, media transfer, and sterilizing) | 2 | 6 | Negative (outdoors) [#] |
| Physical and hydrotherapy rooms | 2 | 6 | Negative |
| Bronchoscopy, sputum collection, and pentamidine administration | 2 | 12 | Negative (outdoors) |
| Enclosed dental operatory with nitrous oxide* | 3 | 12 | Negative (outdoors) |
| Open dental operatory without nitrous oxide | 2 | 6 | No requirement |
| Endoscopy cleaning; radiology dark room; hazardous materials storage; laundry | 2 | 10 | Negative (outdoors) |
| Dialyzer reprocessing room; sterilizer equipment room | — | 10 | Negative (outdoors) |
| Food preparation | 2 | 10 | No requirement |

*In addition to scavenging systems required for waste anesthetic gases.

[#]In addition to chemical fume hoods, where required by other codes and guidelines.

GENERAL CONTROLS: Setting Priorities

latest addenda to these guidelines. A free read-only copy can be found on the Facilities Guidelines Institute (FGI) website [17]. In general, rooms that generate harmful substances should be under negative pressure relative to surrounding areas (that is, air flows into these rooms from the surrounding areas) and should discharge contaminated air directly outdoors. Rooms where patients could be compromised by the infiltration of harmful substances, especially infectious agents (such as surgery or trauma units), should be under positive pressure (air flows out of the room to surrounding areas) [18].

SETTING PRIORITIES

The measures to control the hazards described in this guide are largely based on practices in many of the wealthiest countries in the world with access to advanced technology. Some go beyond current regulations. Therefore, they may not always be the most practical approach in settings where technology and resources are limited. Solutions will vary according to local factors such as types of patients, treatment options, building construction, climate, and access to resources such as water, power, and basic supplies. The health and safety professional will have to prioritize investments in controls, especially when resources are scarce.

Tools can be used to analyze hazards and trends and to identify areas where hazard control measures need to be improved. These tools include: employer records of injury and illness; accident investigation reports; insurance company (such as workers compensation carrier) injury data and summary reports; walk-through surveys using safety checklists; employee interviews and/or questionnaires; results of air and surface monitoring and radiation dosimeters; and networking and benchmarking with other health and safety professionals (for example, professionals in infection control, radiation safety, employee health, and risk management) within the hospital and region. Government agencies responsible for occupational health and safety and professional practice associations of industrial hygienists, occupational health nurses, health physicists, infection control practitioners, and safety experts can also be helpful in identifying priorities and solutions. Industrial hygienists are professionals trained to recognize and control health hazards in the workplace, and they can be contacted through their local and international professional societies (see www.ioha.net/) [20]. Some of the suggestions for safety improvement in this report can actually save a hospital's resources through decreased injury rates and absenteeism, not to mention enhancing the hospital's reputation in the community at large.

WORKER INPUT

The involvement of HCP in identifying areas of concern and priorities is critical. Front-line workers often can identify problems that managers and

GENERAL CONTROLS: Worker Input

supervisors may overlook. Front-line workers are also often in the best position to identify practical and cost effective solutions to a problem, since they understand the process the best. Money may be wasted if invested on solutions without their input. Participatory approaches to reducing injuries have been successful in healthcare facilities, as well as in many other types of workplaces [21].

It is very important that HCP be involved in the selection of appropriate engineering controls. Their input is necessary because, as the primary users of the new technology, they are in the best position to predict success or failure. They can provide input on the utility of the equipment or device, as well as potential obstacles for its effectiveness and how to overcome those obstacles. Ideally new technology should not only be selected by the users, but also by staff who will maintain, clean, repair, or otherwise interface with the equipment.

Employee involvement can be accomplished by establishing joint labor-management health and safety committees, either in each department, on each unit, for the facility as a whole, or a combination. It is important to include management representatives from key service areas such as purchasing, maintenance, and engineering.

Employee representatives should be selected by their peers or by the labor union, if there is one. They also may be willing volunteers, as long as they have the correct skill set. If management selects the worker representatives, they run the risk of choosing workers who may not have the respect of, ability to communicate with, or access to other workers in their department. Employees should be selected on the basis of their interest, leadership qualities, and communication skills. They will be responsible for communicating information from employees to management and vice versa. Employees from all relevant departments should be represented, including ancillary departments, such as housekeeping, maintenance, and security.

NEW PURCHASES AND DONATED OR BORROWED EQUIPMENT

New purchases that may affect the health and safety of HCP should be approved by the health and safety committee, safety professional, relevant employees, and managers. If possible, the hospital should conduct pilot studies with new equipment or get loans for trials from equipment manufacturers. Employees can then actually use the equipment to see its effectiveness and how practical it is to use before it is purchased.

The hospital policy should require pre-approval of both new and borrowed or donated equipment by facility/physical plant and clinical engineering staff to ensure the hospital's ability to support the equipment (e.g., weight, heat load, electrical requirements, maintenance requirements, compatibility with other equipment).

GENERAL CONTROLS: Renovations and Construction

Equipment that is borrowed or donated must be checked by clinical engineering staff and preventive maintenance must be done on them before using them on patients. PPE purchased and used by individual employees may not provide the intended protection and, therefore, the use of personally owned PPE should be carefully managed if not prohibited altogether. Use of equipment that is not purchased by the employer poses a liability issue as well.

RENOVATIONS AND CONSTRUCTION

Planned renovation and construction is an excellent opportunity to control hazards. If possible, hazards should be eliminated, rather than controlled by other means, at this stage. Controls will be less expensive if worked into the new design, compared to trying to retrofit them after construction is complete. A good example of this is ceiling lifts for patient handling (used to replace portable lifts or manual handling). It is most important to get input from safety and health professionals during the planning stage and from front-line workers who are intimately familiar with their needs, past problems, and designs used in other facilities in which they may have worked. By getting input from safety staff and front-line workers at the planning stage, hospitals can save resources in the long run by identifying and eliminating or controlling hazards before they arise.

Renovation and construction must be performed according to the local building code. In the U.S., the comprehensive Guidelines for the Construction and Renovation of Healthcare Facilities, published by the FGI, are often used. They are updated every four years and form the basis of some building codes. A read-only copy is available on the internet [17]. Codes and guidelines are not only focused on HCP health and safety, however. NIOSH and the American Society of Safety Engineers are promoting a strategy of focusing on safety and health in the design process. More information on these initiatives, known as Prevention through Design (PtD) or Design for Safety (DFS), can be found on the websites of these organizations, listed in the References section [22, 23].

1. BIOLOGICAL HAZARDS: Bloodborne Pathogens

CONTROLS FOR SPECIFIC HAZARDS

Section 1. Biological Hazards

BLOODBORNE PATHOGENS

Somashekhar Nimbalkar

Bloodborne pathogens are microorganisms which transmit disease by contact with blood. Contact may be direct, such as needlesticks or splashes of blood-containing fluids to the mucous membranes or open wounds, or indirect, such as when surfaces contaminated with blood come in contact with someone's mucous membranes or abraded skin. The most common bloodborne risks to HCP are Hepatitis B (HBV), Hepatitis C (HCV), and Human Immunodeficiency Virus (HIV) infections.

HBV can cause persistent infections, chronic liver disease, and hepatocellular carcinoma in the long term. In acute illness, it causes fever, anorexia, and jaundice and, rarely, acute liver failure. HCV infections rarely cause acute illness, but most of those infected will develop chronic infection and 10-15% will develop cirrhosis. HIV infection may cause an initial infection with flu-like symptoms. Without treatment, HIV progresses to Acquired Immune Deficiency Syndrome (AIDS), which damages the immune system.

The World Health Organization (WHO) estimates that in 2003 approximately 16,000 HCV infections, 66,000 HBV infections, and 1,000 HIV infections occur every year worldwide in HCP from needlestick injuries (NSIs) [24, 25]. About one million accidental needlestick injuries have been reported every year in China, translating into one HCP getting a NSI every 30 seconds [26]. In addition to the risk of bloodborne infections, HCP are at risk for the side effects of drugs used in post-exposure prophylaxis, as well as psychological fear and the uncertainty of acquiring the infection.

HCP at risk of bloodborne disease work in a variety of settings. They include intensive care units, operating rooms, emergency rooms, inpatient units, and transport teams, as well as home care. At risk HCP include physicians; surgeons; nurses; nursing assistants; laboratory staff; technicians; students; and service employees in departments such as laundry, dietary, environmental services and maintenance. Also included are personnel involved in handling biomedical waste, especially in developing countries where this is not yet mechanized.

1. BIOLOGICAL HAZARDS: Bloodborne Pathogens

Nursing personnel account for more than 40% of the needlestick injuries (NSIs) even in developed countries. The circumstances in which most NSIs occur involve manipulating a needle in a patient (26%), sharp disposal (21%), collision with a worker or sharp (10%), clean-up (9%), and recapping needles (5%) [27]. However, the relative percentages may vary in different countries as the engineering safety controls and education of the HCP regarding patient safety vary as well. Disposable syringes (30%), suture needles (20%), winged steel needles (12%), scalpel blades (8%), IV catheter stylets (5%) and phlebotomy needles (3%) are the kind of devices most often involved [27].

OSHA's Bloodborne Pathogen Standard requires a written exposure control plan (ECP), the use of engineering controls (safe needles, sharps containers, needleless systems), PPE, hepatitis vaccinations, training, and post exposure evaluation and follow-up [28]. There are no ACGIH guidelines for bloodborne pathogen exposure.

Controls (see also [Table 4](#))

Blood and body fluids from all patients must be treated as if they were infectious, whether or not an infection has been confirmed. This practice is called standard precautions, and includes hand hygiene, use of PPE, safe injection practices, safe handling of potentially contaminated equipment or surfaces, and respiratory hygiene (cough etiquette) [29].

Needleless systems should replace sharps, where possible. Decrease injection use and eliminate unnecessary sharps, such as towel clips used in surgery. Where possible, replace the following: hollow bore needles; needle devices that need to be pulled apart by the health care provider; needles that are left exposed on a syringe after use; and needles attached to tubing, such as butterflies, that can be difficult to place in sharps containers.

Sharps with engineered sharp injury protections: An ideal sharp is "passive," meaning that it has an integrated safety feature which does not require activation by the user. For active devices, the user should be able to easily activate it. There is a significant drop in the number of NSIs if a passive device is used (0.06 NSI/10,000 devices used) compared to an active device being used (5.2 NSI/10,000 devices used) [30].

Infusion therapy and vascular access: Needleless or protected-needle IV systems decrease needlestick injuries related to IV connectors by 62-88% [31, 32]. Needleless systems are available that deliver medication and fluids through a catheter port using non-needle connections. Jet injection systems, which administer medications below the skin or through the muscle, are available. Needles should be able to retract, sheath or blunt immediately after use. Needleless IV delivery system with blunt cannula access, safety lock winged needles, and single use safety syringe with sliding sheath, are other examples of engineered controls.

1. BIOLOGICAL HAZARDS: Bloodborne Pathogens

Syringes: Use syringes with needlestick prevention features such as those in which the needle retracts after use or those containing a shield which caps the used needle. Recapping of used needles is strictly prohibited and they should be disposed in sharps containers after use or destroyed using electrical equipment designed for this purpose.

Blood Collection: Phlebotomy injuries can be reduced by needle shields (by 82%), self-blunting needle (by 76%), hinged needle shield (by 66%), sliding shield, and winged-steel (butterfly-type) needle (by 23%) [33].

Suture needles: Blunt tip suture needles reduce the risk of NSI by 69% and are recommended to reduce percutaneous injuries; however their utility varies with operative site. They can be used to suture less dense tissue such as facial and muscle wherein more than 50% of suture NSIs occur. Blood vessels, bowel, and skin are often done with sharp-tip suture needles, but suture-free techniques are available for them as well [34].

Sharps containers: The containers must be provided in all areas where sharps are generated. They must be closable, puncture-resistant, leak-proof, spill-proof, free of contamination, and changed when three-quarters full. It should be easy to tell if they are full. They must be placed no higher than 54 inches from the floor with easy accessibility. If not wall-mounted, the sharps container must be in close proximity to the work site to prevent injuries while objects are being carried.

PPE: Gloves, gowns, and eye and face protection must be provided by the employer under OSHA regulations, in adequate sizes and quantities and at no cost to the employee, depending what part of the body is exposed. When there is a potential hazard to the eyes, nose, or mouth, then masks in conjunction with eye protection (such as goggles or glasses with solid side shields) should be worn. Face shields are an alternative in situations where it is not anticipated that fluids could go around the shield. Use of PPE must be enforced [35].

Work-practice controls: When sharps must be used, work practices include using instruments rather than fingers to hold needles, instructing verbally while passing sharps, avoiding hand-to-hand transfer of sharps by using a defined area where they are placed, minimizing splash or splatter; and double gloving [27].

Training: HCP should be trained on risks related to bloodborne pathogens on initial assignment, annually, and whenever changes in exposure are introduced.

Vaccination and treatment: Workers at risk of bloodborne exposure should be offered the HBV vaccine, since this protects them from infection. In case exposure does occur, HCP should have access to physicians immediately because post-exposure prophylaxis against HIV is most effective within two hours of exposure. Post-exposure prophylaxis for HBV is most effective within 24 hours.

Internet Resources

International Healthcare Worker Safety Center — UVA Health System:
www.healthsystem.virginia.edu/pub/safetycenter/

1. BIOLOGICAL HAZARDS: Latex

Safety Device List — UVA Health System:

www.healthsystem.virginia.edu/pub/epinet/new/safetydevice.html

CDC - Bloodborne Infectious Diseases - HIV/AIDS, Hepatitis B Virus, and Hepatitis C Virus - NIOSH Workplace Safety and Health Topic:

www.cdc.gov/niosh/topics/bbp/

Hospital eTool: Healthcare Wide Hazards - Bloodborne Pathogens:

www.osha.gov/SLTC/etools/hospital/hazards/bbp/bbp.html

WHO | Protecting Healthcare Workers: Preventing needlestick injuries toolkit:

www.who.int/occupational_health/activities/pnitookit/en/index.html

WHO | The SIGN alliance: http://www.who.int/injection_safety/sign/en/

CDC - Stop Sticks: Safer Sharps Devices - NIOSH:

<http://www.cdc.gov/niosh/stopsticks/safersharpdevices.html>

Needle Safety:

<http://www.Nursingworld.org/safeneedles>

FDA, NIOSH, and OSHA Joint Safety Communication: Blunt-Tip Surgical Suture Needles Reduce Needlestick Injuries and the Risk of Subsequent Bloodborne Pathogen Transmission to Surgical Personnel:

www.fda.gov/MedicalDevices/Safety/AlertsandNotices/ucm305757.htm

LATEX (NATURAL LATEX RUBBER)

Jaime Szeinuk

Natural latex rubber (NLR) is derived from the white, milky sap of rubber trees that are grown commercially, especially *Hevea brasiliensis*. This NLR contains the so-called pathogenicity-related proteins, such as hevein, chitinase, and β -1,3-glucanase, a number of organelles, and other basic proteins. When NLR goods are manufactured, chemicals, curing agents, and accelerators are added. The allergic response to NLR generally is a reaction to the protein in NLR and/or the chemicals used in the manufacturing process. NLR contains more than 200 identified allergens.

NLR gloves are the latex product most commonly used in the healthcare industry. Although their use in preventing exposure to bloodborne pathogens is extremely important, some healthcare workers, patients, and visitors may be allergic to NLR and need to be protected. Pre-powdered gloves are treated with cornstarch and then pass to a vulcanizing oven, at which time much of the allergenic protein in the NLR is absorbed by the cornstarch. The repeated donning and removal of gloves in the healthcare settings can generate an

1. BIOLOGICAL HAZARDS: Latex

atmosphere heavy with protein-charged cornstarch particles that are the main source of exposure to NLR allergens both via skin contact as well as by inhalation of the airborne particles. These particles can remain airborne for up to 24 hours, even posing danger for people who are not present when the gloves are being used. In addition, particles can travel through the ventilation systems of a facility [36].

The cornstarch slurry into which the gloves may be dipped during production is a highly favorable environment for bacterial growth. Although the bacteria themselves are subsequently killed on sterilization, endotoxic cell-wall lipopolysaccharides from gram-negative organisms may persist to cause dermatitis in the wearer. There is also some evidence that starch powder may itself be immunogenic. Surgical gloves are finally sterilized usually by irradiation. Ethylene oxide gas may be used as an alternative but NLR proteins can become more allergenic as a result and ethylene itself may act as a hapten.

Some other common medical devices that may contain NLR are: blood pressure cuffs, bulb syringes, catheters, dental coffer dams, elastic bandages, electrode pads, endotracheal tubes and airways, enema syringes, ventriculoperitoneal shunts, finger cots, IV-access injection ports, manual resuscitators, Penrose surgical drains, pulse oxymeters, stethoscope tubing, stretcher mattresses, tourniquets, and vascular stockings. NLR also may be found in some common household goods like adhesives, balloons, carpet backing, condoms, contraceptive diaphragms, elasticized fabrics, feeding nipples, household gloves, diapers and incontinence pads, infant pacifiers, rubber bands, and shoes.

The population at greatest risk of NLR allergies is health personnel who wear NLR powdered gloves daily and people who have undergone multiple surgical procedures as a result of injury, disease, or chronic conditions (spina bifida, genitourinary congenital defect). Others at risk are individuals who have experienced severe allergic reactions to certain foods such as banana, kiwi, avocado and other nuts, or who are atopic [36].

Health effects due to NLR are either allergic or irritant in nature. NLR allergy reactions can be type I (systemic, generally immediate and possibly life-threatening IgE-mediated allergy), that occur after skin contact or inhalation of NLR proteins; or type IV (delayed hypersensitivity), usually dermatologic reactions that can be seen several days after initial exposure but may last for several weeks or spread to other areas of the skin. Type I allergy produces symptoms such as rhinitis, conjunctivitis, asthma, urticaria (hives), facial edema, bronchospasm, and in some cases, anaphylaxis and death.

Irritant reactions are non-allergic in nature, affecting most commonly the skin, and may be reversible. Irritant dermatitis manifests as dry, itchy, scaly areas of skin that have come into contact with NLR. This reaction is aggravated by repeated hand washing, moisture left on the hands, or contact with irritating chemicals (such as alcohol-based hand sanitizer).

1. BIOLOGICAL HAZARDS: Latex

Controls

Converting to powder-free gloves in all healthcare settings is the single most important way to reduce occupational exposure to NLR, thereby reducing further sensitization and minimizing symptoms in already sensitized individuals [37]. Non-NLR gloves, such as vinyl, nitrile, polymer, or neoprene pose no risk to NLR-sensitive people and should be used for as many routine tasks and procedures as possible where appropriate. If a task requires NLR gloves, use of NLR-powder free gloves is recommended.

Healthcare personnel should take the initiative to develop policies and procedures for avoiding exposure to NLR. Education and training on NLR-related issues are key to controlling the problem of NLR-related allergies (see [educational materials under Internet Resources](#), below) [37, 38]. Identification of individuals with symptoms of NLR allergy and avoidance of contact with NLR until medically evaluated are essential in order to avoid medical consequences of further exposure. Washing hands with a mild soap and drying them thoroughly after using NLR gloves; avoiding oil-based creams or lotions when using NLR gloves, since they may cause the gloves to break down, thus releasing NLR proteins; and frequently cleaning work areas contaminated with NLR dust (such as upholstery, carpets, ventilation ducts and plenums) are recommended (see [NIOSH resources](#), below). NLR-safe areas, environments containing only non-NLR materials, should be provided for NLR allergic patients and health-care workers [39]. NLR-free materials should be available to HCP. There are no OSHA standards or ACGIH guidelines for NLR allergens. However, OSHA's PPE standard requires employers to select the most appropriate glove based on a risk assessment of exposure.

In some cases, facilities give pre-employment screening to assess NLR sensitivity risk, generally through questionnaires. This measure is not adequate to protect healthcare personnel since it usually does not detect individuals who may have been previously sensitized to NLR through other exposures such as cross-reaction with foods, prior surgery or others.

Internet Resources

Sussman G, Gold M. Guidelines for the management of NLR allergies and safe NLR use in health care facilities. American College of Allergy, Asthma and Immunology:

<http://www.aaaai.org/allergist/allergies/Types/latex-allergy/Pages/latex-allergies-safe-use.aspx>

New York State Department of Health. Latex allergy: information for health care professionals:

www.health.ny.gov/publications/1453/

1. BIOLOGICAL HAZARDS: Medical Waste

NIOSH Fast Facts. How to prevent latex allergies. DHHS (NIOSH) Publication No. 2012-119, February 2012:

www.cdc.gov/niosh/docs/2012-119/pdfs/2012-119.pdf

NIOSH Alert: Preventing allergic reactions to natural rubber latex in the workplace. DHHS [NIOSH] Publication 97-135:

www.cdc.gov/niosh/docs/97-135/

MEDICAL WASTE

Theresa Gorman

The definition of medical waste differs across countries and individual states in the U.S. The term “medical waste” is often used to describe waste products generated by hospitals, laboratories, and other medical facilities that are potentially infectious to humans. Medical waste generally includes cultures and stocks of infectious agents (i.e., discarded vaccines and culture dishes), liquid human and animal waste, materials stained with blood or body fluids, pathological waste (i.e., tissues or organs), used sharps, and waste from animals that have been exposed to agents infectious to humans. Different countries have different guidelines for handling medical waste, and most require some type of treatment to minimize exposure of the general public and hospital employees to infectious materials. Medical waste treatment typically involves four main goals: (1) inactivate or destroy infectious pathogens or microbes; (2) destroy sharps; (3) render waste unrecognizable for ethical and confidentiality considerations; and (4) reduce the volume of waste [40].

Other waste streams generated by hospitals, such as discarded PPE, excess prescription medication, chemical wastes, and radioactive materials may have adverse effects on both people and the environment, however, they generally do not pose risk of infection. Therefore, these hazardous waste streams are typically separated from infectious waste and do not have to undergo sterilization and disinfection procedures. However, some medical wastes may be classified as radioactive waste and will require additional controls.

There are no OSHA standards or ACGIH guidelines specifically for medical waste.

Controls (see also [Table 4](#))

Exposure to medical waste can be effectively minimized by management and disinfection procedures. Until the late 1990s, incineration was the most common method of medical waste treatment, both in the U.S. and worldwide [41]. Although effective and relatively inexpensive to maintain, burning medical waste emits pollutants such as dioxins, furans, hydrochloric acid, sulfur dioxide, nitrogen oxides, lead, mercury, and cadmium. These contaminants pose

1. BIOLOGICAL HAZARDS: Medical Waste

a significant threat to hospital workers, residents of the surrounding communities, and the environment [42]. In 1997, the U.S. EPA passed new air emissions standards requiring hospitals to either retrofit medical waste incinerators with costly air scrubbers to reduce pollution emissions or invest money in alternative treatment technologies. Three common treatment alternatives to incineration include steam autoclave, microwave, and chemical disinfection. Each technology has advantages and disadvantages (shown in Table 2) and there is no one correct method of medical waste treatment for all facilities.

In developing countries, incineration remains commonly used to treat medical and other types of clinical wastes. Properly designed incineration systems have high investments costs and even in well-designed systems there is risk of exposure to ash and other residue from the combustion process. Many countries do not have resources to construct properly made incinerators and do not use the proper fuel to burn the waste at high enough temperature, resulting in higher pollution emissions [43].

In addition to investing in the appropriate treatment technology, administrative controls, such as proper waste segregation and management, also can help

Table 2. Alternative Treatments for Medical Waste

| Treatment technology | Advantages | Disadvantages |
|-----------------------|--|---|
| Steam autoclave | <ul style="list-style-type: none"> • Used effectively in hospitals • Relatively low maintenance costs • Minimal environmental and health effects | <ul style="list-style-type: none"> • High capital investment cost due to installment of boilers and high pressure steam systems • Need for additional shredding and grinding machinery • Cannot treat hazardous wastes |
| Microwave | <ul style="list-style-type: none"> • Used effectively in hospitals • Minimal environment and health effects | <ul style="list-style-type: none"> • High capital investment and maintenance costs for machines • Need for additional shredding and grinding machinery • Cannot treat hazardous wastes or metals |
| Chemical disinfection | <ul style="list-style-type: none"> • Effective at treating a wide variety of infectious and hazardous wastes • Relatively low investment and maintenance costs | <ul style="list-style-type: none"> • Need to grind or shred waste before treatment which may aerosolize infectious waste • Exposure of hospital staff to hazardous chemical disinfectants |

1. BIOLOGICAL HAZARDS: Medical Waste

reduce exposure to infectious agents. Waste can be separated at the point of generation into the appropriate categories: medical waste, hazardous waste, recyclable materials, and general trash. These different waste streams are separated into color-coded puncture-resistant bins and plastic bags. Waste segregation requires comprehensive and ongoing training of hospital staff. Separating waste into these different streams prevents inflation of the amount of waste that requires disinfection treatment, and can save hospitals energy and money [44]. Regulated medical waste is about five times more expensive to treat and dispose than non-regulated, non-hazardous waste [42]. It is crucial to prevent hazardous waste from entering the regulated medical waste stream. Accidental treatment in autoclaves or incinerators of hazardous chemical waste can result in dangerous levels of toxic air and water emissions.

Waste segregation may be challenging in developing countries due to lack of recycling facilities and lack of money to implement the necessary waste separation practices. Hossain et al. recommend implementation of sterilization practices, specifically supercritical fluid carbon dioxide (SF-CO₂) sterilization for developing countries and other resource poor areas that do not have infrastructure or the money to implement facility-wide segregation practices at the point of waste generation [43]. When the temperature and pressure of CO₂ is increased above standard temperature and pressure to its critical point to where it becomes intermediate between a gas and a liquid and has the properties of both, it is able to permeate surfaces like a gas and has a high dissolving power like a liquid. SF-CO₂ can be used to sterilize medical and other infectious material at the point of generation rather than after segregation, which would allow the sterilized waste to be segregated, reused, or landfilled by non-skilled workers. SF-CO₂ has low toxicity and negligible environmental impacts, and shows promise as a viable alternative to incinerators and other costly alternative treatment technologies for medical waste.

Internet Resources

Health Care Without Harm. “Non-incineration Medical Waste Treatment Technologies.” August 2001:
www.noharm.org/lib/downloads/waste/Non-Incineration_Technologies.pdf

World Health Organization. “WHO core principles for achieving safe and sustainable management of health-care waste.” August 2007:
www.noharm.org/lib/downloads/waste/Safe_Healthcare_Waste_Mgmt.pdf

U.S. Environmental Protection Agency. “Medical Waste Frequent Questions.” November 2012:
<http://www.epa.gov/osw/nonhaz/industrial/medical/mwfaqs.htm>

1. BIOLOGICAL HAZARDS: MRSA

METHICILLIN-RESISTANT STAPHYLOCOCCUS AUREUS (MRSA)

Somashekhar Nimbalkar

Staphylococcus aureus (*S. aureus*) is a human pathogen causing a wide range of infections from mild skin and soft tissue infections to severe blood infection. It is also found on the skin and in the nose of healthy individuals. *S. aureus* strains which are resistant to the antibiotic methicillin and other antimicrobials are increasingly prevalent in the hospital environment [45]. MRSA is responsible for increased mortality in hospital inpatients and preventing nosocomial infections is a priority area in various high prevalence settings. MRSA colonization is seen in 4.6% of HCP with 5.1% of them being symptomatic, especially those with poor infection control (hand hygiene) practices, those with chronic skin diseases, and those working in countries where MRSA is highly endemic [46].

MRSA is in a class of organisms known as multi-drug resistant organisms (MDROs). They are not more likely to cause infection. Their importance is due to the fact that they are more difficult to treat with typical antibiotics. MDROs, including vancomycin-resistant enterococci (VRE), are discussed in more detail in the internet resources listed below.

MRSA can be contracted from patients and thus can be considered an occupational hazard. In certain countries, such as Germany, if it can be proven that an infection was contracted during work, then the worker is entitled to compensation. However, because *Staphylococcus* is a natural commensal, it may not be admissible as an occupationally acquired disease requiring compensation in other countries [47]. In the Netherlands, HCP who are colonized with MRSA have to seek alternative employment in spite of being asymptomatic [48].

A person can get MRSA by contact with their own nasal bacteria, by contact with an infected person's sore, or by contact with a carrier who is colonized, but has no symptoms. Hands are the most important means of transmitting infection. Objects such as clothing, equipment, and furniture can be involved in transmission. Airborne spread is possible, but rare. Workers with openings in their skin, with chronic illness, with compromised immunity or who live in crowded or unhygienic conditions are more likely to get Staph or MRSA.

HCP may transmit infections to their patients [46]. In a study by Lessing et al., nine outbreaks of MRSA were described in which a single HCP was responsible for two of them while the rest involved patients. Yet 22 other HCP were colonized and did not pass on the infection to co-workers or patients [49].

There are no OSHA standards or ACGIH guidelines specifically for MRSA.

Controls (see also [Table 4](#))

MRSA infections can be prevented by using contact precautions, proper hand hygiene, recognition of previously colonized and infected patients, rapid reports of lab results and training of HCP [50]. More novel control strategies

1. BIOLOGICAL HAZARDS: MRSA

have included targeted screening of all patients entering the hospital or patients entering certain high risk areas, such as the intensive care unit (ICU), as well as decolonization and chlorhexidine bathing (CDC) [50]. Strategies have differed according to the population served by the institutions and local prevalence of MRSA [51].

In Illinois, over a period of four years, a quasi-experimental study was done which looked at ICU-based surveillance, standard methods, and universal admission surveillance. It reported reduced MRSA infection in universal surveillance of patients [52]. A subsequent study done in Switzerland did not corroborate these findings [53]. A recent simulation study showed that in contrast to screening of healthcare workers and subsequent decolonization, which was ineffective, decolonization of patients is likely to be very effective [51]. Thus far, monitoring patients in intensive care appears to be a reasonable strategy. These recommendations, however, could change as new evidence accumulates. Monitoring decisions should take into account high risk populations and known outbreaks in the community.

HCP do not need to be tested for MRSA except for the rare occasion when there is a persistent cluster of infections in one unit, and then only after all other efforts to identify the source and educate the staff have failed to resolve the problem [54, 55]. Employees with staph infections, or who are known asymptomatic carriers, can continue working in most patient care areas, unless they have been identified as the source of an outbreak. Infected employees should cover their wounds and follow normal precautions (hand washing, use of gloves, etc.).

There are various measures to reduce the amount of antibiotic resistant organisms in hospitals. These measures are detailed in [Table 3](#) with infection control being of prime importance for reduction in settings where there is already a high prevalence of MRSA [56].

Internet Resources

Center for Disease Control and Prevention guidelines for MDROs in healthcare setting:

www.cdc.gov/hicpac/pdf/MDRO/MDROGuideline2006.pdf

Guide to the Elimination of Methicillin-Resistant Staphylococcus Aureus (MRSA) Transmission in Hospital Settings, 2nd Edition:

www.apic.org/Resource_/EliminationGuideForm/631fcd91-8773-4067-9f85-ab2a5b157eab/File/MRSA-elimination-guide-2010.pdf

Infectious Disease Epidemiology, Prevention and Control Division, Minnesota Department of Health, Recommendations for Prevention and Control of Methicillin-Resistant Staphylococcus Aureus (MRSA) in Acute Care Facilities:

www.health.state.mn.us/divs/idepc/diseases/mrsa/rec/rec.pdf

1. BIOLOGICAL HAZARDS: TB and Airborne Disease

Table 3. Strategies to Reduce Antimicrobial Resistance in a Hospital

Infection Control

- Surveillance for and feedback of laboratory data on antimicrobial resistance
- Hand hygiene
- Contact precautions
- Screening of high-risk patients with active surveillance
- Universal active surveillance
- Decolonization (treating colonized HCP with antibiotics so that MRSA is eliminated)
- Source control
- Cohorting of patients and staff
- Antimicrobial prophylaxis and decontamination to prevent infections
- Implementation of evidence-based best practices for invasive procedures and devices
- Disinfection and sterilization
- Cleaning the hospital environment

Antibiotic Stewardship

- Antibiotic restriction
- Decreasing unnecessary or inappropriate antimicrobial use
- De-escalation of therapy (in therapy of patients, changing antibiotics according to sensitivity as soon as results become known, rather than persisting with antibiotics that are broad spectrum and initiated on admission)
- Clinical decision support (having protocols to allow the HCP to manage antibiotics more rationally)
- Antibiograms (antibiotic sensitivity testing)

TUBERCULOSIS AND OTHER AIRBORNE DISEASES

Somashekhar Nimbalkar

Mycobacterium tuberculosis is a bacterium that infects humans, causing tuberculosis (TB). It flourishes in high oxygen-containing tissues such as lungs. It replicates slowly and can remain in a latent state for a long time [57]. *M. tuberculosis* is transmitted through airborne particles called droplet nuclei which are formed when individuals with pulmonary or laryngeal TB cough, sneeze, shout or sing. The droplets are sized 1-5 μm and remain airborne for prolonged periods of time spreading throughout the health facility [58]. Individuals suffering from HIV, diabetes, under-nutrition and vitamin deficiencies, silicosis and end stage renal failure are at a higher risk for developing tuberculosis. Overcrowded living conditions, smoking, indoor air pollution, alcohol,

1. BIOLOGICAL HAZARDS: TB and Airborne Disease

corticosteroid therapy, malignancy and genetic susceptibility are other risk factors associated with tuberculosis [57].

For HCP, latent tuberculosis infection (LTBI) can vary from 20% in the developed world [59] to 40% in Russia [60] to about 70% in the developing world [61]. The annual rate of tuberculosis infection (ARTI) in health care workers varies from 0.1% to 2% in unexposed hospital personnel as compared to 1 to 10% among highly exposed HCP. Administrative areas, outpatient and inpatient medical services, inpatient infectious services, surgical services, and laboratory services vary as to the degree of risk [59]. Nurses and doctors are more affected than students [60]. However, risk will vary depending on the healthcare setting, the prevalence of tuberculosis in the general population, and the exposures to the HCP. In low- to middle-income countries, the LTBI in HCP was 54% (33% to 79%), and ARTI was between 0.5% and 14.3%. The annual incidence of TB in HCP ranged from 60 to 5,780 per 100,000 compared to the general population incidence of 25 to 5,361 per 100,000 per year [62]. Hence, relying on data specific to the geographic location will help in making reasonable decisions. In a study from South Africa, the largest proportion of hospital staff infected with TB was in the pediatric, internal medicine, and surgical services at the time of diagnosis [63].

Active tuberculosis may be asymptomatic (nearly 25% newly diagnosed cases) or may have clinical signs such as: cough persisting for more than two to three weeks, low-grade evening rise in temperature, weight loss, and night sweats. Tuberculosis causes pulmonary tuberculosis most commonly, but it can infect almost any organ, and hence signs and symptoms may vary according to the organ affected [57].

Influenza, measles, rhinovirus, varicella, and severe acute respiratory syndrome (SARS) virus are among many other microorganisms which can be transmitted in healthcare settings by the airborne route (see the [California standard](#), below for an expanded list). Most of the above viruses will present with fever, coryza, headache, sneezing, and, if the illness worsens, shortness of breath, and rapid onset of respiratory failure. Unlike tuberculosis, these infections are not latent and do present with signs and symptoms on acquiring them. They are very contagious and infected individuals can transmit disease in the few hours before becoming symptomatic. Consult an infectious disease handbook or website such as that for the U.S. Centers for Disease Control and Prevention at <http://www.cdc.gov/DiseasesConditions/az/.html> (accessed 6/18/13) for more specific information.

There are no OSHA standards or ACGIH guidelines for airborne pathogens. The State of California's Aerosol Transmissible Diseases standard requires employers to implement detailed precautionary measures to protect workers from airborne pathogens (see [resources](#) below). The U.S. Center for Disease Control provides extensive guidelines (see [resources](#) below).

1. BIOLOGICAL HAZARDS: TB and Airborne Disease

Controls (see also [Table 4](#))

Administrative measures are critical to reduce the risk of exposure to persons with suspected or confirmed TB or other airborne illness [64]. These measures include a written infection control plan, prompt detection and isolation of suspected cases, training of staff, rapid reporting of diagnostic tests, education of patients and increasing community awareness (www.who.int/hiv/pub/guidelines/malawi.pdf [65]). Routine Tuberculin Skin Testing (TST) should be done in HCP and those showing positive reaction should be evaluated for tuberculosis [66].

Environmental controls are also an important line of defense to prevent airborne infection. These controls include LEV, general ventilation (natural as well as mechanical), or room air cleaners (filters or ultraviolet germicidal irradiation (UVGI)). LEV, in the form of an enclosed ventilated and filtered booth, is recommended for cough-inducing and aerosol-generating procedures, such as sputum induction and inhalation therapy. LEV should be considered in the autopsy room to reduce exposure to pathogens and embalming vapors. Class I or Class II biological safety cabinets should be used in the laboratory where infectious aerosols could be generated.

General ventilation systems prevent the spread of infection by diluting and removing pathogens. Patients suspected or confirmed to have airborne infections should be put in airborne infection isolation (AII) rooms. A single pass ventilation system (no recirculation; all air is exhausted to the outside) is preferred with 12 AC/H (6 AC/H in older buildings). Single pass systems are expensive to heat and cool. If recirculation occurs, then room air should pass through HEPA filters. All patient rooms (including those such as examination rooms wherein airborne pathogens are likely) are maintained at a minimum negative pressure with a differential of 0.01 inches of water [64, 67]. The ventilation system in AII rooms should be optimally designed to control airflow patterns so that aerosols generated by the patient are directed away from the HCP. More detail on designing AII rooms can be found in the Center for Disease Control guidelines below. In developing countries where such an elaborate arrangement may be expensive, recourse to natural ventilation can be taken with measures to ensure open windows and doors, using fans, and performing sputum collection in areas with appropriate ventilation. This approach may be as good as expensive systems requiring mechanized air ventilation [68].

Passing the room air through HEPA filters or UVGI can be equivalent to increasing the air exchange rate. Manufacturers should provide information on the clean air delivery rate. These systems have to be carefully installed and maintained. UVGI relies on a slow enough flow rate that allows enough time for the air to receive a certain amount of irradiance. The airflow must be such that contaminated air circulates past the light. Use of upper room ultraviolet germicidal inactivation is rendered less effective when humidity is greater than 70% and from poor maintenance, such as not replacing lamps (which lose

1. BIOLOGICAL HAZARDS: TB and Airborne Disease

effectiveness over time) and dust accumulation [69]. However it is an effective, low-cost intervention in high risk situations in developing countries provided that there is adequate mixing of room air [70]. It is important that the ultraviolet lights are not placed lower in the room where exposure to the eyes of room occupants, for even seconds to minutes, can cause eye injury [71].

Respirators are the last line of defense and are used at the point of care where risk of exposure is persistent. The drawback is that they may not be worn continuously and would be absent when caring for a low suspicion patient. In a highly infective environment, they may be absent in other expectedly low risk areas, such as cafeterias. OSHA requires annual fit testing to ensure that HCP are using appropriate sized respirators. Decreasing face-seal leakage of the respirator is required to ensure protection [64].

Where HCPs are exposed to airborne transmission of microorganisms, CDC and the HIPAC recommend the use of N95 respirators or higher respiratory protection. Examples are airborne anthrax, tuberculosis in high risk situations, monkey pox, Severe Acute Respiratory Syndrome (SARS), Middle East Respiratory Syndrome (MERS), certain strains of influenza, aerosol-generating procedures for seasonal influenza and viral hemorrhagic fever, and smallpox [29, 72, 73]. Higher levels than N95 may be needed for certain high risk procedures or exposures [29]. Cadavers must be considered as well as patients.

CDC currently recommends N95 or higher level respirators for personnel exposed to patients with suspected or confirmed tuberculosis [72]. The WHO also made a strong recommendation for the use of particulate respirators in healthcare facilities in its 2009 Policy on TB Infection Control [74]. WHO recommends the use of particulate respirators that meet or exceed the N95 standards set by NIOSH or the FFP2 (filtering facepiece with medium level of protection) standards that are CE certified (that is, they comply with European Union directives) particularly during high-risk aerosol-generating procedures associated with high risk of TB transmission (e.g., bronchoscopy, intubation, sputum induction procedures, aspiration of respiratory secretions, and autopsy or lung surgery with high-speed devices) and when providing care to infectious MDR-TB and XDR-TB patients or people suspected of having infectious MDR-TB or XDR-TB.

The U.S. Institute of Medicine has conducted several extensive reviews of respirator issues in healthcare settings [75]. Many lab studies have shown N95 masks to be superior to surgical masks [76]. A handful of field studies comparing the effectiveness of N95 respirators and surgical masks (SM) at preventing respiratory infection have been conducted. Some have reported that they are equally effective, or, more recently, that N95s are superior to surgical masks [77-79]. These field studies have limited value due to small numbers of participants, lack of control groups (no protection), and lack of information or analysis of important variables [80]. Such variables include other simultaneous interventions (such as hand washing), level of infection risk at the workplaces being compared, influenza vaccine status (in studies on influenza transmission),

1. BIOLOGICAL HAZARDS: TB and Airborne Disease

compliance with wearing respirators/masks (how often they were worn), and exposures outside of work. Because leakage around the mask is the most important route for inhalation, N95s are expected to be superior to surgical masks because they are designed to, and can be tested to, obtain a tight seal around the face; whereas surgical masks are not designed for this purpose. N95s also have a highly efficient filter which, together with the face seal, gives them a total protection factor of 10 (that is they reduce outside particles by 90%) when fitted and used correctly.

It is important to note that if N95s and other respirators are used without fit-testing and the other components of a full respirator program (including training and seal-checking), their usefulness may be minimal. A recent review of the controversy around respirators in healthcare settings concluded, “much of the resistance to respirators is because they require fit-testing, are more expensive than surgical masks, and may be uncomfortable to wear...” [81]. For the above reasons, several government agencies and occupational health and safety professional organizations recommend the use of N95 or higher level respirators to supplement other more reliable control methods, as discussed above.

Administrative, engineering, and respirator controls are specified for specific departments in the CDC guidelines, below.

