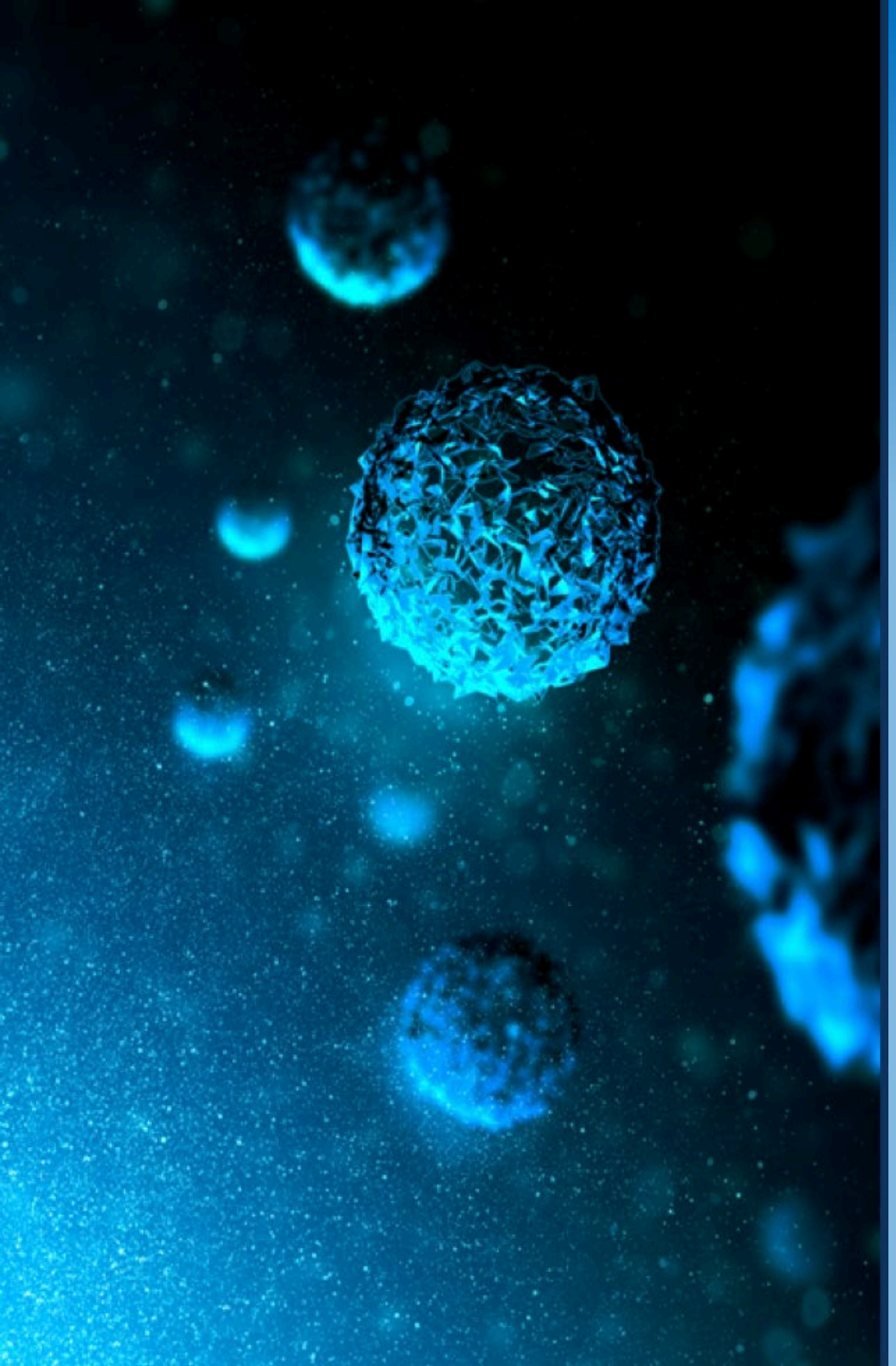


Resilience is in the Air
A Risk-based Approach to Air Quality Management

Kathy Warye

Principal, Infection Prevention Partners

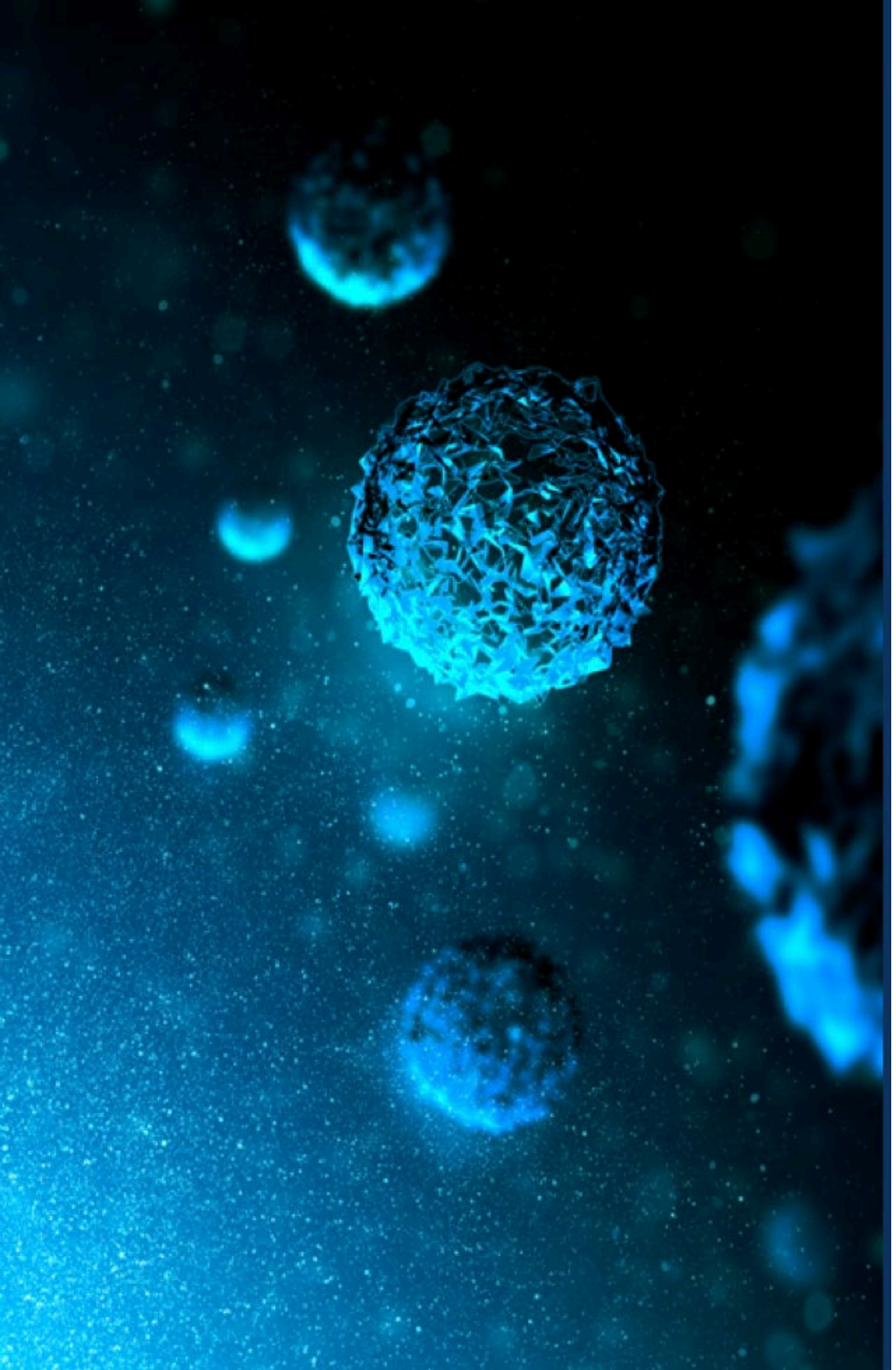
Learning Objectives

