APIC State-of-the-Art Report: The role of infection control during construction in health care facilities

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The Association for Professionals in Infection Control and Epidemiology, Inc (APIC), is a multidisciplinary organization of more than 12,000 health care professionals who practice infection control and epidemiology within a variety of health care settings.

This report reviews issues the infection control professional should consider related to construction and renovation projects in health care facilities. Preventing transmission of infectious agents to vulnerable patient populations, health care workers, and visitors remains an important component of infection control programs. Environmental dispersal of microorganisms during construction, resulting in nosocomial infections, has been described previously, and select examples are provided in Table I as a reminder that there is a solid, scientific basis for these concerns. Environmental airborne contaminants and infectious agents are closely related to water and moisture-related conditions and figure prominently in construction activity. Weems et al have established construction activity as an independent variable for infectious risks in such circumstances. Construction-related outbreak literature will not be revisited in detail; however, pertinent citations will identify resources as appropriate. (AJIC Am J Infect Control 2000;28:156-69)

Section I outlines the broad semiregulatory foundation for direct infection control participation in strategic planning for construction. Section II describes initial steps of planning through policy development, and suggests initial, basic elements for inclusion. Section III examines the infection control implications of the process in detail and is structured on the typical stages of construction. Section IV addresses common questions related to remediation after environmental emergencies or special structural design issues that remain somewhat controversial or unresolved. Recommendations are provided from a variety of reasonable and practical sources not always available as published controlled studies. Section V identifies a number of future research areas that remain important challenges. Terms and abbreviations used frequently throughout the text are highlighted in Table II.

I. CURRENT BASIS OF STRATEGIC PLANNING AND THE ROLE OF INFECTION CONTROL

AIA Guidelines

The current authority for construction design for federal and state health care providers is the 1996–1997 edition of the *Guidelines for Design and Construction of Hospitals and Health Care Facilities*. The American Institute of Architects (AIA) Academy of Architecture for Health publishes this consensus document with concurrence from the US Department of Health and Human Services. Many states adopt the Guidelines in their entirety as minimum standards for design and construction.[19] Prior editions of the Guidelines required construction and renovation assessments during project planning related to specific risks. The new AIA Guidelines strongly support infection control input at the initial stages of planning and design by requiring a new element termed an Infection Control Risk Assessment (ICRA) for broad and long-range involvement of infection control/epidemiology leadership.[19]

The AIA Guidelines state that "Design and planning for such [renovation and new construction] projects shall require consultation from infection control and safety personnel. Early involvement in the conceptual phase helps ascertain the risk for susceptible patient and disruption of essential patient services." Each subsequent section requires an ICRA (eg, numbers and type of isolation rooms) and is predicated upon an "infection control risk assessment" by the infection control committee or a multidisciplinary group designated for that purpose. An ICRA provides for strategic, proactive design to mitigate environmental sources of microbes and for prevention of infection through architectural design (eg, handwashing facilities, separation of patients with communicable diseases), as well as specific needs of the population served by the facility.

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Table 1. Selected events of nosocomial infection associated with the dispersal of microorganisms during construction

Year, author	Organism	Population	Epidemiologic factors
Airborne			
1976 Aisner et al[1]	*Aspergillus* spp	Acute leukemia	Fireproofing insulation
1982 Lentino et al[2]	*Aspergillus* spp	BMT; renal	Road construction; window air conditioners
1985 Krasinski et al[3]	*Rhizopus*; *Aspergillus*	Neonatal	False ceiling
1987 Streifel et al[4]	*Penicillium* spp	BMT	Rotted wood cabinet
1987 Weems et al[5]	*Rhizopus; Mucor* sp;	Hematologic BMT	Construction activity
1990 Fox et al[6]	*Penicillium* sp; *Cladosporium* sp	OR	Ventilation duct fiberglass insulation
1991 Arnow et al[7]	*Aspergillus* sp	Cancer-melanoma	Tiles; humidified cell incubators; air filters
1993 Flynn et al[8]	*Aspergillus terreus*	ICU	ICU renovation; elevators
1994 Gerson et al[9]	*Aspergillus* sp	General	Carpeting
1995 Alvarez et al[10]	*Scedosporium prolificans* (*inflatum*)	Neutropenic hematology	Construction, presumed environmental
1996 Pittet et al[11]	*Aspergillus* sp	COPD	Air filter replacement
Waterborne			
1976 Haley et al[12]	*Legionella* spp	Immunosuppressed	Soil; water
1980 Dondero et al[13]	*Legionella* spp	Adults, employees	Cooling towers
1980 Crane et al[14]	*Pseudomonas paucimobilis*	ICU	Potable water used to fill flush water bottles
1985 Claesson et al[15]	Group A *Streptococcus*	Maternity	Shower head
1993 Sniadeck et al[16]	*Mycobacterium xenopi*	Endoscopy-pseudo	Potable water; scopes
1997 Dearborn et al[17]	*Stachybotrys atra*	Infants	Water-damaged homes
1997 Fridkin et al[18]	*Acremonium kiliense*	Ambulatory surgery	Vent system humidifier

BMT, Bone marrow transplant; *OR,* operating room; *ICU,* intensive care unit; *COPD,* chronic obstructive pulmonary disease.