Internet Resources

Johns Hopkins Safety Manual. Tuberculosis and other airborne pathogens:
www.hopkinsmedicine.org/hse/policies/hse_policies/indiv_sections/HSE601.pdf

California Code of Regulations. Aerosol Transmissible Diseases. Subchapter 7, Group 16, Article 109, Section 5199:
www.dir.ca.gov/title8/5199.html

OSHA, Safety and Health Topics. Tuberculosis:
<https://www.osha.gov/SLTC/tuberculosis/>

Director General of Health Services, New Delhi, Guidelines on Airborne Infection Control in Healthcare and other settings:
www.tbcindia.nic.in/pdfs/Guidelines_on_Airborne_Infection_Control_April2010_Provisional.pdf

Center for Disease Control and Prevention Guidelines for Preventing the Transmission of *Mycobacterium Tuberculosis* in the Healthcare Setting, 2005:
www.cdc.gov/mmwr/preview/mmwrhtml/rr5417a1.htm

1. BIOLOGICAL HAZARDS: Table of Control Studies

Table 4. Studies of Controls for Biological Hazards

| Hazard | Population studied | Control method(s) studied | Conclusions | Authors |
|----------------------|---|--|---|--------------------------------|
| Bloodborne pathogens | Nurses in a pediatric hospital in Boston | Engineering: implementation of a needleless system and transition to safety intravenous (IV) catheter products | Switching to a needleless system resulted in a decrease of exposures to bloodborne pathogens. However, implementation of safety IV catheters presented a challenge because many safety devices of small gauge tubing needed for pediatric procedures. | Marini et al. (2004) [82] |
| Bloodborne pathogens | All employees at risk for sharps injuries at a university hospital in Belgium | Engineering: implementation of vacuum systems and needleless infusion systems. Administrative: implementation of Universal Precautions and employee training sessions | The combination of safe needle devices and administrative changes resulted in an approximate reduction of 67 sharps injuries for nurses per 100 person-years and five sharps injuries per 100 person-years for all hospital employees. | Moens et al. (2004) [83] |
| Bloodborne pathogens | None; review article | Engineering: utilization of safe needles and needleless systems as required by the Needlestick Safety and Prevention Act of 2000 | All studies reviewed showed a 22% to 100% decrease in the rate of percutaneous injuries among healthcare workers since the Needlestick Safety and Prevention Act. | Tuma and Sepkowitz (2006) [84] |
| Bloodborne pathogens | Nurses from 32 hospitals in France | Engineering: utilization of safe needles as recommended by the French Ministry of Health | Use of safe needle devices resulted in an overall 75% decrease of needlestick injuries since recommendations were adopted; the decrease varied among different medical procedures. | Lamontagne et al. (2007) [85] |
| | | | Fully automatic devices were associated with the lowest NSIs. Semiautomatic safety devices were significantly more effective than those with a manually activated toppling shield, which were significantly more effective than those with a manually activated sliding shield ($P < .001$, χ^2 test). | Tosini et al. (2010) [30] |

1. BIOLOGICAL HAZARDS: Table of Control Studie

Table 4. (Cont'd.)

| Hazard | Population studied | Control method(s) studied | Conclusions | Authors |
|----------------------|--|---|--|----------------------------------|
| Bloodborne pathogens | NSIs in an 800 bedded Australian hospital | Engineering: replacement of conventional hollow-bore needles with simultaneous introduction of safety engineered devices (SEDs) such as retractable syringes, needle-free intravenous (IV) systems, and safety winged butterfly needles | A fall of 49% (43.1%-55.7%) in hollow-bore NSIs, contributed mainly by the virtual elimination of NSIs related to accessing IV lines. Retractable syringe use reduced high-risk injuries by 57%. | Whitby et al. (2008) [86] |
| Bloodborne pathogens | HCP in a major U.S. medical center | Engineering: intravenous (IV) catheter stylet with a retractable protection shield | Post implementation incidence of percutaneous injuries resulting from IV catheters with retractable shield decreased significantly compared to pre-implementation ($P < .01$). | Azar-Cavanagh et al. (2007) [87] |
| Bloodborne pathogens | Nurses in the emergency room and wards in Spain | Engineering: received training in using engineered devices and devices were made available in emergency room and half the wards | A 93% reduction in the relative risk of percutaneous injuries in areas where safety devices were used with rates remaining stable in wards where intervention not done. | Valls et al. (2007) [88] |
| Bloodborne pathogens | 427-bed tertiary care hospital in U.S. | Engineering: safety-engineered devices to allow for needle-safe IV delivery, blood collection, IV insertion, and intramuscular and subcutaneous injection | Mean annual incidence of percutaneous injuries decreased from 34.08 per 1,000 full-time-equivalent employees pre-intervention to 14.25 post-intervention. Nurses had the greatest decrease (75%) followed by other staff (61%) | Sohn et al. (2004) [89] |
| Bloodborne pathogens | Before-after trial of winged steel needle. Injuries in 1,190-bed acute care hospital in U.S. | Engineering: Safety re-sheathable winged steel needle | Injury rate dropped from 13.41 (pre-trial) to 6.41 per 100,000 after implementation (RR 0.48, 95% CI 0.31 to 0.73). | Mendelson et al. (2003) [90] |

1. BIOLOGICAL HAZARDS: Table of Control Studie

Table 4. (Cont'd.)

| Hazard | Population studied | Control method(s) studied | Conclusions | Authors |
|---------------|--|--|---|-----------------------------|
| Latex | HCP and at-risk patients (literature review) | Engineering controls: converting to powder-free gloves Administrative controls: develop policies and procedures to avoid latex exposure | Decreased exposure | Reed (2003) [37] |
| Latex | Healthcare workers (literature review, guidelines) | Work practices: primary prevention was education, avoidance of exposure, wearing of warning bracelets Engineering controls: latex-free environments | Decreased exposure | Cullinan et al. (2003) [36] |
| Latex | HCP, patients (literature review) | Work practices: screening, education Engineering controls: latex-free environment | Decreased exposure | Scanlan et al. (2007) [38] |
| Medical waste | None, review article | Engineering: supercritical fluid carbon dioxide sterilization (SF-CO ₂) as an alternative to incinerators | Hospitals lacking financial and personnel resources to invest in waste segregation should adopt SF-CO ₂ at the point of initial waste collection to eliminate infectious risk and minimize management costs. | Hossain et al. (2011) [43] |
| Medical waste | Three city hospitals in Massachusetts | Engineering: various cost-effective medical waste treatment technologies | The most cost effective treatment option was a combination of on-site incineration and microwave technologies, in conjunction with improved segregation of medical and non-medical waste streams. | Lee et al. (2004) [44] |
| Medical waste | Review article on biomedical research facilities | None, review article on best practices for biomedical research facilities | Improve training efforts, establish an information clearinghouse for all stakeholders, improve drug disposal practices, and update regulatory framework on regulated medical waste. Waste minimization and pollution prevention design elements should be incorporated. | Rau et al. (2000) [40] |

1. BIOLOGICAL HAZARDS: Table of Control Studie

Table 4. (Cont'd.)

| Hazard | Population studied | Control method(s) studied | Conclusions | Authors |
|--------------------------|---|---|---|--|
| Airborne pathogens | Various hospital rooms in Australia | Engineering: ventilation with air exchanges | Air exchange measurements combined with modeling gives an idea of room ventilation ability to prevent transmission. | Knibbs et al. (2011) [91] |
| Tuberculosis (TB) | HCP Latent TB infection (LTBI) in Brazil | Administrative and Personal Protective Measures | Number of tuberculin skin test (TST) conversions per 1,000 person-months decreased from 5.8 to 3.7. Physicians and nurses had highest reduction, with wards and ICU having the most reductions. | Costa et al. (2009) [92] |
| TB | HCP LTBI in U.S. | Administrative and Engineering controls PPE: N-95 respirators with one time qualitative fit testing | Sharp decrease in TST conversions after administrative and engineering controls. A less significant decline after use of N-95 respirators. | Welbel et al. (2009) [66] |
| TB | HCP-annual rate of TB infection (ARTI) in Italy | Administrative: organizational and educational interventions Engineering: containment of biohazard | Reduction of ARTI by 1.3/100 person years. | Baussano et al. (2007) [59] |
| Airborne pathogens | Sputum collection room in Montreal | Engineering: air changes and UVGI | Exhaust ventilation and UVGI do not reduce airborne bacterial concentrations adequately. Hence HCP need to wear personal respirators. | Menzies et al. (2003) [93] |
| Airborne pathogens: SARS | Workers and patients in a community hospital in Ontario | Engineering: dedicated negative pressure isolation rooms, local and dilution ventilation, HEPA filtration Administrative: restricted visitors, medical surveillance, worker training, hazard communication PPE: N-95 particulate respirators, double gowns and gloves | No secondarily infected cases of SARS were reported in this hospital after implementation of control measures. | Dwosh et al. (2003) [94] and Thorne et al. (2004) [95] |

1. BIOLOGICAL HAZARDS: Table of Control Studie

Table 4. (Cont'd.)

| Hazard | Population studied | Control method(s) studied | Conclusions | Authors |
|---|---|--|--|---|
| Airborne pathogens: TB | Healthcare workers in a public hospital in Brazil | PPE: evaluated the use of N-95 respirators to reduce risk of tuberculosis exposure | N-95 respirators were not frequently used in high-risk exposure areas. Therefore, PPE alone is not an effective control measure for hazardous occupational exposures. | Biscotto et al. (2005) [96] |
| Airborne pathogens: TB | All healthcare workers in one teaching hospital in Brazil | Engineering: patient isolation rooms Administrative: patient isolation rooms, employee training, and education PPE: N-95 respirators | Engineering and administrative control measures significantly reduced the risk of latent tuberculosis infection among all employees, with the greatest reduction found among doctors and nurses. | Albuquerque da Costa et al. (2009) [92] |
| Airborne pathogens: influenza | Nurses in eight hospitals in Ontario | PPE: effectiveness of N-95 respirators compared to surgical masks at protecting healthcare workers from influenza | Surgical masks provided the same protection as N-95 respirators for influenza, but should not be used for high risk settings, such as treating patients with suspected tuberculosis. | Loeb et al. (2009) [79] |
| Airborne pathogens: viral and respiratory illness | 1669 HCP in 19 hospitals in China | PPE: effectiveness of N-95s compared to surgical masks | Continuous use of N-95s was more effective against clinical respiratory illness (CRI) than continuous use of surgical masks. Rate of CRI was 17% for SM compared to 7.2% for N-95. | MacIntyre et al. (2013) [77] |
| Airborne pathogens: viral and respiratory illness | 1441 HCP in 15 Beijing hospitals | PPE: effectiveness of fit-tested and non-fit-tested N-95s and surgical masks | Rates of CRI (3.9 vs. 6.7%), influenza-like illness (0.3 vs. 0.6%), lab confirmed respiratory virus (1.4 vs. 2.6%), and lab-confirmed influenza (0.3 vs. 1.0%) were lower for N-95 group. | MacIntyre et al. (2011) [78] |

2. CHEMICAL HAZARDS: Cleaning Agents

Section 2. Chemical Hazards

CLEANING AGENTS

Theresa Gorman

There are a variety of cleaning products used during hospital housekeeping activities (excluding sterilization and disinfection of surgical or medical instruments) on floors, windows, bathrooms, carpets, and other surfaces throughout the hospital and waiting areas. Hospital environmental service workers and housekeeping staff are at highest risk of exposure; however, hospital patients, visitors, and other hospital staff also can be exposed. Accidental exposures to large concentrations can occur through spills or during mixing of incompatible chemicals.

The primary routes of exposure to cleaning agents are inhalation of aerosolized droplets or vapors and skin exposure. Several cleaning agents are known sensitizers and can lead to dermatitis upon repeated skin exposure. “Wet work,” or exposure to water during cleaning procedures, can increase the risk of skin irritation and skin absorption [97]. [Table 5](#) shows the health effects of commonly used cleaning agents based on epidemiological studies on janitors, cleaners, and other housekeeping staff employed in hospitals, office buildings, schools, and private homes. The health risk associated with cleaning agents varies depending on the type of cleaning agent used and the concentration in which it is used. Review articles on environmental service workers also have reported an association between exposures to cleaning agents; particularly those with low molecular weights and chlorine bleach products, and new-onset and work-exacerbated asthma [98, 99].

There are no exposure guidelines for cleaning agents per se. However, OSHA, ACGIH, and NIOSH may have occupational exposure limits for specific ingredients.

Controls (see also [Table 6](#))

Substitution may not be feasible for certain cleaning agents; however, hospitals can purchase cleaning agents that have no added synthetic fragrances. Natural ventilation, such as keeping the windows opened in the area that is being cleaned, is important during application of heavy cleaning products, which

2. CHEMICAL HAZARDS: Cleaning Agents

Table 5. Main Chemical Components of Cleaning Products [97]

| Type of product | Purpose | Chemical components | Primary health effects |
|----------------------------------|--|--|--|
| Detergents (surfactants) | Lower surface tension of water | Fatty acid salts (soap), organic sulphonates | Skin, eyes, and mucous membrane irritation |
| Complex agents (water softeners) | Dissolve and bind calcium and other cations; regulate pH | Ethylenediamine tetraacetic acid (EDTA), tripolyphosphates | Skin, eyes, and mucous membrane irritation |
| Alkaline agents | Dissolve fatty substances, disinfection, inhibit corrosion of metal surfaces | Silicates, carbonates, sodium hydroxide, ammonia | Skin, eyes, and mucous membrane irritation |
| Acids | Dissolve calcium | Phosphoric, acetic, citric, sulphamic, hydrochloric acid | Skin, eyes, and mucous membrane irritation |
| Solvents | Dissolve fatty substances | Alcohols, glycol ethers | Neurotoxin |
| Corrosion inhibitor | Protection of metal surfaces | Ethanol amines | Sensitization |
| Film formers, polishes | Surface care | Wax, acryl polymers, polyethylene | Sensitization |
| Disinfectants | Destroy bacterial and other micro-organisms | Hypochlorite, aldehydes, quaternary ammonium compounds | Sensitization, mucous membrane irritation |
| Preservatives | Avoid microbial growth during product storage | Benzalkonium chloride, isothiazolines, formaldehyde | Sensitization |
| Perfumes, scents | Introduce pleasant smell | d-limonene, terpenes (pinene) | Sensitization, irritation |

2. CHEMICAL HAZARDS: Ethylene Oxide

is typically done at night when general building ventilation is reduced. Replacing spray cleaning formulas with wipes or liquid formulas reduces the risk of inhalation exposure. Ordering ready-to-use cleaners instead of cleaners that need to be mixed together or diluted can reduce the risk of spills. Automated mixing and dilution systems eliminate worker exposure to concentrated solutions and prevent dilution errors. Using disinfectants and antiseptics only when necessary and cleaning heavily soiled areas more frequently with less harsh detergents can also minimize exposures. For example, many hospitals have eliminated the routine use of disinfectants on floors and instead use less hazardous cleaning solutions. Administrative controls may also be effective in reducing occupational exposures such controls include work shift rotations and documented employee training. Suitable PPE includes appropriate gloves, non-absorbent gowns, and eye protection to minimize skin and eye exposure. Carefully selected respiratory protection is recommended when using high concentrations of harsh cleaning agents that may become aerosolized or vaporized [97].

In an effort to be environmentally conscious, some hospitals are switching to “green” cleaning products, however there is no standard as to what “green” means. Switching to more environmentally friendly cleaners does not mean that these products are safer for workers.

Internet Resources

Risks to Asthma Posed by Indoor Health Care Environments: A Guide to Identifying and Reducing Problematic Exposures, 2006:

www.noharm.org/lib/downloads/cleaners/Risks_to_Asthma_Guide.pdf

Health Care Without Harm, “Cleaning in Healthcare Facilities: Reducing human health effects and environmental effects” April 2009:

www.sustainableproduction.org/downloads/CleaninginHealthcareFacilities.pdf

Occupational Safety and Health Administration, “OSHA/NIOSH InfoSheet: Protecting workers who use cleaning chemicals” 2011:

www.osha.gov/Publications/OSHA3512.pdf

University of Massachusetts Lowell, “Cleaner Solutions Database”:

www.cleanersolutions.org/

ETHYLENE OXIDE

Theresa Gorman

Ethylene oxide (EtO) is a flammable colorless gas used to sterilize medical equipment that cannot tolerate heat, moisture, and abrasive chemicals such as optical, rubber, and plastic instruments and devices. Small cartridges containing

2. CHEMICAL HAZARDS: Ethylene Oxide

100% EtO are used in fully automated sterilizing machines. Large cylinders of 12% EtO and 88% Freon are used for multi-chamber manual machines [100]. Workers at risk of exposure are staff working in central supply, who change EtO cylinders, and workers in other areas where sterilization takes place. The principal route of exposure is inhalation.

EtO is a known human carcinogen and reproductive toxin. Acute health effects include irritation of the eyes and upper respiratory system, depression of the central nervous system, headache, and nausea.

The OSHA PEL and ACGIH TLV for EtO is a TWA of 1.0 parts per million (ppm). The OSHA action level is 0.5 ppm and the excursion limit is 5 ppm. The NIOSH REL is a TWA of less than 0.1 ppm and a ceiling limit of less than 5 ppm for any 10-minute period per day.

Controls (see also [Table 6](#))

The use of a fully enclosed, automated, single chamber sterilizing machine can reduce airborne concentrations of EtO to well below the PEL and TLV [101, 102]. These types of sterilizers eliminate direct worker contact with EtO because the cartridge of EtO is automatically punctured inside the machine when the door is closed and locked shut. The single chamber also eliminates worker exposure that would otherwise occur while transporting the sterilized objects from the sterilizer to an aeration chamber for off-gassing the removal of the EtO. As a result, PPE is not required when using enclosed automatic EtO sterilizers. When using a manual, multi-stage EtO sterilizing machine, LEV is recommended near the sterilizer door, the exhaust drain of the machine, and in storage areas of EtO cylinders to prevent exposures in the loading and aeration processes, as well as overexposures from leaks in the system. Alarm systems can be installed to alert workers when EtO has escaped into the environment [102, 103].

Possible substitutes for EtO include peracetic acid and plasma phase hydrogen peroxide (see [EPA Newsletter](#), below).

Internet Resources

NIOSH, “Safety and health topics: ethylene oxide”:
www.cdc.gov/niosh/topics/ethyleneoxide

Environmental Protection Agency newsletter: “Best practices for health care facilities: replacing ethylene oxide and glutaraldehyde”:
www.epa.gov/region9/waste/p2/projects/hospital/glutareth.pdf

2. CHEMICAL HAZARDS: Formaldehyde

FORMALDEHYDE

Theresa Gorman

Formaldehyde is primarily used as a tissue preservative in hospital laboratories and autopsy suites. It is usually found in a solution called formalin, which is 37% to 50% formaldehyde in water with a 6-15% alcohol stabilizer (see [OSHA Fact Sheet](#), below). Lab and autopsy suite workers are at risk of exposure to formaldehyde. Inhalation and skin absorption are the main routes of exposure.

Formaldehyde is a confirmed human carcinogen [104]. Skin exposure can cause sensitization, which can lead to dermatitis upon contact with small amounts of formaldehyde or formalin. Other health effects of formaldehyde exposure are irritation and burning of nose and throat, irritation of mucous membranes, burning of the skin, coughing, and vomiting. Formaldehyde is also highly flammable.

The OSHA PEL is 0.75 ppm with a 15-minute ceiling of 2 ppm, and the ACGIH TLV-Ceiling limit is 0.3 ppm. NIOSH recommends a TWA of 0.016 ppm and a ceiling of 0.1 ppm.

Controls (see also [Table 6](#))

Localized ventilation systems should be installed where formaldehyde is used and stored. Labs that use formaldehyde should be under negative pressure with a minimum of 10 air changes per hour. Containers of formaldehyde and/or formalin should be tightly sealed to prevent off-gassing [105]. Latex gloves should be avoided when handling formaldehyde due to risk of developing skin allergies. Suitable PPE include rubber gloves, face shields or safety goggles, and aprons [105].

Internet Resources

OSHA Fact Sheet: Formaldehyde:

www.osha.gov/OshDoc/data_General_Facts/formaldehyde-factsheet.pdf

NIOSH Health and Safety Topics: Formaldehyde:

www.cdc.gov/niosh/topics/formaldehyde/

New Jersey Hazardous Substance Fact Sheet, Formaldehyde:

<http://nj.gov/health/eoh/rtkweb/documents/fs/0946.pdf>

CCOHS Basic Information on Formaldehyde Solutions:

www.ccohs.ca/oshanswers/chemicals/chem_profiles/formaldehyde.html

2. CHEMICAL HAZARDS: Glutaraldehyde

GLUTARALDEHYDE

Theresa Gorman

Glutaraldehyde is used as a cold high level disinfectant for heat sensitive medical equipment, primarily endoscopes. It is typically found in a 2% concentration in liquid disinfectants under the brand names Cidex, Metricide, or Sporicidin. Unlike sterilization procedures that are performed in a central location, disinfection of medical instruments is often performed throughout the hospital and in hospital clinics, including endoscopic units, operating rooms, ICU, and dialysis wards where quick turnaround times are needed to meet patient demands. Therefore, all workers in these areas where glutaraldehyde is used are at risk of exposure (see [NIOSH alert](#), below). Inhalation and dermal absorption are the principal routes of exposure.

Respiratory and skin sensitization effects of glutaraldehyde have been well documented in the literature [3] and can lead to asthma, rhinitis, and contact dermatitis (see [NIOSH alert](#), below). Other health effects of glutaraldehyde include irritation of the upper respiratory system, wheezing, nosebleed, and headache.

There is no OSHA PEL for glutaraldehyde. However, the ACGIH is 0.05 ppm as a short-term exposure limit (STEL). The NIOSH REL is a ceiling of 0.2 ppm.

Controls (see also [Table 6](#))

Fully automated and enclosed disinfecting machines with LEV can reduce airborne exposures [106, 107]. Manual disinfecting procedures, especially the practice of using open trays of glutaraldehyde, should not be used. Perdelli et al. documented disinfecting procedures in an outpatient endoscopic department where glutaraldehyde concentrations were kept well below the TLV due to successful utilization of automatic closed-cycle disinfecting machines, LEV, isolation of the disinfecting machines, and proper disposal of used glutaraldehyde at the end of each work shift [11]. Recommended PPE for handling glutaraldehyde are safety goggles, impervious aprons, and nitrile or rubber gloves. NLR gloves should not be used due to the risk of developing latex allergies when handling glutaraldehyde and the permeability of the gloves varies based on the manufacturer [105].

Many health facilities have begun to phase out the use of glutaraldehyde due to its sensitization effects. In 2002, glutaraldehyde was removed from the market in the United Kingdom in favor of ortho-phthalaldehyde (marketed as Cidex OPA) and peracetic acid alternatives. (For more information on the safety of these substitutes, refer to the 2002 Health and Safety Executive report, below).

2. CHEMICAL HAZARDS: Mercury

Internet Resources

Occupational Safety & Health Administration. “Best Practices for the Safe Use of Glutaraldehyde in Health Care”:

<http://www.osha.gov/Publications/3258-08N-2006-English.html>

NIOSH, “Safety and health topic: glutaraldehyde”:

www.cdc.gov/niosh/topics/glutaraldehyde/

NIOSH Alert Publication No. 2001-115, “Glutaraldehyde – occupational hazards in hospitals”:

www.cdc.gov/niosh/docs/2001-115/

Health and Safety Executive, “An evaluation of chemical disinfecting agents used in endoscopy suites in the NHS”:

www.hse.gov.uk/research/rrpdf/rr445.pdf

MERCURY

Alice Freund

Mercury is primarily used on nursing floors in thermometers and blood pressure machines where it is present as metallic mercury, although many hospitals around the world are phasing out these uses. Mercury is also found in dental clinics; in medical devices used in the digestive tract, and in eye surgery; in laboratory chemicals; in pharmaceutical products; as contaminants of cleaning products formed in the manufacture of certain ingredients; in batteries; in fluorescent, high-intensity-discharge, and ultraviolet lamps; in electrical switches and relays; in gas thermostats; in industrial thermometers and pressure gauges, including barometers; and as waste in plumbing. The U.S. EPA, reference (below), Reducing Mercury Use in Healthcare, Promoting a Healthier Environment, Chapter 3, includes a more detailed list, including the form of mercury in these sources. Metallic mercury and other forms of mercury can be inhaled or absorbed through the skin. Exposure is possible when mercury is spilled, during improper cleaning of a spill, during the maintenance of mercury-containing equipment, when mercury is transferred, or from inadequate ventilation to control vapor from sources and from past spills.

The nervous system is very sensitive to all forms of mercury. Metallic mercury vapors are more harmful than other forms found in hospitals, because more mercury reaches the brain. The primary long-term effects from exposure to high levels of metallic, inorganic, or organic mercury are permanent damage to the brain, kidneys, the lining of the mouth and lungs, and the developing fetus. Mercuric chloride, used in some laboratory solutions, is a mutagen and carcinogen.

2. CHEMICAL HAZARDS: Mercury

Symptoms of mercury poisoning can include skin, eye, nose, throat and lung irritation; coughing, wheezing or shortness of breath; metallic taste in the mouth; nausea, vomiting and abdominal pain; increases in blood pressure or heart rate; skin allergy and discoloration; tremors, personality changes, trouble remembering and concentrating; gum problems; and kidney damage [108-110].

The OSHA PEL for metallic and inorganic mercury is 0.1 mg/m³ as an eight-hour TWA. The ACGIH TLV for elemental and inorganic mercury is a TWA of 0.025 mg/m³. The NIOSH REL is 0.05 mg/m³ as an eight-hour TWA with a ceiling of 0.1 mg/m³ for mercury vapor. ACGIH also has guidelines for blood and urine levels of elemental mercury.

Controls (see also [Table 6](#))

The most effective control for mercury is substitution with a safer chemical solution or process. In the last ten years, most U.S. hospitals have phased out the use of mercury thermometers and many states have banned or severely limited sales or use of mercury-containing blood pressure machines. Mercury thermometers were banned in the European Union in 2007. In 2008, the WHO and Health Care Without Harm began a global initiative to eliminate mercury-based thermometers and blood pressure machines. A number of countries, including Argentina and the Philippines, have issued national policies to phase them out, and other countries and cities (including New Delhi, Mexico City and Sao Paulo) have launched voluntary phase-out programs [111]. Substitutes for mercury-containing equipment and chemical solutions can be found on the U.S. EPA website below.

Where mercury is still in use, it should be handled carefully. Work on blood pressure machines should be conducted under a chemical exhaust hood or in a well vented area. Mercury vapor respirators should be considered for this job. Bench tops and floors where mercury is handled should be constructed so that they can be easily cleaned. Laboratories and dental clinics should have good ventilation (see [Introduction](#)). Smooth surfaced tables or benches where mercury is commonly handled should be designed with troughs to collect mercury spills. Spills must be cleaned thoroughly to prevent future vaporization.

Never use an ordinary vacuum or broom to clean up mercury, as doing so spreads the contamination and disperses mercury into the air. Use a commercially available spill kit or a portable vacuum that is specifically designed for mercury clean-up (it separates out the liquid for recycling and it filters out particles and mercury vapor). A small spill would include breakage of a fever thermometer (about a half of a gram of mercury), an amalgam capsule (0.1-1 gram of mercury), old long fluorescent light bulbs (less than 40 milligrams of mercury), or compact fluorescent light bulbs (less than 5 milligrams). Anything more than a small spill requires cleaned-up by specially trained personnel. This would be the case

2. CHEMICAL HAZARDS: Mercury

for spills from blood pressure machines (these spills may contain up to a few hundred grams of mercury). See resources below for more information on spills.

Latex gloves do not protect against many forms of mercury. Skin protection for mercury varies by the type of compound. Elemental mercury (found in thermometers, blood pressure machines, dental amalgam, and electric switches) will be absorbed by the skin very slowly and in small amounts, so double disposable 8 millimeter thick nitrile gloves will be sufficient for incidental contact while cleaning small spills [112, 113]. Some mercury compounds may be deadly if absorbed through skin and they penetrate latex within seconds [114]. Therefore, for compounds other than elemental mercury, the manufacturer's recommendations should be followed.

Dental amalgam is being looked at as an important source of global mercury pollution [115]. Japan and some Nordic countries have regulations to reduce its use and it has been nearly eliminated in Sweden and Norway [116]. Dental clinics that use mercury should: use pre-capsulated amalgam to avoid spillage and excess handling; recap single-use capsules after use if feasible and store them in a closed container with other amalgam waste and dispose of through a mercury reclamation company; and use high-volume evacuation systems with filters when finishing or removing amalgam. The highest exposure to dentists is reported to be the vapors and particles produced during removal of amalgam fillings and, therefore, the use of LEV and respirators (with cartridge for both mercury vapor and particulates) has been suggested for this procedure [117, 118]. Although there are no research studies on their effectiveness, there are some portable LEV machines on the market that are designed to capture vapors and particles at the patient's mouth [119]. LEV or respirators also can be used for other activities where exposure can occur, such as preparing and polishing the fillings, and handling amalgam waste. Any LEV system used for the control of mercury should remove the vapors and particles before discharging the air back into the room or outdoors. Dental clinics that have no other option but to handle or store mercury in bulk should follow the FDI World Dental Federation's Mercury Hygiene Guidance.

Internet Resources

OSHA on mercury in hospitals, including spill clean-up:
www.osha.gov/SLTC/etools/hospital/hazards/mercury/mercury.html

Environmental Protection Agency, "Mercury Releases and Spills":
<http://www.epa.gov/mercury/spills/index.htm#whatnever>

Environmental Protection Agency, "Mercury: Best Management Practices for Health Care Facilities":
www.epa.gov/mercury/healthcare.htm

2. CHEMICAL HAZARDS: MMA

Environmental Protection Agency, “Reducing Mercury Use in Healthcare, Promoting a Healthier Environment, A How-To-Manual “ describes substitutes for mercury chemical solutions and equipment (see Chapter 3):

<http://infohouse.p2ric.org/ref/14/13928.htm> – or –

www.epa.gov/greatlakes/bns/mercury/pdfs/reducing-mercury-healthcare-1998.pdf

Health Care Without Harm “Mercury, Global Overview”:

www.noharm.org/all_regions/issues/toxins/mercury/

Agency for Toxic Substances and Disease Registry ToxFAQs general information on mercury:

<http://www.atsdr.cdc.gov/toxfaqs/tf.asp?id=113&tid=24#bookmark05>

New Jersey Hazardous Substance Fact Sheets:

Elemental and inorganic mercury:

<http://nj.gov/health/eoh/rtkweb/documents/fs/1183.pdf>

Mercuric oxide: <http://nj.gov/health/eoh/rtkweb/documents/fs/2537.pdf>

Mercuric chloride: <http://nj.gov/health/eoh/rtkweb/documents/fs/qr/1170qr.pdf>

FDI World Dental Federation Mercury Guidance:

www.fdiworldental.org/content/fdi-policy-statements-english

New York State guide on managing dental mercury:

www.dec.ny.gov/chemical/8513.html

METHYL METHACRYLATE AND OTHER BONDING MATERIALS (GLUES)

Jaime Szeinuk

Methyl methacrylate (MMA; C₅H₈O₂; CAS No. 80-62-6) is a clear liquid with a distinctive, sharp, fruity odor. Chemically, it is an unsaturated ester monomer (single molecule) which is produced in large volumes and used widely to make polymers (chains of molecules) that bond tightly to a variety of other substances. MMA is employed in a wide range of industrial and consumer applications, including dental and surgical cements. The methacrylates found most often in dental resins and bonding materials are 2-hydroxyethyl methacrylate (2-HEMA), 2,2-bis(4-(2-hydroxy-3-methacrylopropoxy) phenyl)propane (bis-GMA), and triethyleneglycol dimethacrylate. Other uses of this product are: surface coatings, injection molding and extrusion, transparent impact-resistant plastic sheets and in cosmetic products (sculpt and enhance finger nails). The current OSHA occupational exposure limit (PEL) for MMA is 100 ppm over an eight-hour work day. Surgeons usually hand mix the cement in an open bowl before applying it, however, use of the vacuum mixing devices or a surgical

2. CHEMICAL HAZARDS: MMA

helmet or local surgical field suction resulted in a substantial reduction of exposures [120].

The main exposure to MMA results from breathing the vapors of the monomer liquid. Acute health effects include:

- Irritation of the eyes (causing tearing) and upper respiratory airways (causing sore throat, cough, and nasal irritation). Prolonged exposure may result in more permanent damage to the tissue of the airways.
- Asthma and hypersensitivity pneumonitis. The mechanism of MMA-related asthma may be irritant-induced or sensitizer-induced.
- Direct contact with the skin may result in itching, burning, redness, swelling, and cracking. Repeated skin contact can cause irritant or allergic dermatitis. MMA easily penetrates most ordinary clothing and also can penetrate surgical gloves.
- Overexposure to MMA can result in headache, drowsiness, nausea, weakness, fatigue, irritability, dizziness, loss of appetite, and sleeplessness.
- Some studies have suggested that MMA can cause birth defects when pregnant women are exposed to extremely high levels.
- It is not known whether MMA is a carcinogen to humans.

The current OSHA PEL for MMA is 100 ppm over an eight-hour work day. The ACGIH TLV is 50 ppm and the short-term exposure limit (STEL) is 100 ppm.

Controls (see also [Table 6](#))

Suppliers and producers of MMA-containing dental, surgical, and cosmetic products should provide more informative MSDS and labels, including complete descriptions of mixture components. Operating rooms and dental laboratories should be equipped with vacuum exhaust mixing bowls or negative-pressure hoods for preparation of bone cement and dental composites [120, 121]. Use of laminar air flow ventilation in operating rooms has also been shown to decrease exposures (see [California Fact Sheet](#), below). If frequent or prolonged skin contact with liquid MMA is necessary, or if splashing may occur, other protective equipment, such as gloves, goggles, or a face shield, should be worn. Protective clothing should be made of a material which is resistant to MMA, such as polyvinyl alcohol. Latex gloves, polyethene-copolymer or neoprene gloves offer the best protection for exposure to MMA [122]. However, even the most resistant materials will be penetrated quickly, so gloves should be replaced often. Finally, there is need to ensure more frequent exposure monitoring of MMA workers, including a focus on peak excursions rather than time-weighted-average exposures, which may not adequately identify the actual risks of working with volatile irritants such as MMA [121].

2. CHEMICAL HAZARDS: Surgical Smoke

The decision on which types of gloves to use also should take into account the risks of latex allergy and contact allergy to rubber chemicals and the convenience of the gloves for fine manual work.

Internet Resources

Methyl Methacrylate Fact Sheet. Hazard Evaluation System and Information Service, State of California Department of Health Services:
<http://www.cdph.ca.gov/programs/hesis/Documents/mma.pdf>

SURGICAL SMOKE

George Piligian

Surgical smoke is an irritant of human mucous membranes (eyes, nose, throat, respiratory tract) consisting of a mixed variety of gases and particulates, which can damage the lungs and respiratory tract. It also can contain inflammatory, mutagenic, carcinogenic, infectious, cytotoxic, and clastogenic disease-causing substances which can be absorbed into the bloodstream of both patient and operating room (OR) staff [123, 124]. Examples of particulates include potentially infectious virus particles, e.g., human papilloma virus (HPV) with in vitro documentation of infective potential as well as a case report of viral infection transmission to a surgeon burning a viral-induced lesion with a laser [125]. Mutagenicity of 1 gram of surgical smoke corresponds to that of three cigarettes when burned with laser and six cigarettes with use of electrocautery. Among the numerous gases found in surgical smoke are carbon monoxide, acrylonitrile, hydrogen cyanide, and benzene [125].

Surgical smoke is a byproduct of heat-generating instruments. They include electrosurgery, which produces the smallest particulates (about 0.07 micrometers), laser, and ultrasonic scalpel (producing tissue particulates of 0.35–6.5 micrometers), as well as radiofrequency ablation and power tools. These instruments are used for cutting, cauterizing, and burning biological tissue in the course of open, laparoscopic or minimal access surgical procedures (e.g., mammoplasty, wart ablation, laparoscopic cholecystectomy, LASIK) [126]. Procedures generating surgical smoke exist in clinical settings outside of the operating room, including interventional radiology, cardiac catheterization, endoscopy, emergency room, and physician offices [127]. The smoke can obstruct the surgeon's view of the surgical site in closed and open surgical procedures. During laparoscopic surgically related pneumoperitoneum, carbon monoxide gas, one of many toxins present in the smoke, can be absorbed into the patient's blood resulting in carboxyhemoglobinemia [128].

Workers at risk of exposure include operating room staff (e.g., perioperative nurses, surgical technicians, surgeons, anesthesia providers) and personnel

2. CHEMICAL HAZARDS: Surgical Smoke

in proximity to any procedures generating surgical smoke who are exposed to the uncaptured or unfiltered smoke from the smoke-generating procedure. They may include people in other indoor areas where ventilation transports untreated smoke exhaust.

The main route of exposure is inhalation and direct contact with mucous membranes. Acute health effects include irritation of the eyes and upper respiratory system (coughing, tearing), unpleasant odor, headache, nausea, and vomiting.

There are no current specific OSHA or ACGIH standards for surgical smoke exposure limits. However, recommendations to control exposure, primarily by the use of local exhaust ventilation (LEV), are made by a variety of governmental regulatory and health-related groups, including OSHA, NIOSH, the Health and Safety Executive (UK) the American National Standards Institute (ANSI), the Association of Perioperative Registered Nurses (AORN), the Canadian Standards Association (CSA), and The Joint Commission (TJC).

Controls (see also [Table 6](#))

Engineering control in the form of local exhaust ventilation (LEV), when used properly, is the most effective means to avoid exposure to surgical smoke. There are two options for LEV: commercially available portable or permanent smoke evacuators, or the use of suction systems that are designed primarily for fluid suction. The first option, smoke evacuators, is preferred because these machines have a higher capture velocity; that is they pull the smoke at a higher speed and therefore capture more of it [127, 129, 130]. Wall unit suction devices when used with adequate room ventilation are sufficient only for low plume situations, e.g., laparoscopic procedures [129, 131].

The LEV should have a capture *velocity* at the nozzle inlet of 100-150 feet per minute (0.51–0.76 meters per second) and the nozzle must be placed within two inches (five centimeters) of the surgical site to effectively capture the particles and gases generated at the site of smoke generation. The LEV should incorporate ultra-low penetration air (ULPA) filters or high efficiency particulate air (HEPA) filters; the former captures smaller 0.1 micron particles with higher efficiency. Ideally there should be a means of capturing or neutralizing gases and vapors from the procedure as well [130]. Used filters, tubing, and suction wands must be considered to be biohazards and handled as such [132].

Commercially available smoke evacuators include various features, such as adjustable flow rate, “sleeve” attachments that can be put directly on the surgical instruments to capture the smoke at the point of generation, foot-activated controls, automated monitoring of filter usage and various sized tubing and other attachments. Users must consider several factors, such as the capture effectiveness (which generally increases with flow rate); their own infection

2. CHEMICAL HAZARDS: Surgical Smoke

control policy on whether filters can be re-used after each patient; and noise (which also increases with flow rate).

Surgical smoke components are not all visible to the naked eye [133]. Because all smoke may not be captured with LEV, it is important that the room meet general ventilation requirements. The American Society of Heating, Refrigeration, and Air-conditioning Engineers (ASHRAE) recommends 20 air changes per hour in operating rooms in newly constructed facilities and the Association of Perioperative Registered Nurses (AORN) recommends 15 air changes per hour.

Although OSHA's Bloodborne Pathogens standard does not specifically apply to surgical smoke, given the case report showing transmission of infective agents to an operating room surgeon and in vitro demonstrations of blood fragments and viable viral particles in surgical smoke, it is prudent to follow standard precautions including use of gloves, eye protection, gowns and surgical caps to protect against infectious particles when exposure to surgical smoke occurs from clinical procedures [125]. The handling of tubing and filters from the suctioning devices, when contaminated with blood or other potentially infectious material, should be governed by the OSHA Bloodborne Pathogen standard [28]. More study is needed to test the efficacy of preventing exposure to operating room personnel under actual operating conditions using the recommended control measures and equipment [127].

Typical surgical and laser masks do not seal to the user's face and, therefore, do not protect users against surgical smoke [132]. A fit-tested, N95 filtering facepiece respirator is advised as secondary protection against surgical smoke particles that escape LEV [129]. To capture some of the gases and vapors that would normally penetrate an N-95 respirator, there are N-95s with added charcoal to capture low levels of organic vapors. However, none of these N-95 respirators with added charcoal are approved by the U.S. Food and Drug Administration as surgical masks, nor have they been tested for their effectiveness against surgical smoke vapors and gases. This circumstance may change in the future and there are likely different regulations and practices in other countries. Respirators, however, are not a substitute for properly designed engineering controls. For operations involving the added potential hazard of disease transmission (e.g., human papillomavirus [HPV], tuberculosis, varicella, rubeola), respiratory protection at least as protective as the fit-tested N95 respirator is also advised [127, 129].

Recent survey studies have demonstrated that a) motivation, teamwork, and education of all operating room personnel in the proper use of the most effective control measures, b) availability of such equipment, and c) health care facilities' leadership in developing clear and enforced policies on their use (including acceptable performance characteristics of purchased equipment, such as noise levels) are all needed to ensure that adequate surgical site smoke evacuation methods are effectively employed on a routine basis [134-136].