1. Describe the correlation between airborne contamination and transmission of organisms of concern.

2. Review the current approach to air quality management in healthcare facilities.

3. Compare risk of exposure by department or service.

4. Outline the components an air quality management program.

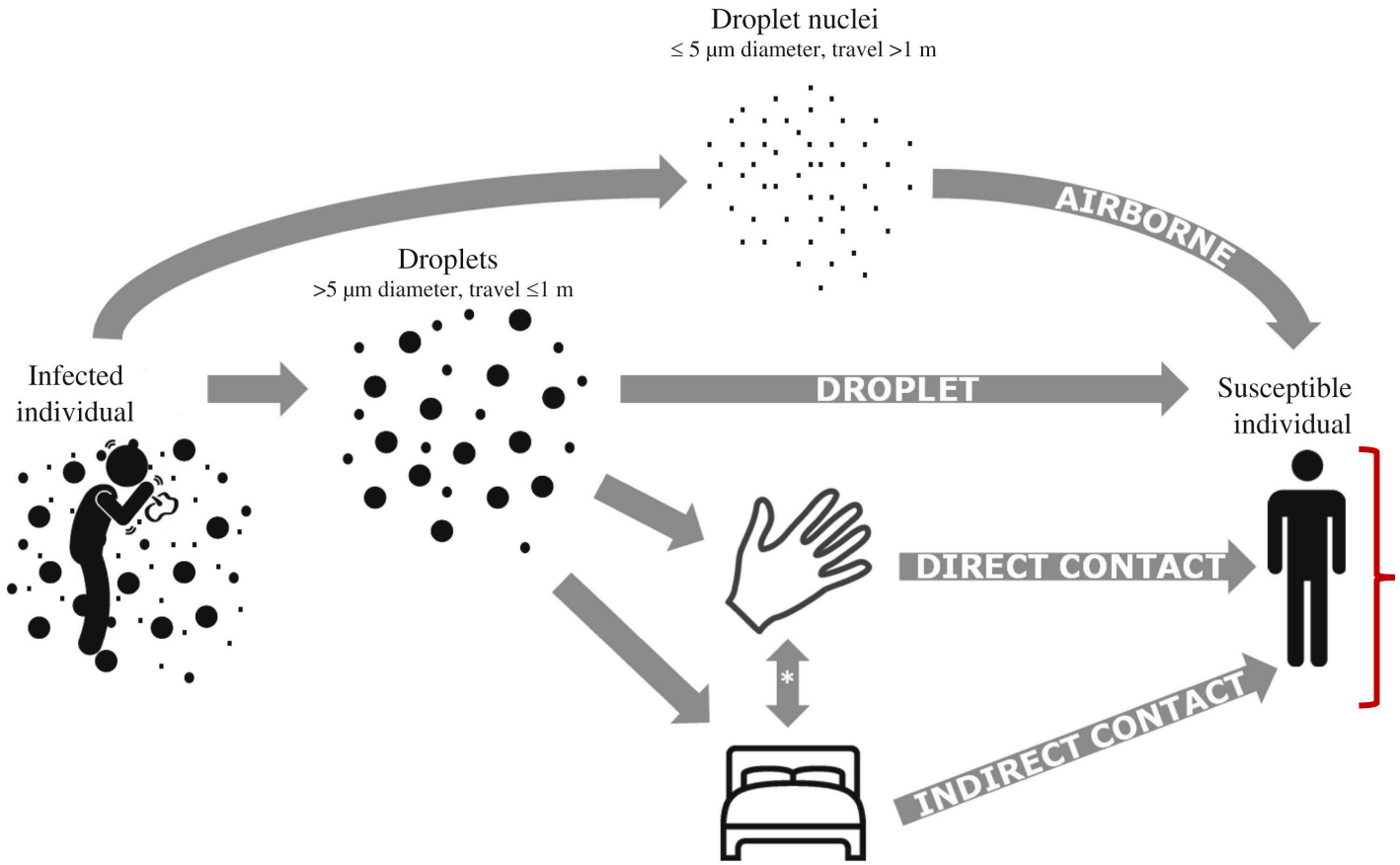


Routes of Transmission

Healthcare-Associated Infections
and
Antimicrobial Resistance

Behavior of Airborne Pathogens: Routes of Transmission

Transmission routes: droplet, airborne, direct contact, and indirect contact.