To carry out an ICRA in the design phase, AIA identifies a multidisciplinary planning group that should involve, at minimum, the health systems' infection control/epidemiology department, the infection control committee (or committee charged with development and review of the infection control policy), and administrators representing special program needs. The planning group's charge is to consider communicable disease prevalence in the community while recognizing the importance of disease variation and distribution across geographic regions and to weigh the availability of public support agencies, as well as to consider the needs of health systems that manage patients with communicable disease, patients who are severely immunosuppressed, or both.

Implementation

The role of infection control is multifaceted and will be required throughout and after completion of the construction project. Infection control staff members provide important leadership and a communication link with program administrators, architects, and engineers. Completion of an ICRA is only the first step; input also is needed in early stages of project design as well as during later blueprint reviews. For example, early coordination with facility management during construction phase identifies necessary support structures required to prevent and control airborne contamination, thus avoiding costly rework or redesign. Newer design challenges include "retrofitting" older buildings into offices and clinics to meet needs for patient examination and instrument cleaning rooms, laboratories, and storage. In the absence of clear-cut rules or regulations, infection control staff members serve to bridge gaps with health agencies and facility administration regarding infection control guidelines and essential design features needed for safe practice. The ICRA sets the scene for involving infection control and supports continuing implementation of infection control principles.[20-33]

II. CONSTRUCTION AND RENOVATION POLICY

A comprehensive construction and renovation policy (CRP) operationalizes the facility's ICRA, ensures management's understanding of the ICRA, and specifies essential participants. A well-designed policy will ensure timely notification of the infection control professional and designated committee(s) for early program planning efforts. In addition, the CRP calls for infection control to evaluate the project from conception through completion and supports a systematic approach for project management. The policy should be submitted for approval by the facility's board of trustees and reviewed/approved periodically.

Elements

Numerous publications have identified a common set of elements to address the planning, designing, and

Table 2. Terms and abbreviations

Term or abbreviation	Description
AIA Guidelines	American Institute of Architects: 1996–1997 Guidelines for Design and Construction of Hospitals and Healthcare Facilities
AII	Airborne infection isolation room (old isolation room)
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating, and Air Conditioning Engineers Inc
BMT	Bone marrow transplant
CFU/m^3	Colony forming units per cubic meter (of air)
CRP	Construction and renovation policy
HEPA–filter	High efficiency particulate air filters (99% of .3 micron size particles)
High efficiency	Filtration at 95% efficiency
HVAC	Heating ventilation air conditioning (air handler or air handling unit)
ICRA	Infection control risk assessment
LDRP	Labor/delivery/recovery/postpartum
PE	Protected environment (old protective isolation room)
PPE	Personal protective equipment
SSI	Surgical site infection
UVGI	Ultraviolet germicidal irradiation
VAP	Ventilator-associated pneumonia

monitoring processes. These topics are grouped and itemized below, though many options for development and effective implementation of each have been described in the literature.[20-34]

- Authority and responsibility for establishing internal and subcontractor coordination of (1) construction preparation and demolition; (2) intraconstruction operations and maintenance; (3) project completion and postconstruction cleanup; and (4) monitoring
- Authority and communication lines to determine if or how patient unit closure will occur
- Planning for air handling and water systems/plumbing as appropriate
- Expectations for contractor accountability in the event of breaches in infection control practices and related written agreements
- Patient area risk assessment; criteria for emergency work interruptions (stop and start processes)
- Education: for whom and by whom
- Occupational health expectations for subcontractors before start, as needed
- Traffic patterns for patients, health care workers, and visitors
- Transport and approval for disposal of waste materials
- Emergency preparedness plans for major utility failures with infection control implications, including location and responsibilities.

Process

The CRP must ensure continuous input from infection control into the structural design process to identify appropriate and timely infection control practices. The CRP should require:

- routine submission of scheduled project lists from facility management to infection control, enabling infection control to be proactively aware of projects and to anticipate infection control needs.
- submission of an "infection control (IC) permit" or "project approval signature block" before the beginning of projects, beyond required project lists.[31] Formats may range from simple checklists to questionnaires designed to assist staff members in assessing risks and identifying prevention strategies.
- submission of an IC permit designed to assess the complexity of the project as a matrix of risk groups (patients and environment).

The score determines needed interventions based on:

- construction activity—project complexity in terms of dust generation and duration of activity.
- patients—assessment of the population at risk and location in terms of invasive procedures.

The matrix grid format immediately leads to identifying:

- number and types of necessary controls and IC interventions.
- signatures of all parties, thus providing accountability for the mutually agreed upon plan.[31]

III. INFECTION CONTROL IMPLICATIONS FOR CONSTRUCTION AND RENOVATION

Planning—design and preconstruction

IC participation is critical in the initial planning and approval meetings during the design phase. Issues frequently addressed include budget, space constraints including storage and equipment cleaning areas, air-handling units, handwashing facilities, appropriate finishes, specific products with infectious implications, and applicable regulations. Infection control professionals (ICPs) should be prepared to support their position and recommendations with published citations whenever feasible, especially when a recommendation is not budget neutral.[20,21,26,33–35] ICPs frequently work with consultants during the planning phase, including architectural and construction companies in a "partnering" process. Consulting an environmental expert might also be necessary if the size and complexity of construction provides considerable risk to highly susceptible patients because of location, prolonged time of construction, work conducted over continuous shifts, and likelihood of air handlers sustaining frequent interruptions. These variables increase risks to patients and personnel and may require monitoring. If appropriate, budgets for environmental consultants and anticipated testing or environmental monitoring needs to be considered at the earliest stage of planning.