2. CHEMICAL HAZARDS: Surgical Smoke

Internet Resources

American Society for Laser Medicine and Surgery (ASLMS). Smoking guns (Statement approved by the ASLMS Board of Directors) 2007:

www.aslms.org/public/smokingguns2.shtml

Health and Safety Executive. Evidence for exposure and harmful effects of diathermy plumes (surgical smoke). Evidence-based literature review prepared by the Health and Safety Laboratory for the Health and Safety Executive 2012:

www.hse.gov.uk/research/rrpdf/rr922.pdf

LiNA Medical:

www.linamedical.co.uk/assets/files/penetration_brochure.pdf

National Institute of Occupational Safety and Health. Control of Smoke from Laser/Electrical Surgical Procedures. HC11. Department of Health and Human Services Publication 96-128; 1996:

www.cdc.gov/niosh/docs/hazardcontrol/hc11.html

National Institute of Occupational Safety and Health National Personal Protective Technology Lab Meeting Presentation, 2011:

www.pitt.edu/~super7/45011-46001/45401.ppt

Occupational Safety and Health Administration:

www.osha.gov/SLTC/etools/hospital/surgical/surgical.html#LaserPlume

Association of Peri-Operative Registered Nurses (AORN) Management of Surgical Smoke Toolkit:

www.aorn.org/Secondary.aspx?id=21878&terms=surgical%20smoke

IC Medical Inc. Controlling Surgical Smoke: A Team Approach, 2001:

www.icmedical.com/informationalbooklet.pdf

2. CHEMICAL HAZARDS: Table of Control Studies

Table 6. Studies of Controls for Chemical Hazards

| Hazard | Population studied | Control method(s) studied | Conclusions | Authors |
|--|---|---|--|---------------------------|
| Cleaning products | Case control study conducted in France | None; exposure assessments performed by different methods to determine associations between exposure to cleaning tasks and different cleaning products in hospital workers, and current asthma status | Female hospital cleaning workers are exposed to numerous cleaning products, some, such as decalcifiers, were associated with current asthma. Objective measures of exposure are needed to understand the relationship between occupational exposures to cleaning products and asthma. | Dumas et al. (2012) [137] |
| Cleaning products | Two Massachusetts hospitals: short-term airborne exposures | None; pilot study on exposures to VOCs generated from three common cleaning tasks in the hospital: cleaning of mirrors, sink, and toilet bowls | VOCs remained airborne even after the completion of cleaning tasks; peak concentrations of 2-butoxyethanol approached the occupational exposure limits. Common cleaning tasks contribute to poor indoor air quality, which can present a risk of adverse health effects for cleaning employees, hospital patients, and other hospital employees. | Bello et al. (2010) [138] |
| Cleaning products | Several hospitals in Massachusetts: quaternary ammonia compounds, glycol ethers, alcohols, ammonia, and several phenols | None; pilot study assessing exposures during common hospital cleaning tasks: cleaning of floors, mirrors, toilet bowls, counters, and floor finishing | Hospitals cleaners are often exposed to a mixture of chemicals, and can be exposed to both respiratory and dermal irritants. Hospitals should use both product evaluations and workplace exposure data to develop strategies for protecting workers from cleaning hazards. | Bello et al. (2009) [139] |
| Ethylene oxide, glutaraldehyde, and formaldehyde | Workers in central supply, pathology labs, and endoscopy units | Engineering: local ventilation systems | Hospitals with local ventilation systems had lower airborne concentrations of sterilants and disinfectants than a hospital which used mostly general dilution ventilation. | Koda et al. (1999) [140] |

2. CHEMICAL HAZARDS: Table of Control Studies

Table 6. (Cont'd.)

| Hazard | Population studied | Control method(s) studied | Conclusions | Authors |
|----------------|--|---|---|--------------------------------|
| Ethylene oxide | Staff assigned to sterilization units (nurses, operators, and nursing auxiliaries) | Engineering: compared airborne exposures of ethylene oxide between an automated self-contained sterilization unit and a manually operated dual chamber unit | Automated sterilization chamber decreased air concentrations drastically. Manual chambers resulted in higher degree of exposure and over-exposure due to frequent leaks. | Sobaszek et al. (1999) [102] |
| Glutaraldehyde | Hospital-wide survey of endoscope disinfecting procedures | Substitution: alternatives for glutaraldehyde were researched Engineering: assessed the use of fully automated washers and localized ventilation Work practices: evaluated disinfecting procedures for compliance with British Society of Gastroenterology and British Thoracic Society disinfecting guidelines | Peracetic acid, chlorine dioxide, and super-oxidized water are possible substitutes; switching to automatic washers with localized ventilation, using fully immersible endoscopes, and autoclaving items when possible, will help reduce exposures. | Ruddy and Kibbler (2002) [141] |
| Glutaraldehyde | Hospital-wide surveys | Substitution: alternatives for glutaraldehyde were evaluated for disinfecting properties and potential health effects | Health effects of many glutaraldehyde alternatives are unknown. Orthophthaldehyde (OPA) is a potential sensitizer, but peracetic acid is not. Both are good substitutes but can cause skin and respiratory tract irritation. | Rideout et al. (2005) [142] |
| Glutaraldehyde | Environmental air sampling in endoscope disinfecting rooms in six hospitals | Engineering: local exhaust ventilation Work practices: closing containers | Leaving out opened vats of glutaraldehyde and using automatic washers without ventilation resulted in the highest air concentrations. | Katagiri et al. (2006) [107] |
| Glutaraldehyde | Environmental air sampling in an outpatient endoscopic department | Engineering: enclosed disinfecting and washing machines, local exhaust ventilation | Air concentrations of glutaraldehyde in the facility were very low due to successful implementation of control methods; all staff wore appropriate PPE. | Perdelli et al. (2008) [11] |

2. CHEMICAL HAZARDS: Table of Control Studies

Table 6. (Cont'd.)

| Hazard | Population studied | Control method(s) studied | Conclusions | Authors |
|----------------|---|--|--|-------------------------------|
| Glutaraldehyde | Workers disinfecting endoscopes in operating suites, and workers who developed X-ray film | Engineering: compared manual disinfecting techniques with automated machines | Workers using fully automated disinfecting machines had lower exposures compared to workers using manual disinfecting procedures. X-ray workers had minimal exposures. | Leinster et al. (1993) [106] |
| Mercury | Vapor levels in mouths of dental patients | Engineering: water coolant | Water coolant had no effect on vapors emitted during low speed polishing of amalgam restorations with no high volume extraction (HVE) in use. | Haikel et al. (1990) [143] |
| Mercury | Particle levels at patient and dentist during simulation of amalgam removal | Engineering: water spray, HVE and rubber dam | Water spray, HVE, and rubber dam reduced patient exposure to particulates but did not reduce dentist exposure. Respirators recommended for dentists. | Nimmo et al. (1990) [117] |
| Mercury | Vapor levels in a glove/box type chamber | Engineering: water spray, high volume evacuator, pre-encapsulated and screw-closed capsules of amalgam, various alloys | Dry polishing, removal, placement, wet polishing, and trituration of amalgam released mercury in that order. Pre-encapsulation more effective than screw-closed capsules. Water and HVE each greatly reduced mercury, compared to dry polishing. Extending the evacuation for one minute after removal greatly lowered vapors. | Engle et al. (1992) [144] |
| Mercury | Breathing zone of dentists while cutting, filling, and polishing | Engineering: high volume evacuators, mirror evacuators, saliva evacuator, water spray coolant | Polishing generated less vapors than cutting and filling. HVE was especially effective during cutting of amalgam, which generated highest vapor levels. Mirror and saliva evacuators were not effective when HVE was used. Adequate water coolant during cutting and polishing is needed due to high temperatures. | Pohl and Bergman (1995) [145] |

2. CHEMICAL HAZARDS: Table of Control Studies

| | | | | |
|---------|--|--|--|----------------------------------|
| Mercury | Questionnaires and urine samples of 1,352 American dentists | Work practices: Use of squeeze cloths, spills, number of procedures | Use of squeeze cloths, years in current office and recent (last year) spill history were all significantly correlated to mercury levels in urine. There was no correlation with the number of amalgams removed per week. Use of free or bulk mercury and squeeze cloths should be discontinued. Spills should be thoroughly cleaned. | Martin et al. (1995) [146] |
| Mercury | Questionnaires and blood samples of 2,041 American dentists | Engineering: Ventilation Work practices: Spill history, number of procedures, skin contact | Accidental spills correlated to inorganic mercury blood levels. Weak effect shown for ventilation. No effect shown for number of restorations placed or removed. | Chang et al. (1992) [147] |
| Mercury | Air monitoring and questionnaires at 82 Swedish dental clinics | Engineering: ventilation, heating, wall and floor covering, evacuation system Work practices: amalgam preparation, cleaning methods | High levels of mercury recorded near open containers, sterilizer, and on floors. Spillage most important contributor to high mercury levels. | Nilsson and Nilsson (1986) [148] |
| Mercury | Urine samples and questionnaires from 945 Norwegian dentists | Engineering: ventilation, heating, floor covering, vacuum ejector Work practices: number of procedures, trituration method, waste storage | High urine levels correlated to number of placed, polished, and replaced amalgam restorations per week; wooden floors; and presence of amalgam filters and separators. | Jokstad (1990) [149] |
| Mercury | Urine and questionnaires from 4,272 American dentists | Engineering: type of amalgam capsule, ventilation system Work practices: years in office, hours and restorations per week, amalgam preparation and mercury expression | Urine levels were statistically related to years in office and specialty, hours of practice per week, and number of restorations placed. Using pre-proportioned capsules, not expressing excess mercury, having forced air central heating, and not having window air conditioning resulted in lower levels. | Naleway et al. (1985) [150] |

2. CHEMICAL HAZARDS: Table of Control Studies

Table 6. (Cont'd.)

| Hazard | Population studied | Control method(s) studied | Conclusions | Authors |
|------------------------|--|--|--|-----------------------------|
| MMA | Orthopedic surgeon (pregnant); literature review | Engineering controls: vacuum mixing devices or local surgical field suction, fume hood, or vapor control device | Decreased exposure | Keene et al. (2011) [120] |
| MMA | Literature review, production workers to end users including medical and dentistry | Work practices: MSFS and labels. Engineering controls: vacuum exhaust mixing bowls, negative-pressure hoods. Administrative controls: ensures more frequent air monitoring. | Operating rooms and dental laboratories should be equipped with vacuum exhaust mixing bowls or negative-pressure hoods for preparation of bone cement and dental composites. Other workers using MMA-based composites should be instructed in appropriate ways to increase ventilation and minimize exposures. MSDSs and labels should be more informative. Conduct more frequent air monitoring, focusing on peak excursions, rather than average exposures. | Borak et al. (2011) [121] |
| MMA | Dentistry, literature review | Engineering controls: adequate ventilation | Decreased exposure. | Legatt et al. (2007) [151] |
| Surgical smoke: lasers | Laboratory rats exposed to CO ₂ laser exhaust from vaporization of pig skin | Engineering: a) smoke evacuator with filter made of fiberglass pads and charcoal, suctioning air at 35-40 ft ³ /min; b) above plus a filter that removes 0.1 micrometer particles | Use of smoke evacuator a) alone: resulted in interstitial pneumonia and emphysematous pathology albeit in less quantity than in rats breathing the unfiltered smoke; b) addition of 0.1 micrometer particle filter: no microscopic pathology in rat lungs. | Baggish et al. (2007) [152] |

2. CHEMICAL HAZARDS: Table of Control Studies

| | | | | |
|---------------------------------|--|--|---|----------------------------|
| Surgical smoke: lasers | No human exposure; aerosol smoke particulates measured in ambient air of CO ₂ laser exhaust from cutting a pork chop | Engineering: smoke evacuator with HEPA and "odor elimination" filter suctioning air at 50 cfm mounted at distances of 2, 6, and 12 inches from laser cutting site with evacuator on for entire measurement period of laser operation | Use of the described smoke evacuator at two inches or less from site of laser cutting and running without interruption achieves complete smoke evacuation. Drawbacks: evacuator is noisy; evacuator nozzle may need to be re-sterilized at distance of two inches from laser site; may block view of surgical site; presence of surgeon may block view of surgical site; possible effects of surgeon's inhalation/expiration on smoke dispersion in surgeon's breathing zone needs study. | Smith et al. (1989) [153] |
| Surgical smoke: lasers | No human exposure; a tracer gas released from mannequin visualized by IR camera during CO ₂ laser cutting meat at 30, 60, and 100 Watts | Engineering: smoke evacuators with different muzzle sizes and shapes operating at differing angles, flow rates, and with various external (ambient) air speeds | Efficient smoke evacuation required: a) higher evacuator flow rates for higher powered lasers; b) close proximity (less than or equal to two inches) of evacuator nozzle to surgical site; and c) addition of external air flow if distance between evacuator and surgical site is greater than two inches. Drawbacks included high noise level, obstruction of surgeons' view, and effect of external air flow on patient. | Smith et al. (1990) [154] |
| Surgical smoke: electro-cautery | Surgical personnel present during electrosurgery over one year | Engineering: "high-flow" smoke evacuator and filtration of greater than or equal to 0.12 micrometer particulates with no repositioning of hose which is oriented vertically and held in place using surgical field drapes (distance not specified) | The "effective smoke evacuation" was not quantified. Based on clinical experience it is "highly effective in rapidly evacuating essentially all visible smoke and odor from operative field." The drawback is high noise level. | Hunter et al. (1996) [155] |

2. CHEMICAL HAZARDS: Table of Control Studies

Table 6. (Cont'd.)

| Hazard | Population studied | Control method(s) studied | Conclusions | Authors |
|---|---|--|--|--------------------------------|
| Surgical smoke: diathermy | Smoke from 30W diathermy pencil cutting human skin and muscle during surgery (30 patients over two-month period). | Engineering: standard diathermy pencil smoke extraction system operating at 30 liters/min. compared to no use of smoke extraction. | The extraction system reduced the mean intra-operative smoke level from 0.14 mg/m ³ (measured behind the surgeon) to 0.012 mg/mg ³ . It reduced the maximum smoke level from 2.41 mg/m ³ to 0.26 mg/m ³ . | Pillinger et al. (2003) [156] |
| Surgical smoke: pulsed endoscopic laser | Plastic models simulating small body cavities in micro-endoscopic procedures. | Engineering: liquid injection at the inlet of a suction tube bound particulates being suctioned at the inlet of the 20 G (0.9 mm) suction tube. The closed system uses a pressure sensor and control units to maintain a high volume of gas exchange (up to 8 times/sec) and low intracavitary pressure. | The suction system stopped surgical smoke plume from filling a 2 cm diameter cavity. The injected liquid bound particulates entering the suction tube, preventing their deposition and avoiding clogging of the suctioning tube. The suction gas-fluid-particulate was filtered in the system. | Mattes et al. (2010) [157] |
| Surgical smoke | Review article | Engineering: evaluated different types of smoke scavengers and proper scavenging techniques | Smoke scavengers placed within two inches of the surgical site at high flow rates are effective at collection of surgical smoke from lasers and electrosurgical units. Surgical masks offer no protection from surgical smoke. | O'Grady and Easty (1996) [158] |

3. ERGONOMICS: Health Effects and Regulations

Section 3. Ergonomic Hazards

HEALTH EFFECTS AND REGULATIONS

Alice Freund and Jonathan Dropkin

This section contains specific control measures for computer workstations; hand held devices; laboratories; laparoscopy (minimally invasive surgery); patient handling; radiology; slips, trips and falls; and sonography.

Ergonomic exposures include the use of excessive force, as in lifting, pushing, or pulling; awkward, constrained postures, such as bending, twisting, working overhead; repetitive motion; and vibration. Transferring patients to the bed, chair, toilet, diagnostic and treatment tables, and stretchers may expose workers to many of these risks. The exposures are often compounded because patients may be moving, resisting, or physically or mentally unstable. Risks may be increased also due to time constraints and inadequate staffing resources. Combative and bariatric patients can exacerbate these exposures. Patient handling exposures can occur in nursing; surgery; intensive care; physical, respiratory, and occupational therapy; imaging; mortuary; and emergency departments.

Manual material handling (MMH) involves many of the exposures described above. Moving heavy objects, including medical equipment, instruments, specimens, supplies, linen, garbage, buckets of cleaning solutions, furniture, tools, food carts, and other equipment, occurs throughout the hospital.

Many hospital workers are exposed to prolonged sitting or standing, such as employees working in nursing, surgery, imaging, dietary, laundry, laboratory, pharmacy, dentistry, administrative and maintenance areas. Sitting or standing in a static posture can be more stressful on the musculoskeletal system than dynamic movements.

Users of computers and hand-held electronic devices, surgeons, lab workers, radiologists, and sonographers are exposed to static postures and repetitive motions in the upper extremities. These exposures occur in administrative, billing, and patient care areas. They are increasing throughout the hospital with the use of electronic medical records (EMRs).

Some radiation protection controls, such as lead aprons, overhead ceiling-suspended shields, and rolling shields can also represent ergonomic hazards. A holistic approach to prevention is to ensure that when implementing one control

3. ERGONOMICS: Health Effects and Regulations

to reduce an exposure (e.g., radiation), another exposure (e.g., high loading forces) is not created.

Slippery floors, trip hazards, and uneven work surfaces can result in falls. Falls can result in serious injuries to multiple body parts.

Some symptoms of ergonomic injuries or illnesses include: fatigue; soreness, aching, burning sensations; muscle or tendon pain, with or without movement; joint pain; reduced range of joint motion; clumsiness or loss of coordination; numbness, tingling or a feeling of coldness in the fingers; hand arm vibration syndrome; Reynaud's phenomenon; low back pain or sciatica; venous insufficiency and varicose veins; and plantar fasciitis.

There are no federal ergonomic or lifting standards in the U.S. Some states have passed legislation related to safe patient and/or resident handling. Although not specifically directed at patient handling, the European Economic Community's Directive 90/269/EEC requires mechanical devices be employed to reduce manual handling of loads that increase risk to workers. Absent these controls, organizational measures are required to reduce the risk.

The Display Screen Equipment (DSE) regulation, European Economic Community's Directive 90/270/EEC, outlines the minimum safety and health requirements for working with DSE. Similar regulations apply in Australia, New Zealand, and several South East Asian countries. If employees use a computer for a substantial proportion of their job, the employer must provide ergonomics training and a risk assessment for these employees. This training must be done upon hire, following considerable job changes, and periodically.

Slip, trip, and fall hazards covered in this section are regulated under OSHA's Walking-Working Surfaces standard. They include regulations for floors, stairs, ladders, and scaffolds. Local building codes also cover floor and stairway design.

Internet Resources

OSHA ergonomic guidelines for nursing homes (includes laundry, housekeeping, kitchen, patient handling):

www.osha.gov/ergonomics/guidelines/nursinghome/final_nh_guidelines.html

Comprehensive guide to exposure and controls in health care:

<http://bookshop.europa.eu/en/occupational-health-and-safety-risks-in-the-healthcare-sector-pbKE3111047/>

Enacted state safe patient handling legislation:

<http://www.nursingworld.org/MainMenuCategories/Policy-Advocacy/State/Legislative-Agenda-Reports/State-SafePatientHandling>

3. ERGONOMICS: Computer Workstations

Slip, trip, fall prevention for health care workers:

www.cdc.gov/niosh/docs/2011-123/

Ergonomics and musculoskeletal disorders:

www.cdc.gov/niosh/topics/ergonomics/

COMPUTER WORKSTATIONS

Jonathan Dropkin

Controls (see also section on *Radiology Controls* and *Table 7*)

In general, computer work can be conducted in patients' rooms, corridors, patients' bedside, offices, and other patient care areas [159]. Workstations for physicians, nurses, and allied health professionals should be adjustable for height and pitch/tilt; the pitch/tilt is important for keyboard and pointing device use. Adjustable workstations can be achieved most effectively using sit/stand workstations. Fully adjustable and well-padded chairs should also be implemented. Armrests are optional and depend on the computer user's preference. Waterfall seats are recommended on the seat pan of the chair to reduce mechanical compression behind the thighs. When possible (that is, in relatively quiet environments), speech recognition software and an appropriate sound-reducing headset should be used for performing dictation and entering information in the computer. Appropriate workstation design for computer work is particularly important because the introduction of EMRs will likely lead to an increase in mechanical exposures from computer use.

An adjustable monitor arm and work platform that holds the keyboard and pointing devices at the same level are required for all HCP to promote neutral working postures throughout the head, upper extremities and trunk. The ideal monitor height range, from a 5th percentile woman to a 95th percentile man, while sitting is 40 to 53 inches (101.6 to 134.6 centimeters) and while standing is 48 to 60 inches (121.9 to 152.4 centimeters) [160]. While an adjustable monitor arm and monitor can be positioned in nearly unlimited positions, in general, the distance between the eyes and monitor should range between 28-36 inches (71-91 centimeters) [161]. The viewing angle should range between -10 degrees and -30 degrees from the horizontal line of sight [162]. However, monitor viewing depends on numerous factors, such as age, illumination, flicker, and glare. Vision issues may also be problematic for computer users. Controls to

3. ERGONOMICS: Computer Workstations

reduce this hazard include up-lighting or parabolic louvers, glare control using monitor hoods, and eye hygiene, including frequent lubrication and periodically re-focusing on far distances.

The work platform, which will hold the keyboard and pointing devices, should be positioned in a negative tilt (the far side of the keyboard should be lower than the near side) to allow the user to keep their wrist neutral (Hedge defines a neutral wrist posture or “zone” as < 15 degrees extension, < 30 degrees flexion, and < 15 degrees ulnar or radial deviation [163]). An alternative to a traditional keyboard can also be used. The type of keyboard should be adjustable for splitting and tenting (raised in the middle for more comfortable hand positions). The keyswitch force on the keyboard should be less than 0.47 Newtons [164] to prevent excessive force in the upper extremities when keying. Alternative pointing devices include tented mice, touch pads, track balls, roller bar mice, foot pedals (but not designed to function as a mouse), and digitizing tablets and pens. In the seated position, the chair should be fully padded and adjustable for height, backrest height and angle, seat pan angle, and sliding the seat pan forward and back.

Two specific applications for computer use are in patients’ rooms and physicians’ offices due to the introduction of EMRs. Vertical wall mounts with adjustable monitor arms and keyboard mouse trays are ideal. While platform stability is an issue during keyboard and mouse use, two, rather than one, adjustable arm mechanisms that hold the platform will increase stability. Appropriate infection control cleaning measures are crucial to help maintain hygienic conditions. A keyboard/mouse cover is one option. Covers should be easily removed to be disinfected. Washable, sealed keyboards may also be employed. Hand hygiene should be performed before using the computer. Gloves should not be worn during computer use. Keyboards and mice should be disinfected daily. If possible, install vertical wall mounts at least three feet (one meter) from the sink. Splashguards should be used between computer and sink, and made of clear plastic that can be cleaned [165].

Another application for computer work is computers on wheels (COWs). These are heavy push carts with computers that can be moved from room to room. In addition to weight and force, wheel design is often problematic between surfaces and for steering. Limited on-cart storage and area for paperwork, the lack of a battery power indicator, and the stability of work surface platforms are also problematic [166], although a second adjustable arm mechanism will increase stability while inputting data.

Rather than hand-written medical records, a tablet computer is a third application that can be used for inputting data by HCP. While this increases mobility among staff throughout medical units, these products can be difficult to use and often do not function as intended (for example, when uploading data into personal computers or laptops). One control to improve comfort and precision is to install lightweight handles, approximately 1.25 to 2 inches (3.2-5.1 centimeters) thick, on three sides of the tablet.

3. ERGONOMICS: Hand Held Devices

Internet Resources

OSHA site on computer workstations:

www.osha.gov/SLTC/etools/computerworkstations/index.html

Cornell University site on computer workstations:

www.ergo.human.cornell.edu/ergoguide.html

Ergonomics of nurse computer workstations:

www.medscape.com/viewarticle/455618

HAND HELD DEVICES

Jonathan Dropkin

Controls (see also [Table 7](#))

Neck and upper extremity musculoskeletal symptoms and disorders have been reported among people due to intensive texting on mobile phones, although there is a lack of literature on this phenomenon in healthcare settings. Controls include support of mobile phone/PDA device, support of forearms, use of both thumbs, sitting, but avoid sitting with the head bent forward greater than 10 degrees and the upper extremities in extreme elevated postures, and avoid texting with high velocity.

Ringtones and mobile phone-generated noise have an impact on work processes, focus and concentration among healthcare providers. These noises should be minimized. Loud noise can lead to errors, such as prescribing incorrect medication dosages or while conducting procedures; they can also lead to poor work quality issues. Moreover, multitasking with mobile phones and performing procedures can lead to medical errors since there are limits to the number of tasks an individual can safely perform simultaneously.

Microbial contamination of HCP' mobile phones is a widely documented health hazard. HCP' mobile phones are potential vectors for transferring pathogens between HCP. No federal or state laws mandate the cleaning of mobile phones. However, hand hygiene and routine cleaning of devices with alcohol wipes can reduce this risk.

Internet Resources

Controls for hand held devices and texting:

www.biomedsearch.com/nih/Ergonomic-recommendations-when-texting-mobile/22317659.html

The Puget Sound Chapter of the Human Factors and Ergonomics Society, Controls for texting:

www.pshfes.org/Resources/Documents/SafeText%20final%20brochure.pdf

3. ERGONOMICS: Laboratory

Hazards and controls for texting:

www.howtodothings.com/health-fitness/how-to-avoid-blackberry-thumb

Hazards and controls for texting:

www.the-hospitalist.org/details/article/1498091/Smartphones_Present_Both_Risks_and_Opportunities_for_Hospitalists.html

The New York Times, as doctors use more devices, potential for distraction grows:

<http://mieuxprevenir.blogspot.com/2012/10/do-cell-phones-and-tablets-affect.html>

www.nytimes.com/2011/12/15/health/as-doctors-use-more-devices-potential-for-distraction-grows.html?pagewanted=all&_r=0

LABORATORY

Alice Freund

Controls (see also the section on [Computer Workstation Controls](#) and [Table 7](#))

Commonly used equipment or objects should be as close to the worker as possible to avoid awkward postures. If sitting, there must be leg room under the work surface. These controls plus a chair with appropriate back support that is fully adjustable and well-padded will ensure that they sit upright, in good posture, without bending the neck forward or too far down or up. If the work surface is adjustable, they can alternate between sitting and standing. Footrests may be necessary for petite individuals or non-adjustable workspaces so that feet are supported. Arm supports on the chair or workbench are useful for tasks such as microscopy and working at a bench or hood. For extended standing, use anti-fatigue matting.

Ergonomically designed pipettes require less force to activate, have a neutral grip, and use the pointer finger as well as the thumb. Electronic and multi-channel pipettes are available (see [NIH website](#), below). Select pipette tips that are easy to eject. Ergonomically designed safety cabinets have a reduced front grille to reduce reach, are height-adjustable, have non-glare windows and contain “wells” to hold tall containers. Traditional microtomes, or cryostats, that require repetitive turning of handles, can be replaced by electronically powered devices with a foot pedal. The handle can be retrofitted with an adapter to allow a neutral wrist posture. For micro-manipulation, use plastic vials with fewer threads. Use small pieces of foam on forceps to reduce forces on the finger’s soft tissue. Microscopes should have adjustable eyepieces, a video screen for easy viewing, or should be tilted or elevated to avoid bending the neck.

3. ERGONOMICS: Laparoscopy

Internet Resources

OSHA fact sheet:

www.osha.gov/Publications/laboratory/OSHAfactsheet-laboratory-safety-ergonomics.pdf

U.S. National Institute of Health website:

www.ors.od.nih.gov/sr/dohs/HealthAndSafety/Ergonomics/atwork/Pages/lab1.aspx

LAPAROSCOPY

Alice Freund

Controls (see also the sections on *Patient Handling, Radiology, and Computer Workstation Controls and Table 7*)

Handles of laparoscopic instruments should be ergonomically designed [167]. Foot pedals should also follow recommended guidelines [168]. Table height should be adjustable. Adjustments should be able to go lower than a normal surgical table because the instruments are longer. It will enable the surgeon to keep the instruments at a comfortable height [169, 170]. Position monitors in front of the surgeon [171], using flat screens if necessary [172]. Consider robotic systems if appropriate [173].

Internet Resources

None at this time

PATIENT HANDLING

Alice Freund

Controls (see also *Table 7*)

Programs to eliminate manual patient handling in all but life-threatening situations are recommended [174]. Although the equipment is costly, it pays for itself very quickly, often in fewer than three years [175]. One staff member should not lift a patient weighing more than 35 pounds or 16 kilograms [176]. Bariatric departments require specialized equipment for very heavy patients.

Devices for patient transfers from one surface to another include a variety of mechanical lifting devices, including total lifts, sit/stand lifts, stand aids, and adjustable height beds and baths [177, 178]. Selection depends on the patient's

3. ERGONOMICS: Patient Handling

weight-bearing status and his or her medical condition [178]. Lifts may be portable or permanent, such as those installed in ceilings. Electrically powered ceiling lifts are preferable to electric portable floor-based lifts. They create less stress on the spine (there is more friction and difficulty turning floor-based lifts) and they avoid problems with storing and accessing portable lifting equipment [179]. If portable lifts are used, there must be enough available so the staff has ready access to them. Storage locations should be identified near the point of use, properly labeled, and accessible at all times; they should be unlocked during all shifts. A suggested ratio is one mechanical lift for up to every eight patients who need that device [175]. The Facility Guidelines Institute (FGI) recommends ceiling lifts for each patient in need, or a portable lift for every 8-10 such patients [17]. Information on how to assess need can be found in the FGI white paper listed under internet resources, below.

Slide sheets, especially those with handles, are effective when moving patients up in bed or transferring them to another surface at the same height (such as bed to stretcher) [180]. Powered lateral transfer devices are available. A maximum of 157 pounds (or 71 kilograms) has been suggested as the maximum weight of a patient for a four-person manual lateral transfer [181].

To roll the patient from one side to another, or to make an occupied bed, extra staff, and a friction reducing device (such as a slide sheet or mechanical lift) should be used. To apply anti-embolism stockings, a high risk activity, use a mechanical lift and sling or an extra caregiver to lift the leg of any patient over 54 kilograms (120 pounds). Put on the stockings using a slide device to reduce friction, and push from the bottom of the bed.

More than one caregiver should be used to manually move patients up in bed with a friction reducing device, as this is a high risk activity. Alternatively, use a ceiling lift [182]. Use a powered patient transport device if pushing patients on beds or stretchers more than once every 30 minutes [182]. Walking belts with two caregivers should be used to assist patients who can bear most of their weight [177].

Neither back belts nor training in transfer techniques alone are effective control measures [183, 184]. In a review of the use of back belts while handling patients, Nelson and Baptiste reported that back belt use was associated with a reduction in mean oxygen consumption [178, 185]. They also reported there was no association between back belt use and decreased incidence of low back pain or back injury [186]. Government agencies such as NIOSH and OSHA do not recommend back belts. In fact, OSHA warns that back belts may increase the risk of injury by providing a false sense of security that could cause workers to lift more weight than they would without a belt [187]. NIOSH notes there is “strong evidence” that back belts are ineffective for injury prevention among nursing personnel. NIOSH’s summary of this issue can be found at www.cdc.gov/niosh/topics/ergonomics/beltsumm.html [188].

3. ERGONOMICS: Patient Handling

Internet Resources

Facility Guidelines Institute white paper on conducting patient handling assessments:

www.fgiguideelines.org/pdfs/FGI_PHAMA_whitepaper_042810.pdf

Australian Nurses Federation No Lifting Policy:

www.anf.org.au/pdf/policies/P_No_lifting.pdf

British Columbia alternatives to manual lifting:

https://www.worksafebc.com/publications/health_and_safety/by_topic/assets/pdf/handling_patients_bk97.pdf

British Columbia safe patient handling website:

<https://www2.worksafebc.com/Portals/HealthCare/PatientHandling.asp>

American Nurses Association on patient handling:

www.nursingworld.org/MainMenuCategories/WorkplaceSafety/SafePatient

Note: ANA published a national safe patient handling and mobility standard in 2013.

NIOSH lifting equation and safe patient handling:

www.cdc.gov/niosh/docs/94-110/

NIOSH guidelines on safe patient handling:

www.cdc.gov/niosh/topics/safepatient/

U.S. States that have Enacted State Safe Patient Handling Legislation:

<http://www.nursingworld.org/MainMenuCategories/Policy-Advocacy/State/Legislative-Agenda-Reports/State-SafePatientHandling>

RADIOLOGY

Jonathan Dropkin

Controls (see also the section on [Computer Workstations](#), [Patient Handling](#), and [Table 7](#))

The radiology reading room is a fourth application in which extensive computer work is performed (see [Computer workstations](#)). It includes the use of

3. ERGONOMICS: Radiology

Picture Archiving and Communication Systems (PACS). Computer controls are similar to those described in the overall text of this section. A 39-item checklist has been developed to evaluate the work environment in radiology reading rooms, including monitor placement, monitor characteristics (such as flicker and lighting), inputting devices, workstations, and chairs [189, 190]. Lower levels of ambient light can improve the radiologists' performance in the soft-copy interpretation of PACS, yet is problematic for vision tasks when using inputting devices. Other recommendations in radiology reading rooms include the use of separate task up-lights (lights that are directed upwards from the work surface or floor to prevent glare), monitor hoods, neutral-colored surfaces, and partitions to separate individual workstations. Task up-lighting can be utilized in either a fixed or movable form, and should be controlled by a dimmer [191]. To avoid neck strain, three rather than four monitors are recommended for PACS [181].

To prevent awkward postures, use a video display next to the X-ray control panel if the operator cannot comfortably operate controls and simultaneously view the patient [192]. A wall-mounted film holder can be used to label the film to avoid holding the film in an awkward posture while applying the label [192]. To reduce non-neutral postures at the shoulders, overhead X-ray machines should be moved to chest level to avoid reaching overhead.

PPE, such as lead aprons worn to reduce the risk of radiation exposure among interventional cardiologists or radiologists, expose these physicians to heavy loads over long durations. Inappropriate design of their work environment and PPE promotes non-neutral and inefficient postures and movement. An association has been found between wearing these PPE and spinal conditions in cardiologists and radiologists. Lower extremity conditions also have been documented as a result of wearing heavy and awkward PPEs. A better design in interventional laboratories to reduce non-neutral postures while using equipment and tools during procedures, coupled with engineering out the use of lead aprons and other PPE, should be developed. For example, to reduce non-neutral postures of the head and neck, monitors should be positioned so that the head and neck can remain neutral and the line of sight of the interventionist can be directly in front of the monitor. To reduce exposure to radiation in the head and neck, ceiling-suspended lead shields should be used rather than lead caps. The use of aprons should be eliminated. They do not distribute weight evenly across the shoulders and spine or use muscle groups whose origins and insertions are at a biomechanical advantage to distribute and hold the load. Two-piece garments or garments with waistbands are better for distributing the load than a single heavy apron. Similarly, kilts designed of lighter materials show promise in the pelvic region and lower extremity regions [193].

3. ERGONOMICS: Slips, Trips, and Falls

Internet Resources

Checklist for radiology reading rooms:

www.ergo.human.cornell.edu/ahprojects/hronn06/HBthesisdefense.pdf

Ergonomics work environment for radiology:

www.healthimaging.com/topics/practice-management/rsna-keep-reading-room-ergonomics-mind-says-siegel

Cornell University on radiology reading rooms:

www.ergo.human.cornell.edu/CDRREC.htm

SLIPS, TRIPS, AND FALLS

Jonathan Dropkin

Controls (see also [Table 7](#))

Facility design and renovation can help prevent the risk of slip, trip, and fall injuries among healthcare workers. There should be auxiliary and back-up lighting above floors, in stairways and ramps, and at the entrance and grounds.

Floors: Each floor surface (sanitary room, wards and units, operating theaters, kitchens, corridors and stairs) requires different types of flooring and coefficients of friction. Higher coefficients of friction have better slip-resistance properties. Steps should have high coefficients of friction. Use non-slip mats in areas where floors are continually wet or greasy. Rugs and runners must be secured. Replace loose or bundled carpet, mats that are curled or ripped, and tile that is blistered or indented. Keep work areas and corridors uncluttered. Use suitable barriers and signage or enclose obstructions. Push in open drawers.

Stairways and ramps: Stairways require handrails, slip-resistant coating for steps, high visibility (clear of obstructions), non-slip markings for the edges of steps, and adequate illumination (200-500 lux). Highlight the nosing of each step with contrast painting or strips. Negotiating stairs with poor illumination and lack of handrails during physical therapy can pose a fall hazard to a patient, even while being held. Similar risks are seen while ambulating and walking patients. Ramps should be well marked with appropriate signage for visibility. The United Nations Enable sitemap titled “Accessibility for the Disabled” states the maximum recommended slope of ramps should be 1:20 [194]. The American with Disabilities Act reports a maximum ramp incline of no greater than 1:12 slope, which is 12 inches (or 30.5 centimeters) for every one inch (or centimeter) rise [195]. The latter recommendation results in approximately a five-degree angle.

3. ERGONOMICS: Slips, Trips, and Falls

Cables and cords: Cables and electric cords represent trip hazards. Ideally, cover cords on floors with beveled protective covers. Cables and cords should not be in areas where people walk and never placed across walkways. Enclose and provide high visibility and non-slip markings over cables crossing pedestrian routes. Cable covers should securely fix cables to surfaces. Secure loose cords and wires, use tubing to secure cord bundles, or cord containers to secure cords under desks, computers, medical equipment and the kitchen. Organize operating rooms so that equipment cords are not stretched across walkways. Use retractable telephone cord holders in patient rooms and nursing stations.

Lighting: The function, positioning, and location of lights require different levels of illumination. Use natural light when possible; artificial light must provide adequate illumination. For example, stairways and hallways have different lighting/illumination requirements, as do conference rooms and operating theaters. Minimum illuminance levels for safety in non-patient care areas are 5.4-11 lux (0.5-1.0 footcandles, or fc) for infrequent (small risk) hazards requiring visual detection and 22-54 lux (2-5 fc) for common (significant risk) hazards requiring visual detection. The range depends on whether the activity level is low or high. In patient care areas, the illuminance recommendations vary by task and are based on other factors besides safety. Many patient care areas require horizontal illuminance levels of 500 lux or more. The nursing station, for example, should have a general horizontal illuminance of 300 lux, with 500 lux at the desk. Corridors in nursing areas should have a horizontal illuminance of 200 lux during the day and 50 lux at night. While noting specific lighting standards are beyond the scope of this report, we refer the reader to the ANSI standard for Lighting in Hospitals and Healthcare Facilities which includes comprehensive standards for many patient care areas as well as emergency lighting standards [196]. Broad recommendations for hospitals are made in the FGI construction guidelines, which are accessible at [17]. Recommendations for some specific areas of the hospital may be found in the U.S. Department of Energy presentation listed under References [197].

Spills: In areas with frequent spills, install wall-mounted spill pads and paper towel holders to clean up contaminants, and ensure easy access to cleaning materials. Provide cups, paper towel holders, and trashcans near water fountains. Spills should be cleaned up as soon as can be arranged and they should be blocked until that time. Spill-absorbent products and compounds should be used to maximize the effectiveness of the clean-up. Use signs that will get peoples' attention such as wall-mounted signs, barrier signs, red warning signs, tension rods with hanging signs, cones with chains, hallway barriers, and tall signage (48 inches or 122 centimeters) with flashing light on top of signs.

Cleaning: Cleaning methods and equipment must be suitable for the surface being cleaned. When possible, use dry cleaning methods. This will prevent slippery or wet floors that can result in falls and it will also reduce the use of

3. ERGONOMICS: Slips, Trips, and Falls

toxic chemicals. Choose appropriate cleaning products for degreasing kitchen floors. Ideally, use specially formulated cleaning products for commercial and industrial food service areas that are bio-degradable and can be used with hot or cold water. Place door stopper barriers to prevent wax from overflowing during floor waxing.

Entrance and Grounds: At the hospital entrance, provide water-absorbent walk-off mats with beveled edges and umbrella stands. Provide adequate lighting in outside level areas, parking garages, and outdoor stairwells. Provide external ice and snow removal. Provide bins for anyone to spread ice-melting chemicals. Eliminate wheel stops in parking lots. Patch or fill holes, cracks, or uneven pavement in walkways and parking areas. Create visual cues that highlight changes in curb or walkway elevation with yellow paint. Drains should be directed away from walkways with high pedestrian traffic. Check that pipes are directly aligned with the drain.

Internet Resources

Canadian Center for Occupational Health and Safety factsheet on prevention:
www.ccohs.ca/oshanswers/safety_haz/falls.html

NIOSH Hospital-specific prevention of slips, trips, and falls:
<http://www.cdc.gov/niosh/docs/2011-123/pdfs/2011-123.pdf>

OSHA etools on slip, trip, and fall hazards:
www.osha.gov/SLTC/etools/hospital/hazards/slips/slips.html

Prevention of trips, slips, falls in UK:
www.hse.gov.uk/research/hsl_pdf/2006/hsl0680.pdf

Prevention of trips, slips, falls in EU:
www.osha.europa.eu/en/publications/e-facts/efact37

Prevention of trips, slips, falls at work in UK:
www.hse.gov.uk/slips/workers.htm

SONOGRAPHY

Alice Freund

Controls (see also sections on *Computer Workstations*, and *Patient Handling* and *Table 7*)

Ultrasound controls include: adjustable height beds, tables and chairs; and room for knees under the table and bed so the sonographer can get close to the patient and not have to extend or elevate his or her arm (NIOSH). The table

3. ERGONOMICS: Sonography

should be as narrow as possible to limit the amount of reach to the patient's far side and should have removable rails. Support cushions or counter weights or suspension devices for transducers can alleviate stress on the arms and upper body. Chairs should have lockable castors [198]. Transducers should be designed to be used in both hands to promote neutral right and left-hand and wrist postures [199]. The monitor should have a high resolution screen, with brightness control, and be positioned in front of the sonographer (see [NIOSH bulletin](#) below). The keyboard should be at a height that allows the upper arm to relax. Work practice and administrative controls include frequent breaks, scheduling limited and different types of exams for each sonographer, varying postures throughout the day, and loosening the grip on the transducer.