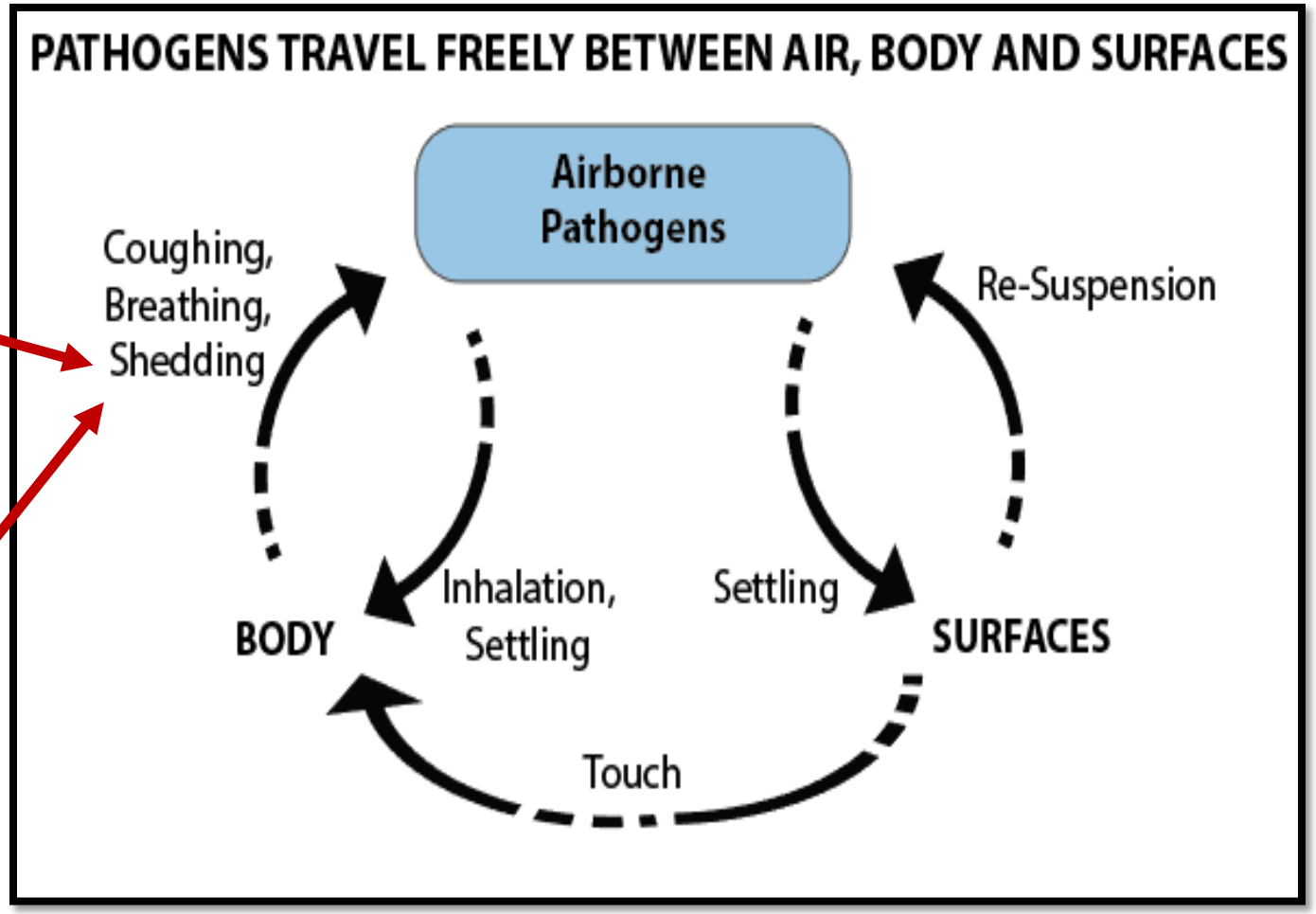
* Transmission routes involving a combination of hand & surface = indirect contact.

Particles carrying infectious microorganisms do not exclusively disperse by airborne or droplet transmission, but by both methods simultaneously.[1]

Aerosolized micro-droplets of certain pathogens can stay aloft for hours.[2]

1.Gralton J, Tovey E, McLaws ML, Rawlinson WD. The role of particle size in aerosolised pathogen transmission: a review. *Journal of Infection*. 2011;62(1):1–13.
2.Otter JA, et al. Transmission of SARS and MERS coronaviruses and influenza virus in healthcare settings: The possible role of dry surface contamination. *J Hosp Infect*. 2016;92(3):235-250.