Design and structure. IC should ensure that major design components are addressed as appropriate and justified by relevant guidelines, standards, codes, and regulations.[19,24,36–48] Guidance for many elements is described in the resources already referenced; asterisked items below are requirements for new construction addressed in the 1996–1997 AIA Guidelines.[19] Major design components that need to be addressed include:

- Design to support IC practice.*
- Design, number, and type of isolation rooms (ie, airborne infection isolation [AII] or protective environment [PE]).* (AIA Guidelines outline the design characteristics for AII, including no requirement for anterooms, nor support for "reversible" ventilation [ie, rooms "switched" from negative to positive air pressure]; the AIA appendix provides suggestions for PE design.[19-21] These designs are deliberately consistent with Centers for Disease Control and Prevention guidelines regarding tuberculosis and pneumonia.[38,39])
- Heating, ventilation, and air conditioning systems (HVAC), including recommended ventilation and filtration charts.*
- Mechanical systems involving water supply and plumbing.*
- Number, type, and placement of handwashing fixtures,* clinical sinks,* dispensers for handwashing soap,* paper towels, and lotion.
- Sharps disposal unit placement.
- Accommodation for personal protection equipment.*
- Surfaces: ceiling tiles, walls, counters, floor covering, and furnishings.*
- Utility rooms: soiled, clean, instrument processing, holding, workrooms.*
- Storage of movable and modular equipment.

Preparation for demolition and construction. The project teams provide ongoing planning and monitoring during area preparation and throughout the demolition, construction, cleanup, preparation for return to service, and final project review.[19,21,26,34,42,43] Before construction begins, the focus of preparations should be on isolation of the construction/renovation area. Some sources categorize projects in terms of minor or major risk based on the level of needed barriers; checklists are developed accordingly.[26,28–34,49–51]

Type and extent of construction. Project complexity varies with time, numbers of workers, whether contractors work continuous shifts, scope and degree of activity (high or low dust generation), and proximity to patients with varying degrees of risk for infection. Internal renovations may require as much consideration as external construction. Patient areas or units that cannot be closed or that are adjacent to a major renovation require special planning, (eg, operating room additions adjacent to an active surgical suite). These situations may justify environmental monitoring beyond visual inspection to detect increased airborne contamination and to plan interventions.[5,21,25,28–30,39,51–54]

External excavation is ideally conducted during off-hours so that air handlers can be shut down and sealed; the goal is to protect the intake as much as possible. Small projects require similar planning and vary by degree, but preparation still requires early communication with facility management. Specific educational needs (eg, Occupational Safety and Health Administration [OSHA]) regulations and health issues for patients and workers need to be addressed. A summary of common issues is provided below within 3 major categories of tasks; items will vary by facility, but the final customized list should be appended to the CRP.[5,21,22,26,33,43,49,51]

Dust and debris control.

- Medical waste containers (sharps or other medical regulated waste): These should be removed by the facility before start of the project.
- Barrier systems: The area should be isolated, as the project requires. Small, short duration projects generating minimal dust may use fire-rated plastic sheeting, but should be sealed at full ceiling height with at least 2-foot overlapping flaps for access to entry. Any project that produces moderate to high levels of dust requires rigid, dust-proof, and fire-rated barrier walls (eg, drywall) with caulked seams for a tight seal. Large, dusty projects need an entry vestibule for clothing changes and tool storage. The entry area should have gasketed doorframes; tight seals should be maintained at the full perimeter of walls and wall penetrations. An inter-

im plastic dust barrier may be required to protect the area while the rigid impervious barrier is being constructed. Cleaning is required at completion of the barrier construction; plans should also describe a terminal barrier removal process that minimizes dust dispersal.[33,34,43]

- Traffic control: Designated entry and exit procedures must be defined. Egress paths should be free of debris; designated elevators should be used during scheduled times; and only authorized personnel should be allowed to enter the construction zone. Signage should direct pedestrian traffic away from the construction area and materials.[5,21,26,34]
- Demolition: Debris should be removed in carts with tightly fitted covers, using designated traffic routes. Efforts should be made to minimize use of elevators with transport during the lowest period of activity. Debris should be removed daily and at times specified by agreements. If chutes are used to direct debris outside, HEPA-filtered negative air machines should be used, and the chute opening should be sealed when not in use. Filters should be bagged and sealed before being transported out of the construction area.[5,21,22,33]
- Exterior windows: Windows should be sealed to minimize infiltration from excavation debris.
- Visual monitoring: Compliance with barrier maintenance includes education of staff for simple clues (eg, accumulation of visible dust evidenced by footprints, opened doors/windows evidenced by presence of insects and flies, wet ceiling tiles, etc).[21,26,55]

Ventilation and environmental control.