Internet Resources

NIOSH bulletin on workplace solutions for sonography:
www.cdc.gov/niosh/docs/wp-solutions/2006-148/pdfs/2006-148.pdf

OSHA's etool for sonographers:
<https://www.osha.gov/SLTC/etools/hospital/sonography/sonography.html>

Guidelines of the Society of Diagnostic Medical Sonography:
www.sdms.org/pdf/wrmsd2003.pdf

NIOSH prevention of MSDs for sonographers:
<http://www.cdc.gov/niosh/docs/wp-solutions/2006-148/>

3. ERGONOMICS: Table on Control Studies

Table 7. Studies of Controls for Ergonomic Hazards

| Hazard | Population studied | Control method(s) studied | Conclusions | Authors |
|------------------------|---|---|---|-----------------------|
| Computer work-stations | Literature review | Engineering controls: adjustable vertical track wall mounts and adjustable computers on wheels (COWs) Work practice controls: health-care ergonomic training and education programs | Healthcare information technology (IT) is used in numerous areas of healthcare delivery. This is changing the nature of most healthcare jobs. However, little attention is paid to ergonomic design principles. The consequences are increased work-related musculoskeletal disorders. A summary of ergonomic design principles is described to reduce IT exposures. | Hedge (2011) [200] |
| Computer work-stations | Eight doctors and 27 nurses evaluated on two wards in one hospital. Assessment of physical attributes of three devices | Engineering controls: generic COWs, tablet PCs with handles, and stationary computers in office | Choice of device was related to clinical role, nature of clinical task, degree of mobility required, and device design. Nurses and doctors on ward rounds showed a preference for generic COWs over all other devices. The design of the devices and ward space configurations place limitations on how and where devices are used. In selecting hardware devices, consideration should be given to who will be using the devices, the nature of their work, and the physical layout of the ward. | Andersen (2009) [159] |
| Computer work-stations | One hundred computerized tomography (CT) examinations were selected at random and reviewed by four radiologists | Engineering controls for filmless radiology: moveable room partitions; two-monitor work-stations; high brightness, active-matrix liquid crystal displays (LCD); walls of the reading rooms painted with neutral or dark colors; and carpeting with acoustic-dampening materials | The use of picture archiving and communication systems (PACS) or filmless radiology was associated with increases in inpatient and outpatient utilization of radiologic services. Inpatient utilization increased by 82% after a transition to filmless operations. Outpatient utilization increased by 21%. | Reiner (2000) [201] |

3. ERGONOMICS: Table on Control Studies

Table 7. (Cont'd.)

| Hazard | Population studied | Control method(s) studied | Conclusions | Authors |
|------------------------|---|--|---|--------------------------------|
| Computer work-stations | None: review of best practices for European healthcare professionals | Engineering controls: computer working height/work surface, sit/stand workstations, work chair, height adjustable footrest. Work practice controls: forearm and hands resting and supported on desktop; surface area for inputting devices, document holders and telephone. | A basic risk inventory covering musculoskeletal risks by interview and observation should be conducted. A project plan should be prepared. At the technical/structural level, redesigning patient rooms, nursing stations, and all other units should be implemented within the hospital. Modification of structural arrangements and designs is often required. Special features are the ergonomic design of counters. Ergonomic technicians should help employees adjust tables and chairs. | European Commission (2011) [9] |
| Hand-held devices | 200 staff (15 senior doctors, 79 assistant doctors, 38 nurses, and 68 healthcare staff) were screened in ICU and 14 operating rooms | Engineering controls: decontamination of mobile phones with alcohol disinfectant, antimicrobial additive materials with alcohol cleansing disinfectant, protective material on the mobile phone. Work practice controls: training of HCPs about strict infection control procedure, hand hygiene, and environmental disinfection. | 94.5% of phones demonstrated evidence of bacterial contamination with different types of bacteria. Distributions of the isolated micro-organisms from mobile phones were similar to hands isolates. Some mobile phones were contaminated with nosocomial important pathogens. Mobile phones used by HCP in daily practice may be a source of nosocomial infections in hospitals. | Ulgar (2009) [202] |
| Hand-held devices | A microbiological analysis of 75 doctors' mobile phones | Engineering controls: decontamination of mobile phones with alcohol disinfectant wipes | A total of 90 bacterial pathogens were isolated. Male doctors' mobile phones were more (69%) contaminated than female doctors' phones (31%). The study demonstrates that mobile phones in a clinical setting become contaminated by contact with HCP' hands. They act as a potential source to spread infection. | Tambekar (2008) [203] |

3. ERGONOMICS: Table on Control Studies

Table 7 (Cont'd.)

| Hazard | Population studied | Control method(s) studied | Conclusions | Authors |
|-------------------|--|--|--|--------------------------|
| Hand-held devices | Review article | Engineering and administrative controls: lower ringtones; mobile phones switched off near critical care life support equipment; restriction on use of mobile phones near sensitive equipment and ICU; education of HCP on data storage and confidentiality; surface decontamination and hand hygiene techniques; HCP educated to avoid phone and charger use near oxygen; patients informed of risk of cross-contamination | Mobile phone technology is now common and popular. Applications are found in varied and distinct areas of healthcare delivery. However, there have been identifiable clinical risks with such technology reported over recent years. HCP and institutions should be aware of the potential problems of this technology to protect patients and users from dangers, such as electromagnetic interference with other hospital equipment, confidentiality, cross-contamination, distraction, and noise. | Visvanathan (2011) [204] |
| Laparoscopy | 12 surgeons in the Netherlands | Engineering: flat-screen monitors vs. cathode ray tube (CRT) monitors | Video analysis of postures and a questionnaire showed that the use of flat screen monitors placed over the patient is better for the physical and psychological comfort of the users even though the performance is inferior compared to CRT monitors placed out of the sterile zone. | Veelen (2002) [205] |
| Laparoscopy | Eight Dutch surgeons performed two tasks | Engineering: operating surface height | The frontal eye level position required the least electromyographic (EMG) activity. To optimize personal preference and performance, it is recommended to place two monitors in front of surgeon: one at eye level and one at height of operating field. | Veelen (2002) [170] |

3. ERGONOMICS: Table on Control Studies

Table 7. (Cont'd.)

| Hazard | Population studied | Control method(s) studied | Conclusions | Authors |
|-------------|---|--|---|-----------------------|
| Laparoscopy | 18 subjects simulated a surgical task | Engineering: position of monitor | The frontal eye level position required the least electromyographic (EMG) activity. To optimize personal preference and performance, it is recommended to place two monitors in front of surgeon: one at eye level and one at height of operating field. | Matern (2005) [171] |
| Laparoscopy | 21 U.S. surgeons simulated cutting task | Engineering: height of operating table | Using subjects' ratings of difficulty and discomfort and electromyographic measurements, it was determined that the handles of the long instruments used for laparoscopy should be positioned near the surgeons' elbow level. Table height should be 64 to 77 cm above floor level. | Berquer (2002) [206] |
| Laparoscopy | Two German surgeons simulated insertion of instrument at different angles | Engineering: height of operating table | With elbow angle held constant, the most comfortable height was selected. Different types of handles required different height tables. Optimal height varied from 30.0 to 60.5 cm. | Matern (2001) [169] |
| Laparoscopy | 13 U.S. medical trainees simulated four tasks related to endoscopic surgery | Engineering: robotic system | Job strain scores were significantly lower for telerobotic compared to manual tasks. | Lee (2005) [173] |
| Laparoscopy | 19 subjects simulated a laparoscopic task in the U.K. | Engineering: arm rests | Error rates and discomfort measures were improved with use of arm rests. | Galleano (2006) [207] |

3. ERGONOMICS: Table on Control Studies

Table 7. (Cont'd.)

| Hazard | Population studied | Control method(s) studied | Conclusions | Authors |
|------------------|---|---|---|--------------------------|
| Laparoscopy | Observation of seven procedures in four hospitals; analysis of 33 questionnaires in the Netherlands | Engineering: foot pedals | New guidelines were derived for foot pedals including 10 criteria such as avoiding static standing posture and excess force and angle of the foot. | Veelen (2003) [168] |
| Patient handling | Nursing staff of six U.S. long-term care facilities and one chronic care hospital | Engineering and administrative: patient handling devices and comprehensive ergonomic program | 60% reduction in patient handling; 87% reduction in lost workdays; and 90% reduction in workers compensation costs. Payback period averaged 15 months. | Garg (2012) [175] |
| Patient handling | Nursing staff at one large U.S. medical center and one community hospital | Engineering and administrative: lifting equipment, minimum lift policy, change in incident reporting, and change in who paid for workers compensation | No change in patient handling injuries at medical center. 44% decrease in injuries at the community hospital. | Schoenfisch (2013) [208] |
| Patient handling | None: literature review | Engineering, administrative, and work practices: Exercise, training, back belts, stress management, mechanical transfer equipment | Study quality overall was poor and there was no strong evidence regarding efficacy of interventions to reduce back injury or back pain. Moderate evidence that training alone is not effective. Multidimensional interventions are effective. | Dawson (2007) [183] |
| Patient handling | 10 U.S. students and simulated patient | Engineering: ceiling lift versus floor-based lift | As concerns spinal loading, ceiling lifts and floor lifts are better than one or two caregiver manual lifts. Ceiling lifts present little spinal load risks. Under some maneuvers studied, floor-based lifts can present shear forces that can damage the spine. Therefore, ceiling lifts are preferable. | Marras (2009) [179] |

3. ERGONOMICS: Table on Control Studies

Table 7. (Cont'd.)

| Hazard | Population studied | Control method(s) studied | Conclusions | Authors |
|------------------|---|--|---|----------------------------------|
| Patient handling | Literature review | Engineering, administrative, and work practice controls were reviewed. | Back belts are not effective. Ceiling and mobile lifting devices are effective for patient transfers. Electric and height-adjustable features are effective for patient handling tasks such as bathing. Friction reducing slide sheets, air-assisted devices, and mechanical aids are available for repositioning. Beds with lateral rotation therapy are designed to turn patients from side to side. Gait belts are used to transfer patients from sitting to standing. | Nelson and Baptiste (2006) [178] |
| Patient handling | One investigator using 11 lateral transfer devices | Engineering: lateral transfer aides, including air mattresses, slide sheet, plastic bag, and traditional draw sheet. | Draw sheet and plastic bag required the most force. The Lateral Transfer Aid and Flat Sheet Set (Phil-E-Slide, Inc.) performed best in terms of minimizing mechanical stress. Extended handles or pull straps were important in relieving flexion of the spine. | Lloyd (2006) [180] |
| Patient handling | Staff on 19 nursing units and four spinal cord injury units at seven Veterans Affairs hospitals in U.S. | Engineering and administrative: ergonomics assessment protocol, patient handling assessment criteria, peer leaders, equipment, after action reviews and zero lift policy | Nine months after the program there was a statistically significant decrease in injury rate and the rate of modified duty days taken per injury. There was a decrease in lost workdays, but it was not statistically significant. | Nelson (2005) [209] |
| Patient handling | None: literature review | Engineering: patient moving devices such as hoists, slide sheets | Moderate evidence that mechanical hoists and slide sheets are preferable to manual lifting. If walking belts are used, they should require two caregivers. Height adjustable beds and baths are recommended. | Hignett (2003) [210] |

3. ERGONOMICS: Table on Control Studies

Table 7. (Cont'd.)

| Hazard | Population studied | Control method(s) studied | Conclusions | Authors |
|------------------|--|--|--|------------------------|
| Patient handling | Literature review | Engineering and administrative: training, alone, and with exercise or equipment | Training and education combined with an ergonomic intervention were effective for reducing musculoskeletal symptoms. | Bos (2006) [184] |
| Patient handling | Nursing staff in three units of a small community hospital in Missouri | Engineering and administrative: mechanical lifts and training | Significant reduction in symptoms after six months. Injury rates, lost workdays, and workers compensation costs decreased, but not significantly. | Li (2004) [211] |
| Patient handling | Employees of 31 rural hospitals in Washington State, some of which included nursing homes | Engineering and administrative: zero lift program (equipment, policies, training, and patient screening) | Patient handling injury rate decreased by 43% and lost-time injury rate by 50% after program implementation. | Charney (2006) [212] |
| Patient handling | Employees in four hospitals and five nursing homes in Missouri | Engineering: mechanical lifts | In hospitals, reportable injury rate declined by 14%, lost-time injury rate declined 33% and lost day rate declined 53% after introduction of lifting equipment. | Evanoff (2003) [213] |
| Patient handling | 37 staff on medical-surgical units of two U.S. rural hospitals | Engineering: mechanical lifts, slide sheets, toileting device, and walking belts | Injuries and restricted days were reduced within 18 months and continued to decline over another four years. Patients felt more comfortable and secure. | Owens (2002) [214] |
| Radiology | Observations, questionnaires and interviews of eight radiology technologists in Rio de Janeiro | Engineering: modified film holder and control panel Other: Exercise | Wall-mounted film holder was used to place patient identifier on film chassis. A video display was installed next to control panel to avoid awkward posture when viewing patients. Kinesiotherapy program was implemented. | Pais (2012) [192] |
| Radiology | Observation and questionnaire in academic radiology department in U.S. | Redesign of picture archiving and communications system (PACS) input devices and dictation system | Designed new input devices to decrease use of mouse and designed hands-free dictation. | Robertson (2012) [215] |

3. ERGONOMICS: Table on Control Studies

Table 7. (Cont'd.)

| Hazard | Population studied | Control method(s) studied | Conclusions | Authors |
|---------------------------|--|--|---|----------------------|
| Slips, trips, falls (STF) | 10-year longitudinal study of occupational STF events in hospitals | Engineering controls: wall mounted spill pads; paper towel holders; wet floor signage; walk-off mats and umbrella bags; cups, paper towels, and trash cans near water fountains; degreasing cleaning chemical for kitchen; drains redirected away from high pedestrian walkways; barrier signs; cord bundlers and covers; retractable cord holders on phones; floor materials; lighting; wheel stops; curb changes with yellow paint; nosing of stairs; bins with ice-melting chemicals; drains in kitchens; equipment and cords in OR | Workers' Compensation claims rate for STF declined by 58% from the pre-intervention rate. STFs due to liquid contamination were the most common cause (24%) of STF claims. Food services, transport/emergency medical service, and housekeeping staff were at highest risk of an STF claim in the hospital. Nursing and office administrative staff had the largest numbers of STF claims. STF injuries in hospitals have a range of causes. Implementation of a broad-scale prevention program can reduce STF injury claims. | Bell (2008) [216] |
| Slips, trips, falls | Review paper of best practices in the operating room | Engineering controls: no cords and cables across walking paths; articulating ceiling-mounted booms; bundling, taping, or braiding cords; cables integrated into OR bed; absorptive mats; unobstructed view of walking paths; illumination; ring of fluorescent lights around diffusers and an outer ring of dimmable down lights; modular, structural ceiling systems that have multiple mounting locations; voice activation for lights and OR beds; round corners, walls shaped to transition into doorways, and floor material patterns; dripless, brush-free gel solutions; gel-based skin preps; fluid solidifies | Traditional approaches for controlling STFs are important in nearly all environments, such as the OR. Best practices in OR suite layout, design, and operation can help reduce the risk of STFs. Best practices can positively affect work performance and efficiency and patient care. | Brogmus (2007) [217] |

3. ERGONOMICS: Table on Control Studies

Table 7. (Cont'd.)

| Hazard | Population studied | Control method(s) studied | Conclusions | Authors |
|---------------------|---|--|--|-----------------------------------|
| Slips, trips, falls | U.S. HCP reporting events to one of seven occupational health departments over a three-year period | Engineering controls: floor slipperiness Administrative controls: hospital reporting procedures | Greatest risks were seen when walking on an unusual pathway and when contamination was present. Other risks were carrying objects, being distracted, and being rushed. Pushing or pulling equipment reduced the risk of STF. This suggests that there are several modifiable exposures to help prevent STF events. | Lombardi (2007) [218] |
| Sonography | 22 sonographers in U.S. | Engineering: Foam pads and closeness to patient and console | Electromyography showed 88% reduction in shoulder activity by using foam supports compared to unsupported arm raised at 75-degree angle. There was a 64% reduction in activity by placing console close to body. | Murphy and Milkowski (2006) [219] |
| Sonography | Anesthesia providers in U.S. | Engineering: inexperienced and experienced anesthesia providers rated seven machines | Physical and adjustable features, data management ease of use, image quality, and cost should be evaluated when selecting a machine. | Wynd (2009) [220] |
| Sonography | 10 inexperienced workers simulated breast ultrasound 10 experienced Brazilian physicians evaluated new designs | Engineering: two commercial transducers and three mock-up designs | Movement recordings on an electrogoniometer showed unsatisfactory results for two commercial transducers. Two mock-ups with wires coming out at a perpendicular angle to the transducer allowed a more neutral wrist posture and better grip. Left- and right-handed grips are needed. | Paschoarelli (2008) [221] |

3. ERGONOMICS: Table on Control Studies

Table 7. (Cont'd.)

| Hazard | Population studied | Control method(s) studied | Conclusions | Authors |
|------------|---|--|---|------------------------------|
| Sonography | Survey of 220 ultrasonographers in U.S. | Engineering and administrative: questionnaire included type of equipment, scan position, bed type, and time between patients | Performing more than 100 scans per month, average scan time of more than 25 minutes, ultrasonographer height less than 63 inches (160 cm) and use of manually propelled portable equipment (not motorized) were correlated with pain. | Smith (1997) [222] |
| Sonography | 2,041 physicians in Italy | Engineering and work practices: questionnaire asked about working conditions and technique | Transducer design was best predictor of hand-wrist complaints. Manipulating the transducer while sustaining applied pressure, shoulder abduction, and sustained twisting of the neck and trunk were reported as aggravating pain. | Magnavita (1999) [199] |
| Sonography | Sonographers throughout U.S. | Engineering and administrative: survey of preferred ergonomic interventions | Out of 19 interventions, sonographers preferred the following in order of preference: height adjustable bed with accessible controls, frequent breaks at least 15 minutes every two hours, use an adjustable chair, vary position throughout the day while scanning, perform stretching exercises throughout the day. | Horkey and King (2003) [211] |

4. Hazardous Drugs: Aerosolized Medications

Section 4. Hazardous Drugs

AEROSOLIZED MEDICATIONS

Debra Milek

Aerosolized delivery of medications has an advantage to the patient of direct delivery to the target organ, the respiratory tract, rather than indirectly via oral or parental routes. Medications for asthma such as beta agonists and anticholinergic bronchodilators and inhaled corticosteroids are the most commonly used, but the types of medications administered via this delivery system continue to increase. Aerosolized mucolytics (mucous thinning drugs) and antibiotics have been used to treat chronic lung infections in bronchiectasis (permanent widening of the bronchial tubes) and cystic fibrosis. The prostacyclin analogs have been utilized in a nebulized route for treatment of severe pulmonary hypertension. Other aerosols include anti-inflammatory medications to treat severe asthma and to prevent lung transplant rejection. Morphine has been aerosolized for the treatment of severe shortness of breath. Since the surface area of the lungs is vast and in communication with the circulatory system, the aerosolized route can be used to deliver medications systemically, as well as to the lungs. Aerosolized ergotamine is used for the treatment of migraine headaches; replacement therapy for nicotine and narcotics has been aerosolized; and administration of gene therapy for genetic deficiencies is likely to be administered by aerosol.

Aerosolized substances given to patients may also be agents that challenge an organ system such as methacholine administered with the intention of provoking bronchospasm in susceptible (asthmatic) patients. As with aerosolized medications, consideration should also be given toward the person administering the challenge. In a survey of 600 allergy specialists, about 20% reported symptoms among staff who performed methacholine challenge tests [223]. Two cases of asthma have been reported in nurses who frequently administered methacholine challenge tests over a period of more than two years [224]. While the precautions toward minimizing exposure are always the first level of control and precautions are similar to those for aerosolized medication administration, there may be a consideration toward re-assignment of a technician with asthma to an area not administering the drug. Additionally, some labs have considered administering a methacholine challenge under a controlled situation

4. HAZARDOUS DRUGS: Aerosolized Medications

to technicians who will be working with aerosolized methacholine to determine if there is a susceptibility to bronchospasm.

Aerosolized medications may be administered by a respiratory therapist, nurse, physician or other healthcare workers, depending on the country. Unlike ribavirin, pentamidine, or anesthetic gases (discussed elsewhere in this section), which have been better studied for their impact on healthcare workers and for which there are extensive engineering controls, including isolation and ventilation, the administration of the other medications above has been less well studied. Consequently, there are fewer studied or published recommendations for the protection of workers administering these aerosolized medications.

Healthcare workers administering aerosolized medications may have repeated low dose exposures to a variety of agents or cumulative dosing of the same agent which may act as the medication is intended to act on the person administering the medication as well as the patient. The potential side effects (unintended effects) of the various aerosolized agents are diverse, depending on the medication. Examples of potential side effects range from stimulation of the nervous system to constricting blood vessels, to suppressing immunity, if in sufficient dose. Decreased pulmonary function testing and acute respiratory symptoms have been reported on days when healthcare workers are in contact with aerosolized antibiotics. Repeated exposure to antibiotics could pose a risk for the development of drug-resistant strains, or fungal infection of the HCP, or possible allergic reaction.

There are no OSHA standards or ACGIH guidelines for aerosolized medication. Consideration may be given to medical screening of HCP prior to potential job exposure to identify individual susceptibility and further recommendations.

Controls (see also [Table 8](#))

Exposure to the healthcare worker administering the aerosolized medication may occur from a number of different routes. Exposure may occur through leaks in a mask that does not fit the face of the patient or in holes in the mask for breathing. Exposure also may occur during exhalation of the patient, even when using a closed system, if there are breaks or leaks in the system, planned or unexpected. Toward an effort to decrease healthcare worker exposure, attempts should be made to decrease loss of the drug during administration and/or exhalation and limiting environmental release through a filter. Means of accomplishing this include:

- A nebulizer with a mouthpiece rather than a face mask may more than double the amount of the medication delivered to the airway so it may be more beneficial to both the patient and the healthcare worker.
- The patient should be educated to not routinely remove the mouthpiece during therapy in order to prevent escape of the drug into the environment.

4. Hazardous Drugs: Aerosolized Medications

- A demand-only delivery system may be utilized to prevent administration of aerosolized medication when it is not likely for the medication to enter the patient's lungs.
- A nebulizer with a 0.2 micron filter for exhaled breath, such as that used for pentamidine, may be considered.
- Utilize a portable HEPA filter for local exhaust. The exhaust opening must be placed very close to the source to adequately capture the aerosol.
- Perform administration of aerosolized medications in negative pressure rooms with at least six air exchanges per hour or through a HEPA filter.
- In areas where multiple patients are treated, booths or stalls should be designed to provide airflow to draw aerosol and droplet nuclei from the patient and into an appropriate filtration system with exhaust directed to an appropriate outside vent [225].
- If no measures for capture are available, consideration may be given to PPE such as a NIOSH-approved respirator, depending on the agent aerosolized.
- Consider anterior and posterior auscultation of lungs, a routine part of aerosolized therapy, from behind the patient, so as to minimize exhalation and leakage exposures.
- Consideration may also be given to pre-treatment with a bronchodilator in patients likely to cough during nebulizer treatment.
- Different types of nebulizer (ultrasonic, jet, vibrating mesh-aperture) technologies are under development and should be reviewed for cost/benefit for patient treatment efficacy and healthcare worker safety.

While there is a paucity of literature on the issue of controls to protect HCP delivering aerosolized medications in pediatric ERs, the same recommendations should be followed as that outside the ER. If possible, it would be prudent to isolate the case, ER or otherwise, in an area with appropriate ventilation as previously described.

To optimize the child's compliance with treatment and to achieve effective medication delivery, which also reduces HCP exposure, a mouthpiece or well-fitted face mask should be an adjunct to the pressurized metered dose inhaler plus spacer (pMDI+S). Children younger than five years of age typically will require the additional use of a face mask. The valved holding spacer has a one-way valve with the particular advantage of allowing aerosol to move out of the chamber at inhalation but holding particles in the chamber during exhalation. Valved spacers should not be used for neonates or infants who are unable to generate the inhalational flow to open the one-way valve. Children should graduate to a mouthpiece by about five years of age [226].

In areas where costs can be prohibitive, a low-cost spacer made from a plastic bottle is effective for use with a metered-dose inhaler, but use must be included in conjunction with asthma educational initiatives with training in this technique provided by those familiar with this methodology [227].

4. HAZARDOUS DRUGS: Aerosolized Medications

Internet Resources

Links to a seven-part article by Le J et al., “Consensus Summary of Aerosolized Agents: Application of Guideline Criteria,” [228] are listed below (must be signed into Medscape to view articles, sign-up is free):

<http://www.medscape.com/viewarticle/724844>

http://www.medscape.com/viewarticle/724844_2

http://www.medscape.com/viewarticle/724844_3

http://www.medscape.com/viewarticle/724844_4

http://www.medscape.com/viewarticle/724844_5

http://www.medscape.com/viewarticle/724844_6

http://www.medscape.com/viewarticle/724844_7

OSHA Technical Manual (1999), Prevention of Worker Exposure to Hazardous Drugs:

www.osha.gov/dts/osta/otm/otm_vi/otm_vi_2.html#app_vi:2_2

Occupational Risk Factors and Asthma Among Health Care Workers:

<http://ajrcm.atsjournals.org/content/175/7/667.long>

This paper discusses asthma in healthcare personnel, including those who administer aerosolized medication:

www.ncbi.nlm.nih.gov/pmc/articles/PMC1899286/

“Guidelines for Methacholine and Exercise Challenge Testing-1999,” American Journal of Respiratory and Critical Care Medicine, Vol. 161, No. 1 (2000), pp. 309-329:

<http://www.atsjournals.org/doi/full/10.1164/ajrcm.161.1.ats11-99>

Hazardous Drug Exposures in Health Care:

<http://www.cdc.gov/niosh/topics/hazdrug/>

ANESTHETIC GASES

Theresa Gorman

Common anesthetic gases used for surgical procedures are nitrous oxide combined with isoflurane, desflurane, and sevoflurane (see [OSHA Guidelines](#), below). Nitrous oxide is also commonly used as an anesthetic in dental procedures. Hospital occupational exposures can occur in the operating suite during surgical procedures and in patient recovery rooms through leaking in the

4. Hazardous Drugs: Anesthetic Gases

anesthetic delivery system, leaks in the patient's mask, improper use of the gas scavenging system, or through exhalation of residual gas from the patient (see [NIOSH publication](#), below). Nitrous oxide is also used to obtain cold temperatures for cryosurgical procedures (see [NIOSH Publication](#), below).

Inhalation is the primary route of exposure. Anesthesiologists, surgeons, and staff working in surgical suites, dental exam rooms, and recovery rooms are at risk of exposure.

Chronic exposure to waste anesthetic gases may result in reproductive toxicity (see [OSHA Guidelines](#), below). Acute health effects include drowsiness, fatigue, depression, impaired judgment, headache, and nausea.

There are no exposure limits for anesthetic gases per se; however, there are occupational exposure limits for specific anesthetic gases. The ACGIH TLV for nitrous oxide is 50 ppm. Since nitrous oxide comprises the majority of anesthetic gases, it is assumed that if nitrous oxide is kept below the TLV, then other gases are also below dangerous concentrations. NIOSH makes the following recommendations: 25 ppm for nitrous oxide over the time exposed; and a ceiling of 2 ppm for fluoroxene, halothane, and enflurane over 60 minutes. France and Switzerland have limits of 2 ppm and 7 ppm, respectively, for isoflurane [9].

Controls (see also [Table 8](#))

Scavenging systems are effective in reducing concentrations of waste anesthetic gases originating from the anesthesia machine and exhaled residual gases from the patient. Waste gases should be vented to the outside or into a non-recirculated air system. Proper operation, leak testing, and maintenance of the scavenging system and anesthesia machine are critical in reducing exposures. Even if the scavenging units are working correctly, leaks can occur that result in very high levels of nitrous oxide. Many anesthetic machines have safety features such as keyed fillers, interlocks, and secured vaporizers to minimize staff exposure to waste gases. Proper sizing of masks, especially for pediatric patients, will help reduce leakage. The use of cuffed endotracheal tubes, when appropriate, can also help minimize exposure to waste gases. Work practices such as those listed in the 2007 NIOSH publication, below, can reduce levels. These practices include making sure the mask is in place before turning the gas on, and turning the gas off before turning off the breathing system. If the scavenging system is in proper working order, no PPE is necessary to control exposures to waste anesthetic gases.

Good ventilation in the recovery room is important. See [Table 1](#) for recommended ventilation rates and also the European Commission manual listed under the Discussion section, below, for a discussion of recovery room exposure [9].

4. HAZARDOUS DRUGS: Antineoplastic and Others

Internet Resources

NIOSH Publication No. 2007-151: Waste Anesthetic Gases - Occupational Hazards in Hospitals:

www.cdc.gov/niosh/docs/2007-151/

OSHA: Anesthetic Gases: Guidelines for Workplace Exposures:

www.osha.gov/dts/osta/anestheticgases/index.html/

NIOSH, Control of nitrous oxide in dental operatories:

www.cdc.gov/niosh/docs/hazardcontrol/hc3.html

NIOSH, Control of nitrous oxide during cryosurgery:

www.cdc.gov/niosh/docs/99-105/

ANTINEOPLASTIC AND OTHER HAZARDOUS DRUGS

Theresa Gorman

The NIOSH Working Group on Hazardous Drugs defines hazardous drugs as those that exhibit one or more of the following characteristics in humans or animals: (1) carcinogenicity; (2) teratogenicity or other developmental toxicity; (3) reproductive toxicity; (4) organ toxicity at low doses; (5) genotoxicity; and (6) structure and toxicity profiles of new drugs that mimic existing drugs determined hazardous by the above criteria.

Antineoplastic drugs make up the majority of NIOSH-defined hazardous drugs, which also include antiviral drugs, hormones, and bioengineered drugs. Antineoplastic agents treat cancer by inhibiting the growth and development of cancerous or malignant cells. Many commonly used antineoplastic drugs have carcinogenic, mutagenic, and teratogenic properties [229]. Acute exposure can cause dermal irritation (NIOSH Alert, below).

Exposure to antineoplastic drugs and other hazardous drugs can occur in many different areas of the hospital including the shipping and receiving area, hospital pharmacy, inpatient and outpatient cancer wards, laundry, and hospital waste collection areas. Pharmacists, nurses, nurses' aides, housekeeping staff, and maintenance workers are all at risk of exposure to hazardous drugs. Inhalation, dermal, and ingestion are all possible routes of exposures. Improper disposal of these drugs presents an environmental hazard.

Currently, there are no OSHA PELs, ACGIH TLVs or NIOSH RELs for antineoplastic drugs.

Controls (see also [Table 8](#))

Hazardous drug preparation and reconstitution should be performed in a Class II or Class III (i.e., a fully enclosed glove box) biological safety cabinet

4. Hazardous Drugs: Antineoplastic and Others

(BSC) or a compounding aseptic containment isolator (CACI). A vertical laminar flow bench should always be used, never a horizontal flow bench. The BSC is essential to protect both the worker and the product. Biological safety cabinets should be cleaned at the end of each work day and at least twice daily during 24-hour shifts to prevent surface contamination. Facilities that handle antineoplastic agents should have a protocol in place to handle any accidental spills. Waste materials that contain trace antineoplastic amounts such as needles, empty vials, gowns, and gloves should be disposed in yellow chemotherapy waste containers. Chemotherapy wastes should be kept separate from other types of medical and infectious wastes. Bulk amounts of antineoplastic and other hazardous drugs should be treated as hazardous waste and disposed of following appropriate federal regulations.

Administering the hazardous drugs intravenously using a needleless system and closed-system transfer devices will reduce risk of exposure to nurses and pharmacy staff (see [NIOSH Alert](#), below). Proper labeling is necessary to ensure safe handling. Disposable long-sleeved gowns made of polyethylene-coated polypropylene with tight fitting cuffs and double chemotherapy-specific gloves certified by the American Society for Testing and Materials (ASTM) should be used and changed hourly. Safety goggles or face shields are also recommended when in high-exposure scenarios, such as cleaning spills or handling damaged shipping containers [230]. Respirators are also indicated in situations where aerosolization of the drug is likely. (See also [NIOSH Alert](#), below.)

Internet Resources

American Society of Health-System Pharmacists, “Guidelines on Handling Hazardous Drugs, 2006.”:

<http://www.ashp.org/DocLibrary/CE/AJHP06002.aspx>

NIOSH Alert, “Preventing Occupational Exposures to Antineoplastic and Other Hazardous Drugs in Health Care Settings”:

www.cdc.gov/niosh/docs/2004-165/

NIOSH, “List of Antineoplastic and Other Hazardous Drugs in Healthcare Settings, 2012.”:

<http://www.cdc.gov/niosh/docs/2012-150/pdfs/2012-150.pdf>

NIOSH, “Occupational Exposure to Antineoplastic Agents”:

www.cdc.gov/niosh/topics/antineoplastic/

NIOSH: “Hazardous Drug Exposures in Health Care”:

<http://www.cdc.gov/niosh/topics/hazdrug/>

NIOSH: “Personal Protective Equipment for Health Care Workers Who Work with Hazardous Drugs”:

<http://www.cdc.gov/niosh/docs/wp-solutions/2009-106/pdfs/2009-106.pdf>

4. HAZARDOUS DRUGS: Nitric Oxide

Occupational Safety & Health Administration. OSHA Technical Manual Section VI: Chapter 2: Controlling Occupational Exposures to Hazardous Drugs:
http://www.osha.gov/dts/osta/otm/otm_vi/otm_vi_2.html

NITRIC OXIDE

Theresa Gorman

Nitric oxide (NO) has been used as inhalation therapy to treat pulmonary hypertension in adults and newborns since the 1990s. Inhaled NO is delivered through the patient's ventilator. The main safety concerns regarding inhaled NO therapy are the potential exposure of both the patient and health care worker to nitrogen dioxide (NO₂) which is formed by the reaction between NO and oxygen. This oxidation process is relatively slow; however, it increases in high oxygen environments. NO₂ is a common indoor and outdoor pollutant. It is an irritant gas that causes respiratory health effects even at low doses [231].

The eight-hour OSHA PEL and ACGIH TLV for NO are 25 ppm. The eight-hour ACGIH TLV for NO₂ is 0.2 ppm (no STEL). The OSHA ceiling limit for NO₂ is 5 ppm. NIOSH recommends a short-term exposure limit of 1 ppm for NO₂.

Controls (see also [Table 8](#))

Inhaled NO is administered through the patient's ventilator. To ensure patient and healthcare worker safety, NO delivery systems should be designed to minimize the formation of NO₂ by keeping the contact time between NO and oxygen as short as possible; using the minimum effective dose of NO; and matching the flow rate of NO to the patient's rate of ventilation [232].

Several studies have been published assessing exposures of healthcare workers to NO and NO₂ during inhaled NO therapy administration to adults and newborns. All of the studies found that concentrations of NO and NO₂ during actual work activities and simulated worst case scenarios remained well below the PEL and TLV values for both gases [233-237].

NO and NO₂ should be continuously monitored, both at the end of inspiratory limb to measure concentrations delivered to the patient, and at the patient's bedside to measure exposures to the healthcare worker. Chemiluminescence and electrochemical cell analyzers have been shown to accurately measure NO and NO₂, however each technology has certain advantages and disadvantages. Chemiluminescence analyzers provide accurate readings of NO at smaller concentrations, but can underestimate the amount of NO₂. The equipment may be too bulky or noisy for patient ICU rooms. On the other hand, electrochemical analyzers can provide accurate measures of NO, but with a higher limit of detection, and can accurately measure NO₂. The equipment is smaller and can

4. Hazardous Drugs: Pentamidine

easily be fit around ICU ventilators. However, they have a slower response time [238].

Passive or active scavenging systems can be used in the inspiratory limb of the ventilator to scavenge inspired NO₂, and the expiratory limb to scavenge expired NO and NO₂. Charcoal filters are not effective absorbers of NO and NO₂, therefore soda lime containing potassium permanganate indicators should be used [232]. Environmental scavenging may not be necessary in hospitals that have ventilation standards for ICU rooms because the air exchange rate is able to dilute any excess NO or NO₂. However, environmental scavenging is still recommended to ensure patient and healthcare worker safety [232].

Internet Resources

Nitric Oxide Guidelines, St. Vincent's Hospital Intensive Care Services, New South Wales, Australia:

http://intensivecare.hsnet.nsw.gov.au/five/doc/inhaled_nitric_oxide_V_svh.pdf

New Jersey Department of Health & Senior Services Right to Know Fact Sheet: Nitric Oxide:

www.nj.gov/health/eoh/rtkweb/documents/fs/1357.pdf

PENTAMIDINE

Norman Zuckerman

Aerosolized pentamidine isethionate (AP) is an antimicrobial agent used in the treatment of pneumocystis pneumonia (PCP). PCP is an opportunistic infection that occurs in immuno-compromised and HIV positive individuals. It is included on the 2012 NIOSH list of hazardous drugs [239]. AP is used in hospital rooms and airborne isolation therapy rooms. Exposed workers are respiratory therapists, nursing staff members and physicians. Potential routes of exposure are inhalation, ingestion, and skin absorption [240].

HCP have reported the following symptoms: bronchospasms; a metallic taste; and nose, throat, and eye irritation [241, 242]. Studies have linked AP to decrements in certain lung function indicators [243, 244]. Because pentamidine may interact with DNA and nucleotides, it is a potential reproductive hazard [245, 246]. Due to the cough-inducing nature of this treatment, HCP administering pentamidine have an elevated risk of exposure to *M. tuberculosis*.

There is currently no OSHA Permissible Exposure Limit or ACGIH TLV.

Controls (see also [Table 8](#))

Facilities using AP should have protocols in place for the safe handling and use of AP, a written respirator program and a TB Infection-Control Program

4. HAZARDOUS DRUGS: Pentamidine

that includes any staff member potentially exposed to TB [58, 244]. Patients should receive a medical evaluation for TB before initiating AP treatment. Pentamidine should be administered in a full enclosure HEPA-filtered booth. Please refer to [Table 1](#) in the Ventilation section of this report for current ventilation requirements in rooms where pentamidine is administered. Proper precautions should be taken when using pressurized oxygen. A “treatment in progress” sign should be placed outside the room. HCP should don an elastomeric tight fitting 100 series particulate respirator and eye protection *prior* to initiating treatment and any time the booth is opened and treatment is underway (refer to manufacturer’s instructions for correct use of the booth).

Before beginning treatment, the HCP should explain the procedure to the patient, including instructions to pinch off the tube anytime they remove the nebulizer from their mouth. The nebulizer expiratory filter should meet industry standards for bacterial and viral efficiency. After treatment has been completed, operate the chamber for an additional three minutes (refer to manufacturer’s instructions for correct use of the booth). Exposed surfaces should be cleaned with an aseptic cleaner [247, 248]. The tent, nebulizer, and other disposable equipment should be treated as hazardous waste [249]. HCP should be informed of the risks of AP exposure, including reproductive risks. Asthmatic or pregnant staff members or those trying to get pregnant who are required to enter the treatment room should be offered alternative job assignments. Due to the potential reproductive risks, it is advised that HCP trying to conceive avoid exposure to AP. Pregnant staff members should not administer AP [249]. Companies should provide alternative and equal employment opportunities to employees who exercise this option.

All healthcare facilities should refer to the NIOSH Alert, below, regarding exposure to hazardous drugs in healthcare facilities whenever any staff member is potentially exposed to a hazardous drug in the workplace.

Internet Resources

Duke University, safe handling of hazardous drugs (08-29-11):

www.safety.duke.edu/safetymanuals/university/V-HazardousDrugs.pdf

ECRI (formerly Emergency Care Research Institute) Medical Device Safety Report (12-93):

www.mdsr.ecri.org/summary/detail.aspx?doc_id=8179

Morbidity and Mortality Weekly Report Guidelines for Preventing the Transmission of Mycobacterium tuberculosis in Health-Care Settings, 2005:

www.cdc.gov/mmwr/preview/mmwrhtml/rr5417a1.htm#tab1

State compensation insurance fund (California) Aerosol Transmissible Diseases - Exposure Control Plan:

www.statefundca.com/safety/losscontrol/LossControlArticle.aspx?ArticleID=623

4. Hazardous Drugs: Ribavirin

NIOSH Preventing Occupational Exposures to Antineoplastic and Other Hazardous Drugs in Health Care Settings:

www.cdc.gov/niosh/docs/2004-165/pdfs/2004-165.pdf

NIOSH HHEs for Pentamidine isethionate:

www.cdc.gov/niosh/hhe/reports/pdfs/1991-0187-2544.pdf

www.cdc.gov/niosh/hhe/reports/pdfs/1990-0140-2221.pdf

RIBAVIRIN

Norman Zuckerman

Ribavirin (1-beta-D-ribofuranosyl-1,2,4-triazole-3-carboxamide) is a synthetic nucleoside, antiviral drug. Aerosolized ribavirin is used for the treatment of respiratory syncytial virus (RSV) among highly compromised infants and young children and for immuno-compromised individuals with respiratory viral infections. It is a water soluble, odorless, white- to-off-white powder. It is included on the 2012 NIOSH list of hazardous drugs [239]. A compressed air driven nebulizer is used to produce respirable aerosolized particulates, 1.0 - 1.3 microns mass median aerodynamic diameter. The aerosol can be delivered by tent, mask, or mechanical ventilation. Potentially exposed groups are nurses, respiratory therapists, housekeeping and maintenance staff. In animal studies, ribavirin has been shown to cause fetal death and birth defects. Acute effects include irritation of the eye, nose, and throat; runny nose; headaches; nausea; chest pain; and asthma-like symptoms.

There is no OSHA standard or ACGIH guideline for ribavirin. The California Department of Health Services adopted a TWA of 2.7 µg/m³ by applying a safety factor of 1,000 to the no-observed-exposure-level for the most sensitive endpoint for the most sensitive species tested (rabbits).

Controls (see also [Table 8](#))

The most effective control is avoidance of medically unnecessary use of aerosolized ribavirin. Some medical centers have reduced potential exposure by using a higher concentration, shorter duration dosing schedule [250]. The shorter duration treatment permits HCP time to perform scheduled nursing and respiratory therapy duties during times of decreased exposures. A double tent system with a scavenging device is used to reduce exposure. For patients on a ventilator, a filter installed in the exhaust loop will reduce environmental exposure levels. Exposed workers and visitors must be advised of reproductive and respiratory risk. Concerned workers should be offered alternative, equal job responsibilities. Good work practices should be established such as turning off aerosol generators five minutes before any staff member/visitor enters the room (if required, an on/off switch can be located outside the treatment area).

4. HAZARDOUS DRUGS: Ribavirin

Prior to entering the room, all staff members should don proper personal protective equipment including goggles. When appropriate, a tight fitting 100 series negative pressure particulate respirator should be used. In the case of immuno-suppressed patients, select respirators without an exhaust valve. Employees should avoid re-aerosolizing particulates during cleaning and maintenance procedures (a damp cloth can be used to wipe down affected areas). When feasible, the room should be kept under negative pressure (a tissue paper near the door frame can be used to check for negative pressure).

Whenever any staff member is potentially exposed to a hazardous drug in the workplace, health care facilities should refer to the NIOSH Alert for Preventing Occupational Exposure to Hazardous Drugs, below, for guidance.

Internet Resources

NIOSH Health Hazard Evaluation Report:

www.cdc.gov/niosh/hhe/reports/pdfs/1998-0048-2688.pdf

California Department of Public Health Hazard Alert:

www.cdph.ca.gov/programs/hesis/Documents/riba.pdf

American Association for Respiratory Care, Clinical Practice Guidelines:

www.rjournal.com/cpgs/dalpcpg.html

Duke University Medical Center information for personnel:

www.safety.duke.edu/OHS/Documents/RibavirinInfosheetE.pdf

American Federation of Teachers Health and Safety Program:

www.aft.org/pdfs/healthsafety/fs_ribavarin0806.pdf

NIOSH Preventing Occupational Exposures to Antineoplastic and Other Hazardous Drugs in Health Care Settings:

www.cdc.gov/niosh/docs/2004-165/pdfs/2004-165.pdf

4. HAZARDOUS DRUGS: Table on Control Studies

Table 8. Studies of Controls for Hazardous Drugs

| Exposure | Population studied | Control method(s) studied | Conclusions | Authors |
|----------------------|---|---|---|-------------------------------------|
| Anesthetic gases | Personnel in operating and recovery rooms in 74 hospitals | Engineering: general and localized ventilation, fresh air circulation | Dilution ventilation alone is not an effective control method; increasing fresh air intake and effective use of scavenging systems is best for reducing exposures. | Rajhans et al. (1989) [251] |
| Anesthetic gases | 26 anesthesiologists in six hospitals | Engineering: ventilation rate of 22 changes/hour, proper maintenance of anesthesia machines, use of double mask scavenging system Administrative: anesthesiologists trained on proper use of scavenging system | Combination of engineering and administrative controls resulted in reduction of nitrous oxide exposure during adult surgeries from 61-90 ppm to 2-15 ppm and during pediatric surgeries from 134-764 ppm to 9-42 ppm. | Schuyt and Verberk (1996) [252] |
| Antineoplastic drugs | Wipe sampling performed in pharmacies of two hospitals | Engineering: tested efficacy of isolators (glove boxes) in protecting pharmacists from exposure | Contamination was found in both hospitals inside and outside the isolator; contamination may stem from the presence of drugs on the outside of drug vials; decontamination of drug vials is recommended. | Crauste-Manciet et al. (2005) [253] |
| Antineoplastic drugs | Hospital pharmacy workers | Work practices: wipe sampling of the outside of drug vials and packaging and of pharmacy surfaces in and around the BSC before and after new maintenance procedures were implemented | Very small amount of contamination was found on drug packaging; improved maintenance and cleaning of the BSC resulted in lower contamination throughout the pharmacy preparation area. | Hedmer et al. (2005) [12] |

4. HAZARDOUS DRUGS: Table on Control Studies

Table 8. (Cont'd.)

| Exposure | Population studied | Control method(s) studied | Conclusions | Authors |
|-----------------------------------|---|---|---|------------------------------|
| Antineoplastic drugs | Air and surface sampling in one hospital oncology pharmacy and oncology nurses' station | Engineering: vertical laminar flow Class II BSC PPE: disposable gowns, double latex gloves | Antineoplastic drugs were present in more wipe samples than air samples; drugs were present in the workers' breathing zone outside the BSC, surfaces outside the BSC, and at the nurses' station. Current use of engineering and PPE controls may not be effective in reducing exposures. | McDevitt et al. (1993) [254] |
| Antineoplastic drugs | Hospital pharmacy workers | Work practices: conducted wipe samples of the outside of drug vials to test for possible contamination | Suggested bottles should be decontaminated before handling by pharmacy staff; recommended protective sleeves for vials to prevent surface contamination. | Connor et al. (2005) [255] |
| Nitric oxide and nitrogen dioxide | Nursing staff in pediatric intensive care | Engineering: different room ventilation scenarios with worst case being a closed room and no natural ventilation vs. room with natural ventilation, exhaust, and air conditioning units | Even under worst case scenarios with minimal ventilation, air levels of NO and NO ₂ did not approach occupational exposure limits; ventilation further reduced exposures close to background levels. | Markhorst et al. (1886) |
| Nitric oxide and nitrogen dioxide | Staff in surgical ICUs in Paris, France | General room ventilation of two air changes per hour in each ICU room | NO and NO ₂ concentrations in ICU rooms were well below the occupational exposure limits and fluctuated based on outdoor concentrations and pollution levels. | Mourgeon et al. (1997) |
| Pentamidine | Female nurses | Engineering: containment booth | Using a containment booth to reduce pentamidine exposure below detection limit. | McDiarmid (1992) [256] |
| Pentamidine | 17 health care workers, nine nurses/ eight respiratory therapists | Engineering: containment booth | The Emerson booth and the Demestifier tent reduced exposure outside the booth below the limit of quantification (50 ng) or detection (50 ng), respectively. | Decker (1992) [257] |

4. HAZARDOUS DRUGS: Table on Control Studies

Table 8. (Cont'd.)

| Exposure | Population studied | Control method(s) studied | Conclusions | Authors |
|-------------|--|--|--|--------------------------------------|
| Pentamidine | Flow direction; no individuals were involved | Engineering: respiratory isolation room | Airflow direction of designated healthcare unit respiratory isolation rooms not always correct. Fifty-two of 115 hospital respiratory isolation rooms were, incorrectly, positively pressurized. | Fraser (1993) [258] |
| Ribavirin | Pediatric HCP | Engineering: tested efficacy of two different systems, a two-tent system with two and three exhaust units/ventilator with filter in exhaust loop Work practices: protocols established for; planned entry, emergency entry, returning child to tent, and for system maintenance | A two-tent, two-unit scavenging system (one inside hood, one inside the containment tent) and work practice controls, successfully reduced exposure levels. | Kacmarek and Kratochvil (1992) [259] |
| Ribavirin | Nurses and respiratory therapists | Engineering: Exhaust hood/room ventilation (air changes/hour) Work practice: Shut down nebulizer before entering the room | Exhaust hoods reduced exposure when used in conjunction with other controls. | Bradley et al. (1990) [260] |
| Ribavirin | Used mock patient | Engineering controls: In-house extraction system using hospital wall suction | System reduced exposure levels from a mean of 54 $\mu\text{g}/\text{m}^3$. | Mueller and Waldon (1996) [261] |

5. RADIATION: Ionizing Radiation and General Controls

Section 5. Radiation

IONIZING RADIATION AND GENERAL CONTROLS

Jacob Kamen

Radiation control in hospitals generally falls under the supervision of specially trained professionals known as health physicists, medical health physicists, or radiation safety officers. The equipment and facilities are usually regulated by government agencies that are devoted solely to radiation safety.