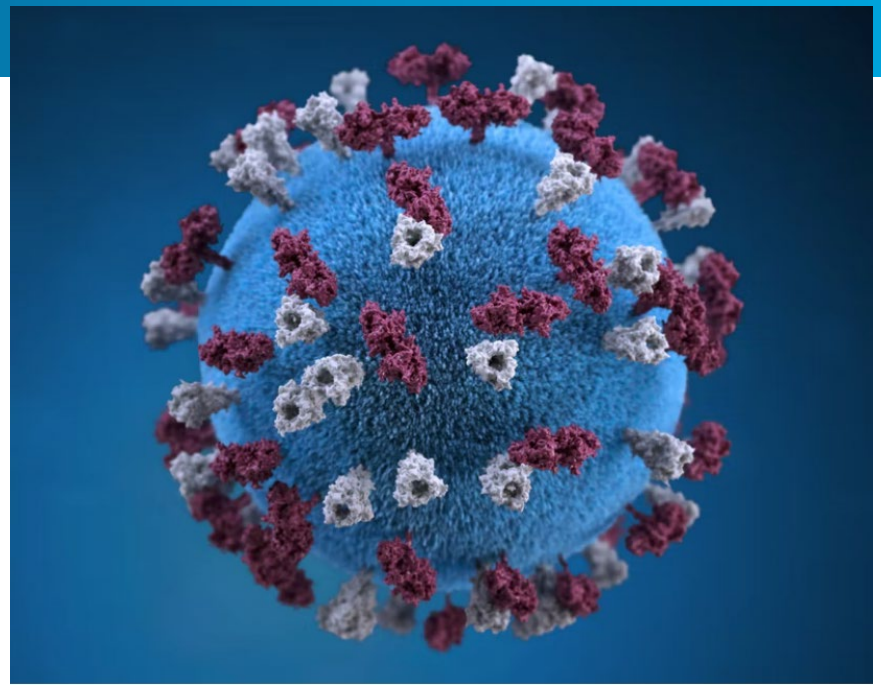
Behavior of Airborne Pathogens



- We *shed* about 10 million particles per day, and approximately 5–10% of these particles carry bacteria.
- Continual redistribution of microbes at the air, body, surface nexus.[1]
- Bacterial and fungal counts in air showed a significantly positive correlation with bacterial surface contamination.[2]

1. Ijaz, M. Khalid, et al. "Generic aspects of the airborne spread of human pathogens indoors and emerging air decontamination technologies." *American Journal of Infection Control* 44.9 (2016): S109-S120.
2.Luksamijarulkul P, Pipitsangjan S. Microbial air quality and bacterial surface contamination in ambulances during patient services. Oman Med J. 2015 Mar;30(2):104-10.

Airborne contamination: An *underappreciated* source of Healthcare-Associated Infection (HAI)



Peer-reviewed sources suggest, **10-16% of HAIs result directly** from airborne pathogen transmission and **up to 30% have airborne contribution**.

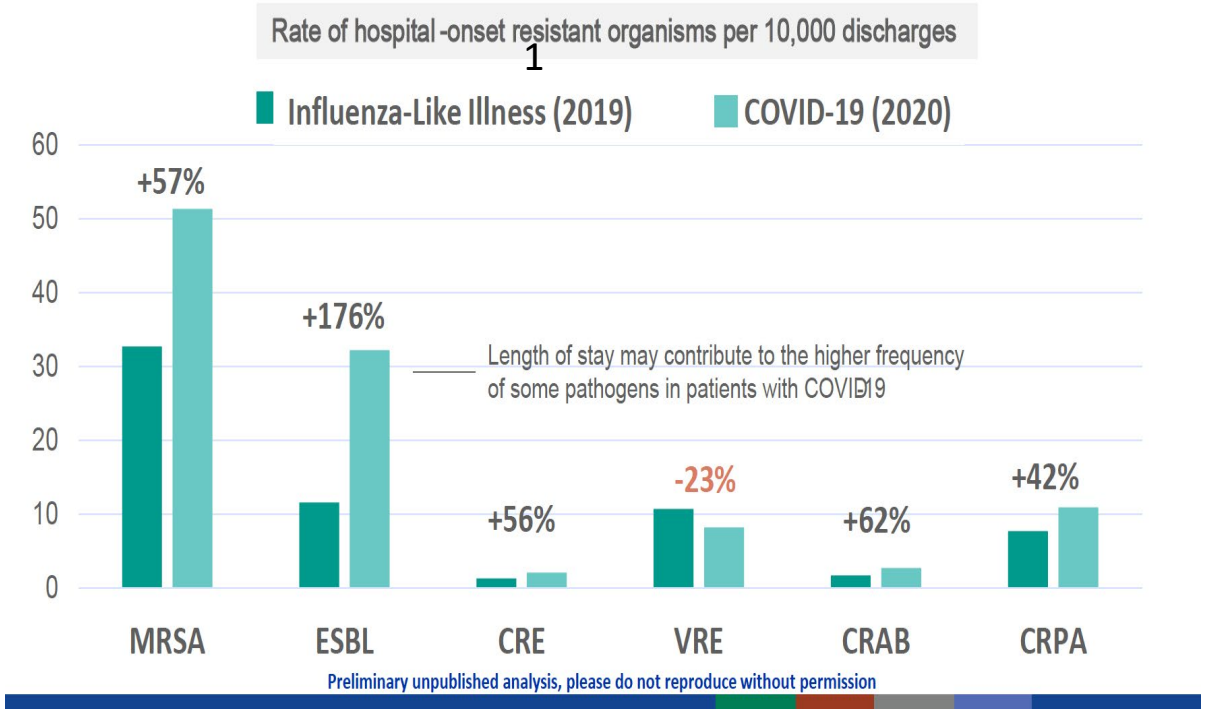
- Over 60 years of evidence supporting contribution of airborne microbial contamination to **Surgical Site Infection** (SSI). Kundsin: Airborne transmission accounts for 20%–24% of post operative wound infections.[1]
- Brachman: Airborne transmission responsible for 10%–20% of all *endemic* Hospital-Acquired Infections[2]
- Kowalski estimates approximately one-third of all HAIs involve airborne transmission at some point between the origin and the susceptible host[3].