- Air system flow: It should be determined whether the construction area uses fresh/outside or recirculated air; filters should be added or return vents covered as needed with filter material or plastic. Air must flow from clean to dirty areas.[19,20,21,33,34,43]
- Negative air pressure: The air within the construction area must be negative with respect to surrounding areas and with no disruption of air systems of adjacent areas. Constant negative pressure within the zone should be monitored with an alarmed device, which must be maintained and monitored by construction personnel. Exhaust from construction air should be directed outside with no recirculation if possible. If the exhaust must tie into a recirculated air system, a pre-filter and high efficiency filter (95%) should be used before exhaust to prevent contamination of the ducts. Fans should be turned off before opening ductwork and necessary interruptions (eg, fire drills) should be planned for to minimize risk.[20–22,33,34,43,51]
- Adjacent areas: The status of sealed penetrations and intact ceilings should be verified.
- Air exchange rates and pressure relationships: It should be verified that the facility can:
  - maintain proper rates in critical areas near construction activity.
  - ensure air is not being recirculated without filtration from the construction area elsewhere.
  - provide accountability for and frequency of testing air pressure throughout the project.[20–22,26,33]
- Vibration or disturbances: Drilling and other sources of vibration have potential to dislodge dust collected above suspended or false ceilings; vibrations loosen corrosion within water pipes as well. Plans should require vacuuming of affected areas and flushing debris from water systems before reoccupancy.[5,21,50,55,56]
- Specification of temperature and humidity ranges: Determine limits as appropriate.[20–22,35]
- Monitoring must consider risks of malfunction or complete loss of utilities. Both visual cues and particulate air monitoring may be used. The type and frequency of monitoring, evaluation of results, and follow-up action by designated parties are essential to planning.[20,21,26,33,57]

Contamination of patient rooms, supplies, equipment, and related areas.

- Worksite garb: Contractor personnel clothing should be free of loose soil and debris before leaving the construction area. If protective apparel is not worn, a HEPA-filtered vacuum should be used to remove dust from clothing before leaving the barricade. Personal protective equipment (eg, face shields, gloves, respirators) are worn as appropriate. Contractors entering invasive procedure areas should be provided with disposable jump suits and head and shoe coverings. Protective clothing should be removed before exiting the work area. Tools and equipment should be damp wiped before entry and exit from the work areas.[20–22,26,33]
- Barriers around construction should be monitored to maintain protection of in-use patient care areas as described. Patient doors adjacent to construction area should be kept closed, with appropriate traffic control.[20–22,26]
- Storage should be designated for construction materials.[22,33,43]
- Contractor cleaning: The construction zone should be maintained in a clean manner by contractors and swept or HEPA-vacuumed daily or more frequently as needed to minimize dust. Adjacent areas should be damp mopped daily or more frequently as needed. Walk-off mats may minimize tracking of heavy dirt and dust from construction areas.[21,26,33,43]

- Facility cleaning: Contracts should clearly specify responsibilities and expectations for routine and terminal cleaning before opening the newly renovated or construction zone.[21,22,25,51]

Intraconstruction and the role of IC. Once renovation or construction has begun, the ICP should be available to provide maintenance and operational input. Frequency of input or meetings will depend on the scope of the project. Specific concerns need to be customized in each project and include IC practices, education, and monitoring. The ICP is vital in educating and supporting "users/owners" to manage their area under construction (eg, educating staff members on how to monitor their own performance as much as possible). In more complex projects, the ICP may assist directly or make provisions for items already outlined. A number of areas involving specific ICP involvement are discussed below.

Environmental rounds. An efficient method to integrate key IC and life safety issues is the use of rounds, using simple checklists based on the items addressed above. ICPs can advise or participate in rounds, which should be scheduled as often as necessary and include a variety of observable "indicators" such as barriers (doors, signage), air handling (windows closed), project area (debris, cleaning), traffic control, and dress code. It may be necessary on occasion to schedule rounds after normal hours or on weekends if that is when construction or renovation is scheduled.[20–22,26,33,34,43,49,51]

Outcome or process measures. Projects may be approached as performance improvement initiatives using outcome measures (eg, surgical site infection rates) or process measures (measuring compliance) using visual observations, airborne particulate monitors, satisfaction surveys, etc.[51–54]

Impact on special areas. Patients requiring AII need close monitoring to ensure negative pressure relationships are maintained, particularly when there is potential for disruption of pressure relationships.[20,21,58–61] Intake areas such as emergency departments need planning to triage potentially infectious patients.[19,45,62] If highly susceptible patients cannot be relocated, indicators should be identified to trigger planned intervention.[5,21,25,26–29,33,52–54] Immunosuppressed populations in bone marrow transplantation units or protected environments, intensive care units, etc, require special planning. The goal is to minimize patient exposure to major construction activity; therefore, nonemergency admissions should be avoided during periods of major excavation. If delaying admissions is not an option, patients should be located in areas as remote as possible from construction activity.[20,21,26]

Patient location and transport. Health care providers should plan patient care activities to minimize exposure to construction sites.[20–21] At least one study found that critically ill, ventilator-dependent patients transported from the ICU for diagnostic or therapeutic procedures was an independent risk factor for development of ventilator-associated pneumonia.[63] To decrease exposure for patients during construction activities the following should be considered:

- Provide treatment in the patient's room.
- Transport via an alternate route.
- Schedule transport or procedures during periods with minimal construction activity.
- Minimize waiting and procedure times near construction zones.
- Mask patient or provide other barriers (eg, covering open wounds) based on patient's clinical status.

Interruption of utility services. Utility services may be interrupted during any type of construction. Infectious agents may contaminate air-handling units, medical vacuum, and water systems after planned or unplanned power disruptions. IC provides input into emergency preparedness to reduce the potential risks of contamination.[20–22,42,57] Response plans should include assessment of the population at risk and cleanup should focus on steps to prevent, detect, and reduce risk from infectious hazards. For example, as power is reestablished after an interruption, dampers and fans of air handling units resume operation. Dust and particulate matter released during this process may transmit allergenic or infectious agents such as *Aspergillus* sp to patients and staff.[3,5,20–22,26,33,50,64] Therefore, IC policies for areas in which invasive procedures are performed should require sufficient time to clear the air of potential contaminants before resuming the room(s) use. Ventilation time should be based on the number of air changes per hour required by the area. The National Institute for Occupational Safety and Health (NIOSH) chart for removal efficiency of airborne contaminants may provide guidance, but its use should be tempered by its assumptions.[39] In the event of major contamination of patient care areas, plans should specify responsibilities for these decisions as well as for intensified cleaning, environmental surveillance of airborne infectious agents, and restriction of water use until testing or flushing determines safe usage.