Ionizing radiation is atomic particles or electromagnetic waves that possess enough energy to produce ions, or charged particles, when interacting with matter. Radiation cannot be seen, tasted, or smelled. The hazard level of radiation depends on the activity, energy, and the type of radiation. In hospitals, ionizing radiation is used in diagnostic and therapeutic procedures. It is produced either by a machine, such as an X-ray machine, or from radionuclides, which are unstable elements (or isotopes) that emit ionizing radiation as they decay.

Ionizing radiation may cause different types of cancer (including stomach, liver, colon, lung, breast, uterine and thyroid cancer and leukemia), as well as genetic effects. While substantial evidence exists that radiation is capable of causing cancer in humans, genetic effects have been only clearly demonstrated in animals. High radiation exposures can also damage blood and tissues, including the heart, eyes, intestine, skin, and reproductive organs, depending on the type of radiation (alpha, beta, gamma), the route of absorption, and its potency [262]. High radiation exposure could affect the organs targeted directly by the radiation itself and indirectly by free radicals. High doses to pregnant workers may put the fetus at risk for cancer and mental retardation [263]. There are many acute effects of high doses of ionizing radiation, but they are very unlikely to be encountered by a radiation worker in a hospital setting. They include; nausea and vomiting, malaise and fatigue, increased temperature, blood changes (change in the lymphocytes count), and skin redness. Evaluation of adverse health effect due to low doses of low LET radiation is challenging. However, according to the BEIR VII report, the current scientific evidence is consistent with the hypothesis that, at the low doses (near zero up to about 100 mSv), there is a linear dose-response relationship between exposure to ionizing radiation and the development of solid cancers in humans [264].

5. RADIATION: Ionizing Radiation and General Controls

In the United States, the average dose for a radiation worker is approximately 2.2 milliSieverts (mSv)/year (yr) and 81% of hospital workers have an annual dose of less than 1 mSv [265].

The Nuclear Regulatory Commission (NRC) regulations (10CFR20) in U.S. and International Commission on Radiological Protection (ICRP) radiation limits for radiation workers are given in [Table 9](#) [266, 267].

Because the health risk for radiation exposure at occupational levels is unknown, radiation safety programs generally follow the principle to keep all

Table 9. Maximum Permissible Dose (MPD) Limits for Ionizing Radiation

| Organ | NRC dose limit | ICRP dose limit |
|--|--|---|
| Whole body (DDE*) | 50 mSv (5 rem) per year | 100 mSv (10 rem) over 5 years (<i>effectively 2 rem/year</i>) with no year exceeding 50 mSv (5 rem) |
| Lens of eye (LDE**) | 150 mSv (15 rem) per year | 150 mSv (15 rem) per year |
| Extremities and skin (SDE***) | 500 mSv (50 rem) per year | 500 mSv (50 rem) per year |
| Worker under 18 | 5 mSv (0.5 rem) per year | — |
| Embryo/fetus of declared pregnant worker | 5 mSv (500 mrem) per gestation period 0.5 mSv (50 mrem) per month | 1 mSv (0.1 rem) per gestation period |
| Lifetime limit for radiation worker | Age of worker multiplied by 10 mSv (1 rem) | — |

*DDE – Deep Dose Equivalent. Applies to external body exposure; dose equivalent at a tissue depth of 1.0 cm.

**LDE – Lens Dose Equivalent. Applies to the external exposure of the lens of the eye; dose equivalent at a tissue depth of 0.3 cm.

***SDE – Shallow Dose Equivalent. Applies to the external exposure of the skin or extremity; dose equivalent at a tissue depth of 0.007 cm averaged over one square centimeter.

5. RADIATION: Ionizing Radiation and General Controls

the radiation exposures as low as reasonably achievable (ALARA). Hospitals should have an ALARA Policy that sets forth local exposure limits for different classes of users to effectively minimize total radiation dose.

Controls (see also sections on [Nuclear Medicine](#), [Radiation Therapy](#), and [X-rays](#))

There are three main methods for controlling all types of ionizing radiation. These methods are time, distance, and shielding. Radiation drops off exponentially with distance from the source. Therefore all procedures should be designed to enable staff to perform their jobs in the least amount of time and at the greatest distance possible from the radiation source. When that is not possible, shielding is used to decrease the radiation exposure to a more acceptable level. Shielding depends on the type and energy of the radiation. Shielding materials may be lead, leaded glass, tungsten, or acrylic plastics, which reduce exposure, or simply gloves and lab coats to prevent contamination.

A key to evaluating ionizing radiation exposures and assessing control activities is continuous monitoring of high-risk personnel with personal monitoring devices such as film badges, thermoluminescent dosimeters (TLD) or optically stimulated luminescent (OSL) dosimeters that measure cumulative exposures of ionizing radiation. This includes workers in radiation therapy, nuclear medicine, radiology departments, and laboratories that use machines or radioisotopes that emit gamma rays, X-rays or high energy beta particles. Personnel, who may enter a radiation area where they could receive over 5 mSv/yr or more; or who may receive more than 10% of the annual exposure limit, should be monitored. Generally, the dosimeter is worn on the body (between the neck and the waist) to determine whole body dose. According to NCRP Report #122, one could estimate the Effective Dose Equivalent (EDE) for workers who use lead aprons. There are two methods to estimate EDE. If one dosimeter is used, then it must be worn outside the lead apron on the collar to measure lens-of-eye dose (NCRP Report #168) and estimate the EDE using EDE2 calculations. If two dosimeters are used, then one should be worn under the lead apron and the other one outside the lead apron on the collar. EDE1 calculation is used to estimate EDE [268]. Extremity dosimeters may be recommended during procedures where the fingers are close to the source [269]. In Nuclear Medicine, a ring badge is recommended on the finger to estimate the dose received during dose preparation and administration [270, 271]. To actively monitor and control radiation exposures and maintain doses in compliance with ALARA principles, if within a three-month period, an individual's radiation exposure exceeds 10% of the annual limit, the worker should be notified. If 30% is exceeded in three months, an investigation and controls to minimize dose are recommended [272]. Workers may be removed from work involving the potential for radiation exposure at the annual permissible dose limit.

5. RADIATION: Nuclear Medicine

Radiation control regulations have a special provision that limits the dose to a person who has declared a pregnancy and expected due date. When declared, the exposure to the fetus is limited to 500 mrem in the nine-month period. In addition, the exposure to fetus cannot exceed 50 mrem per month. Hospitals should have a policy for declared pregnant employees that includes fetal dose monitoring and restrictions from high exposure procedures, such as radiation therapy. Sample policies can be found at OSHA's website, listed below.

More controls for specific procedures are discussed under the relevant sections, below.

Internet Resources (see also sections *Nuclear Medicine, Radiation Therapy, and X-rays*)

A general description of ionizing radiation:

www.epa.gov/radiation/understanding-radiation-overview.html

Controls, guidelines, training material from ORAMED for preventing exposures to medical staff:

www.oramed-fp7.eu/en

Controls for ionizing radiation: American College of Radiology Radiation Safety page:

<http://www.acr.org/Quality-Safety>

Scroll down for information for pregnant workers:

www.osha.gov/SLTC/radiationionizing/index.html

RADIONUCLIDES: NUCLEAR MEDICINE AND DIAGNOSTIC MEDICAL IMAGING

Jacob Kamen

Nuclear medicine is a medical specialty that uses radioactive materials to diagnose and treat disease. The majority of procedures are diagnostic. The use of radioactive materials in these applications will generate radioactive waste, which must be properly managed, usually by the nuclear medicine department.

Technologists in nuclear medicine work with many different isotopes and many patients in any day. Job tasks of technologists include: receipt and processing of radioactive materials, elution of Mo-99 generators, preparation of radiopharmaceuticals, injection of patients, positioning and imaging of patients, post-imaging processing, radioactive waste collection, treatment of thyroid and liver cancer patients, and surveying for contamination.

The most common radioisotopes used in nuclear medicine are Tc-99m, I-131, I-123, Tl-201, F-18, In-111, Kr-81m, Rb-82, and Ga-67. Other, less common isotopes used in nuclear medicine include Y-90, Sr-90, Sm-153, N-13, O-15,

5. RADIATION: Nuclear Medicine

and P-32. Half-lives (the time required to decrease the radioactivity of a sample by 50%) are generally on the order of minutes to days. Some examples using the most common isotopes are 1.8 hours, 6 hours, 13 hours and 8 days for F-18, Tc-99m, I-123, and I-131, respectively. The hot lab is a specially designed room in a nuclear medicine department where the radiopharmaceuticals are delivered, stored, and prepared for dispensing.

Diagnostic studies typically involve: preparing the dose, injecting the patient, and then imaging. Positron Emission Tomography (PET) is a type of diagnostic imaging where workers' exposures are higher compared with other diagnostic nuclear medicine procedures due to the high energy of the radiation. A PET/CT scanner is a unit that overlays PET images (nuclear medicine) on the CT images (X-ray) to create a precise registration of the tumor location. PET imaging uses positron emission radioisotopes (most commonly F-18), which have photons with a high energy (511 keV), and short half-lives (110 minutes for F-18). The majority of the technologist dose is received while in close proximity to the patient.

Through the normal practices in the nuclear medicine department and nuclear cardiology, the hospital produces various types of waste contaminated with radioactive materials. Most of this waste is syringes, absorbent paper, extension tubing, and other medical supplies necessary to perform diagnostic studies. At the end of each day, the technologists collect the radioactive waste and transfer it to a secure radioactive waste storage room. Generally, radioactive wastes with half-lives less than 90 days are stored for "decay in storage." Decay-in-storage waste is stored in the radioactive waste storage room for a period of 10 half-lives from the date of storage, after which it is surveyed with a suitable survey meter. The waste should be surveyed with the most sensitive detector to confirm background radiation levels and then disposed according to the underlying hazard of the waste. Radioactive wastes with half-lives greater than 90 days are stored in a secure central waste storage location for accumulation until there is a sufficient amount to transfer to a licensed radioactive waste broker for proper disposal.

Accidentally, if such radioactive waste finds its way to the regular trash, the medical centers have waste radiation detectors that detect and alarm the staff of contamination in the regular trash. Upon discovery of such contaminated waste, the incident is investigated and thorough root-cause analysis is performed. Appropriate measures are taken to prevent these kinds of incidents from happening again. Radiation waste monitors are usually equipped with scintillation detectors and are installed in the loading dock of the waste disposal area. Wastes are monitored before being loaded into the truck leaving the institutions. As an added security, the exterior part of the truck loaded with the waste, should also be monitored by a hand held survey meter before the truck leaves the institution. The waste monitors are checked with a weak standard radioactive sealed source on a weekly basis to ensure proper operation.

5. RADIATION: Nuclear Medicine

Controls (also see [Ionizing Radiation section](#) and [Table 13](#))

Each radioactive package is surveyed upon receipt in the hospital to determine if damage occurred during shipping. This includes physical inspection, wipe tests, and survey with a meter. Decontamination is performed if needed. The content of the package must be compared to the order that was placed.

Mo-99 generators (used to produce Tc-99m) are always built with significant shielding but most departments locate them in a “vault” built of lead bricks to further reduce worker exposure.

Other than generator elution, radiopharmaceuticals are generally prepared and doses calibrated in the hot lab fume hood. Hot lab fume hoods typically have lead shielding on the base and in the front to protect the worker’s torso. Workers’ hands and arms are not shielded when working in the hood. Workers rely on time and distance to reduce the exposure to their extremities while preparing radiopharmaceuticals.

Radiopharmaceuticals are stored in lead shields called “pigs” and handling is done with tongs to maximize the distance between the radioisotope and the technologist’s hands. Gloves and laboratory coats are used at all times to prevent contamination.

Surveys in the nuclear medicine department are conducted daily to confirm the absence of radioactive contamination, including “personal” surveys before breaking for lunch and before leaving for the day to confirm the absence of radioactive contamination on their persons.

To control radiation during diagnostic procedures, prepared patient doses are stored in a lead “pig” until injection. When the technologist is ready to inject, the dose will be placed in a syringe shield, typically made of tungsten, to reduce exposure. Rolling shields are frequently employed between the patient and technologist to reduce the exposure to the technologist.

For patients in whom venipuncture is difficult, it may be preferable to get access to the vein with a cannula or butterfly needle before the radioisotope is injected [273].

Technologists are specifically trained to maximize their distance and minimize their time spent with radioactive materials and patients. Studies have demonstrated that the largest contributor to technologists’ radiation exposure, 30-40%, occurs while transferring non-ambulatory patients to and from the imaging bed [273]. Exposures can be reduced by using efficient patient handling equipment (see [Ergonomics section on Patient Handling](#)) or by lining up assistance from other staff in advance.

Shielding is used extensively in the nuclear medicine department: lead “vaults” and L-block shields, lead “pigs” and vials, tungsten syringe shields, and acrylic plastic and leaded glass rolling shields are all used to reduce technologist exposure. Glass or plastic is used to shield beta radiation, since lead

5. RADIATION: Radiation Therapy

and other high atomic number materials will emit Bremsstrahlung radiation if exposed to beta radiation.

While not commonly used in nuclear medicine departments, a 0.5mm lead apron has been shown to reduce the worker exposure by a factor of two when positioning patients for gated Tc-99m myocardial scans [274].

PET photons (511 keV) can easily penetrate shielding used for conventional nuclear medicine (140 keV) and diagnostic X-ray (120 keV). Consequently, shielding used in L-blocks, syringes shields and portable shields must be specifically designed for PET photons. Lead aprons used in radiology, are not as efficient to stop PET photons. Lead aprons stop approximately 95% of photons with energy below 100 keV but only 9% of 511 keV photons [275]. Studies have demonstrated that 75% of the dose to the technologist occurs when the technologist is within two meters of the patient [276]. Exposure maps around patients injected with agents have been developed [277]. Therefore, time spent beside the patient must be reduced as much as possible.

Areas where radioactive waste is stored are labeled appropriately and surveyed weekly for contamination. Access is restricted by a locked door and only nuclear medicine technologists or properly trained and monitored workers are allowed to enter the room.

Internet Resources (also see *Ionizing Radiation section and Table 13*)

Nuclear Medicine Resources Manual, Vienna: International Atomic Energy Agency, 2006. Chapter 8 (Radiation Safety Practice in Nuclear Medicine):
http://www-pub.iaea.org/mtcd/publications/pdf/pub1198_web.pdf

Guide for extremity dosing in nuclear medicine:
www.oramed-fp7.eu/en/Guidelines

RADIONUCLIDES: RADIATION THERAPY

Jacob Kamen

Procedures used in radiation therapy are either teletherapy (external sealed sources), brachytherapy (internal sealed sources), or open sources (I-131 treatment). Much larger amounts of radioactivity are used in therapy than used in diagnosis. The radioactive material sealed sources with the highest risk are used in the Radiation Oncology department.

External Sealed Sources

Teletherapy machines use external beams of radiation from sealed, high activity sources (usually Co-60) to deliver the prescribed dose to the tumor of a patient. Hence, it is also known as external beam therapy.

5. RADIATION: Radiation Therapy

Internal Sealed Sources

Brachytherapy is the delivery of radiation by placing sealed sources close to the tumor. In high dose rate (HDR) brachytherapy, a machine inserts a high activity source, usually pellets of Ir-192. They are inserted via a hollow catheter into a specific tumor location for a specific amount of time. Then the pellets are retracted and stored in the shielded HDR machine. Each pellet contains approximately 10-12 Curies (Ci) of activity.

Low dose brachytherapy, which is rapidly being replaced by HDR, uses permanent or temporary sealed source implantation. An example is prostate cancer treatment, which typically uses about 80-100 small seeds of either I-125 or Pd-103 inserted permanently in the prostate. Worker exposure is the highest during the time the seeds are manually implanted. Once they are inside the patient, the radiation is attenuated by the tissues and the patient presents very small external radiation hazard to others.

Ophthalmic applicators are used in the treatment of certain eye disorders, a non-oncological application of radiotherapy, performed by radiation oncologists. It uses beta sources, usually Sr-90/Y-90, with typical activity of 10-50 milliCuries (mCi). Activity is applied with a special applicator to specific parts of the eyeball.

Gynecologic (GYN) implants are typically temporary high activity implants using either Ir-192 or Cs-137. They are usually performed as an inpatient procedure to treat gynecologic cancers and are manually implanted by a radiation oncologist.

Open Sources

I-131-sodium iodide is an "open source" treatment for hyperthyroidism and thyroid cancer. Because the source is not sealed, the main hazard is radioactive contamination. The dose of I-131 is administered orally to the patients either as capsule or liquid form. A typical exposure from a patient receiving 100 mCi I-131 is about 15 mR/hr at one meter. Since these patients generally require very little bedside care, or are sent home, workers do not receive significant exposure from the patient. However, once the patient receives the dose, all bodily secretion (sweat, saliva, tears, urine) will contain some radioactive iodine. Most of the free radioactive iodine leaves the patient's system through urine and feces.

Besides radiation hazards, another hazard in this department deserves mention: that of heavy metal exposure during the creation of blocks used to shape the radiation field used in therapy. The blocks are made by pouring an alloy, which may contain bismuth, lead, tin and cadmium, into a mold. Cutting or sanding of the metal may be needed to finish the blocks. Lead and cadmium, even minute amounts, can be extremely toxic if inhaled or ingested.

5. RADIATION: Radiation Therapy

Controls (also see [Ionizing Radiation section](#) and [Table 13](#))

There should be a room designated for the storage and preparation of radioactive sealed sources for manual brachytherapy by designated and trained personnel. It should be provided with a locked door to control access and maintain source security. Consideration may need to be given for a security plan depending on the total amount of radioactivity present [266]. A radiation sign should be posted on the door.

There should be shielded storage (a safe) available for all sources. The outer surface of the storage shall be made of fireproof materials. The safe should be located near the preparation workbench to reduce the exposure of personnel during the handling and transfer of sources. The safe should have compartments for different source activities. Each compartment should be marked so as to permit immediate and easy identification of its contents from the outside with a minimum of exposure.

The workbench should be provided with an L block shield with a lead glass viewing window. The source handling area should be well illuminated and a magnifying glass in a fixed mounting should be available to handle sources efficiently and with a minimum of radiation exposure.

Devices for handling sources, especially forceps, should be available. They should be as long as practicable and compatible with efficient source handling. A device should be provided for threading sources expeditiously, with the fingers protected by distance. Sources should be readily identifiable by sight. When radioactive sources of the same appearance but of different activities are used, they should be distinguishable, for example by different colored threads or beads.

The working surface for source preparation should be smooth and seamless to avoid losing small sources such as Ir-192 wire fragments. Absorbent materials can be used to cover the benches to promote easy decontamination. The source storage and preparation laboratory should have a sink for cleansing sources, provided with a filter or trap suitable for preventing loss of sources through the drainage system.

There should be a clear indication of the radiation level in the room. This may be achieved by an area radiation monitor that is visible on entering the room and during any handling of unshielded sources, or a survey meter should be available and in use during source handling.

Space should be available for secure storage to enable the decay of short half-life sources such as Ir-192.

Hand-carried transport containers must be provided with long handles and the lid of the container must be securely fastened to prevent tipping and dropping of sources during transport. Containers should bear the radiation symbol as well as a "Caution Radioactive Material" warning sign. Space should be available for source transport trolleys with source containers.

Pregnant workers should not be in rooms where radiation therapy occurs.

5. RADIATION: Radiation Therapy

Foods are delivered by trained personnel and housekeeping staff are not allowed in the room during the therapy.

In teletherapy, a door interlock should prevent the external beam machine from removing the sources from the shielding if the door to the room is open. No one other than the patient should be inside the room when the machine is on. Shielding on teletherapy machines should be a thickness of 10 times the half-value layer.

The HDR machine is locked and shielded to prevent any exposure to workers from occurring when the machine is not in operation. During the procedure the dose to the worker is minimal because the patient is in a controlled room and the dose is delivered remotely. The room needs to be posted with a radiation label.

During low dose brachytherapy treatment, the sources are implanted in the body cavities through an applicator or catheter. Treatment is performed in a shielded room, which is posted with warning signs. At the end of the treatment, the room and the patient must be surveyed to make sure no source is lost or left inside the patient. If a source becomes dislodged, the worker is trained to use tweezers to pick it up to reduce the dose to his hands and to store the source in a shielded container. In case of death with radioactive seeds inside the patient, the worker needs to notify the Radiation Safety Office (RSO) who will make proper recommendation to reduce exposure to the workers in the morgue and funeral home if needed.

During GYN therapy with temporary implants, the room becomes a controlled area after the source is implanted and is posted as such. Special entrance instructions are required. Nurses should minimize the time spent closer than six feet from the patient and try to stay behind a shield if possible. If a source is found outside of the patient, it must not be handled directly and the RSO should be contacted to properly manage the source.

For thyroid therapy with I-131, extensive room preparation for inpatient treatments is performed, including covering most surfaces commonly contaminated to minimize the chance of contamination and to facilitate room decontamination when the patient is released. Physicians frequently prescribe anti-nausea medication beforehand, to reduce the risk of the patient vomiting. When patients are treated in the hospital, they are placed in private rooms with appropriate shielding to reduce exposure to staff and other patients. Visitation times will be limited by the radiation safety office. Visitors are instructed to maintain a recommended distance from the patient all the time. During the treatment, the radiation safety staff monitors the patient's radiation level, which decreases each day, until the point where they are allowed to go home (usually two to three days). If a patient vomits, urinates, or defecates, the nurse should cover the spill with blue absorbent papers to prevent the spread of contamination. Then they should call the radiation safety staff to decontaminate the area.

Foods are provided on disposable paper trays and delivered by trained personnel. All unfinished food and other trash remain in the room in designated

5. RADIATION: X-Rays

containers during the course of the treatment. Housekeeping and food service staff are not permitted to enter the room during the therapy. After patient discharge, the room must be cleaned by Radiation Safety staff. Radioactive Waste, if any, must be removed for decay in storage. A survey and wipe test of the room must be documented to ensure no contamination is left behind. Only once this is finished may the radiation signs be removed from the door and the room made available to the housekeeping staff for their routine services.

When melting metal used for creating blocks for field shaping, use good ventilation, such as a chemical fume hood with a minimum face velocity of 100 feet per minute. A portable High Efficiency Particulate Air (HEPA) vacuum should be used to pick up loose pieces of alloy and Styrofoam. Local exhaust ventilation (dust collector) should be used if particles or fumes are generated (such as from grinding, sanding, or welding the metal) [278].

Internet Resources

Australian safety guide to radiation therapy:
www.arpana.gov.au/pubs/rps/rps14_3.pdf

Radiation Oncology Physics: A Handbook for Teachers and Students. Vienna: International Atomic Energy Agency, 2005. Chapter 16:
<http://www-pub.iaea.org/books/iaeabooks/7086/Radiation-Oncology-Physics-A-Handbook-for-Teachers-and-Students>

American Thyroid Association Taskforce On Radioiodine Safety:
<http://thyca.org/ataradiation.pdf>

X-RAYS

Alice Freund

X-rays are a form of ionizing radiation used in stationary and portable X-ray machines, fluoroscopes, and computed tomography (CT). Fluoroscopes are used in many departments for image-guided procedures, also called interventional radiology, or IR. The procedures include cardiac catheterization, angiograms, pain management, and other procedures. Occasionally CT fluoroscopy is used for IR. For X-ray and most CT, the worker is in a shielded booth and receives minimal exposure. Fluoroscopy workers, however, are usually near the radiation source during the procedure resulting in a higher dose to the workers. In addition, fluoroscopy procedures can last from a few minutes up to a few hours and can result in higher doses to both patients and workers. CT fluoroscopy radiation doses can be orders of magnitude higher than conventional (fluoroscopy only) IR. Sources of radiation for all these procedures include the primary X-ray beam (which the physician is trained to avoid exposure to), scatter from the patient (major source of exposure) and surroundings, and leakage from X-ray generation equipment. The leakage is negligible and is regulated to be less than 100 milli-Roentgens per hour at one meter distance [279].

5. RADIATION: X-Rays

Controls (see also *Ionizing Radiation section and Table 13*)

Rooms where X-ray, fluoroscope, and CT machines are used should be specially constructed to reduce the radiation levels outside the room to permissible radiation exposure levels for members of the general public. In designing the shielding, consideration should be given to the specific machine, and use of the spaces on all sides of the installation. Non-essential personnel should not be in the room during the procedure. Except where patient safety is a concern (such as during procedures in interventional radiology), X-ray imaging rooms should be provided with interlocks to shut down the X-ray beam if someone enters the room. Dental offices are the exception because there is almost no scattering of low-energy X-rays. A sign posted outside the door should have a lighted indicator noting “X-ray in use” when the machine is activated. X-ray equipment should be checked on a regular basis for performance, leakage, and malfunctions.

In X-ray rooms, operators should be in a control booth or behind a shield. If this is not practical, protective lead aprons must be worn. Holding devices, rather than people, should be used to position or support children or weak patients. When people must be present, they should be provided with protective lead aprons and lead gloves, and be positioned so as to avoid the primary beam [280] and minimize exposure.

Interventional radiology (IR) fluoroscopy exposures should be minimized by reducing the procedure length, pulse rate, and beam intensity [281]. It can be done, in some circumstances, by using a low dose-rate mode, and “last frame hold mode.” The exposure can also be reduced by using other imaging techniques such as removing anti-scatter grid, adding beam filtration, and increasing X-ray beam energy.

Over-the-table tubes should not be used for IR procedures, as they cause more exposure to the upper body of the worker. New equipment should incorporate dose-reduction technology and comply with the most current International Electrotechnical Commission Standards [269].

IR personnel should wear protective aprons (with minimum equivalent to 0.25 mm lead) and a leaded thyroid collar. Ceiling-suspended shields may be used to protect the head and neck. Leaded eyewear is needed for parts of procedures where this is not possible. Under-table drapes should be used to protect the legs. Disposable protective patient drapes have also been shown to reduce the radiologist’s dose. Gloves are recommended only outside of the primary beam. Using them inside, in some circumstances, can worsen exposure [269].

CT fluoroscopy is a unique procedure, often used for biopsies. Radiation exposures to workers’ hands can be reduced by using a long needle holder; a lead drape on the patient; gloves; non-continuous, low amperage procedures [282]; and turning off the beam at certain angles.

5. RADIATION: Non-Ionizing

For mobile X-ray units, the operator should wear a protective apron (with minimum equivalent to 0.25 mm lead) or use a shielding-screen. Care must be taken to prevent exposure to people in the vicinity of the patient (including those beyond curtains or walls). Generally, a distance of 3 meters from the patient is considered an adequate distance for mobile X-rays as long as you are not in the primary beam path. A sign should be posted when using mobile machines which reads “CAUTION: X-RAYS” [280].

Internet Resources (see also [Ionizing Radiation section](#))

On reducing radiation doses to children:

www.asrt.org/Content%5CProfResources%5CImageGently.aspx

On reducing doses to adults:

www.imagewisely.org/

NON-IONIZING RADIATION

Alice Freund

Non-ionizing radiation is electromagnetic radiation, like ionizing radiation, but it has less energy and therefore is not powerful enough to cause the ionization (or removal of electrons) of molecules. It includes many types of electromagnetic radiation ranging in energy from extremely low frequency radiation to ultraviolet radiation. Hospitals employ equipment that generates many types of non-ionizing radiation, including those listed in [Table 10](#).

The health effects of non-ionizing radiation are expected to be related to the dose received; that is they would be expected to be greater for people exposed to higher levels or for longer periods. Health effects also will depend on many other factors including the wavelength (or frequency), the change in electric and magnetic fields over time and space, and even the shape of the waves that are generated. The biological effects of extremely low frequency (ELF), and in particular the 60 Hertz (Hz) current that is used in most residential and commercial buildings and hospitals, is very controversial. Research has focused on possible carcinogenic, reproductive, and neurological effects. Other suggested health effects include cardiovascular, brain and behavior, hormonal and immune system changes [289]. Similarly, the health effects of very low frequency (VLF), radiofrequency (RF), and microwave radiation have received a lot of attention, especially due to cell phone use. Reviews of health effects explore possible carcinogenic, reproductive, and neurological effects [289].

The known health effects and some of the possible health effects are described in [Table 11](#).

The standards for non-ionizing radiation are often wavelength-specific and more detailed than can be described here. [Table 12](#) lists partial standards from ACGIH. Other sources, such as the International Commission on Non-Ionizing Radiation Protection (ICNRP), should also be consulted.

5. RADIATION: Non-Ionizing

Table 10. Non-Ionizing Radiation Exposures from Various Types of Medical Equipment

| Medical equipment | Type of radiation | Frequency (Hertz (Hz)) or wavelength (nanometers (nm)) | Workers most exposed |
|-----------------------------|---|--|---|
| MRI Magnet | Static magnetic | 0 Hz | Radiologist, anesthesiologist, radiology technician, nurse, cleaners, maintenance staff, patient supervisor |
| Gradient fields | Extremely low frequency (ELF), and very low frequency (VLF) | 110 Hz-5,000 Hz [283] | Same as above |
| Radiofrequency coils | RF | 10-400 MHz | Same as above |
| Microwave diathermy [384] | RF | 433.92, 915 and 2045 MHz | Physiotherapists |
| Shortwave diathermy [384] | RF | 13.56, 27.12, and 40.68 MHz | Physiotherapists |
| Electro surgery units [284] | RF | 0.5-100 MHz [285] | Surgeon, nurse, anesthesiologist |

5. RADIATION: Non-Ionizing

Table 10. (Cont'd.)

| Medical equipment | Type of radiation | Frequency (Hertz (Hz)) or wavelength (nanometers (nm)) | Workers most exposed |
|---|--|--|---|
| Buildings' electrical current | ELF | 60 Hz | Radiologist, physiotherapist, all other employees |
| Electromagnetic nerve stimulators [284] | ELF, VLF | 2-10,000 Hz | Pain therapists |
| Magnetic bone stimulators [284] | ELF | 0-150 Hz | Orthopedists |
| Lasers | Infrared (IR), visible, ultraviolet (UV) | 10,600-193 nm [286, 287] | Surgeons, dermatologists, ophthalmologists, gynecologists, gastroenterologists, urologists, otolaryngologists, podiatrists, pain management specialists, orthopedists, biomedical engineering technicians, anesthesiologists, nurses, support staff |
| Lights for treating infant jaundice | Visible | 490-430 nm [288] | Pediatric nurses |
| Ultraviolet germicidal lamps | Ultraviolet | 254 nm | Maintenance workers |

5. RADIATION: Non-Ionizing

Table 11. Health Effects and Symptoms of Non-Ionizing Radiation

| Type of non-ionizing radiation | Frequency (kilo-, mega-, or gigahertz) or wavelength (millimeters or nanometers) | Known biological or health effects of overexposure | Possible health effects of overexposure | Symptoms |
|-------------------------------------|--|--|---|--|
| Static electric and magnetic fields | 0 Hz | Shock or annoyance from electric fields. Effects on the cardiovascular (heart rate, blood pressure) and central nervous systems from magnetic fields. Disruption of implanted medical devices. Injury from forces on ferromagnetic objects in the body [290, 291]. | Temporary worsening of eye-hand coordination, memory [291, 292]. | Temporary visual flashes, vertigo, nausea, metallic taste [291, 292] |
| Extremely Low Frequency (ELF) | 3-3,000 Hz | Peripheral and central nerve tissue stimulation [293]. | Leukemia [290, 293], miscarriages [293, 294], brain effects that affect task performance [293]. | Visual flashes [293] |
| Very Low Frequency (VLF) | 3-30 KHz | Shock, central nervous system excitability, peripheral nerve stimulation, painful muscular contractions. Disruption of implanted medical devices [291, 295-297]. | | Tingling, tapping, tickling [291] |

Table 11. (Cont'd.)

| Type of non-ionizing radiation | Frequency (kilo-, mega-, or gigahertz) or wavelength (millimeters or nanometers) | Known biological or health effects of overexposure | Possible health effects of overexposure | Symptoms |
|--------------------------------|--|--|--|---|
| Radiofrequency (RF) | 30 KHz-300 MHz | Temporary heating of tissues, of metals, wires, piercings, tattoos, permanent make-up. Disruption of implanted medical devices. Electric shock [291, 297]. | Carcinogenic, reproductive, neurological, and ocular effects [285]. Glioma from cell phones [298]. | Warming of body parts |
| Microwave | 300 MHz-300 GHz | Heating of body, electric shock, excessive surface heating. Noise from rapid pulses [297]. | Carcinogenic, reproductive, neurological, and ocular effects [285]. Glioma from cell phones [298]. | Warming of body parts, annoyance from noise |
| Infrared (IR) | 1 mm-770 nm | Skin, cornea, and retina damage, cataracts [287, 297]. | | Warming of outer tissues |
| Visible | 770-400 nm | Skin and retinal damage, photoreinitis [297]. | | Temporary blindness |
| Ultraviolet (UV) | 400-100 nm | Skin reddening, keratitis, conjunctivitis, cataracts, cornea damage, photoretinitis, accelerated skin aging, skin cancers [287, 297]. | | Skin burns, temporary blindness |

5. RADIATION: Non-Ionizing

5. RADIATION: Non-Ionizing Radiation

Table 12. Guidelines for Non-Ionizing Radiation

| Type of non-ionizing radiation | Frequency (kilo-, mega-, or gigahertz) or wavelength (millimeters or nanometers) | ACGIH guidelines | | |
|-------------------------------------|--|--|-----------------------|----------------------|
| Static electric and magnetic fields | 0 Hz | Magnetic: Whole body: 2T ceiling Whole body with special worker training and controlled environment: 8T ceiling Limbs: 20T ceiling Medical device wearers: 0.5 mT ceiling Electric: $E(TLV) = 5.535 \times 10^6/f$ | | |
| Extremely Low Frequency (ELF) | 3-3,000 Hz | Magnetic: $B(TLV) = 60/f$ Electric: $E(TLV) = 5.535 \times 10^6/f$ | | |
| Very Low Frequency (VLF) | 3-30 KHz | Magnetic: $B(TLV) = 60/f$ Electric: $E(TLV) = 5.535 \times 10^6/f$ | | |
| | | Frequency | E (6 min)* H (6 min)* | |
| Radiofrequency (RF) | 30 KHz-300 MHz | 30-100 KHz | 1842 | 163 |
| | | 100 KHz-1 MHz | 1842 | 16.3/F |
| | | 1 MHz-30 MHz | 1842/F | 16.3/F |
| | | 30 MHz-100 MHz | 61.4 | 16.3/F |
| | | 100 MHz-300 MHz | 61.4 and S = 10 | 0.163 |
| | | Frequency | S | min |
| Microwave | 300 MHz-300 GHz | 300 MHz- 3 GHz | F/30 | 6 |
| | | 3 GHz- 30 GHz | 100 | $33,878.2/F^{1.079}$ |
| | | 30 GHz- 300 GHz | 100 | $67.62/F^{0.476}$ |
| Infrared (IR) | 1 mm-770 nm | *Protection against thermal injury to cornea and lens: $E_{IR-only} [W/cm^2]$ less than $1.8/t^{0.75}$ for t less than 10^3 seconds (17 minutes) $E_{IR-only} [W/cm^2] \leq 0.01$ for t greater than 10^3 seconds (17 minutes) | | |
| | | *Protection against retinal thermal injury from near infrared (NIR): $L_{NIR} [W/(cm^2sr)] = \sum_{770}^{1400} L_{\lambda} \cdot R(\lambda) \cdot \Delta\lambda$ | | |

5. RADIATION: Non-Ionizing

Table 12. (Cont'd.)

| Type of non-ionizing radiation | Frequency (kilo-, mega-, or gigahertz) or wavelength (millimeters or nanometers) | ACGIH guidelines |
|--------------------------------|--|--|
| Lasers | 10.6 mm-193nm | ANSI exposure limits for a variety of medical lasers can be found in OSHA's technical manual (see resources , below) |
| Visible | 770-400 nm | <p>*Protection against thermal injury:</p> $L_R [W/(cm^2sr)] = \sum_{380}^{1400} L_\lambda \cdot R(\lambda) \cdot \Delta\lambda$ <p>*Protection against retinal photochemical injury from chronic blue-light:</p> $L_B [W/(cm^2sr)] = \sum_{305}^{700} L_\lambda \cdot B(\lambda) \cdot \Delta\lambda$ |
| Ultraviolet (UV) | 400-100 nm | For 8 hour ACGIH exposure limits, see: http://www.ccohs.ca/oshanswers/phys_agents/ultravioletradiation.html |

T = Tesla; B(TLV) = magnetic flux density in millitesla (mT); f = frequency in Hz; E(TLV) = root mean square electric field strength in volts per meter (V/m); F = frequency in MHz; H = Magnetic field strength in Amperes per meter (A/m); E = electric field strength in volts per meter (V/m); min = averaging time in minutes; S = power density in Watts per square meter (W/m²); E_{IR -only} = total infrared irradiance; E_λ = special irradiance; L_{NIR} = spectral radiance; L_R = effective spectral radiance of the lamp; sr = steradian; L_λ = spectral radiance; R(λ) = thermal hazard function; λ = wavelength; L_B = effective spectral radiance of the light source; B(λ) = blue-light infusion function; t = time in seconds.

*Space does not permit a full description. Consult ACGIH for more details. These values may be relaxed by reference to specific absorption rate (SAR) limits or for partial body exposure.

Controls (see also [Table 13](#))

For non-ionizing radiation, the primary methods of control are time, distance, and shielding, as is the case for ionizing radiation. In this section, we address more specific controls for three types of equipment that are of particular concern in hospitals: magnetic resonance imaging devices, ultraviolet lights, and lasers.

Magnetic resonance imaging devices (MRIs): MRIs emit three types of fields that pose health risks: a static magnetic field, which is on constantly; and gradient fields and RF fields produced only during MRI scanning. The strong magnet of the MRI is a safety and health concern because it will pull anything that is

5. RADIATION: Non-Ionizing

ferromagnetic into the bore of the machine. For this reason, standard practices include establishing: access restrictions for personnel depending on their training level and screening; device and object screening; marked zones (even in typically non-occupied work areas such as roof tops and storage rooms); “Magnet On” lights for the scanning room; emergency preparedness plans; and restrictions for pregnant employees, and those with implanted medical devices and pacemakers (see [resources](#), below). MRIs are becoming more powerful (exceeding the commonly used 0.5-3.0 T closed and the 0.2-1.0 T open machines [291]. MRIs are being used and redesigned for interventional procedures, requiring the presence of personnel near the patient during scanning. A number of studies have projected exposures to personnel over recommended guidelines, especially for the gradient fields, and particularly in open systems designed for interventional work [295, 296, 299]. Noise and emergency exposure to cryogenic liquids are two other hazards from MRIs.

Control measures to reduce radiation exposures to workers from MRIs include: RF shielding around the room or machine (“Faraday cage”) designed to block incoming or outgoing radiation [291]; purchasing new equipment with improved shielding or reduced gradient strength; using automated injectors for injections during scanning; using movable control panels that can be placed at greater distance from the magnet; mounting RF coils on the movable patient table so workers do not have to crawl into the magnet bore; improving the design of bore or cleaning equipment so cleaners do not have to enter the bore; using disposable sheets under the patient to reduce cleaning; using a mirror for inspection of patients or objects in the magnet bore; avoiding unintended use of MRI equipment such as having a second person (worker) in the bore to accompany an anxious patient; instructing workers to limit their speed of movement near the bore end to reduce symptoms; using robots for interventions during scanning; improving signage; and regulation of access to high exposure areas [300].

Ultraviolet (UV) lights: UV lights are used to kill micro-organisms, such as for the control of tuberculosis or to kill organisms inside biological safety cabinets or inside ductwork. They work by irradiating air as it circulates past the light. These lights are not a hazard unless they shine directly on a person, as may be the case for maintenance or laboratory workers, where they become a significant hazard. To control this hazard, the lights should be turned off during maintenance and no one should work directly within their sight. Eyeglasses or shielding, designed for the specific wavelengths emitted, also can protect skin and eyes from UV light.

Lasers: Lasers are used in many hospital departments and usually emit a single wavelength or a few specific wavelengths of infrared, visible, or ultraviolet radiation. Some lasers can be tuned to more than one wavelength. Lasers are classified by how hazardous they are with Class 1 being not normally hazardous and Class 4 being the most hazardous. Most lasers used in hospitals are

5. RADIATION: Non-Ionizing

Class 4 (hazardous to view the beam or specular or diffuse reflection; also skin and fire hazard). Because some lasers are not visible, people are unable to use their normal reflexes to avoid an exposure and the power density is so high that short exposures may cause harm.

Laser safety should be overseen by a Laser Safety Officer (LSO) who, along with the users, support staff, and maintenance and repair technicians must have specialized training. Based on the manufacturers' recommendations, the LSO determines the nominal hazard zone (NHZ) within which exposure levels are above the maximum permissible exposure. The LSO also determines the laser treatment controlled area, often defined as the procedure room, for the purpose of protecting staff by instituting controls in that area. Administrative controls include limiting access, room signage, written procedures, checklists, warning labels on the laser, avoiding the use of clamps on fiber optics to prevent breakage, using standby mode when not aiming the laser at the target, medical surveillance of staff, and special procedures for alignment and calibration, including use of low-power visible light for path simulation. Certified eyewear, with side shields, designated for specific wavelengths and optical density is required inside the NHZ and may be required beyond that if there is a chance of fiber optic breakage. *The eyewear is not designed for looking directly at the beam.* Engineering controls include filters on microscopes and other optical viewing instruments; alternative indirect viewing, such as image converters and closed circuit television, especially when there is more than one wavelength involved; covering reflective surfaces (mirrors, windows, glass); curtains for entrance and windows; use of matted or blackened surgical retractors and other instruments; emergency stop control; door interlocks, when practical (non-surgical applications); and shielding of UV radiation from laser discharge tubes and pumping lamps. Filters are required for viewing certain laser interactions with hard tissues and bone that can generate intense plasma emissions [301].

Internet Resources

Health effects of radiofrequency radiation from the UK Health Protection Agency:
www.hpa.org.uk/web/HPAweb&HPAwebStandard/HPAweb_C/1254510622253

Health effects of extremely low frequency radiation from the World Health Organization:

www.who.int/mediacentre/factsheets/fs322/en/index.html

www.who.int/peh-emf/publications/elf_ehc/en/index.html

MRI safety guidelines:

<http://www.acr.org/Quality-Safety/Radiology-Safety/MR-Safety>

MRI practical rules for employees:

http://www.myesr.org/html/img/pool/20081210_Dutch_Guidelines_on_MR_Safety.pdf

5. RADIATION: Non-Ionizing

Laser description and safety:

www.osha.gov/SLTC/etools/hospital/surgical/lasers.html

Information from the ANSI medical laser standard:

www.osha.gov/dts/osta/otm/otm_iii/otm_iii_6.html#6

Laser guidelines from the Association of Surgical Technologists:

www.ast.org/pdf/Standards_of_Practice/RSOP_Laser_Safety.pdf

Laser exposure limits and control procedures from the American Association of Physicists in Medicine and the American College of Medical Physics:

www.aapm.org/pubs/reports/rpt_73.pdf

Dentistry article on “Safety concerns regarding the use of dental lasers”:

http://www.jaypeejournals.com/eJournals/ShowText.aspx?ID=3574&Type=FREE&TYP=TOP&IN=_eJournals/images/JPLOGO.gif&IID=282&isPDF=YES

American College of Radiology Guidance document on MR Safe Practices: 2013:

<http://onlinelibrary.wiley.com/doi/10.1002/jmri.24011/pdf>

5. RADIATION: Table on Control Studies

Table 13. Studies of Controls for Radiation

| Exposure | Population studied | Control method(s) studied | Conclusions | Authors |
|----------|---|---|--|----------------------------------|
| X-rays | Dose to radiologist during 191 CT fluoroscopy procedures | Engineering: low amperage and non-continuous exposure | Using low amperage technique and non-continual exposure with the "quick-check" method reduced dose to radiologist. | Paulson et al. (2001) [282] |
| X-rays | Dose to radiologist's hand during CT fluoroscopy of phantom | Engineering: angular beam modulation | Turning off the beam at certain angles reduced hand exposure from scatter by 27% and from direct beam by 72%. | Hohl et al. (2008) [302] |
| X-rays | Dose to operator's hand during CT fluoroscopy on a phantom | Engineering: drapes on patient, needle holders PPE: gloves | Bismuth gloves, the longer of two needle holders, and patient drapes reduced dose to operator's hand by 99.6%. | Stoekelhuber et al. (2005) [303] |
| X-rays | Dose to operator during CT fluoroscopy on a phantom | Engineering: O-arm versus C-arm configuration of fluoroscope PPE: Thyroid shield | O-arm fluoroscope delivered higher doses to the breasts and gonads. Thyroid shield reduced dose by 89%. | Park et al. (2011) [304] |
| X-rays | Dose to physician's hands during CT fluoroscopy on patients | Engineering: use of a robot | Robot dramatically reduced exposure. | Solomon et al. (2002) [305] |
| X-rays | Scatter radiation near phantom during CT fluoroscopy | Engineering: drapes on patient | Use of a lead drape reduced scatter radiation at the distance of the physician's hands by 71%. | Nawfel et al. (2000) [306] |

5. RADIATION: Table on Control Studies

Table 13. (Cont'd.)

| Exposure | Population studied | Control method(s) studied | Conclusions | Authors |
|----------|--|--|---|------------------------------|
| X-rays | Dose to mock interventional radiologist during IR on a phantom | Engineering: suspended suit composed of apron, arm shields, and face shield | Compared to the use of a lead apron, the suspended suit reduced exposure by orders of magnitude at the armpit, eyes, and gonads. | Marichal et al. (2011) [307] |
| X-rays | Nine interventional radiologists during four procedures | Engineering: Bismuth surgical drape and collimation | Drape reduced exposure to hands 30-fold, thyroid 25-fold, and eyes 12-fold. Collimation also reduced exposures. | King et al. (2002) [308] |
| X-rays | Simulated various procedures with a phantom patient | Engineering: Tungsten antimony shield (pad) | Dose reductions to operator were estimated at 47, 71, and 95% at distance of 25 cm, 50 cm, and 1 meter from center of radiation field. | Dromi et al. (2006) [309] |
| X-rays | Three interventional cardiologists performing 615 coronary angiographies | Engineering: Transparent lead glass screen suspended from ceiling | Use of screen reduced eye exposure 19-fold but had weak effect on dose to hands. | Maeder et al. (2006) [311] |
| X-rays | Nine radiologists performed normal procedures over four weeks | Engineering: Lead shield hung from tables with C-arm under-couch fluoroscopy systems | Lead shield reduced exposure at both legs by 64%. | Shortt et al. (2007) [310] |
| X-rays | Simulated spine interventions | Engineering: Table shield, mobile shields. PPE: patient apron | Table shield, 0.5 mm equivalent mobile shield, and 1.0 mm lead equivalent mobile shield reduced dose at 1 meter from radiation source side of table at 1.16 meter above the floor by 95.9, 96.3, and 97.9%, respectively. | Luchs et al. (2005) [312] |
| X-rays | Interventional radiologists, cardiologists, and radio-nuclide workers in numerous procedures and facilities. | Engineering: Leg shield for fluoroscopy. Syringe shield for isotopes | Monitor the base of the little finger during IR. Lead/rubber shields for legs reduced dose 50-fold. Use of syringe shield reduced dose to top of index finger by 80-90%. | Martin et al. (2003) [313] |

5. RADIATION: Table on Control Studies

Table 13. (Cont'd.)

| Exposure | Population studied | Control method(s) studied | Conclusions | Authors |
|----------|---|--|--|-------------------------------|
| X-rays | 10 IRs performing 83 procedures | Engineering: Two types of facilities, lead screen PPE: glasses and thyroid shield | Facility that used system with X-ray filter had 20% lower dose. Ceiling suspended screen reduced dose 3-fold. | Vano et al. (1998) [314] |
| X-rays | Nine cardiologists | Engineering: Shielding Other: Training | Over a decade, annual dose decreased an order of magnitude presumably due to training, use of ceiling suspended shields, and reduced patient dosage. | Vano et al. (2006) [315] |
| X-rays | Pediatric patients who had fluoroscopy procedures | Engineering: Pulsed (non-continuous) fluoroscopy | Pulsed fluoroscopy reduced patient dose by 50-70 percent. | Hernandez et al. (1996) [316] |
| X-rays | One IR performed 234 catheterizations and 96 angioplasties | Engineering: shielding and patient dose reduction PPE: apron, collar, and glasses | Reductions of 11 and 13% were achieved by reducing patient dose. Use of lead apron, collar, glasses, foot-switch shield, 1.0 mm lead cover over patient's thighs, 0.5 mm plus an additional 1.0 mm over-couch lead glass shield, and undercouch lead shielding, reduced operator dose further to 0.8% of typical levels. | Kuon et al. (2002) [317] |
| X-rays | Doses to patients and staff during IR procedures at two hospitals | Engineering: Use of manual versus automatic features on X-ray equipment | Manual setting of relatively high tube voltage and low tube current resulted in significant dose reduction. | Zweers et al. (1998) [318] |
| X-rays | 30 IRs were monitored for two months | Engineering: lead aprons | Lead aprons of 0.5 mm and 1.0 mm reduced dose to 2.2 and 1.1% of the over-apron dose. | Marx et al. (1992) [319] |
| X-rays | Two radiologists performed 30 exams in the same X-ray unit | PPE: Lead gloves | Average dose reduction from lead gloves was 19.5% | Damilakis et al. (1995) [320] |

5. RADIATION: Table on Control Studies

Table 13. (Cont'd.)

| Exposure | Population studied | Control method(s) studied | Conclusions | Authors |
|---|---|--|---|------------------------------|
| Non-ionizing radiation: static, gradient and RF fields from MRI | Literature review and calculation of exposure studies near open systems | Administrative: proper operation of system, warning signs on devices or room doors, training, distance | Exposure limits may be exceeded, especially for gradient fields. Institute controls. | Bassen et al. (2005) [299] |
| Non-ionizing radiation: static, gradient fields from MRI | Static fields of 19 radiographers and gradients using simulation | Administrative: distance | European Union exposure limits for gradient fields were exceeded when standing closer than 18 cm from the bore opening. | Bradley et al. (2007) [295] |
| Radio-nuclides: Energy Proton Beam | Occupational dose to radiotherapy staff | Administrative: delay of entrance to the therapy room for 2-4 min following high energy proton irradiation to keep the occupational dose ALARA | This will cut the effective dose by more than 30%. | Petrović et al. (2011) [321] |
| Radio-nuclides: Beta emitting radioisotopes | Exposure to medical personnel during radionuclide therapy practices | Administrative and engineering: time, distance, shielding | Doses were always lower than the limits reported in the European Directive. | Lancelot et al. (2008) [322] |

5. RADIATION: Table on Control Studies

Table 13. (Cont'd.)

| Exposure | Population studied | Control method(s) studied | Conclusions | Authors |
|--|---|--|--|-------------------------------|
| Radio-nuclides: F-18 Fludeoxy-glucose | Radiation exposure to technologists | Engineering: radiation protection devices (homemade syringe drawing device, semi-automated injector, and video tracking of patients allowing a shorter duration of contact between the technologist and the patient) | Because of the use of special radiation protection techniques, technologist radiation doses in this PET department were lower than those reported in the literature. | Guillet et al. (2005) [323] |
| Radio-nuclides: Tc-99m | Healthcare professionals involved in sentinel lymph node (SLN) procedures | Engineering and administrative: basic radiation safety controls (time, distance, shielding) | Guidelines are proposed that may be used to control occupational radiation doses and handling of SLN contaminated tissues. | Michel and Hofer (2004) [324] |
| Radio-nuclides: Intensity Modulated Radiation Therapy (IMRT) | Radiation therapists | Engineering: stricter control on treatment delivery energy | To reduce dose it is recommended that IMRT treatments should be delivered at energies lower than 18 MV, that in multienergy IMRT, high-energy treatments should be scheduled in the latter part of the day, and that equipment manufacturers should strive to minimize activation in the design of high-energy accelerators. | Rawlinson et al. (2002) [325] |
| Radio-nuclides: I-123, I-131, Tc-99m, and In-111 | Nuclear medicine professionals involved in high dose radiopeptide therapy | Engineering and administrative: applying stricter controls on basic radiation safety techniques | The personnel protection, contamination control, and other safety techniques required significant modification to ensure effective contamination and radiation exposure control. | Espanan et al. (1999) [326] |
| Radio-nuclides: F-18 | Nuclear medicine professionals involved in PET imaging procedures | Administrative: acquiring detailed knowledge on the practical aspects of radiation safety during the use of F-18 | The technologist should be able to: (a) reduce the radiation dose during the performance of PET imaging procedures with F-18; (b) understand the relationships between gamma-ray energy, the amount of activity administered to a patient, exposure time, and occupational dose; and (c) describe one strategy to minimize the radiation dose to the bladder in patients who have received F-18. | Bixler et al. (1999) [327] |

5. RADIATION: Table on Control Studies

Table 13. (Cont'd.)

| Exposure | Population studied | Control method(s) studied | Conclusions | Authors |
|------------------------------------|---|--|---|--------------------------------|
| Radio-nuclides: Tc-99m | Nuclear medicine technologists | Engineering and work practices | Synchronize aerosol pulse with patient's breath, patient should hold breath at end, good mouth-piece seal, patient should breathe room air before disconnecting, and patient should use mask after procedure. | Pityn et al. (1996) [328] |
| Radio-nuclides: Tc-99m, F-18, Y-90 | Nuclear medicine staff | Engineering and administrative: shielding, positioning, and volume of the source | Shield syringes with 2 mm tungsten for Tc-99m, 5 mm tungsten for F-18, and 5 mm tungsten for Y-90. Shield vial with 3 mm lead for Tc-99m, 3 cm lead for F-18, and 10 mm PMMA plus external lead for Y-90. Use tools to increase distance from source. Shield and distance are more effective than working fast. | Sans-Merce et al. (2011) [329] |
| Radio-nuclides: Tc-99m | Simulated transfer from one vial to another | Engineering: syringe shield and automatic dispenser were compared to no shield at various volumes | Shield and automatic dispenser reduced doses by 90%. Syringes greater than the volume to be transferred should be employed. | Montgomery et al. (1999) [330] |
| Radio-nuclides: various isotopes | 20 nuclear medicine personnel | Administrative: compared policy allowing technicians to choose control method to mandatory shield policy | Performance-based rule just as effective as syringe shield rule. Hold syringe at flared end. Shield may increase exposure time. | Ponto et al. (2002) [331] |
| Radio-nuclides: Tc-99m | Nuclear technologists | Engineering: compared types of nebulizers while sampling nasal passage of personnel | Recommended respirators, cover gowns and head covers; good ventilation; and use of absorbent material at exhaust vent of nebulizer unit. | Huff et al. (1994) [332] |
| Radio-nuclides: Tc-99m | Nuclear medicine technologist | Engineering and PPE: syringe shield and lead apron | Stand away from the patient while waiting for assistance with transfers, use tungsten syringe shield for injections, and wear 0.5 mm lead apron for patients with high activities, such as those having myocardial imaging. | Smart et al. (2004) [273] |

6. SHIFT WORK, STRESS, AND VIOLENCE: Shift Work

Section 6. Shift Work, Stress, and Violence

SHIFT WORK

Norman Zuckerman

Shift work includes any shift that differs from the traditional eight-hour work schedule, between the hours of 0700-1700, five days a week. Examples of shift work include night or evening shifts, extended work day(s), extended work week(s), and rotating or permanent off-hour shifts. The industrial revolution, the incandescent bulb, and the establishment of reliable electrical power opened the door to the 24-hour work day. Approximately one-quarter of HCP in the U.S are engaged in some form of shift work [333].

Our sleep-wake cycle is based on an interplay between our need to sleep, which is directly related to the number of hours we are awake, and our internal circadian (approximately the length of a day) rhythm system. Many of our common physiological and mental functions, such as hormone and blood pressure levels, renal function, core body temperature and performance levels, follow a daily rhythmic pattern. Production of melatonin, the primary sleep-mediating hormone, is suppressed by exposure to light. Denmark is the first country to officially recognize light at night as an occupational health risk. Our circadian system is entrained (synchronized) by both internal and external cues, called zeitgebers. The most important zeitgeber is the diurnal light, dark cycle. Any change in our daily schedule has the potential to misalign our intrinsic cyclical patterns. In the morning for instance, a shift worker may be trying to sleep, while their circadian program is promoting wakefulness. The effects of fatigue may be magnified if work hours occur during a trough in an individual's circadian rhythm.

Extended work hours or shift work has been associated with; job performance issues [333], sleep disturbance, fatigue, job dissatisfaction [334], absenteeism, accidents and issues related to individual workers' health and safety. Health effects that have been associated with shift work include; elevated cortisol and body mass index levels [335], endometrial [336], breast [337-339], and possibly colorectal cancer [339], peptic ulcers [340], myocardial infarction [341], and obesity among nurses [342]. A meta-analysis of observational studies found that

6. SHIFT WORK, STRESS, AND VIOLENCE: Shift Work

shift work was associated with coronary and cerebrovascular events [343]. The IARC has classified shift work that disrupts circadian rhythm as a probable human carcinogen (group 2A). Numerous studies have found that shift workers report getting less sleep than their day shift colleagues [333, 344-346]. In addition to the increased morbidity, extended work hours have been linked to medical errors [347, 348] and near errors [348], including an increase in needlestick injuries [349] and car crashes [349, 350].

A study on fatigue, alcohol, and performance impairment found that 17 hours of wakefulness (6:30 A.M -11:30 PM) is the equivalent of a blood alcohol level of 0.05% [351]. One particularly insidious aspect of fatigue and sleepiness is the inability of sleep-deprived individuals to self-assess personal decrements in performance and alertness [352]. This inability has been compared to performance self-assessments following alcohol consumption [349]. Official inquiries into the space shuttle Challenger explosion, a near-miss incident with the shuttle Columbia, and the grounding of the Exxon Valdez oil tanker, all cited fatigue as one of the causes [353, 354]. Of the 1,424 flight crew members surveyed by NASA, 80% acknowledged having nodded off at some time during a flight [355].

Trying to sleep at non-traditional hours can put a tremendous burden on family and interpersonal relationships. In some instances, it can result in feelings of social isolation [356]. Shift workers also face some unanswered questions, such as the potential consequences of taking prescription medications at an unusual time of day (11 p.m. instead of 8 a.m.).

The ability to cope with shift work varies from individual to individual. Some people have no problem adjusting to a different schedule; some individuals never adjust. For most individuals, total adjustment to an out-of-phase schedule is limited by their need to interact with a 9-5 world.

Unlike many other safety sensitive occupations, such as airplane crews or interstate truckers that have mandatory work and rest schedules, there are few regulatory controls in health care to help mitigate the effects of shift work. The Accreditation Council for Graduate Medical Education has recently instituted guidelines for residents' work schedules (July 2011). These guidelines limit first-year residents to a maximum daily work shift of 16 hours; second-year and senior residents are limited to no more than 24 hours. The European Union Work Time Directive (2003) mandates a maximum 48-hour work week.

Controls (see also [Table 14](#))

Several different types of controls have been recommended and or implemented by regulatory or professional organizations to help individuals adapt to a non-conventional sleep-wake schedule. These controls include coping mechanisms such as administrative type controls, lifestyle modifications, regulations, engineering, and pharmacological aids.

6. SHIFT WORK, STRESS, AND VIOLENCE: Shift Work

Administrative controls such as the use of forward-rotating shifts, (day-evening-night), gradual shift changes (one to three hours), and encouraging worker participation in designing shift work schedules, can be helpful in easing adaptation to a non-regular work schedule. Because shift work is often overlooked as a hazard, it is especially important that everyone (managers, supervisors, and staff members) be educated about the potential health and social issues and controls designed to reduce the effects of shift work.

Employers can mitigate some of the effects of shift work by providing employees an opportunity to take a nap before driving home. **Do not drive while sleepy; it is extremely dangerous.**

Good sleep hygiene can improve sleep quality and duration. It includes maintaining a quiet, darkened bedroom, regulated at a comfortable temperature, and avoiding stimulants such as caffeine or nicotine, excessive fluids, alcohol, exercise and large meals before going to bed. It is best to maintain a similar sleep/wake schedule even on days off.

Pre-shift naps of 20 minutes or less, in order to avoid sleepiness, can be useful in maintaining alertness. Though alertness and performance levels rise quickly after awakening, individuals, especially those with a high level of sleep debt, are still prone to fatigue-related error, especially immediately after awakening. This problem can last up to 30 minutes. It can take several hours to achieve full alertness [349]. While some individuals are very sensitive to the effects of caffeine, for most individuals judicious caffeine consumption can help manage the symptoms of fatigue. Used in conjunction, napping and caffeine have been found to be more effective in relieving the subjective effects of sleepiness than either one by itself [357]. Avoiding long commutes, napping after work, and judicious use of caffeine, can help alleviate some of the symptoms of fatigue.

The only cure for sleepiness is sleep.

Controlling light exposure levels can help improve wakefulness and performance, and help workers get a better night's sleep when they get home. Because the principal zeitgeber is light, bright light has been used in several studies to successfully reset the internal sleep/wake cycle. Using dark glasses during the commute home can help night workers achieve a better nights' sleep [358, 359].

Individuals who are unable to adapt to the rigors of shift work should consult a sleep medicine professional.

Internet Resources

Centers for Disease Control and Prevention (CDC):
www.cdc.gov/niosh/topics/workschedules/

Canadian Centre for Occupational Health and Safety (2010):
www.ccohs.ca/oshanswers/ergonomics/shiftwrk.html

6. SHIFT WORK, STRESS, AND VIOLENCE: Stress

National Sleep Foundation:

<http://www.sleepfoundation.org/>

Centers for Disease Control and Prevention (2011):

www.cdc.gov/sleep/pdf/states/Insufficient_Sleep_Fact_Sheet_2011_CA.pdf

The Joint Commission Sentinel Event Alert (2011):

www.jointcommission.org/assets/1/18/sea_48.pdf

American Medical Association, Virtual Mentor (2009):

<http://virtualmentor.ama-assn.org/2009/11/cpr11-0911.html>

Optimizing Health, Safety and Performance, Journal of Occupational and Environmental Medicine (2011): (You must log into Medscape to view the full article):

www.medscape.org/viewarticle/733587

Strategies for Nurses to Prevent Sleep-Related Injuries and Errors (2010):

www.rehabnurse.org/pdf/rnj326.pdf

STRESS

Thomas Lowe

Workplace stress is the deleterious physiological and psychological response to continuous pressures encountered at the worksite. The traditional definition, adapted from Hans Selye, a stress physiologist, is: the nonspecific response of the body to any event in which environmental demands, internal demands, or both, tax or exceed the adaptive resources of an individual, social system, or tissue system. Workplace stress is a condition, not a disease. Left unresolved, however, workplace stress can result in disease, illness and, in extreme circumstances, death.

Factors that appear to increase work-related stress in a hospital setting include: lack of control over the work environment, excessive work load demands, lack of support, inadequate or insufficient resources to accomplish the assigned work, or a feeling that optimal care is not being provided. In fact, a large study in China in 2008 of Chinese female healthcare workers found that medical professionals usually suffer from occupational stress resulting from high expectations coupled with insufficient time, skills, and/or social support at work [360, 361].

Stressors cause the body to release hormones and chemicals resulting in a stress response called “fight or flight” which increases breathing and heart rates. Constant release of the fight or flight stress hormones causes the release of free fatty acids, increases the creation of fat and subsequent obesity, and causes the breakdown of tissues and suppression of the immune system. These

6. SHIFT WORK, STRESS, AND VIOLENCE: Stress

developments, in turn, result in an increased susceptibility to disease and illness [362, 363].

The long-term activation of the stress-response system, and the subsequent overexposure to cortisol and other stress hormones, can disrupt almost all of the body's processes. They put the healthcare worker at increased risk of numerous health problems, including: heart disease; sleep problems; digestive problems; depression; obesity; memory impairment; and the worsening of skin conditions, such as eczema.

There is no OSHA or ACGIH standard for stress. Europe does have "standard guidelines" for eliminating, preventing and dealing with workplace stress. These standard guidelines can be found at the websites, listed below, of the WHO, the UK Health and Safety Executive, and BSI (a global standards, certification, and assessment provider in cooperation with Nottingham University).

Controls

Mitigation controls fall into three categories as discussed below [364].

The first mitigation category is that of prevention through elimination. In the OSHA hierarchy of controls, it is the most preferred method. However, at least in the U.S., personal control measures are most prevalent. These elimination and prevention strategies include (but are not limited to):

- Re-organize the work structure to eliminate organizationally induced stress.
- Review and revise policies and procedures that produce work load stress.
- Provide adequate staff so as not to overburden any one staff member.
- Provide resources, equipment, and training to meet the tasks and demands of the job.
- Empower staff to participate in governance of the work environment.

The second level of mitigation seeks only to lessen the frequency and duration of the stressor. This strategy most often entails rotation of assignments, use of teams to decrease the effects of the stressor on any one staff member, and other such administrative and work practice controls.

Most mitigation strategies noted in the literature are aimed at dealing with existing stress through personal stress relief techniques such as:

- Breathing and relaxation exercises
- Visualization
- Improved personal habits: rest, sleep, play, healthy nutrition, and achievement of a work-life balance
- Exercise
- Avoidance of negative coping mechanisms (self-medication and illegal drugs, alcohol, binge eating)
- Recognition of the stressors and avoiding them

6. SHIFT WORK, STRESS, AND VIOLENCE: Violence

A combination of organizational change and personal stress management techniques is often the most useful approach for preventing and coping with stress at work, as was proven in several studies conducted by the St. Paul Fire and Marine Insurance Company [365].

Internet Resources

Occupational health and safety risks in the healthcare sector:
<https://osha.europa.eu/en/topics/stress/index.html>

United Kingdom publication of guidelines to control stress in the workplace:
www.hse.gov.uk/stress/standards/

Global perspective on occupational stress and control measures:
www.who.int/occupational_health/publications/07_Standards.pdf

United States guidance from the Center for Disease Control (CDC):
www.cdc.gov/niosh/topics/stress/

Stress at Work, WorkSafe, Department of Commerce, Western Australia:
www.commerce.wa.gov.au/WorkSafe/Content/Safety_Topics/Stress/Stress_at_the_workplace.html

VIOLENCE

Thomas Lowe

According to occupational health researchers, workplace violence is one of the most complex and dangerous occupational hazards facing nurses working in today's healthcare environment [366].

OSHA and NIOSH define workplace violence as “violent acts, including physical assaults and threats of assault, directed toward persons at work or on duty” [367]. A broader and widely accepted definition states that violence is “behavior by persons against persons that intentionally threatens, attempts, or actually inflicts physical harm” [368].

In healthcare, there is an increased anticipation of violence due to several factors: a patient population under the influence of intoxicants such as drugs and alcohol, metabolic disorders, trauma, psychosis, and personality disorders, to name a few. The hospital is open 24 hours, seven days a week, giving a compromised patient population easy access to the facility and its staff. Additionally, personal and organizational stressors affecting the patient, the family and the healthcare worker put the healthcare worker at increased risk for violence. A study of violence in the emergency department done in 2001 showed that “a primary safety issue was the ease with which others could access entry into the

6. SHIFT WORK, STRESS, AND VIOLENCE: Violence

emergency department” [369]. The “others” the study refers to are those with the above mentioned issues.

The exposure to violence can be identified using the OSHA typology of violence [370, 371].

Type I – Criminal Intent: violence as a result of criminal activity. Usually from a person who has no legitimate business reason for being in the facility.

Type II – Customer or Client: violence arising out of an interaction between the customer or client being served and staff providing the care.

Type III – Worker on Worker: violence which occurs between two or more workers, (current or past) while on duty.

Type IV – Personal Relationship, Partner, or Domestic: violence between individuals who have a personal relationship, at least one of whom is an employee.

HCP are exposed to all four types of violence, however, exposure to Type II violence is most prevalent [366]. HCP who interact directly with the public, the patients and their families are most likely to be the targets of violence in the healthcare setting. Areas of particular concern in hospitals are the emergency department, the psychiatric units, and critical care areas. However, a comprehensive risk hazard assessment must include all areas of the facility where all employees work [372]. The Emergency Nurses Association’s violence surveillance study in 2009-2010 revealed that 97.1% of physical violence in the emergency department was perpetrated by patients and relatives of patients.

Exposure to violence has both short-term and long-term effects, including anxiety, life disturbances, increased absenteeism, poor work quality, and leaving the profession. Post-traumatic stress disorder (PTSD) is not an uncommon effect from assaults [373].

While there are no OSHA, standards ACGIH or NIOSH guidelines for workplace violence prevention, OSHA has published Guidelines for Preventing Workplace Violence in Healthcare and Social Service Workers, (CPL 02-01-052 Effective Date: September 8, 2011). Examples of regulatory efforts toward violence can be found in Europe and in New York State, as discussed below.

Controls (see also [Table 14](#))

In Europe, anti-violence programs are the responsibility of the employer and must be included in all collective bargaining agreements. Furthermore, the employer is required to train employees in the recognition and interventions necessary for acts of violence. This requirement stems from the Council Directive 89/391 passed in 1989 in Europe that directs all employers to provide and maintain a “safe working conditions” work environment. This provision for a safe work environment is similar to the U.S. OSHA general duty clause.

6. SHIFT WORK, STRESS, AND VIOLENCE: Violence

A framework for a practical approach to prevention of workplace violence can be found in New York State law, Public Employee Safety and Health Violence Prevention Act, 2009 [374]. This law provides a guideline for conducting a violence risk hazard assessment, creating a policy statement and a written program for prevention, mitigation, and intervention. The framework of the law emphasizes employee involvement and management commitment. It includes not only the need to perform a comprehensive risk hazard assessment, but also develop and implement effective mitigation strategies and provide appropriate training.

In England, the National Health Service commissioned a design team to create prototypes aimed at a reduction of violence and aggression against staff in the emergency departments of the NHS hospitals [375]. The team was formed as a result of increasing hospital violence. A study showed that in 2009-2010 there were more than 150 physical assaults on staff per day in England alone [375]!

The design team came up with several simple, inexpensive approaches to decrease violence. Among the suggestions:

- Increase the effectiveness and frequency of communications to patients and families regarding the wait time to be seen by a healthcare professional.
- Improve line of sight, department layouts, and patient flow patterns. Use physical barriers to prevent violence in areas that are not open to patients or the public.
- Provide staff with more accurate training to recognize and intervene earlier in escalating behaviors likely to turn violent.
- Set and meet patient expectations for care, explaining the process that is used to provide such care and information on how far “through the system” a patient is at any given time.
- Establish sanctions, which are publicized and enforced, against persons who perpetrate violence.

OSHA issued a guidance document on the prevention of workplace violence for healthcare and social service workers [376]. Among the suggestions:

- Conduct a hazard analysis.
- Establish a workplace violence prevention program.
- Eliminate or reduce security hazards through facility design.
- Install and maintain alarm systems.
- Enclose nurses’ stations and install deep service counters or bullet resistant shatter proof glass in reception, triage, and admitting areas or client service rooms.
- Provide for two means of egress to all client service areas.
- Have and enforce clearly communicated violence policies.
- Ensure adequate and qualified staff are available at all times to address patient, client, and family needs.

6. SHIFT WORK, STRESS, AND VIOLENCE: Violence

- Buy and arrange appropriate furniture so as not to entrap staff or have furniture used as weapons.
- Have a trained response to escalating behaviors which includes internal and external resources (i.e., police).
- Train all staff to the appropriate level needed to respond efficiently to the threat(s) identified on the risk hazard assessment.
- Evaluate the program on a regular and periodic basis.

Internet Resources

Survey results on effects of violence on nurses:

<http://nursingworld.org/workplaceviolence>

Research to practice information on controls:

www.cdc.gov/niosh/docs/2006-144/pdfs/2006-144.pdf

WHO. global view of violence:

www.who.int/violence_injury_prevention/violence/world_report/en/index.html

OSHA Guidelines:

www.osha.gov/Publications/osha3148.pdf

ILO training manual guide on violence:

http://www.ilo.org/wcmsp5/groups/public/—ed_protect/—protrav/—safework/documents/instructionalmaterial/wcms_108542.pdf

Workplace Violence in the Health Sector: Management of Workplace Violence Victims:

www.who.int/violence_injury_prevention/violence/interpersonal/en/WVmanagementvictims.pdf

NIOSH Occupational Violence:

www.cdc.gov/niosh/topics/violence/

NIOSH Violence on the Job:

www.cdc.gov/niosh/docs/video/violence.html

6. SHIFT WORK, STRESS, AND VIOLENCE: Table on Control Studies

Table 14. Studies of Controls for Shift Work and Violence

| Exposure | Population studied | Control method(s) studied | Conclusions | Authors |
|---|---|--|--|---|
| Violence: assaults or disruptive behavior | Nurses, physicians, and other HCP | Administrative: flag charts with history of violence | Flagging reduced assaults by 91% in one study. | Drummond et al. (1989) [377] |
| Violence: type 1, 2, 4 violence | OSHA guideline for emergency department nurses and staff, critical care staff, general medical staff | Engineering: use of alarms, metal detectors, bullet-resistant partitions, limited access Administrative: written program based on thorough risk hazard assessment | Physical barriers and other engineering controls effectively reduce violence through prevention of hazard. Written programs provide for consistent response to identification, prevention, and intervention. | OSHA 3148-01R (2004) [376] |
| Violence type: type 1, 2, and 4 violence | NIOSH guideline for emergency department nurses and staff, critical care staff, general medical staff | Engineering: enclose nurses' stations, install deep counters, restrict free movement of visitors | Physical barriers and other engineering controls effectively reduce violence through prevention of hazard. | NIOSH publication No. 2002-101, (2002) [378] |
| Violence: type 1-4 | All HCP | Administrative and work practices: Multidisciplinary approach, written program, training | Interdisciplinary approach improves worker/management commitment, acceptance of diversity, and fosters team cohesiveness. | DHHS (NIOSH) Publication Number 2006-144 (2006) [380] |
| Violence type 1-4 | All HCP | Work practices: adequate training in recognition of predictors of violence and intervention techniques | Authors assert that violence does not happen at random or "out of the blue." Perpetrators usually display some behaviors of concern. | Romano et al. (2011) [380] |

6. SHIFT WORK, STRESS, AND VIOLENCE: Table on Control Studie

Table 14. (Cont'd.)

| Exposure | Population studied | Control method(s) studied | Conclusions | Authors |
|------------|---|--|--|--------------------------------|
| Shift work | 608 Male, Nuclear plant operators/ validated questionnaires | Adaptation to shift work | Workers with better self-perceived adaptation to shift work had better outcomes in regard to chronic fatigue and sleepiness. | Takahashi et al. (2005) [381] |
| Shift work | 24 medical interns | Administrative: reduced work shift load to 16 hours or less. Reduction of hours per week worked. | Reduced the rate of attentional failures by more than 50% on on-call nights. | Lockley et al. (2004) [349] |
| Shift work | 24 medical interns | Administrative: reduction of hours worked | Interns on a traditional schedule made 35.9% more serious errors. | Landrigan et al. (2004) [347] |
| Shift work | 39 healthy males and females; simulated night shifts | Caffeine and napping | Caffeine and napping more effective than either napping or caffeine alone. | Schweitzer et al. (2006) [357] |
| Shift work | 23 healthy male and female subjects; simulated work routine | Intermittent bright light exposure at night, sun glasses for commuting, fixed sleep interval in dark room. | Achieved a sleep/wake phase delay for experimental group using exposure to lights at night and sun glasses. | Lee et al. (2006) [359] |

DISCUSSION AND ADDITIONAL RESOURCES

DISCUSSION AND ADDITIONAL RESOURCES

This report summarizes the control methods to eliminate or reduce health hazards in hospitals. More than 300 papers were reviewed and more than 150 control methods with an emphasis on engineering or substitution were identified. We compiled a summary of studies that were performed to evaluate the efficacy of these controls. The summaries were done to make the information easily accessible to health and safety professionals, hospital administrators, and employees and union representatives working in healthcare settings. The information in this report can be used as a way to select and implement solutions to more than 30 health hazards that are common in hospitals and other healthcare settings.

Some of the hazards discussed are fairly unique to hospitals, such as surgical smoke and waste anesthetic gases. Others, like ergonomics of patient handling and performing ultrasound imaging are also found in outpatient clinics, long-term care facilities, and other healthcare institutions. Finally, some of the hazards apply to many non-healthcare institutions; examples of these hazards include cleaning agents, computer workstations, and workplace stress.

Infection control issues in hospitals are usually addressed by medical experts in infectious diseases. The hospital's primary concern is the transmission of infectious diseases to patients. Therefore, it is not under the management of the environmental health and safety department. Employees, however, are at higher risk of certain diseases because of their occupation. In recent years there has been concern about healthcare workers contracting bloodborne illnesses, tuberculosis, SARS, influenza, and, most recently, *Clostridium difficile* [382, 383]. We have covered some of the illnesses of most concern for which control guidelines for employees have been established.

Limitations are listed below. This report does not include controls for health hazards that are not unique to the hospital setting, but nevertheless pertain to hospitals. They were omitted due to limitations in space and resources and because there are existing, appropriate resources that discuss, more generally, these hazards and their controls. These hazards include extreme temperatures, material handling, noise, solvents in laboratories, and indoor air quality.

DISCUSSION AND ADDITIONAL RESOURCES

Similarly, we did not include hazards of certain occupations in hospitals, such as laundry, dietary, maintenance, security, office, and housekeeping workers. They are covered by literature or web resources that address these specific occupations.

For the hazards discussed above we recommend the following resources (see [Table 15](#), listed in alphabetical order):

Table 15. Resources for Hazards Not Covered Elsewhere

| Hazard or occupation | Resources |
|---|---|
| Cryosurgery with nitrous oxide | NIOSH, Control of Nitrous Oxide during Cryosurgery: www.cdc.gov/niosh/docs/99-105/ |
| Dietary | OSHA Hospital eTool: www.osha.gov/SLTC/etools/hospital/dietary/dietary.html |
| Extreme temperatures | NIOSH Heat Stress: www.cdc.gov/niosh/topics/heatstress/ NIOSH Cold Stress: www.cdc.gov/niosh/topics/coldstress/ |
| Film development in Radiology | New Zealand guidelines for glutaraldehyde (see page 9): www.osh.dol.govt.nz/order/catalogue/pdf/glutaral.pdf |
| Housekeeping | OSHA Hospital eTool: www.osha.gov/SLTC/etools/hospital/housekeeping/housekeeping.html |
| Indoor air quality (odors, ventilation, sick building syndrome) | NIOSH on indoor air quality: www.cdc.gov/niosh/topics/indoorenv/buildingventilation.html |
| Infection control | CDC Guidelines for Environmental Infection Control in Healthcare Facilities: http://www.cdc.gov/mmwr/preview/mmwrhtml/rr5210a1.htm NIOSH site for Hospital Hazards (see Biological Hazards and Controls; includes influenza): www.cdc.gov/niosh/topics/healthcare/#c CDC Guideline for Infection Control in HCP: www.cdc.gov/hicpac/pdf/infectcontrol98.pdf Immunization of healthcare workers: www.cdc.gov/mmwr/PDF/rr/rr6007.pdf |

DISCUSSION AND ADDITIONAL RESOURCES

Table 15. (Cont'd.)

| Hazard or occupation | Resources |
|-------------------------|---|
| Laboratory/ solvents | OSHA Hospital eTool: www.osha.gov/SLTC/etools/hospital/lab/lab.html OSHA on Laboratory Hazards: www.osha.gov/SLTC/laboratories/index.html |
| Laundry | OSHA Hospital eTool: www.osha.gov/SLTC/etools/hospital/laundry/laundry.html |
| Maintenance | OSHA Hospital eTool: www.osha.gov/SLTC/etools/hospital/engineering/engineering.html Maintenance worker health and safety from the EU (includes asbestos, welding, and other hazards): www.osha.europa.eu/en/publications/literature_reviews/maintenance_OSH_statistics |
| Material Handling | NIOSH Material Handling Guidelines: www.cdc.gov/niosh/docs/2007-131/ |
| Noise | NIOSH Noise and Hearing Loss Prevention: www.cdc.gov/niosh/topics/noise/ |
| Security | OSHA Preparing and Protecting Security Personnel in Emergencies: www.osha.gov/Publications/3335-security-personnel.pdf |

More generally, [Table 16](#) lists publications that are internet accessible and cover a wide variety of hospital hazards and their controls.

Not included are hazards that generally fall under the category of safety hazards. Although equally important, they are not the focus of this report. They include fire, explosion, compressed gases, electrical hazards, machine guarding, and emergency response.

Another limitation is that we did not attempt to eliminate literature on the basis of the scientific merit of the studies. Rather we listed studies on control methods that have been tested and how well they succeeded. Many of these studies were not rigorous; they may have lacked control groups or random allocation of participants. Selection and information bias were not always described or discussed. There were not always adjustments made for other variables that could have influenced the results. Studies often reported a certain percentage drop in exposure or health indicator after a control was implemented, or compared different controls strategies, without a statistical analysis of the

DISCUSSION AND ADDITIONAL RESOURCES

Table 16. General Internet Resources for Hospital Hazards

| Hospital hazard resource | Website |
|--|---|
| NIOSH site for hospital hazards | www.cdc.gov/niosh/topics/healthcare/ |
| OSHA's Hospital eTool | www.osha.gov/SLTC/etools/hospital |
| European Commission: Occupational Health and Safety Risks in the Healthcare Sector | https://bookshop.europa.eu/en/occupational-health-and-safety-risks-in-the-healthcare-sector-pbKE3111047/ |
| FGI guidelines for construction of hospitals | http://www.fgiguideines.org/guidelines2010.php#o1 |

outcome. Nevertheless, many of the studies are based on existing or practical controls about which readers should be aware. Although there may be an absence of evidence of their effectiveness, this does not mean they are not effective. Moreover, they provide evidence of controls that are currently being used in facilities in search of the best practical technologies.

CONCLUSION, ACKNOWLEDGMENTS, INDEX

CONCLUSIONS

Research and guidelines for controlling biological, chemical, drug-related, ergonomic, radiation, violence, stress, and shift work health hazards in hospitals are summarized in this paper. More than 150 engineering controls are identified to eliminate or reduce these hazards by such methods as substitution, ventilation, mechanization, shielding, and equipment design. Internet-based resources are identified so the reader may obtain more detailed information.

ACKNOWLEDGMENTS

We thank the New York State Nurses Association and the Mount Sinai School of Medicine for providing the resources for authoring the report, and the Mount Sinai Irving J. Selikoff Center for funding free access to the report. We thank Justin Davies and Nicole Abbott for entering the references. We thank Kay Ball and Debra Novak for their comments, and Dan Palmerton at Buffalo Filter, and I.C. Medical, Inc. for their technical advice on controlling surgical smoke. We thank Mark Catlin for his advice on respiratory protection for airborne pathogens. We are grateful to Elliot N. Cohen and Edward Fominyam for arranging enlightening tours of their facilities. We are extremely grateful to our peer reviewers, including Lisa Baum, Jim Boiano, Larry Dauer, Marta Figueroa, and Nick Rice.