Worker risk assessment and education. Health risk evaluations for potential exposures depend on the type of construction planned. Facility staff overseeing or working with outside contractors should assist in determining potential environmental risks for facility workers or contractors. Policies should include provisions for training and by whom (facility or contractor). Training must be appropriate to the task (eg, staff entering air systems for preventive maintenance [changing filters] should be alerted to the potential for airborne dust containing spores of microorganisms and arrange to first turn off fans and don a mask). Staff members working in sanitary or septic sewage systems, drainage pipes, etc, should be alerted to the risks of moisture and fungal contamination.[20–22,57,65–67] Agreements should be developed appropriate to the project regarding provisions for pertinent health protection, vaccinations, tuberculosis assessment/PPD skin testing, or related education before workers begin construction. Requirements will vary with degree of environmental risk and proximity to patient population.

Documentation of health/training issues. As agreements are completed, they should provide evidence that workers have received appropriate health protection as noted above and should include the following information:

- Facility exposure control plan(s) for IC, hazardous chemicals, and life safety.
- How to seek help and report exposures (eg, first aid location and initial steps to report exposures).
- Use of particulate respirators or other PPE.
- Risk prevention for unexpected safety issues, such as noxious fumes, asbestos, etc.[22,66,67]

The facility should be satisfied that provisions have been made for effective IC education designed to address facility-specific needs related to potential infectious risk exposures as described above.[45–48]

Postconstruction and cleanup

Project checklists. Check-off lists of expected practices identified at the beginning of the project should be reviewed for items agreed upon before the area is returned to full service or patient occupancy. A useful tool during review is the contractor's "punchlist" that will ensure missed details have been addressed (eg, installations of soap dispensers or designated types of handwashing/sink controls).[33,34]

Postconstruction agreements. Cleanup agreements (eg, cleaning, air balancing, filter changes, flushing of water systems, etc) and other utility service checks/cleaning must be established in the early planning phase as discussed in Section II. These include at minimum[33,34]:

- Contractor cleaning to include area clearance, cleaning, and decontamination/wipedown.
- Cleaning after removal of partitions around construction area, minimizing dust production.
- Facility-based routine/terminal cleaning before returning area to service.
- Provision of time frames for facility review (eg, 2 weeks) after completion of the project to ensure all issues were addressed properly.[33,34]
- Systematic review of outcomes in the facility's designated review process, whether by contract or committee structure. Items may range from sealed cabling/electrical penetrations and ceiling tile replacements to the completed punchlist.
- Cleaning and replacement of filters and other equipment if affected by major or minor disruptions or conditions that could have contaminated the air or water supply.[4,23,33,68,69]

Steps before occupancy: Checklists specific to the project should be developed for a walk-through just before occupancy. Core IC issues for inclusion are listed below as applicable. The designated team should do the following:

- Check that sinks are properly located and functioning.
- Verify that sinks in critical patient care areas have properly functioning fixtures.
- Check for the presence/absence of aerators in these fixtures according to facility policy.
- Test whether soap and towel dispensers are filled and functioning.
- Check whether surfaces in procedure/service areas are appropriate for use (eg, smooth, nonporous, water-resistant).
- Verify that air balancing has been completed according to specifications.
- Test whether air flows into negative pressure rooms or out of positive pressure rooms.

Monitoring activities during construction[20,23]

There are currently no recommendations for routine environmental culturing during construction. Enhanced targeted patient surveillance (eg, respiratory illnesses consistent with aspergillosis or legionellosis) near construction areas should be part of the ICRA. Other control measures previously discussed need to be continuously monitored.

However, when an outbreak associated with construction is suspected or identified, water or air sampling may be indicated. It is vitally important to establish a hypothesis with clear and measurable goals. Culturing or sampling procedures should be defined before initiation (eg, asbestos, fungal, or particulates). Sampling procedures relative to the suspected agent(s) and sources should be used. The investigator must be cognizant of the many pitfalls associated with the interpretation of environmental data. Therefore, as part of the investigation planning, it is important to establish parameters for interpreting collected data.*

IV. ENVIRONMENTAL EMERGENCIES AND REMEDIATION

Environmental emergencies may occur during construction disruptions; when they occur, timely IC con-

*References 5, 6, 23, 25, 27–29, 38, 41, 45, 51–53, 56, 59, 70-75 sultation is critical. Practical applications of IC principles, generalized from experience in related industries, are offered here within stated limitations. In addition, other structural design issues which lack support if AIA Guidelines or scientific studies will be addressed.