INDEX

We recommend that readers search this report by using the find function on their computers. On PCs, hold the control key down and press F (for find). On MACs, hold the command key down and press F (for find). A find box will appear, and the reader should type in the word for which he or she is searching.

REFERENCES

REFERENCES

1. A Yassi and LJ Warshaw, Health Care: Its Nature and Its Occupational Health Problems. In: *Encyclopedia of Occupational Health and Safety*. Fourth ed: International Labour Office; 1998. cq 97.2.
2. J Lipscomb and B Borwegen, "Health Care Workers," in: *Occupational Health: Recognizing and Preventing Work-Related Disease and Injury*. Levy B, Wegman D, editors. Fourth ed: Lippincott, Williams, and Wilkins; 2000.
3. B Ballantyne and SL Jordan, "Toxicological, Medical and Industrial Hygiene Aspects of Glutaraldehyde with Particular Reference to Its Biocidal Use in Cold Sterilization Procedures," *Journal of Applied Toxicology* 21(2) (2001): 131-51.
4. D Vecchio, AJ Sasco and CI Cann, "Occupational Risk in Health Care and Research," *American Journal of Industrial Medicine* 43(4) (2003): 369-97, (DOI:10.1002/ajim.10191).
5. LH Clever and GS Omenn, "Hazards for Health Care Workers," *Annual Review of Public Health* 9 (1988): 273-303, (DOI:10.1146/annurev.pu.09.050188.001421).
6. J Gestal, "Occupational Hazards in Hospitals: Accidents, Radiation, Exposure to Noxious Chemicals, Drug Addiction and Psychic Problems, and Assault," *British Journal of Industrial Medicine* 44(8) (1987): 510-520.
7. W Charney, editor. *Handbook of Modern Hospital Safety*. (Boca Raton: CRC; 2010).
8. H-M Hasselhorn, A Toomingas and M Lagerström, *Occupational Health for Health Care Workers: A Practical Guide* (Amsterdam: Elsevier Science Health Science Division, 1999).
9. European Commission Directorate-General for Employment: Social Affairs and Inclusion, Occupational Health and Safety Risks in the Healthcare Sector: Guide to Prevention and Good Practice. Luxembourg: Publications Office of the EU; 2011.
10. TH Connor, et al., "Surface Contamination of Chemotherapy Drug Vials and Evaluation of New Vial-Cleaning Techniques: Results of Three Studies," *American Journal of Health-System Pharmacy* 62(5) (2005): 475-484.
11. F Perdelli, et al., "Evaluation of Environmental Contamination by Glutaraldehyde in an Outpatient Facility for Digestive Endoscopy in an Italian Hospital," *International Journal of Environmental Health Research* 18(1) (2008): 73-78.
12. M Hedmer, et al., "Surface Contamination of Cyclophosphamide Packaging and Surface Contamination with Antineoplastic Drugs in a Hospital Pharmacy in Sweden," *Annals of Occupational Hygiene* 49(7) (2005): 629-637.
13. ACGIH, *2012 TLVs and BEIs* (Cincinnati: ACGIH, 2012).

REFERENCES

14. DJ Burton, "General Methods for the Control of Airborne Hazards," in: *The Occupational Environment—Its Evaluation and Control*. DiNardi SR, editor. (Fairfax, VA: AIHA Press; 1997), 828-847.
15. ACGIH, *General Industrial Ventilation* 27 ed (Cincinnati: ACGIH, 2010).
16. ANSI/ASHRAE/ASHE, Standard 170-2008: Standard Ventilation of Health Care Facilities. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers; 2008. 7-10.
17. Facility Guidelines Institute, "The 2010 Edition of the FGI guidelines," 2010, www.fgiguidelines.org/guidelines2010.php#o1 (accessed 6/15/13).
18. JM Bartley, RN Olmsted and J Haas, "Current Views of Healthcare Design and Construction: Practical Implications for Safer, Cleaner Environments," *American Journal of Infection Control* 38(5) (2010): S1-S12, (DOI:10.1016/j.ajic.2010.04.195).
19. Indian Health Service, *Dental Ventilation, Technical Handbook for Environmental Health and Engineering, Volume III: Health Care Facilities Design and Construction*, Part 21-Design Criteria and Standards. 2007.
20. International Occupational Hygiene Association, <http://www.ioha.net/> (accessed 6/20/13).
21. S Hignett, JR Wilson and W Morris, "Finding Ergonomic Solutions—Participatory Approaches," *Occupational Medicine* 55(3) (2005): 200-207.
22. National Institute for Occupational Safety and Health, "Prevention Through Design," <http://www.cdc.gov/niosh/topics/ptd/> (accessed 6/17/13).
23. FA Manuele, "Prevention through Design: Addressing Occupational Risks in the Design & Redesign Processes," http://www.asse.org/practicespecialties/engineering/docs/ByDesign_PtDSpecial_Fall2007.pdf (accessed 5/26/13).
24. A Prüss-Üstün, E Rapiti and Y Hutin, "Sharps Injuries: Global Burden of Disease from Sharps Injuries to Health-care Workers," *WHO Environmental burden of disease series* (3) (2003).
25. A Prüss-Ustun, E Rapiti and Y Hutin, "Estimation of the Global Burden of Disease Attributable to Contaminated Sharps Injuries among Health-care Workers," *American Journal of Industrial Medicine* 48(6) (2005): 482-90, (DOI:10.1002/ajim.20230).
26. WX Yao, et al., "Needlestick Injuries among Nursing Students in China," *Nurse Education Today* 30(5) (2010): 435-7, (DOI:10.1016/j.nedt.2009.09.018).
27. CDC, "Workbook for Designing, Implementing, and Evaluating a Sharps Injury Prevention Program," http://www.cdc.gov/sharpsafety/pdf/sharpsworkbook_2008.pdf (accessed 3/15/13).
28. Occupational Health and Safety Administration, "OSHA Bloodborne Pathogen Standard," http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=10051 (accessed 6/13/13).
29. JD Siegel, et al., "The Healthcare Infection Control Practices Advisory Committee: 2007 Guideline for Isolation Precautions: Preventing Transmission of Infectious Agents in Healthcare Settings," 2007, <http://www.cdc.gov/hicpac/2007IP/2007isolationPrecautions.html> (accessed 7/3/13).
30. W Tosini, et al., "Needlestick Injury Rates According to Different Types of Safety-Engineered Devices: Results of a French Multicenter Study," *Infection Control and Hospital Epidemiology* 31(4) (2010): 402-7, (DOI:10.1086/651301).

REFERENCES

31. A Yassi, ML McGill and JB Khokhar, "Efficacy and Cost-Effectiveness of a Needleless Intravenous Access System," *American Journal of Infection Control* 23(2) (1995): 57-64.
32. LW Lawrence, et al., "The Effectiveness of a Needleless Intravenous Connection System: An Assessment by Injury Rate and User Satisfaction," *Infection Control and Hospital Epidemiology* (1997): 175-182.
33. M Foley and A Leyden, American Nurses Association: Independent Study Module, Needlestick Safety and Prevention. 2003.
34. NIOSH, "NIOSH Publication No. 2008-101: Use of Blunt-Tip Suture Needles to Decrease Percutaneous Injuries to Surgical Personnel," 2008, <http://www.cdc.gov/niosh/docs/2008-101/pdfs/2008-101.pdf> (accessed 2/13/13).
35. PD Hart, "Complying With the Bloodborne Pathogen Standard: Protecting Health Care Workers and Patients," *AORN Journal* 94(4) (2011): 393-399, (DOI:<http://dx.doi.org/10.1016/j.aorn.2011.07.014>).
36. P Cullinan, et al., "Latex Allergy. A Position Paper of the British Society of Allergy and Clinical Immunology," *Clinical and Experimental Allergy* 33(11) (2003): 1484-1499.
37. D Reed, "Update on Latex Allergy among Health Care Personnel," *AORN Journal* 78(3) (2003): 409-425.
38. K Scanlan, "More than a Workplace Danger. An Update on Latex Sensitivity," *Advance for Nurse Practitioners* 15(2) (2007): 69.
39. G Sussman and M Gold, "Guidelines for the Management of Latex Allergies and Safe Latex Use in Health Care Facilities," 1996, <http://www.aaaai.org/allergist/allergies/Types/latex-allergy/Pages/latex-allergies-safe-use.aspx> (accessed 5/15/13).
40. EH Rau, et al., "Minimization and Management of Wastes from Biomedical Research," *Environmental Health Perspectives* 108 Suppl 6(2000): 953-77.
41. CC Lee and GL Huffman, "Medical Waste Management/Incineration," *Journal of Hazardous Materials* 48(1-3) (1996): 1-30, (DOI:[http://dx.doi.org/10.1016/0304-3894\(95\)00153-0](http://dx.doi.org/10.1016/0304-3894(95)00153-0)).
42. J Emmanuel, "Non-Incineration Medical Waste Treatment Technologies," August 2001, http://www.noharm.org/lib/downloads/waste/Non-Incineration_Technologies.pdf (accessed 3/4/13).
43. MS Hossain, et al., "Clinical Solid Waste Management Practices and Its Impact on Human Health and Environment — A Review," *Waste Management* 31(4) (2011): 754-66, (DOI:10.1016/j.wasman.2010.11.008).
44. BK Lee, MJ Ellenbecker and R Moure-Eraso, "Alternatives for Treatment and Disposal Cost Reduction of Regulated Medical Wastes," *Waste Management* 24(2) (2004): 143-51, (DOI:10.1016/j.wasman.2003.10.008).
45. EW Tiemersma, et al., "Methicillin-Resistant Staphylococcus aureus in Europe, 1999-2002," *Emerging Infectious Diseases* 10(9) (2004): 1627-1634.
46. WC Albrich and S Harbarth, "Health-Care Workers: Source, Vector, or Victim of MRSA?," *Lancet Infectious Diseases* 8(5) (2008): 289-301, (DOI:10.1016/S1473-3099(08)70097-5).
47. F Haamann, M Dulon and A Nienhaus, "MRSA as an Occupational Disease: A Case Series," *International Archives of Occupational and Environmental Health* 84(3) (2011): 259-66, (DOI:10.1007/s00420-010-0610-7).

REFERENCES

48. AH Simpson, J Dave and B Cookson, "The Value of Routine Screening of Staff for MRSA," *Journal of Bone and Joint Surgery (British Volume)* 89(5) (2007): 565-6, (DOI:10.1302/0301-620X.89B5.19328).
49. MP Lessing, JZ Jordens and IC Bowler, "When Should Healthcare Workers be Screened for Methicillin-Resistant Staphylococcus aureus?," *Journal of Hospital Infection* 34(3) (1996): 205-10.
50. Centers for Disease Control and Prevention, "Top CDC Recommendations to Prevent Healthcare-Associated Infections," 2011, <http://www.cdc.gov/HAI/prevent/top-cdc-reccs-prevent-hai.html> (accessed 7/3/13).
51. TV Gurieva, MC Bootsma and MJ Bonten, "Decolonization of Patients and Health Care Workers to Control Nosocomial Spread of Methicillin-Resistant Staphylococcus aureus: A Simulation Study," *BMC Infectious Diseases* 12(2012): 302, (DOI:10.1186/1471-2334-12-302).
52. A Robicsek, et al., "Universal Surveillance for Methicillin-Resistant Staphylococcus aureus in 3 Affiliated Hospitals," *Annals of Internal Medicine* 148(6) (2008): 409-18.
53. S Harbarth, et al., "Universal Screening for Methicillin-Resistant Staphylococcus aureus at Hospital Admission and Nosocomial Infection in Surgical Patients," *The Journal of the American Medical Association* 299(10) (2008): 1149-57, (DOI:10.1001/jama.299.10.1149).
54. G Hawkins, et al., "Should Healthcare Workers be Screened Routinely for Methicillin-Resistant Staphylococcus aureus? A Review of the Evidence," *Journal of Hospital Infection* 77(4) (2011): 285-9, (DOI:10.1016/j.jhin.2010.09.038).
55. JD Siegel, et al., "Management of Multidrug-Resistant Organisms in Health Care Settings, 2006," *American Journal of Infection Control* 35(10 Suppl 2) (2007): S165-93, (DOI:10.1016/j.ajic.2007.10.006).
56. DJ Anderson and KS Kaye, "Controlling Antimicrobial Resistance in the Hospital," *Infectious Disease Clinics of North America* 23(4) (2009): 847-64, vii-viii, (DOI:10.1016/j.idc.2009.06.005).
57. SD Lawn and AI Zumla, "Tuberculosis," *Lancet* 378(9785) (2011): 57-72, (DOI: 10.1016/S0140-6736(10)62173-3).
58. PA Jensen, et al., "Guidelines for Preventing the Transmission of Mycobacterium Tuberculosis in Health-Care Settings, 2005," *MMWR: Recommendations and Reports* 54(RR-17) (2005): 1-141.
59. I Baussano, et al., "Risk of Tuberculin Conversion among Healthcare Workers and the Adoption of Preventive Measures," *Occupational and Environmental Medicine* 64(3) (2007): 161-6, (DOI:10.1136/oem.2006.028068).
60. F Drobniewski, et al., "Rates of Latent Tuberculosis in Health Care Staff in Russia," *PLoS Medicine* 4(2) (2007): e55, (DOI:10.1371/journal.pmed.0040055).
61. LK Lopes, et al., "Tuberculosis Risk among Nursing Professionals from Central Brazil," *American Journal of Infection Control* 36(2) (2008): 148-51, (DOI:10.1016/j.ajic.2007.01.013).
62. R Joshi, et al., "Tuberculosis among Health-Care Workers in Low- and Middle-Income Countries: A Systematic Review," *PLoS Medicine* 3(12) (2006): e494, (DOI:10.1371/journal.pmed.0030494).
63. I Eshun-Wilson, et al., "TB Infection among Staff at Tygerberg Academic Hospital, South Africa," *Southern African Journal of Epidemiology and Infection* 23(4) (2009): 17-19.

REFERENCES

64. JM Zuckerman, "Prevention of Health Care-Acquired Pneumonia and Transmission of Mycobacterium Tuberculosis in Health Care Settings," *Infectious Disease Clinics of North America* 25(1) (2011): 117-33, (DOI:10.1016/j.idc.2010.11.014).
65. World Health Organization, Guidelines for Infection Prevention and Control for TB Including MDR-TB and XDR-TB. 2008.
66. SF Welbel, et al., "Protecting Health Care Workers from Tuberculosis: A 10-Year Experience," *American Journal of Infection Control* 37(8) (2009): 668-73, (DOI: 10.1016/j.ajic.2009.01.004).
67. CB Beggs, et al., "The Ventilation of Multiple-Bed Hospital Wards: Review and Analysis," *American Journal of Infection Control* 36(4) (2008): 250-9, (DOI:10.1016/j.ajic.2007.07.012).
68. AR Escombe, et al., "Natural Ventilation for the Prevention of Airborne Contagion," *PLoS Medicine* 4(2) (2007): 68, (DOI:10.1371/journal.pmed.0040068).
69. NN Bock, et al., "Tuberculosis Infection Control in Resource-Limited Settings in the Era of Expanding HIV Care and Treatment," *Journal of Infectious Diseases* 196 Suppl 1(2007): S108-13, (DOI:10.1086/518661).
70. AR Escombe, et al., "Upper-Room Ultraviolet Light and n=Negative Air Ionization to Prevent Tuberculosis Transmission," *PLoS Medicine* 6(3) (2009): e43, (DOI: 10.1371/journal.pmed.1000043).
71. Princeton University, <http://web.princeton.edu/sites/ehs/healthsafetyguide/E4.htm> (accessed 6/18/13).
72. Centers for Disease Control and Prevention, "Respiratory Protection in Healthcare Settings," 2010, <http://www.cdc.gov/tb/publications/factsheets/prevention/rphcs.htm> (accessed 7/12/13).
73. Centers for Disease Control and Prevention, "Middle East Respiratory Syndrome: Interim Infection Prevention and Control Recommendations for Patients Hospitalized with Middle East Respiratory Syndrome (MERS-CoV)," 2013, <http://www.cdc.gov/coronavirus/mers/infection-prevention-control.html> (accessed 7/12/13).
74. World Health Organization, "WHO Policy on TB Infection Control in Health-Care Facilities, Congregate Settings and Households," *Geneva: World Health Organization* (2009).
75. EL Larson and CT Liverman, *Preventing Transmission of Pandemic Influenza and Other Viral Respiratory Diseases: Personal Protective Equipment for Healthcare Workers: Update 2010*: National Academies Press, 2011).
76. LJ Radonovich, Jr., MJ Hodgson and HJ Cohen, "Do Respirators Protect Health-Care Workers from Airborne Infectious Diseases?," *Respiratory Care* 53(12) (2008): 1660-4.
77. CR MacIntyre, et al., "A Randomised Clinical Trial of Three Options for N95 Respirators and Medical Masks in Health Workers," *American Journal of Respiratory and Critical Care Medicine* (2013).
78. CR MacIntyre, et al., "A Cluster Randomized Clinical Trial Comparing Fit-Tested and Non-Fit-Tested N95 Respirators to Medical Masks to Prevent Respiratory Virus Infection in Health Care Workers," *Influenza and Other Respiratory Viruses* 5(3) (2011): 170-179.
79. M Loeb, et al., "Surgical Mask vs N95 Respirator for Preventing Influenza among Health Care Workers: A Randomized Trial," *Journal of the American Medical Association* 302(17) (2009): 1865-71, (DOI:10.1001/jama.2009.1466).

REFERENCES

80. L Janssen, et al., "The Use of Respirators to Reduce Inhalation of Airborne Biological Agents," *Journal of Occupational and Environmental Hygiene* (just-accepted) (2013).
81. KH Harriman, "Controversy: Respiratory Protection for Healthcare Workers," 2011, <http://www.medscape.com/viewarticle/741245> (accessed 7/12/13).
82. MA Marini, M Giangregorio and JC Kraskinski, "Complying with the Occupational Safety and Health Administration's Bloodborne Pathogens Standard: Implementing Needleless Systems and Intravenous Safety Devices," *Pediatric Emergency Care* 20(3) (2004): 209-14.
83. G Moens, et al., "Analysing and Interpreting Routinely Collected data on Sharps Injuries in Assessing Preventative Actions," *Occupational Medicine* (Oxford, England) 54(4) (2004): 245-9.
84. S Tuma and KA Sepkowitz, "Efficacy of Safety-Engineered Device Implementation in the Prevention of Percutaneous Injuries: A Review of Published Studies," *Clinical Infectious Diseases* 42(8) (2006): 1159-70, (DOI:10.1086/501456).
85. F Lamontagne, et al., "Role of Safety-Engineered Devices in Preventing Needlestick Injuries in 32 French Hospitals," *Infection Control and Hospital Epidemiology* 28(1) (2007): 18-23, (DOI:10.1086/510814).
86. M Whitby, ML McLaws and K Slater, "Needlestick Injuries in a Major Teaching Hospital: The Worthwhile Effect of Hospital-Wide Replacement of Conventional Hollow-Bore Needles," *American Journal of Infection Control* 36(3) (2008): 180-6, (DOI:10.1016/j.ajic.2007.07.009).
87. M Azar-Cavanagh, P Burdt and J Green-McKenzie, "Effect of the Introduction of an Engineered Sharps Injury Prevention Device on the Percutaneous Injury Rate in Healthcare Workers," *Infection Control and Hospital Epidemiology* 28(2) (2007): 165-70, (DOI:10.1086/511699).
88. V Valls, et al., "Use of Safety Devices and the Prevention of Percutaneous Injuries among Healthcare Workers," *Infection Control and Hospital Epidemiology* 28(12) (2007): 1352-60, (DOI:10.1086/523275).
89. S Sohn, et al., "Effect of Implementing Safety-Engineered Devices on Percutaneous Injury Epidemiology," *Infection Control and Hospital Epidemiology* 25(7) (2004): 536-42, (DOI:10.1086/502436).
90. MH Mendelson, et al., "Evaluation of a Safety Resheathable Winged Steel Needle for Prevention of Percutaneous Injuries Associated with Intravascular-Access Procedures among Healthcare Workers," *Infection Control and Hospital Epidemiology* 24(2) (2003): 105-12, (DOI:10.1086/502174).
91. LD Knibbs, et al., "Room Ventilation and the Risk of Airborne Infection Transmission in 3 Health Care Settings within a Large Teaching Hospital," *American Journal of Infection Control* 39(10) (2011): 866-72, (DOI:10.1016/j.ajic.2011.02.014).
92. P Albuquerque da Costa, et al., "Administrative Measures for Preventing Mycobacterium Tuberculosis Infection among Healthcare Workers in a Teaching Hospital in Rio de Janeiro, Brazil," *Journal of Hospital Infection* 72(1) (2009): 57-64.
93. D Menzies, et al., "Efficacy of Environmental Measures in Reducing Potentially Infectious Bioaerosols during Sputum Induction," *Infection Control and Hospital Epidemiology* 24(7) (2003): 483-9, (DOI:10.1086/502242).
94. HA Dwosh, et al., "Identification and Containment of an Outbreak of SARS in a Community Hospital," *Canadian Medical Association Journal* 168(11) (2003): 1415-30

REFERENCES

95. CD Thorne, S Khozin and Ma McDiarmid, "Using the Hierarchy of Control Technologies to Improve Healthcare Facility Infection Control: Lessons from Severe Acute Respiratory Syndrome," *Journal of Occupational and Environmental Medicine* 46(7) (2004): 613-622.
96. CR Biscotto, et al., "Evaluation of N95 Respirator Use as a Tuberculosis Control Measure in a Resource-Limited Setting," *International Journal of Tuberculosis and Lung Disease* 9(5) (2005): 545-9.
97. JP Zock, "World at Work: Cleaners," *Occupational and Environmental Medicine* 62(8) (2005): 581-4, (DOI:10.1136/oem.2004.015032).
98. LE Charles, D Loomis and Z Demissie, "Occupational Hazards Experienced by Cleaning Workers and Janitors: A Review of the Epidemiologic Literature," *Work* 34(1) (2009): 105-16, (DOI:10.3233/WOR-2009-0907).
99. JP Zock, D Vizcaya and N Le Moual, "Update on Asthma and Cleaners," *Current Opinion in Allergy and Clinical Immunology* 10(2) (2010): 114-20, (DOI:10.1097/ACI.0b013e32833733fe).
100. Centers for Disease Control and Prevention, "Guidelines for Disinfection and Sterilization in Health Care Facilities," 2008, www.cdc.gov/hicpac/pdf/guidelines/disinfection_nov_2008.pdf (accessed 3/18/13).
101. W Charney, "Safe Use of Ethylene Oxide in the Hospital Environment," in: *Handbook of Modern Hospital Safety*. Charney W, editor. Second ed. (Boca Raton: CRC Press; 2010).
102. A Sobaszek, et al., "Working Conditions and Health Effects of Ethylene Oxide Exposure at Hospital Sterilization Sites," *Journal of Occupational and Environmental Medicine* 41(6) (1999): 492-9.
103. LJ Elliott, et al., "Ethylene Oxide Exposures in Hospitals," *Applied Industrial Hygiene* 3(5) (1988): 141-145.
104. IARC Working Group on the Evaluation of Carcinogenic Risks to Humans, *Formaldehyde, 2-Butoxyethanol and 1-tert-Butoxypropan-2-ol*: World Health Organization, 2006.
105. W Charney, "Monitoring Aldehydes," in: *Handbook of Modern Hospital Safety*. Charney W, editor. (Boca Raton: CRC Press; 2010).
106. P Leinster, J Baum and P Baxter, "An Assessment of Exposure to Glutaraldehyde in Hospitals: Typical Exposure Levels and Recommended Control Measures," *British Journal of Industrial Medicine* 50(2) (1993): 107-111.
107. H Katagiri, et al., "Indoor Glutaraldehyde Levels in the Endoscope Disinfecting Room and Subjective Symptoms among Workers," *Industrial Health* 44(2) (2006): 225-229.
108. LJ Casarett, J Doull and CD Klaassen, *Casarett and Doull's Toxicology : The Basic Science of Poisons* 7th ed (New York: McGraw-Hill, 2008).
109. Agency for Toxic Substances and Disease Registry, "ToxFAQs for Mercury," 1999, <http://www.atsdr.cdc.gov/toxfaqs/tf.asp?id=113&tid=24> (accessed 3/15/13).
110. New Jersey Department of Health and Senior Services, "Mercury, Elemental and Inorganic Compounds," 2009, <http://nj.gov/health/eoh/rtkweb/documents/fs/1183.pdf> (accessed 3/4/13).
111. World Health Organization and Health Care Without Harm, *Toward the Tipping Point: WHO-HCWH Global Initiative to Substitute Mercury-Based Medical Devices in Health Care, A Two-Year Progress Report*, 2010. http://www.mercuryfreehealthcare.org/Toward_the_Tipping_Point.pdf (3/8/13).

REFERENCES

112. Centers for Disease Prevention Office of Health and Safety, Chemical Glove Selection Guide. Atlanta; 2007.
113. New York State Department of Environmental Conservation, "Managing Dental Mercury," <http://www.dec.ny.gov/chemical/8513.html> (accessed May 25, 2013).
114. MB Blayney, "The Need for Empirically Derived Permeation Data for Personal Protective Equipment: The Death of Dr. Karen E. Wetterhahn," *Applied Occupational and Environmental Hygiene* 16(2) (2001): 233-236, (DOI:10.1080/104732201460389).
115. United Nations Environmental Programme, "Global Mercury Assessment 2013: Sources, Emissions, Releases and Environmental Transport," 2013, <http://www.unep.org/PDF/PressReleases/GlobalMercuryAssessment2013.pdf> (accessed 6/13/13).
116. EG Pacyna, et al., "Global Emission of Mercury to the Atmosphere from Anthropogenic Sources in 2005 and Projections to 2020," *Atmospheric Environment* 44(20) (2010): 2487-2499.
117. A Nimmo, et al., "Particulate Inhalation during the Removal of Amalgam Restorations," *The Journal of Prosthetic Dentistry* 63(2) (1990): 228-233.
118. GM Richardson, "Inhalation of Mercury-Contaminated Particulate Matter by Dentists: An Overlooked Occupational Risk," *Human and Ecological Risk Assessment: An International Journal* 9(6) (2003): 1519-1531.
119. S Koral, "Safe Removal of Amalgam Fillings," 2007, <http://iaomt.org/safe-removal-amalgam-fillings/> (accessed 6/15/13).
120. RR Keene, et al., "Occupational Hazards to the Pregnant Orthopaedic Surgeon," *The Journal of Bone & Joint Surgery* 93(23) (2011): 141 1-5, (DOI:10.2106/JBJS.K.00061).
121. J Borak, et al., "Methyl Methacrylate and Respiratory Sensitization: A Critical Review," *Critical Reviews in Toxicology* 41(3) (2011): 230-268.
122. H Andreasson, et al., "On Permeability of Methyl Methacrylate, 2-Hydroxyethyl Methacrylate and Triethyleneglycol Dimethacrylate through Protective Gloves in Dentistry," *European Journal of Oral Sciences* 111(6) (2003): 529-535.
123. JE Gatti, et al., "The Mutagenicity of Electrocautery Smoke," *Plastic and Reconstructive Surgery* 89(5) (1992): 781-784.
124. JS Pierce, et al., "Laser-Generated Air Contaminants from Medical Laser Applications: A State-of-the-Science Review of Exposure Characterization, Health Effects, and Control," *Journal of Occupational and Environmental Hygiene* 8(7) (2011): 447-466.
125. E Alp, et al., "Surgical Smoke and Infection Control," *Journal of Hospital Infection* 62(1) (2006): 1-5.
126. WL Barrett and SM Garber, "Surgical Smoke: A Review of the Literature," *Surgical Endoscopy* 17(6) (2003): 979-987.
127. AORN, *Association of Registered Nurses Perioperative Standards and Recommended Practices* 2013 ed, 2013.
128. DE Ott, "Carboxyhemoglobinemia due to Peritoneal Smoke Absorption from Laser Tissue Combustion at Laparoscopy," *Journal of Clinical Laser Medicine and Surgery* 16(6) (1998): 309-315.
129. DA Novak and SM Benson, "Understanding and Controlling the Hazards of Surgical Smoke," 2011, <http://www.beckersasc.com/asc-accreditation-and-patient-safety/understanding-and-controlling-the-hazards-of-surgical-smoke.html> (accessed 6/13/13).

REFERENCES

130. National Institute for Occupational Safety and Health, "Control of Smoke from Laser/Electrical Surgical Procedures, Department of Health and Human Services Publication 96-128," (1996).
131. Legislative Body, *CSA Z305. 13-09 Plume Scavenging Standard in Surgical, Diagnostic, Therapeutic, and Aesthetic Settings* 2009.
132. National Institute for Occupational Safety and Health, "National Personal Protective Technology Lab Meeting Presentation," 2011, <http://www.pitt.edu/~super7/45011-46001/45401.ppt> (accessed 3/3/13).
133. T de Boorder, R Verdaasdonk and J Klaessens, "The Visualisation of Surgical Smoke Produced by Energy Delivery Devices: Significance and Effectiveness of Evacuation Systems," 2007, <http://www.buffalofilter.com/PDF/NetherlandsVisual2008.pdf> (accessed 6/14/13).
134. BE Edwards and RE Reiman, "Results of a Survey on Current Surgical Smoke Control Practices," *AORN Journal* 87(4) (2008): 739.
135. K Ball, "Compliance with Surgical Smoke Evacuation Guidelines: Implications for Practice," *AORN Journal* 92(2) (2010): 142-9, (DOI:10.1016/j.aorn.2010.06.002).
136. BE Edwards and RE Reiman, "Comparison of Current and Past Surgical Smoke Control Practices," *AORN Journal* 95(3) (2012): 337-50, (DOI:10.1016/j.aorn.2011.07.019).
137. O Dumas, et al., "Occupational Exposure to Cleaning Products and Asthma in Hospital Workers," *Occupational and Environmental Medicine* 69(12) (2012): 883-889.
138. A Bello, et al., "Quantitative Assessment of Airborne Exposures Generated during Common Cleaning Tasks: A Pilot Study," *Environmental Health* 9(1) (2010): 76.
139. A Bello, et al., "Characterization of Occupational Exposures to Cleaning Products Used for Common Cleaning Tasks — A Pilot Study of Hospital Cleaners," *Environmental Health* 8(1) (2009): 11.
140. S Koda, S Kumagai and H Ohara, "Environmental Monitoring and Assessment of Short-Term Exposures to Hazardous Chemicals of a Sterilization Process in Hospital Working Environments," *Acta Medica Okayama* 53(5) (1999): 217-223.
141. M Ruddy and C Kibbler, "Endoscopic Decontamination: An Audit and Practical Review," *Journal of Hospital Infection* 50(4) (2002): 261-268.
142. K Rideout, et al., "Considering Risks to Healthcare Workers from Glutaraldehyde Alternatives in High-Level Disinfection," *Journal of Hospital Infection* 59(1) (2005): 4-11, (DOI:<http://dx.doi.org/10.1016/j.jhin.2004.07.003>).
143. Y Haikel, et al., "Exposure to Mercury Vapor during Setting, Removing, and Polishing Amalgam Restorations," *Journal of Biomedical Materials Research* 24(11) (1990): 1551-1558.
144. J Engle, et al., "Quantitation of Total Mercury Vapor Released during Dental Procedures," *Dental Materials* 8(3) (1992): 176-180.
145. L Pohl and M Bergman, "The Dentist's Exposure to Elemental Mercury Vapor during Clinical Work with Amalgam," *Acta Odontologica* 53(1) (1995): 44-48.
146. D Echeverria, et al., "Behavioral Effects of Low-Level Exposure to Hg⁰ among Dentists," *Neurotoxicology and Teratology* 17(2) (1995): 161-168, (DOI:[http://dx.doi.org/10.1016/0892-0362\(94\)00049-J](http://dx.doi.org/10.1016/0892-0362(94)00049-J)).
147. S-B Chang, C Siew and S Gruninger, "Factors Affecting Blood Mercury Concentrations in Practicing Dentists," *Journal of Dental Research* 71(1) (1992): 66-74.

REFERENCES

148. B Nilsson, "Mercury in Dental Practice. I. The Working Environment of Dental Personnel and Their Exposure to Mercury Vapor," *Swedish Dental Journal* 10(1-2) (1986): 1.
149. A Jokstad, "Mercury Excretion and Occupational Exposure of Dental Personnel," *Community Dentistry and Oral Epidemiology* 18(3) (1990): 143-148.
150. C Naleway, et al., "Urinary Mercury Levels in U.S. Dentists, 1975-1983: Review of Health Assessment Program," *The Journal of the American Dental Association* 111(1) (1985): 37-42.
151. PA Leggat, U Kedjarune and DR Smith, "Occupational Health Problems in Modern Dentistry: A Review," *Industrial Health* 45(5) (2007): 611-621.
152. MS Baggish, P Baltoyannis and E Sze, "Protection of the Rat Lung from the Harmful Effects of Laser Smoke," *Lasers in Surgery and Medicine* 8(3) (1988): 248-253.
153. JP Smith, et al., "Evaluation of a Smoke Evacuator Used for Laser Surgery," *Lasers in Surgery and Medicine* 9(3) (1989): 276-281, (DOI:10.1002/lsm.1900090311).
154. JP Smith, JL Topmiller and S Shulman, "Factors Affecting Emission Collection by Surgical Smoke Evacuators," *Lasers in Surgery and Medicine* 10(3) (1990): 224-233, (DOI:10.1002/lsm.1900100303).
155. JG Hunter, "Laser Smoke Evacuator: Effective Removal of Mutagenic Cautery Smoke," *Aesthetic Plastic Surgery* 20(2) (1996): 177-178.
156. S Pillinger, L Delbridge and D Lewis, "Randomized Clinical Trial of Suction Versus Standard Clearance of the Diathermy Plume," *British Journal of Surgery* 90(9) (2003): 1068-1071.
157. D Mattes, et al., "Surgical Smoke Management for Minimally Invasive (Micro) Endoscopy: An Experimental Study," *Surgical Endoscopy* 24(10) (2010): 2492-2501.
158. KF O'Grady and A Easty, "Electrosurgery Smoke: Hazards and Protection," *Journal of Clinical Engineering* 21(2) (1996): 149.
159. P Andersen, "Mobile and Fixed Computer Use by Doctors and Nurses on Hospital Wards: Multi-Method Study on the Relationships Between Clinician Role, Clinical Task, and Device Choice," *Journal of Medical Internet Research* 11(3) (2009): e32, (DOI:10.2196/jmir.1221).
160. Human Factors and Ergonomics Society, *ANSI/HFES 100-2007 Human Factors Engineering of Computer Workstations*, 2007).
161. W Jaschinski-Kruza, "Eyestrain in VDU Users: Viewing Distance and the Resting Position of Ocular Muscles," *Human Factors* 33(1) (1991): 69.
162. CM Sommerich, "Effects of Computer Monitor Viewing Angle and Related Factors on Strain, Performance, and Preference Outcomes," *Human Factors* 43(1) (2001): 39-55, (DOI:10.1518/001872001775992480).
163. A Hedge, "Effects of Keyboard Tray Geometry on Upper Body Posture and Comfort," *Ergonomics* 42(10) (1999): 1333-1349, (DOI:10.1080/001401399184983).
164. D Rempel, "The Effect of Keyboard Keyswitch Make Force on Applied Force and Finger Flexor Muscle Activity," *Ergonomics* 40(8) (1997): 800-808, (DOI: 10.1080/001401397187793).
165. Sue Barnes, "Overview: Infection Prevention and Control for Computers in Patient Care Areas," 2011, <http://www.beckersasc.com/asc-accreditation-and-patientsafety/overview-infection-prevention-and-control-for-computers-in-patie.html> (accessed 3/15/13).

REFERENCES

166. D Whittemore and J Moll, "COWs WOWs, Oh My! Focusing on the Needs of Nurses Can Help Hospital IT Departments Make the Best Technology Decisions and Improve Care Giving at the Bedside.," *Health Management Technology* 29(7) (2008): 32-34.
167. U Matern, "Principles of Ergonomic Instrument Handles," *Minimally Invasive Therapy & Allied Technologies* 10(3) (2001): 169-173.
168. M Van Veelen, et al., "Improvement of Foot Pedals Used during Surgery Based on New Ergonomic Guidelines," *Surgical Endoscopy* 17(7) (2003): 1086-1091.
169. U Matern, et al., "Ergonomics: Requirements for Adjusting the Height of Laparoscopic Operating Tables," *Journal of the Society of Laparoendoscopic Surgeons/ Society of Laparoendoscopic Surgeons* 5(1) (2001): 7-12.
170. MA Van Veelen, et al., "Assessment of the Ergonomically Optimal Operating Surface Height for Laparoscopic Surgery," *Journal of Laparoendoscopic and Advanced Surgical Techniques. Part A* 12(1) (2002): 47-52, (DOI:10.1089/109264202753486920).
171. U Matern, et al., "Monitor Position in Laparoscopic Surgery," *Surgical Endoscopy and Other Interventional Techniques* 19(3) (2005): 436-440, (DOI:10.1007/s00464-004-9030-7).
172. M Van Veelen, et al., "Evaluation of the Usability of Two Types of Image Display Systems, during Laparoscopy," *Surgical Endoscopy* 16(4) (2002): 674-678.
173. E Lee, et al., "Ergonomics and Human Factors in Endoscopic Surgery: A Comparison of Manual vs Telerobotic Simulation Systems," *Surgical Endoscopy* 19(8) (2005): 1064-1070.
174. A Nelson, et al., "Development and Evaluation of a Multifaceted Ergonomics Program to Prevent Injuries Associated with Patient Handling Tasks," *International Journal of Nursing Studies* 43(6) (2006): 717-733.
175. A Garg and JM Kapellusch, "Long-Term Efficacy of an Ergonomics Program That Includes Patient-Handling Devices on Reducing Musculoskeletal Injuries to Nursing Personnel," *Human Factors: The Journal of the Human Factors and Ergonomics Society* 54(4) (2012): 608-625, (DOI:10.1177/0018720812438614).
176. TR Waters, "When Is It Safe to Manually Lift a Patient?," *AJN The American Journal of Nursing* 107(8) (2007): 53-58 10.1097/01.NAJ.0000282296.18688.b1.
177. S Hignett, "Systematic Review of Patient Handling Activities Starting in Lying, Sitting and Standing Positions," *Journal of Advanced Nursing* 41(6) (2003): 545-552.
178. A Nelson and AS Baptiste, "Evidence-Based Practices for Safe Patient Handling and Movement," *Clinical Reviews in Bone and Mineral Metabolism* 4(1) (2006): 55-69.
179. W Marras, G Knapik and S Ferguson, "Lumbar Spine Forces during Manoeuvring of Ceiling-Based and Floor-Based Patient Transfer Devices," *Ergonomics* 52(3) (2009): 384-397.
180. JD Lloyd and A Baptiste, "Friction-Reducing Devices for Lateral Patient Transfers: A Biomechanical Evaluation," *AAOHN journal: official journal of the American Association of Occupational Health Nurses* 54(3) (2006): 113.
181. JH Brusin, "Ergonomics in Radiology," *Radiologic Technology* 83(2) (2011): 141-157.
182. TR Waters, A Nelson and C Proctor, "Patient Handling Tasks with High Risk for Musculoskeletal Disorders in Critical Care," *Critical Care Nursing Clinics of North America* 19(2) (2007): 131.

REFERENCES

183. AP Dawson, et al., "Interventions to Prevent Back Pain and Back Injury in Nurses: A Systematic Review," *Occupational and Environmental Medicine* 64(10) (2007): 642-650.
184. E Bos, et al., "The Effects of Occupational Interventions on Reduction of Musculoskeletal Symptoms in the Nursing Profession," *Ergonomics* 49(7) (2006): 706-723.
185. TG Bobick, et al., "Physiological Effects of Back Belt Wearing during Asymmetric Lifting," *Applied Ergonomics* 32(6) (2001): 541-547.
186. JT Wassell, et al., "A Prospective Study of Back Belts for Prevention of Back Pain and Injury," *The Journal of the American Medical Association* 284(21) (2000): 2727-2732.
187. US Department of Labor Occupational Safety and Health Administration, "Hospital eTool on Ergonomics," <http://www.osha.gov/SLTC/etools/hospital/hazards/ergo/ergo.html> (accessed 6/16/13).
188. National Institute for Occupational Safety and Health, "Summary of NIOSH Back Belt Studies," <http://www.cdc.gov/niosh/topics/ergonomics/beltsumm.html> (accessed May 26, 2013).
189. Hronn Brynjarsdottir, "The Cornell Digital Reading Room Ergonomics Checklist: Development and Evaluation," 2007, ecommons.library.cornell.edu/bitstream/1813/.../hb47_new_final.pdf (accessed 2/23/13).
190. Cornell University Ergonomics Web, "Cornell Digital Reading Room Ergonomics Checklist," 2006, <http://ergo.human.cornell.edu/CDRREC.htm>. (accessed 2/23/13).
191. BI Reiner, "Redesigning the PACS Reading Room: Optimizing Monitor and Room Lighting," *Physics of semiconductor devices* 3662(1999): 276.
192. FL Pais, et al., "Ergonomic Assessment among Radiology Technologists: A Survey in a Hospital," *Work: A Journal of Prevention, Assessment and Rehabilitation* 41(2012): 1821-1827.
193. LW Klein, et al., "Occupational Health Hazards in the Interventional Laboratory: Time for a Safer Environment," *Catheterization and Cardiovascular Interventions* 73(3) (2009): 432-438.
194. United Nations Department of Economic and Social Affairs, "Accessibility for the Disabled," 2003, <http://www.un.org/esa/socdev/enable/designm/AD2-01.htm> (accessed 3/4/13, 2013).
195. US Access Board, "A.D.A. Accessibility Guidelines for Buildings and Facilities," 2002, <http://www.access-board.gov/adaag/html/adaag.htm#4.8> (accessed 2/23/13).
196. ANSI/IESNA, ANSI/IESNA RP-29-06 Lighting for Hospitals and Healthcare Facilities. New York: Illuminating Engineering Society of North America; 2006.
197. E Richman, "ANSI/ASHRAE/IESNA Standard 90.1-2007 An Overview of the Lighting and Power Requirements," 2008, <http://www.energycodes.gov/sites/default/files/becu/lighting07.pdf> (accessed 6/17/13).
198. C Murphy, A Russo and HB Trust, "An Update on Ergonomic Issues in Sonography," *Healthcare Benefit Trust* (2000).
199. N Magnavita, et al., "Work-Related Musculoskeletal Complaints in Sonologists," *Journal of Occupational and Environmental Medicine* 41(11) (1999): 981-988.
200. Alan Hedge, Tamara James and S Pavlovic-Veselinovic, "Ergonomics Concerns and the Impact of Healthcare Information Technology," *International Journal of Industrial Ergonomics* 41(4) (2011): 345-51.