Contamination of ventilation in surgical suites or other invasive areas

Sealing and air intakes. If nearby drilling or excavation occur during surgical activity, it is critical to check for tight room sealing to reduce the potential for air and water leakage. Because operating rooms usually have separate air handlers, the air intakes should be located to determine need for additional protection or sealing during periods of highest construction activity.[20–22,35,51,52]

Operating room ventilation and tuberculosis. AIA guidelines recommend bronchoscopy procedures be performed in treatment rooms meeting AII room ventilation requirements or in a space that exhausts directly to the outside. Optimum methods for managing patients with active tuberculosis requiring urgent surgical intervention have not yet been determined. However, the number of operating room air changes provides increased dilution of potential contaminants. NIOSH ventilation charts are included in the Centers for Disease Control and Prevention 1994 Guidelines and may assist in calculating percentages of particles removed by time and ventilation rates; this offers some guidance for the time needed to air a room, but the underlying assumptions need study as noted earlier.[39] Modifying the pressure relationships of the room to neutral or negative risks overall pressure imbalances, has not been studied for effectiveness, and is not recommended by the AIA.[19]

Air handlers, ducts, and filters. If air handlers are replaced, old ducts must be replaced or cleaned, and the issue should be treated as fundamental to the projected budget. Contaminated ducts have been implicated in outbreaks (eg, the operating room outbreak caused by *Penicillium* reported by Fox et al.[6] The American Society of Heating, Refrigerating, and Air Conditioning Engineers Inc is including language in HVAC system surface standards to prevent future duct lining problems.[40] Experiences vary, but it is important to clean ducts filled with debris observed during inspections, especially on the return air ducts. Hermann and Streifel recommend semiannual inspections of air-handling units for filter integrity.[75] However, definitive evidence specifying frequency of preventive cleaning is lacking.

Water contamination

Water contamination risks and prevention strategies are addressed in multiple sources.[20–23,57,65,76-77] IC should focus on maintaining a dynamic water flow that meets local standards. Water pressure "shock" may send a surge of debris when pressure loss is restored after a rupture.[78] Massive amounts of loosened scale may be released when domestic valves are returned to service after being off during construction or disruptions. If decontamination is necessary, systematic flushing of the water system assists in removing debris shaken loose by drilling or disruptions.

- *Legionella* sp: If testing is warranted because of high-risk populations and suspicion of *Legionella* sp exposure in the facility, major intervention methods should include chlorinating, hot water flushing, or copper-silver ionization treatment.[69,79-82] The last appears to have advantages over prior methods because of penetration of biofilms and reduced pipe corrosion; concerns for heavy metal (silver ions) accumulation remain and warrant additional study.[73,83]
- Fungus: Water seepage and damage are difficult to manage in an occupied building.[69] Reports of moisture/water sources leading to airborne spread of infectious agent(s) have been cited.[17,18,84] Several suggestions for detection and treatment are offered.[4,33,68] Prevention of fungal growth takes on increased importance after any type of flooding or utility failure related to water. Brace and Streifel have both published useful case studies and similar information is available from on-line sources.[33,34] Suggested cleanup protocols after water exposure are summarized here, but the basic approach is one of identifying moisture, followed by cleaning and thorough drying of surfaces.

General remediation procedure after water contamination. A systematized approach to prevent fungal growth in buildings caused by floods, roof leaks, sewage backup, steam leaks, and groundwater infiltration includes the following steps, modified according to the extent of damage sustained[33,34]:

- Inventory of water-damaged areas of the building, materials, and furnishings, paying particular attention to carpeting under cabinets and furnishings.
- Use of moisture meters (electronic wet test meter) to identify extent of water damage to drywall.
- Environmental sampling to monitor stages of cleanup and remediation.
- Removal of materials within 24-48 hours of water damage.
- Decontamination by spraying with chlorine-based mist or diluted bleach, followed by drying.
- Ventilation balancing to reduce supply air volume to effect a negative air pressure area, sealing off area with tape, and checking airflow with a smoke stick. Mobile HEPA machines may assist in provid-

ing the needed negative air balance in areas being remediated.
- Wall areas to be treated are identified and opened (eg, strip off vinyl covering) for drying.
- Decontamination of opened wall area is accomplished with 1:9 dilution of copper-8-quinolinolate compound, using a pressurized spray pump.[33,52]
- Remove surface soil with a detergent (eg, diluted tri-sodium phosphate), followed by use of a liquid disinfectant (eg, diluted bleach).
- Ceilings are vacuumed with a HEPA filtered vacuum cleaner. Walls and ceiling are closed and covered with standard wall finishing materials when the area is completely dry. Brace reported filling the spaces with aerosol foam; Streifel did not.[33,34]

Surfaces: design or disruption/damage issues

Design. Ideally, surfaces are designed to include cleanability; problems can be avoided if surfaces near plumbing fixtures are smooth, nonporous, and water-resistant.[19,85] Operating and delivery rooms, isolation and sterile processing areas also need smooth finishes, free of fissures or open joints and crevices that retain or permit passage of dirt particles. After disruptions, care should be taken to note penetrations (ducts, pipes), with attention to proper replacement, including tight seals.[19–23]

Flooding accidents. Cleaning and decontamination are required for major leaks occurring from the outside, such as broken pipes containing potable water or sprinkler water systems with added chemicals (ethylene glycol). Specific suggestions are itemized below for ceilings, walls, floors, and carpeting.