REFERENCES

201. BI Reiner, et al., "Effect of Filmless Imaging on the Utilization of Radiologic Services," *Radiology* 215(1) (2000): 163-7.
202. F Ulger, et al., "Are We Aware How Contaminated Our Mobile Phones with Nosocomial Pathogens?," *Annals of Clinical Microbiology and Antimicrobials* 8(1) (2009): 7.
203. DH Tambekar, et al., "Nosocomial Hazards of Doctor's Mobile Phones in Hospitals," *Journal of Medical Sciences (Taipei, Taiwan)* 8(1) (2008): 73-6.
204. A Visvanathan, AP Gibb and RR Brady, "Increasing Clinical Presence of Mobile Communication Technology: Avoiding the Pitfalls," *Telemedicine Journal and e-Health* 17(8) (2011): 656-61, (DOI:10.1089/tmj.2011.0018).
205. MA Veelen, et al., "Evaluation of the Usability of Two Types of Image Display Systems during Laparoscopy," *Surgical Endoscopy and Other Interventional Techniques* 16(4) (2002): 674-678, (DOI:10.1007/s00464-001-9116-4).
206. R Berquer, WD Smith and S Davis, "An Ergonomic Study of the Optimum Operating Table Height for Laparoscopic Surgery," *Surgical Endoscopy and Other Interventional Techniques* 16(3) (2002): 416-421, (DOI:10.1007/s00464-001-8190-y).
207. R Galleano, et al., "Can Armrests Improve Comfort and Task Performance in Laparoscopic Surgery?," *Annals of Surgery* 243(3) (2006): 329.
208. AL Schoenfisch, et al., "Musculoskeletal Injuries among Hospital Patient Care Staff Before and After Implementation of Patient Lift and Transfer Equipment," *Scandinavian Journal of Work, Environment and Health* 39(1) (2012): 27-36, (DOI:10.5271/sjweh.3288).
209. AL Nelson, *Safe Patient Handling and Movement: A Practical Guide for Health Care Professionals*: Springer Publishing Company, 2005.
210. S Hignett, "Intervention Strategies to Reduce Musculoskeletal Injuries Associated with Handling Patients: A Systematic Review," *Occupational and Environmental Medicine* 60(9) (2003): e6.
211. J Horkey and P King, "Ergonomic Recommendations and Their Role in Cardiac Sonography," *Work: A Journal of Prevention, Assessment and Rehabilitation* 22(3) (2004): 207-218.
212. W Charney, et al., "Zero Lift Programs in Small Rural Hospitals in Washington State: Reducing Back Injuries among Health Care Workers," *AAOHN Journal: official journal of the American Association of Occupational Health Nurses* 54(8) (2006): 355.
213. B Evanoff, et al., "Reduction in Injury Rates in Nursing Personnel through Introduction of Mechanical Lifts in the Workplace," *American Journal of Industrial Medicine* 44(5) (2003): 451-457.
214. BD Owen, K Keene and S Olson, "An Ergonomic Approach to Reducing Back/Shoulder Stress in Hospital Nursing Personnel: A Five Year Follow up," *International Journal of Nursing Studies* 39(3) (2002): 295-302.
215. MM Robertson, et al., "Examination of Computer Task Exposures in Radiologists: A Work Systems Approach," *Work: A Journal of Prevention, Assessment and Rehabilitation* 41(2012): 1818-1820.
216. JL Bell, et al., "Evaluation of a Comprehensive Slip, Trip and Fall Prevention Programme for Hospital Employees," *Ergonomics* 51(12) (2008): 1906-1925.
217. G Brogmus, et al., "Best Practices in OR Suite Layout and Equipment Choices to Reduce Slips, Trips, and Falls," *AORN Journal* 86(3) (2007): 384-398, (DOI: 10.1016/j.aorn.2007.06.003).

REFERENCES

218. DA Lombardi, "Transient Risk Factors for Slips, Trips, and Falls: A Case-Crossover Study of US Health Care Workers," *Poster at American Public Health Association annual meeting* (2007).
219. SL Murphey and A Milkowski, "Surface EMG Evaluation of Sonographer Scanning Postures," *Journal of Diagnostic Medical Sonography* 22(5) (2006): 298-305, (DOI:10.1177/8756479306292683).
220. KP Wynd, et al., "Ultrasound Machine Comparison: An Evaluation of Ergonomic Design, Data Management, Ease of Use, and Image Quality," *Regional Anesthesia and Pain Medicine* 34(4) (2009): 349-356, (DOI:10.1097/AAP.Ob013e3181ac9e5b).
221. LC Paschoarelli, AB de Oliveira and HJC Gil Coury, "Assessment of the Ergonomic Design of Diagnostic Ultrasound Transducers through Wrist Movements and Subjective Evaluation," *International Journal of Industrial Ergonomics* 38(11) (2008): 999-1006.
222. AC Smith, et al., "Musculoskeletal Pain in Cardiac Ultrasonographers: Results of a Random Survey," *Journal of the American Society of Echocardiography* 10(4) (1997): 357-362.
223. GG Shapiro and RA Sinon, "Bronchoprovocation Committee Report," *Journal of Allergy and Clinical Immunology* 89(3) (1992): 775-778.
224. R Lundgren, et al., "Development of Increased Airway Responsiveness in Two Nurses Performing Methacholine and Histamine Challenge Tests," *Allergy* 47(2) (1992): 188-189.
225. J Nilsestuen, et al., "AARC Clinical Practice Guideline Selection of a Device for Delivery of Aerosol to the Lung Parenchyma," *Respiratory Care* 41(7) (1996): 647-653.
226. C Smith and RD Goldman, "Nebulizers Versus Pressurized Metered-Dose Inhalers in Preschool Children with Wheezing," *Canadian Family Physician* 58(5) (2012): 528-530.
227. HJ Zar and ME Levin, "Challenges in Treating Pediatric Asthma in Developing Countries," *Paediatric Drugs* 14(6) (2012): 353-359.
228. J Le, et al., "Consensus Summary of Aerosolized Antimicrobial Agents: Application of Guideline Criteria. Insights from the Society of Infectious Disease Pharmacists," *Pharmacotherapy: The Journal of Human Pharmacology and Drug Therapy* 30(6) (2010): 562-584.
229. TH Connor and MA McDiarmid, "Preventing Occupational Exposures to Antineoplastic Drugs in Health Care Settings," *CA: A Cancer Journal for Clinicians* 56(6) (2006): 354-65.
230. "ASHP Guidelines on Handling Hazardous Drugs," *American Journal of Health-System Pharmacy* 63(12) (2006): 1172-1191, (DOI:10.2146/ajhp050529).
231. United States Environmental Protection Agency, "Nitrogen Dioxide, Health," 2013, <http://www.epa.gov/oaqps001/nitrogenoxides/health.html> (accessed 3/5/13, 2013).
232. BH Cuthbertson, S Stott and NR Webster, "Use of Inhaled Nitric Oxide in British Intensive Therapy Units," *British Journal of Anaesthesia* 78(6) (1997): 696-700.
233. DG Markhorst, et al., "Occupational Exposure during Nitric Oxide Inhalational Therapy in a Pediatric Intensive Care Setting," *Intensive Care Medicine* 22(9) (1996): 954-8.
234. E Mourgeon, et al., "Factors Influencing Indoor Concentrations of Nitric Oxide in a Parisian Intensive Care Unit," *American Journal of Respiratory and Critical Care Medicine* 156(5) (1997): 1692-5.

REFERENCES

235. ML Phillips, et al., "Assessment of Medical Personnel Exposure to Nitrogen Oxides during Inhaled Nitric Oxide Treatment of Neonatal and Pediatric Patients," *Pediatrics* 104(5 Pt 1) (1999): 1095-100.
236. MA Qureshi, et al., "Exposure of Intensive Care Unit Nurses to Nitric Oxide and Nitrogen Dioxide during Therapeutic Use of Inhaled Nitric Oxide in Adults with Acute Respiratory Distress Syndrome," *American Journal of Critical Care* 12(2) (2003): 147-53.
237. R Lindwall, et al., "Workplace NO and NO₂ during Combined Treatment of Infants with Nasal CPAP and NO," *Intensive Care Medicine* 32(12) (2006): 2034-41, (DOI:10.1007/s00134-006-0393-1).
238. FJ Montgomery and AD Berssenbrugge, "Inhaled Nitric Oxide Delivery and Monitoring," *Journal of Clinical Monitoring and Computing* 15(5) (1999): 325-335.
239. National Institute for Occupational Safety and Health, "NIOSH List of Antineoplastic and Other Hazardous Drugs in Healthcare Settings 2012," 2012, <http://www.cdc.gov/niosh/docs/2012-150/pdfs/2012-150.pdf> (accessed 6/16/13).
240. J Beach, M Campbell and D Andrews, "Exposure of Health Care Workers to Pentamidine Isethionate," *Occupational Medicine* 49(4) (1999): 243-245.
241. W Charney, "Pentamidine," in: *Handbook of Modern Hospital Safety*. Charney W, editor. (Boca Raton: CRC; 2010).
242. W Kowalski, "UVGI Guidelines and Standards," in: *Ultraviolet Germicidal Irradiation Handbook*. Springer; 2009, p. 255-286.
243. JR Balmes, et al., "Respiratory Effects of Occupational Exposure to Aerosolized Pentamidine," *Journal of Occupational and Environmental Medicine* 37(2) (1995): 145-150.
244. M McDiarmid, et al., "Health Effects and Exposure Assessment of Aerosolized Pentamidine Handlers," *CHEST Journal* 104(2) (1993): 382-385.
245. S Ito and G Koren, "Estimation of Fetal Risk from Aerosolized Pentamidine in Pregnant Healthcare Workers," *CHEST Journal* 106(5) (1994): 1460-62.
246. M Paul, "Occupational Reproductive Hazards," *The Lancet* 349(9062) (1997): 1385-88.
247. AARC, "AARC Clinical Practice Guideline," 1996, <http://www.rcjournal.com/cpgs/dalpcpg.html> (accessed 3/15/13, 41).
248. LSUHSC, "Hospital Policy Manual Cardiopulmonary Services General Procedures: 7.5 Aerosolized Pentamidine," <http://www.sh.lsuhs.edu/cps/pandp/7.5.pdf> (accessed 3/15/13).
249. National Institute of Health, "Pentamidine Aerosolization with the Respigard II Nebulizer System," 2000, http://www.cc.nih.gov/ccmd/cctrcs/pdf_docs/Aerosol%20Therapy/05-Pentamidine%20Aero.pdf (accessed 3/18/13).
250. M Leonard R. Krilov, "Safety Issues Related to the Administration of Ribavirin," *Pediatric Infectious Disease Journal* 21(2002): 479-81.
251. GS Rajhans, et al., "Hygiene Aspects of Occupational Exposure to Waste Anaesthetic Gases in Ontario Hospitals," *Annals of Occupational Hygiene* 33(1) (1989): 27-45.
252. HC Schuyt and MM Verberk, "Measurement and Reduction of Nitrous Oxide in Operating Rooms," *Journal of Occupational and Environmental Medicine* 38(10) (1996): 1036-40.

REFERENCES

253. S Crauste-Manciet, et al., "Environmental Contamination with Cytotoxic Drugs in Healthcare Using Positive Air Pressure Isolators," *Annals of Occupational Hygiene* 49(7) (2005): 619-628.
254. JJ McDevitt, P Lees and MA McDiarmid, "Exposure of Hospital Pharmacists and Nurses to Antineoplastic Agents," *Journal of Occupational and Environmental Medicine* 35(1) (1993): 57-60.
255. TH Connor, et al., "Surface Contamination of Chemotherapy Drug Vials and Evaluation of New Vial-Cleaning Techniques: Results of Three Studies," *American Journal of Health-System Pharmacy* 62(5) (2005): 475-484.
256. M McDiarmid, et al., "Efficacy of Engineering Controls in Reducing Occupational Exposure to Aerosolized Pentamidine," *CHEST Journal* 102(6) (1992): 1764-66.
257. JA Decker, et al., "Occupational Exposures to Aerosolized Pharmaceuticals and Control Strategies," *Scandinavian Journal of Work, Environment and Health* (1992): 100-102.
258. VJ Fraser, et al., "Evaluation of Rooms with Negative Pressure Ventilation Used for Respiratory Isolation in Seven Midwestern Hospitals," *Infection Control and Hospital Epidemiology* 14(11) (1993): 623-628, (DOI:10.2307/30149744).
259. R Kacmarek and J Kratochvil, "Evaluation of a Double-Enclosure Double-Vacuum Unit Scavenging System for Ribavirin Administration," *Respiratory Care* 37(1) (1992): 37-45.
260. JS Bradley, et al., "Exposure of Health Care Workers to Ribavirin during Therapy for Respiratory Syncytial Virus Infections," *Antimicrobial Agents and Chemotherapy* 34(4) (1990): 668-670.
261. B Mueller and V Waldon, "Use of an In-House-Built Ribavirin Aerosol Evacuation System to Control Incidental Employee Exposure to Ribavirin Aerosol," *Journal of Clinical Engineering* 21(1) (1996): 46-50.
262. H Cember and TE Johnson, *Introduction to Health Physics* Fourth ed: McGraw-Hill Medical, 2009.
263. EB Douple, et al., "Long-Term Radiation-Related Health Effects in a Unique Human Population: Lessons Learned from the Atomic Bomb Survivors of Hiroshima and Nagasaki," *Disaster Medicine and Public Health Preparedness* 5 (Supplement_1) (2011): S122-133, (DOI:10.1001/dmp.2011.21).
264. National Research Council and Committee to Assess Health Risks from Exposure to Low Levels of Ionizing Radiation, *Health Risks from Exposure to Low Levels of Ionizing Radiation: BEIR VII-Phase 2*: Washington, DC, 2005.
265. ML Maiello, "NCRP Report No. 160: Ionizing Radiation Exposure of the Population of the United States," *Health physics (1958)* 98(3) (2010): 549-550, (DOI: 10.1097/HP.0b013e3181c80d20).
266. International Commission on Radiation Protection, "The 2007 Recommendations of the International Commission on Radiation Protection ICRP Publication 103," *Annals of the ICRP* 37(2-4) (2007).
267. U.S. Nuclear Regulatory Commission, "10CFR37 Physical Protection of Category 1 and Category 2 Quantities of Radioactive Materials," <http://www.nrc.gov/reading-rm/doc-collections/cfr/part037/> (accessed 6/15/13).
268. National Council for Radiation Protection, Protection NciR, *NCRP Report 122 Use of Personal Monitors to Estimate Effective Dose Equivalent and Effective Dose to Workers for External Exposure to Low-LET Radiation*, 1995.

REFERENCES

269. DL Miller, et al., "Occupational Radiation Protection in Interventional Radiology: A Joint Guideline of the Cardiovascular and Interventional Radiology Society of Europe and the Society of Interventional Radiology," *Cardiovascular and Interventional Radiology* 33(2) (2010): 230-9, (DOI:10.1007/s00270-009-9756-7).
270. F Vanhavere, et al., "The Use of Extremity Dosimeters in a Hospital Environment," *Radiation protection dosimetry* 118(2) (2006): 190-195.
271. J Pajic, et al., "Occupational Exposure in Nuclear Medicine," *J Occup Environ Hyg* 8(10) (2011): D101-6, (DOI:10.1080/15459624.2011.613353).
272. The Writing Rad, "NRC Guidelines for the Radiation Safety Officer," <http://www.writingrad.com/doc/NRC-Guidelines-for-RSO.pdf> (accessed 2/20/13, 2013).
273. R Smart, "Task-Specific Monitoring of Nuclear Medicine Technologists' Radiation Exposure," *Radiation protection dosimetry* 109(3) (2004): 201-209.
274. MG Stabin, *Radiation Protection and Dosimetry: An Introduction to Health Physics* (New York: Springer, 2008).
275. RE Reiman, "Radiation Safety Considerations for PET/CT," July 15, 2011, www.safety.duke.edu/radsafety/slides/PET_CT_Web.pps (accessed 3/15/13).
276. T Beyer, SP Muller, G Brix, U Lechel, G Glatting, SI Ziegler, W Munzing, Radiation Exposure During Combined Whole-Body FDG-PET/CT Imaging. 51st Annual Meeting, Society of Nuclear Medicine; June 22, 2004.
277. B Quinn, et al., "Measured Dose Rate Constant from Oncology Patients Administered 18F for Positron Emission Tomography," *Medical Physics* 39(2012): 6071.
278. FM Khan, *The Physics of Radiation Therapy* 3rd ed: Lippincott Williams and Wilkins, 2003.
279. National Council of Radiation Protection, Report No. 049-Structural Shielding Design and Evaluation for Medical Use of X-Rays and Gamma Rays of Energies up to 10 MeV. 1. In Bethesda: National Council of Radiation Protection; 1976.
280. J Gauvin, "Radiation Protection in Hospitals," in: *Handbook of Modern Hospital Safety*. Charney W, editor. (Boca Raton: CRC Press; 2010).
281. National Council on Radiation Protection, Protection NCoR, *NCRP Report No. 168 Radiation Dose Management for Fluoroscopically-Guided Interventional Medical Procedures*, 2010.
282. EK Paulson, et al., "CT Fluoroscopy-Guided Interventional Procedures: Techniques and Radiation Dose to Radiologists," *Radiology* 220(1) (2001): 161-167.
283. D Hill, K Mcleish and SF Keevil, "Impact of Electromagnetic Field Exposure Limits in Europe: Is the Future of Interventional MRI Safe?," *Academic Radiology* 12(9) (2005): 1135.
284. E Litvak, K Foster and M Repacholi, "Health and Safety Implications of Exposure to Electromagnetic Fields in the Frequency Range 300 Hz to 10 MHz," *Bioelectromagnetics* 23(1) (2002): 68-82.
285. RT Hitchcock, et al., "Nonionizing Radiation," in: *The Occupational Environment: Its Evaluation, Control, and Management*. DiNardi SR, editor. (Fairfax: AIHA Press; 2003), p. 490-579.
286. K Gibson and W Kernohant, "Lasers in Medicine — A Review," *Journal of Medical Engineering and Technology* 17(2) (1993): 51-57.
287. American National Standards Institute, American National Standard for Safe Use of Lasers in Health Care Facilities. Orlando: Laser Institute of America; 2005.
288. MJ Maisels, "Neonatal Jaundice," *Pediatrics in Review* 27(12) (2006): 443-454.

REFERENCES

289. Occupational Safety and Health Administration, "Radiofrequency and Microwave Radiation: Health Effects," <http://www.osha.gov/SLTC/radiofrequencyradiation/index.html#healtheffects> (accessed 3/3/13, 2013).
290. International Agency for Research on Cancer, World Health Organization, *Part 1: Static and Extremely Low-Frequency (ELF) Electric and Magnetic Fields*, 2002.
291. G Krestin, P Leijh and P Stubbs, *Using MRI Safely — Practical Rules for Employees*. Netherlands: Radiological Society of the Netherlands; 2008.
292. World Health Organization, *Static Fields*. Environmental Health Criteria 232. Geneva: World Health Organization; 2006.
293. World Health Organization, *Extremely Low Frequency Fields*, Environmental Health Criteria monograph no. 238. 2007.
294. Federal Provincial Territorial Radiation Protection Committee of Canada, *Health Effects and Exposure Guidelines Related to Extremely Low Frequency Electric and Magnetic Fields-An Overview*. 2005.
295. JK Bradley, et al., "Occupational Exposure to Static and Time-Varying Gradient Magnetic Fields in MR Units," *Journal of Magnetic Resonance Imaging* 26(5) (2007): 1204-1209.
296. S Kännälä, et al., "Occupational Exposure Measurements of Static and Pulsed Gradient Magnetic Fields in the Vicinity of MRI Scanners," *Physics in Medicine and Biology* 54(7) (2009): 2243.
297. International Commission on Non-Ionizing Radiation, "General Approach to Protection Against Non-Ionizing Radiation," *Health Physics* 82(4) (2002): 540-548.
298. International Agency for Research on Cancer, "IARC Classifies Radiofrequency Electromagnetic Fields as Possibly Carcinogenic to Humans," 2011, http://www.iarc.fr/en/media-centre/pr/2011/pdfs/pr208_E.pdf (accessed 3/3/13, 2013).
299. H Bassen, et al., IEEE Committee on Man and Radiation (Comar) Technical Information Statement, "Exposure of Medical Personnel to Electromagnetic Fields From Open Magnetic Resonance Imaging Systems," *Health Physics* 89(6) (2005): 684-689.
300. R Stam, Report 610703001/2008, *The EMF Directive and Protection of MRI Workers: Possible Solutions*. Bilthoven: National Institute for Public Health and the Environment; 2008.
301. American National Standard Institute, *American National Standard for Safe Use of Lasers in Health Care*, Orlando: Laser Institute of America; 2011.
302. C Hohl, et al., "Dose Reduction during CT Fluoroscopy: Phantom Study of Angular Beam Modulation1," *Radiology* 246(2) (2008): 519-525.
303. BM Stoeckelhuber, et al., "Radiation Dose to the Radiologist's Hand during Continuous CT Fluoroscopy-Guided Interventions," *Cardiovascular and Interventional Radiology* 28(5) (2005): 589-594.
304. MS Park, et al., "Comparison of Operator Radiation Exposure between C-Arm and O-Arm Fluoroscopy for Orthopaedic Surgery," *Radiation protection dosimetry* 148(4) (2012): 431-438.
305. SB Solomon, et al., "Robotically Driven Interventions: A Method of Using CT Fluoroscopy without Radiation Exposure to the Physician," 225(1) (2002): 277-282.
306. RD Nawfel, et al., "Patient and Personnel Exposure during CT Fluoroscopy-Guided Interventional Procedures," *Radiology* 216(1) (2000): 180-184.

REFERENCES

307. DA Marichal, et al., "Comparison of a Suspended Radiation Protection System Versus Standard Lead Apron for Radiation Exposure of a Simulated Interventionalist," *Journal of Vascular and Interventional Radiology* 22(4) (2011): 437-442.
308. JN King, et al., "Using a Sterile Disposable Protective Surgical Drape for Reduction of Radiation Exposure to Interventionalists," *American Journal of Roentgenology* 178(1) (2002): 153-157.
309. S Dromi, et al., "Heavy Metal Pad Shielding during Fluoroscopic Interventions," *Journal of Vascular and Interventional Radiology* 17(7) (2006): 1201-1206.
310. C Shortt, et al., "Staff Radiation Doses to the Lower Extremities in Interventional Radiology," *Cardiovascular and Interventional Radiology* 30(6) (2007): 1206-1209.
311. M Maeder, et al., "Impact of a Lead Glass Screen on Scatter Radiation to Eyes and Hands in Interventional Cardiologists," *Catheterization and Cardiovascular Interventions* 67(1) (2006): 18-23.
312. JS Luchs, et al., "Radiation Safety during Spine Interventions," *Journal of Vascular and Interventional Radiology* 16(1) (2005): 107-111.
313. C Martin and M Whitby, "Application of ALARP to Extremity Doses for Hospital Workers," *Journal of Radiological Protection* 23(4) (2003): 405.
314. E Vano, et al., "Radiation Exposure to Medical Staff in Interventional and Cardiac Radiology," *British Journal of Radiology* 71(849) (1998): 954-960.
315. E Vano, et al., "Occupational Radiation Doses in Interventional Cardiology: A 15-Year Follow-Up," *British Journal of Radiology* 79(941) (2006): 383-388.
316. R Hernandez and M Goodsitt, "Reduction of Radiation Dose in Pediatric Patients Using Pulsed Fluoroscopy," *American Journal of Roentgenology* 167(5) (1996): 1247-1253.
317. E Kuon, M Schmitt and JB Dahm, "Significant Reduction of Radiation Exposure to Operator and Staff during Cardiac Interventions by Analysis of Radiation Leakage and Improved Lead Shielding," *The American Journal of Cardiology* 89(1) (2002): 44-49, (DOI:[http://dx.doi.org/10.1016/S0002-9149\(01\)02161-0](http://dx.doi.org/10.1016/S0002-9149(01)02161-0)).
318. D Zweers, et al., "Patient and Staff Radiation Dose in Fluoroscopy-Guided TIPS Procedures and Dose Reduction, Using Dedicated Fluoroscopy Exposure Settings," *British Journal of Radiology* 71(846) (1998): 672-676.
319. M Victoria Marx, L Niklason and EA Mauger, "Occupational Radiation Exposure to Interventional Radiologists: A Prospective Study," *Journal of Vascular and Interventional Radiology* 3(4) (1992): 597-606.
320. J Damilakis, et al., "Radiation Exposure to the Hands of Operators during Angiographic Procedures," *European Journal of Radiology* 21(1) (1995): 72-75.
321. N Petroviæ, et al., "Contribution of Activation Products to Occupational Exposure Following Treatment Using High-Energy Photons in Radiotherapy," *Radiation Protection Dosimetry* 143(1) (2011): 109-112.
322. S Lancelot, et al., "Exposure of Medical Personnel to Radiation during Radionuclide Therapy Practices," *Nuclear Medicine Communications* 29(4) (2008): 405-410.
323. B Guillet, et al., "Technologist Radiation Exposure in Routine Clinical Practice with 18F-FDG PET," *Journal of Nuclear Medicine Technology* 33(3) (2005): 175-179.
324. R Michel and C Hofer, "Radiation Safety Precautions for Sentinel Lymph Node Procedures," *Health Physics* 86(2004): S35-S37.

REFERENCES

325. JA Rawlinson, MK Islam and DM Galbraith, "Dose to Radiation Therapists from Activation at High-Energy Accelerators Used for Conventional and Intensity-Modulated Radiation Therapy," *Medical Physics* 29(2002): 598-608.
326. GD Espenan, et al., "Experiences with High Dose Radiopeptide Therapy: The Health Physics Perspective," *Health Physics* 76(3) (1999): 225-235.
327. A Bixler, G Springer and R Lovas, "Practical Aspects of Radiation Safety for Using Fluorine-18," *Journal of Nuclear Medicine Technology* 27(1) (1999): 14-16.
328. P Pityn, M King and R VanderWerf, "Apparent Versus Real Exposures of Nuclear Medicine Technologists during Aerosol Lung Ventilation Scanning," *American Industrial Hygiene Association* 57(2) (1996): 202-204.
329. M Sans-Merce, et al., "Recommendations to Reduce Hand Exposure for Standard Nuclear Medicine Procedures," *Radiation Measurements* 46(11) (2011): 1330-1333.
330. A Montgomery, et al., "Reductions in Finger Doses for Radiopharmaceutical Dispensing Afforded by a Syringe Shield and an Automatic Dose Dispenser," *Nuclear Medicine Communications* 20(1999): 189-194.
331. JA Ponto, "The Syringe Shield Rule: Model for Practitioner-Initiated Regulatory Reform," *Journal of the American Pharmacists Association* 42(6) (2002): 871-874.
332. RD Huff, P Horwitz and SJ Klash, "Personnel Protection during Aerosol Ventilation Studies Using Radioactive Technetium (Tc99m)," *American Industrial Hygiene Association* 55(12) (1994): 1144-1148.
333. C DeMoss, et al., "Health and Performance Factors in Health Care Shift Workers," *Journal of Occupational and Environmental Medicine* 46(12) (2004): 1278-1281.
334. M Shields, "Unhappy on the Job," *Health Reports* 17(4) (2006): 33-37.
335. L Manenschijn, et al., "Shift Work at Young Age is Associated with Elevated Long-Term Cortisol Levels and Body Mass Index," *Journal of Clinical Endocrinology and Metabolism* 96(11) (2011): E1862-E1865.
336. AN Viswanathan, SE Hankinson and ES Schernhammer, "Night Shift Work and the Risk of Endometrial Cancer," *Cancer Research* 67(21) (2007): 10618-10622.
337. RG Stevens, "Light-at-Night, Circadian Disruption and Breast Cancer: Assessment of Existing Evidence," *International Epidemiology Association* 38(2009): 963-970.
338. ES Schernhammer, et al., "Rotating Night Shifts and Risk of Breast Cancer in Women Participating in the Nurses' Health Study," *Journal of the National Cancer Institute* 93(20) (2001): 1563-1568.
339. S Davis, DK Mirick, "Circadian Disruption, Shift Work and the Risk of Cancer: A Summary of the Evidence and Studies in Seattle.," *Cancer Causes and Control* 17(2006): 539-545.
340. K Segawa, et al., "Peptic Ulcer is Prevalent Among Shift Workers," *Digestive Diseases and Sciences* 32(5) (1987): 449-453.
341. A Knutsson, et al., "Shiftwork and Myocardial Infarction: A Case-Control Study," *Occupational and Environmental Medicine* 56(1) (1999): 46-50.
342. K Han, et al., "Job Stress and Work Schedules in Relation to Nurse Obesity," *Journal of Nursing Administration* 41(11) (2011): 488.
343. MV Vyas, et al., "Shift Work and Vascular Events: Systematic Review and Meta-Analysis," *British Medical Journal* 345 (2012): e4800.
344. AM Berger and BB Hobbs, "Impact of Shift Work on the Health and Safety of Nurses and Patients," *Clinical Journal of Oncology Nursing* 10(4) (2006): 465-471.

REFERENCES

345. CE Hartmen et al., "Shift Work and Sleep," *Journal of Occupational and Environmental Medicine* 53(2011): S1-S10.
346. DR Gold, "Rotating Shift Work, Sleep and Accidents Related to Sleepiness in Hospital Nurses," *American Journal of Public Health* 82(1992): 1011-1014.
347. CP Landrigan, et al., "Effect of Reducing Interns' Work Hours on Serious Medical Errors in Intensive Care Units," *New England Journal of Medicine* 351(18) (2004): 1838-1848.
348. AE Rodgers, "The Working Hours of Hospital Staff Nurses and Patient Safety," *Health Affairs* 23(2004): 204-212.
349. SW Lockley, et al., "Effects of Health Care Provider Work Hours and Sleep Deprivation on Safety and Performance," *Joint Commission Journal on Quality and Patient Safety* 33(Supplement 1) (2007): 7-18.
350. LK Barger, "Extended Work Shifts and the Risk of Motor Vehicle Crashes Among Interns," 352(2005): 125-134.
351. D Dawson and K Reid, "Fatigue, Alcohol and Performance Impairment," *Nature* 388(6639) (1997): 235.
352. SK Howard, et al., "The Risks and Implications of Excessive Daytime Sleepiness in Resident Physicians," *Academic Medicine* 77(10) (2002): 1019-1025.
353. J Schirmer, "Health and Safety Hazards of Shiftwork: Implications for Health Care Workers and Strategies for Prevention," in: *Handbook of Modern Healthcare Safety*. Charney W, editor. (Boca Raton: CRC Press LLC; 2010).
354. CA Raymond, "Shifting Work, Sleep Cycles are on the Way to Becoming Another Public Health Issue," *The Journal of the American Medical Association* 259(20) (1988): 2958-2959.
355. JA Caldwell, "Fatigue Countermeasures in Aviation," *Aviation, Space and Environmental Medicine* 80(2009): 29-59.
356. HA Thomas, "Emergency Physician Shift Work," *Clinical and Practice Management*; American College of Emergency Physicians, 2010, www.acep.org/content.aspx?id=29420 (accessed 7/31/13).
357. P Schweitzer, et al., "Laboratory and Field Studies of Naps and Caffeine as Practical Countermeasures for Sleep-Wake Problems Associated with Night Work," *Sleep* 29(1) (2006): 39.
358. RL Sack, et al., "Circadian Rhythm Sleep Disorders: Part I, Basic Principles, Shift Work and Jet Lag Disorders / An American Academy of Sleep Medicine Review," *Sleep* 30(11) (2007): 1460.
359. C Lee, MR Smith and CI Eastman, "A Compromise Phase Position for Permanent Night Shift Workers: Circadian Phase after Two Night Shifts with Scheduled Sleep and Light/Dark Exposure," *Chronobiology International* 23(4) (2006): 859-875.
360. S Wu, et al., "Relationship between Job Burnout and Occupational Stress among Doctors in China," *Stress and Health* 24(2) (2008): 143-149.
361. S Wu, et al., "Relationship between Burnout and Occupational Stress among Nurses in China," *Journal of Advanced Nursing* 59(3) (2007): 233-239.
362. JP Henry, "Biological Basis of the Stress Response," *Physiology* 8(2) (1993): 69-73.
363. DL Ely, "Organization of Cardiovascular and Neurohumoral Responses to Stress," *Annals of the New York Academy of Sciences* 771(1) (2006): 594-608.
364. T Cox, A Griffiths and R Randall, "A Risk Management Approach to the Prevention of Work Stress," *The Handbook of Work and Health Psychology* (2003): 191.

REFERENCES

365. National Institute for Occupational Safety and Health, *Stress at Work*: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, 1999.
366. K McPhaul and J Lipscomb, "Workplace Violence in Health Care: Recognized But Not Regulated," *Online Journal of Issues in Nursing* 9(3) (2004): 7.
367. National Institute for Occupational Safety and Health. Division of Safety Research, *Violence in the Workplace: Risk Factors and Prevention Strategies*: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, Division of Safety Research, 1996.
368. AJ Reiss, JA Roth and KA Miczek, *Understanding and Preventing Violence: Social influences*, National Academies Press, 1993.
369. L Greenlund, "ED Violence: Occupational Hazard?," *Nursing Management* 42(7) (2011): 28-32.
370. California Department of Industrial Relations, "Cal/OSHA Guidelines for Workplace Security," 1995, http://www.dir.ca.gov/dosh/dosh_publications/worksecurity.html (accessed 3/15/13).
371. University of Iowa, "Workplace Violence: A Report to the Nation," 2001, <http://www.public-health.uiowa.edu/iprc/resources/workplace-violence-report.pdf> (accessed 6/15/13).
372. J Gacki-Smith, et al., "Violence Against Nurses Working in US Emergency Departments," *Journal of Nursing Administration* 39(7/8) (2009): 340.
373. D Ditmer, *Presentation at Violence in Healthcare: Impact on the Nursing Community The 17th International Nursing Research Congress Focusing on Evidence-Based Practice, 19-22 July 2006, 2006*. https://stti.confex.com/stti/congrs06/techprogram/paper_29418.htm (2/20/13).
374. New York State Department of Labor, "Public Employer Violence Prevention Programs," 2009, <http://www.labor.state.ny.us/workerprotection/safetyhealth/workplaceviolence.shtm> (accessed 6/15/13, 12 NYCRR Part 800.6).
375. Design Council and Department of Health, "Reducing Violence and Aggression in Accident and Emergency Departments," 2011, www.designcouncil.org.uk (accessed 3/15/13).
376. Occupational Safety and Health Administration, *Guidelines for Preventing Workplace Violence for Health Care and Social Workers* (Publication No. OSHA 3148-01R). 2004.
377. DJ Drummond, LF Sparr and GH Gordon, "Hospital Violence Reduction Among High-Risk Patients," *The Journal of the American Medical Association* 261(17) (1989): 2531-2534.
378. National Institute for Occupational Safety and Health, "Violence: Occupational Hazards in Hospitals .DHHS (NIOSH) Publication 2002-101," 2002, <http://www.cdc.gov/niosh/docs/2002-101/pdfs/2002-101.pdf> (accessed 2/20/2013, 2013).
379. National Institute for Occupational Safety and Health, "Workplace Violence Prevention Strategies and Research Needs, DHHS (NIOSH) Publication 2006-144," 2006, <http://www.cdc.gov/niosh/docs/2006-144/pdfs/2006-144.pdf> (accessed 5/12/13).
380. SJ Romano, et al., "Workplace Violence Prevention Readiness and Response," *FBI Law Enforcement Bulletin*, 2011.

REFERENCES

381. M Takahashi, et al., "Modifying Effects of Perceived Adaptation to Shift Work on Health, Wellbeing, and Alertness on the Job among Nuclear Power Plant Operators," 2005, http://202.241.32.9/en/indu_hel/pdf/43-1-23.pdf (accessed 3/18/13).
382. E Bouza, et al., "Laboratory-Aquired Clostridium Difficile Polymerase Chain Reaction Ribotype 027: A New Risk for Laboratory Workers?," *Clinical Infectious Diseases* 47(11) (2008): 1493-4, (DOI:10.1086/593109).
383. SD Dorn, "Clostridium Difficile Colitis in a Health Care Worker: Case Report and Review of the Literature," *Digestive Diseases and Sciences* 54(1) (2009): 178-80, (DOI:10.1007/s10620-008-0330-y).
384. SGS Shah and A Farrow, "Trends in the Availability and Usage of Electrophysical Agents in Physiotherapy Practices from 1990 to 2010: A Review. *Physical Therapy Reviews* 17(4) (2012): 207-226.

CONTRIBUTORS' BIOGRAPHIES

CONTRIBUTORS' BIOGRAPHIES

JONATHAN DROPKIN, ScD, PT, CPE, is a Senior Ergonomist at the Hofstra North Shore- LIJ Health System. His research interests include developing ergonomic exposure assessment methodologies and examining the relation among age, occupational exposure, and work-related musculoskeletal disorders. He has published several papers on health care workers, office workers, restaurant workers, and garment workers. He is currently involved in a study assessing mechanical and psychosocial exposures and organizational determinants among emergency medical service workers. Write to him at jdropkin@nshs.edu.

ALICE FREUND, CIH, MSPH, is an Industrial Hygienist at Mount Sinai's Irving J. Selikoff Center for Occupational and Environmental Medicine. She has more than 30 years of experience working on safety, industrial hygiene, and ergonomic issues in a variety of institutions, including five years as environmental health and safety director for a 440-bed acute care hospital and seven years implementing ergonomic campaigns and programs in nursing homes for a healthcare workers' union. In her current work at the clinic, and as a consultant to the Mount Sinai Pediatric Environmental Health Specialty Unit, she conducts site investigations and advises patients and physicians on eliminating and reducing environmental and workplace hazards. She has published articles on industrial hygiene investigations and fact sheets on numerous topics, most recently diesel exhaust and polychlorinated biphenyls (PCBs). Email her at alice.freund@mssm.edu.

THERESA GORMAN, MPH, is a Health and Safety Assistant for the International Association of Fire Fighters (IAFF). She provides assistance for the development of health and safety programs and technical information for the IAFF, which represents more than 300,000 professional fire fighters and emergency medical personnel in the United States and Canada. Her address is tgorman@iaff.org.

JACOB KAMEN, Ph.D., C.H.P., CMLSO, is Senior Director of the Radiation Safety Office and Associate Professor of Radiology at Mount Sinai Medical Center. He completed his doctoral degree in nuclear engineering at Columbia University. He spent several years at Brookhaven National Laboratory where he

CONTRIBUTORS' BIOGRAPHIES

was involved in research projects of neutron activation analysis and boron neutron capture therapy, which could be applied in measuring body composition for AIDS patients and detection of explosives in airport luggage. His post-doctoral fellowship was in radiation oncology. He has more than 20 years of experience in the field of health physics. Recently, Dr. Kamen was elected as chairman of the Executive Council of Greater New York Chapter of Health Physics Society (GHNYCHP) for 2013-2014. He was the president of GNYCHPS in 2004 and 2010. He is a certified health physicist (CHP) and also a certified medical laser safety officer (CMLSO). You can reach him at jacob.kamen@mssm.edu.

THOMAS J. LOWE, RN, MPH, COHN-S, is a Health and Safety Representative at the New York State Nurses Association, which represents 37,000 members. He has more than 22 years of experience in occupational health and safety, which includes working as the director of business health services for an area hospital network and as a director of safety and security for a 350-bed community hospital. He has developed and taught workshops at the state, regional, and national level on a variety of health and safety topics. Mr. Lowe has developed several pamphlets to address safety issues for nurses, was a contributing author on a national educational campaign for vaccine-preventable diseases, and has published journal articles on topics of safety for nurses. Send mail to him at thomas.lowe@nysna.org.

DEBRA MILEK, MD, PhD, MPH, is the Medical Director of the Occupational and Environmental Medicine Clinic and Center of Occupational Health Education at Harborview Medical Center at the University of Washington. Dr. Milek is Board Certified in Occupational Medicine and has been a practicing physician in the field and medical director of hospital based occupational health programs. She has been involved with residency training in Occupational Medicine as part of the NIOSH supported Education and Research Centers for Occupational Safety and Health. She is interested in workplace injury and illness treatment and prevention. Her address is dm42@uw.edu.

SOMASHEKHAR NIMBALKAR, MBBS, MD, CPH, is Professor of Pediatrics and Joint Head of Critical Care at Pramukhswami Medical College in India. He is a pediatrician, who received additional training in neonatology and public health. As Joint Head of Critical Care, he is responsible for administration of critical care services at the center. He is also coordinator of a neonatology fellowship program at the medical college. He is on various committees of his organization, including the human research ethics and hospital infection control committees. Dr. Nimbalkar is involved in training nurses, pediatricians, and postgraduates across India on behalf of professional organizations of pediatricians and neonatologists. He has interest in patient safety and nosocomial infections. He has made several presentations at national and international conferences and published extensively in PubMed-indexed journals. His email address is somu_somu@yahoo.com.

CONTRIBUTORS' BIOGRAPHIES

GEORGE J. PILIGIAN, MD, MPH, is an occupational medicine physician and Assistant Clinical Professor at Mount Sinai School of Medicine. He has more than 20 years of experience treating patients with a variety of work-related medical disorders. His primary interest in occupational musculoskeletal disorders of the upper extremities developed while providing medical care for injured sewing machine operators employed in the sweat shops of New York City's garment district and at the Miller Institute for Performing Artists alongside Dr. Emil Pascarelli, who pioneered the treatment of injuries affecting musicians and computer keyboard operators and identified the critical interaction of bio-mechanical forces and postural weakness. He has published articles on the medical management of occupational disorders of the distal upper extremities, occupational respiratory disorders, and the health of medical professionals. Dr. Piligian also serves as visiting faculty at the College of Health Sciences of the American University of Armenia where he has taught environmental health science. His address is george.piligian@mssm.edu.

JAIME SZEINUK, MD, is an Assistant Professor at the Mount Sinai-Irving J Selikoff Center for Occupational and Environmental Medicine. He is a board-certified physician in occupational medicine and has practiced for some 35 years. He was a former co-director of the Selikoff center. Dr. Szeinuk has a special interest in occupational pulmonary disease and has published several articles in peer-reviewed medical journals on occupational lung disease. Write to him at Jaime.Szeinuk@mssm.edu.

NORMAN ZUCKERMAN, IH, MS, is a Clinical Industrial Hygienist at Mount Sinai's IJ Selikoff Center for Occupational and Environmental Medicine. He has worked as an industrial hygienist since graduating from the Hunter College School of Public Health in 1993 with a master's degree in occupational and environmental health science. From 1993-2002 he worked for the Mount Sinai construction hygiene and ergonomics program as a researcher in lead in construction. During that time, he co-authored *The Guides for Managing Lead and Silica Control Programs in Construction and An Assessment of Lead Controls for Torch Cutting and Rivet Removal on Steel Structures*. Contact him at norman.zuckerman@mssm.edu.