Ceiling tiles/porous materials. Water leaks or floods that wet acoustical ceiling tiles or fireproofing and filter materials may produce reservoirs of fungal spores.[1,32,34,52]

- If major water damage has occurred and porous tiles were not removed within 24-48 hours, tiles should be discarded/replaced.
- If tiles are nonporous, or if moisture is a result of small steam leaks, tiles can be cleaned with dilute bleach and air dried before replacement.[33]

Walls. When replacement options exist, the ICP should consider that smooth paint surfaces are easier for cleaning.[19,85] (The potential for antimicrobial effects present in copper paints has been published.[86] However, concerns for unknown efficacy and potential long-term toxicity have yet to be characterized and validated before efficacy can be established.[87]) Vinyl wall coverings risk moisture problems from condensation and have potential for fungal growth on the substrate. Wall cleaning under different conditions is based on the protocol described earlier:

- Water damage addressed in less than 24 hours: Vinyl-covered drywall laths/plaster/plasterboard should be stripped and examined. Portions of drywall may need to be removed to determine the extent of damage with a moisture meter. In some cases, especially if minor water damage was sustained, only minimal cleaning may be required.
- Water damage not addressed within 24–48 hours: If major flooding has occurred and material has not been removed within 24–28 hours, there is increasing probability that damage has already led to microbial growth, and more extensive effort may be required.
- Removal should be done under controlled conditions (area sealed off and removal done under negative air pressure).
- Water-soaked areas should be removed approximately 12 in above water mark and discarded, while allowing opened areas to dry.
- Hard surfaces are cleaned with diluted bleach solution without rinsing.
- Area may be sprayed from top to bottom with a dilution of copper-8-quinolinolate compound.[33,34,52]
- Wall is sealed and finished with standard materials after installing new 12 in wall piece.[33,34]

Floors. Desirable features include surfaces easily cleaned and wear-resistant according to usage. For example, if the floor is subject to frequent wet-cleaning methods, it should not be physically affected by germicidal disinfectants. Floor surfaces subject to traffic when wet (eg, kitchens) should have nonslip surfaces and be resistant to food acids (to avoid discoloration), and the perimeters should be tightly sealed.[20,21,85] After water disruptions, the perimeter should be closely examined for signs of long-standing moisture and possible fungus contamination.

Carpeting. Esthetic considerations related to stains and odor control support recommendations to avoid carpeting in areas of frequent spillage or heavy contamination; however, carpets have not generally been associated with nosocomial infection.[88–90] Carpets require regular vacuuming, shampooing, or extraction depending on use, material, and degree of soiling; cleaning should follow manufacturers' directions for proper cleaning materials, dilution (due to potential for discoloration), and frequency of cleaning techniques.[55,88] Contamination of carpeting after saturation with water or during demolition has been reported as a reservoir for nosocomial fungal infection.[9,91]

- Major damage from flooding: Carpeting and padding exposed to sewage should be discarded and the area disinfected with diluted bleach. If it is wet from steam or water leaks for greater than 24-48 hours, it is potentially already contaminated with fungi and may need to be discarded. If it is wet from steam or potable water leaks, but for *less than 24–48 hours,* protocols require cleaning and disinfection principles similar to those described earlier:

- Remove furniture, extract with water, shampoo with diluted surfactant/detergent.
- Soak with diluted bleach solution (1:10); rinse and extract with clean water to remove bleach; commercial steam cleaning is an alternative to bleach.
- Dry within 12–24 hours of treatment using floor or exhaust fans to aid in drying.[33]

Furnishings, fixtures, and equipment

Furniture. Modular furniture not easily moved should be installed on raised platforms or suspended in some manner to achieve a minimum 6-in to 12-in clearance from the floor to pull out for cleaning or to clean underneath. Attention must be paid to storage units with electrical or computer connections.[85]

Upholstered furniture should be treated the same as carpeting (including disposal) in the event of major soaking and contamination as a result of floods, leaks, or sewage. If it is affected by only steam moisture, it can be dried. Hardwood with intact laminate can be cleaned and disinfected with dilute bleach. If laminated furniture that has exposed particle board beneath the surface or other furniture composed of pressed wood or chip board becomes soaked, it should be discarded.[33]

Handwashing facilities/sinks. This section merits consideration primarily for design and cleaning issues; but plumbing disruptions or lack of preventive maintenance pose risks of contamination as well.

- Number and design: AIA Guidelines for new construction recommend the minimum number of handwashing facilities for patient rooms as one in the toilet room; they recommend handwashing facilities in the patient room only when the toilet room serves more than 2 beds.[19] Having a sink in a patient/resident room and in the toilet room (whether private or shared) supports essential IC practices. Whereas there is support for the ideal, IC plays a critical role in recommending proper placement of handwash facilities, and in both rooms.[85] In addition, IC support for a sink standard of minimum dimensions may prevent installation of small "cup" sinks that challenge proper handwashing.[85] AIA guidelines describe permissible types of controls for handwashing facilities in various areas.[19,21]
- Placement: Improper placement can add to the environmental reservoir of contaminants. Sinks need to be convenient and accessible, but nearby surfaces should also be nonporous to resist fungal growth.[33,85] One source recommends a minimum distance of 15 ft from all inpatient beds/bassinets and 25 ft from outpatient chairs, stretcher, and treatment areas to ensure access.[85] Handwashing facilities should also be situated to avoid splashing (suggesting at least 36 in from patients or clean supplies), or equipped with a splash guard to avoid splash contamination.[85]
- Cabinets: Areas beneath sinks should not be considered storage areas due to proximity to sanitary sewer connections and risk of leaks or water damage. Clean or sterile patient items should be not be placed beneath sanitary sewer pipe connections or stored with soiled items; cleaning materials are the only items acceptable to be stored under sinks, from a regulatory aspect.[85] Facilities may develop design standards excluding storage space beneath sinks, thus preventing misuse and need for cleaning. As noted earlier, cabinet construction materials need to be nonporous to resist fungal growth.
- Aerators: Aerated sink faucets located near patients, particularly in intensive care units, may be a risk because of their ability to enhance growth of waterborne microorganisms. The faucet aerator has been identified as a reservoir and possible source of infection within the hospital. Rutala notes that the most convincing evidence for the role of faucet aerators is provided by Fierer et al (1967). In this study, premature infants became infected with *Pseudomonas aeruginosa* from delivery room resuscitation equipment contaminated by a faucet aerator.[87] Rutala concludes that the degree of importance of aerators as reservoirs for nosocomial pathogens remains unknown. Because *Legionella* sp grow well in the sediment formed in aerators, Freije recommends aerator removal.[50] Proper sink design and dimensions can reduce splashing and risks of general contamination, while eliminating concerns for aerators completely.

Flush sinks/hoppers. Clinical sinks are frequently located in soiled utility rooms for disposal of body fluids and liquids but warrant similar considerations for moisture and contamination.[92] Splash guards are valuable but inclusion may depend on sink usage and design. If staff members are not routinely required to use face protectors, a splash guard should be required.

Whirlpool or spa-like (Jacuzzi) bathing facilities. Various types of bathing facilities are now available for mothers in birthing rooms; recommendations for cleaning have been compared with hydrotherapy tanks and equipment cleaning procedures.[93] However, plumbing for Jacuzzi tubs or similar spa-like tubs have longer piping with higher siphons, resulting in risks for trapped contaminated water after apparent draining;

the trapped water may be flushed into the tub with its next use. Communication with state regulators, cleaning and disinfecting the tub and jets with specific spa-cleaning products, and proper draining and flushing sequences are essential when considering installation.[92–95]

Eyewash stations. OSHA directs proper use and placement of eyewash stations with distance determined by the pH of the involved chemicals. Source water in stationary eyewash stations may stand unused in the incoming pipes at room temperature for long periods, providing a reservoir for potential pathogens.[87] After a report of Acanthamoeba in eyewash stations, OSHA issued a bulletin recommending cleaning and disinfection methods.[96] The schedule follows the American National Standards Institute Z358-1981 recommendations for flushing the system 3 minutes each week.[44]

Placement of sharps containers. Location of disposal containers should consider ease of visibility to avoid overfilling and should be within easy horizontal reach of the user. Systems should have secure locking and enable easy replacement. When containers are fixed to a wall, the vertical height should allow the worker to view the opening or access the container. NIOSH recommendations suggest ergonomic considerations for installation heights or creative approaches for specialty areas.[97] Sufficient temporary storage space for filled containers must be in design planning.[47,92]

V. RESEARCH NEEDS

The role of IC continues to expand and interacts closely with safety and occupational health functions. Studies from indoor air quality research have an increasing impact on current practice. Industrial experiences continue to be evaluated for health care facility application. Some items identified throughout the text but not yet resolved are summarized below and offered for consideration:

- Surgical suite contamination: Many issues remain unanswered and require further study including the effectiveness of laminar air flow, ultraviolet germicidal irradiation, and the approach to managing *Mycobacterium tuberculosis* or other airborne pathogens in the operating room. Designs of future operating rooms to control all sources of environmental contamination are being studied in current IAQ building research.[98]
- Surgical suite air handling systems: Certification and recertification requirements for operating room air handling systems remain unresolved. Frequency of testing HEPA filters, systems, and air pressure balancing for operating rooms has not been determined or recommended.
- Ambulatory care sites: There is a need to identify optimal engineering controls for current ambulatory care surgery settings to improve outcomes; there is also need for further delineation of the role of mobile HEPA units, UVGI, etc, in clinics and nontraditional care settings, especially for highly susceptible, ambulatory patients.
- Fans: Concerns have been raised regarding use of fans in patient care areas. No studies or regulations have directly addressed this issue in terms of infection risk(s).
- Aerators: The degree of risk associated with aerator installation has not yet been determined and may be resolved by examining other methods of water purification or sink design.
- Plumbing and preventive maintenance systems: Better methods to reduce or eliminate *Legionella* sp. contamination in potable water systems continue to be sought. In the setting of continued low-level contamination, determination of the doseresponse relationship from potable water exposures resulting in disease remains elusive. This remains key to preventive water system treatments, as well for clearer indications for environmental surveillance cultures.
- Role and methods of air monitoring: A number of major issues need clarification including (1) determination of electronic versus other sampling methodologies, and (2) need for standards and guidelines for sampling designs according to circumstances and related methodologies (eg, total particulate versus bioparticulates). The development of standards for certain patient care areas needs correlation to disease outcomes.
- Efficacy of remediation protocols: Controlled studies on the efficacy and safety of current or newer antifungal treatments after severe water damage are needed. Clearer determinations regarding the safety of damaged drywall left in place, versus its removal, needs further elaboration. Other studies are needed to determine the efficacy and safety of other types of materials for remediation.
- Ventilation and pressure relationships: Whereas the need for negative air pressure is clear, new studies are needed to determine the ideal room pressure differential related to actual infectious agent transmission and risk for developing actual disease. This is an area beginning to be addressed.[99]

In conclusion, the role of IC/epidemiology in construction and renovation remains a challenging and exciting one and is the ultimate demonstration of its multidisciplinary nature. Interaction and integration of efforts with other disciplines enables disease prevention for patients and health care workers to remain the focus and driving force during construction/renovation processes.

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