1. R. B. Kundsin, "Documentation of airborne infection during surgery," Annals New York Academy of Sciences, vol. 353, pp. 255–261, 1980 1.
2. Brachman PS, "Hospital-acquired infection—airborne or not?" in Proceedings of the Int. Conf. on Hospital-Acquired Infections. 1971. Am Hospital Assn, Chicago, Ill, USA.
3. Kowalski W, Air-Treatment Systems for Controlling Hospital Acquired Infections, HPAC Engineering, Jan 2007

Antimicrobial Resistance

- Resistance: A random change in DNA allows bacteria to survive in the presence of the antibiotic, resistant bacteria outgrow nonresistant bacteria.
    - Some bacteria can transfer resistance genes to other bacteria.
- A growing number of bacteria are resistant to most, some to *all* antibiotics (Multi-Drug or Pan-drug Resistant Organisms)
- Healthcare environment contributes to selective pressure on antibiotics and emergence of resistant organisms.

Antibiotic-Resistant Pathogens in Hospitalized Patients: Hospital-onset [1]



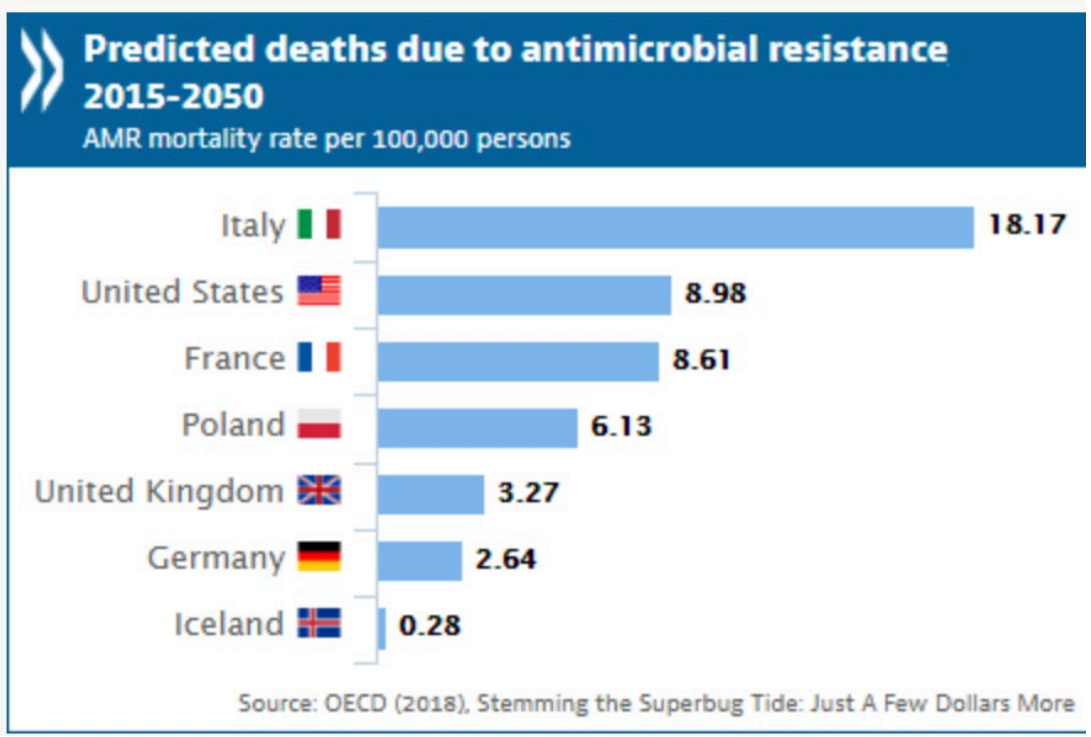
COVID-19 was the "*perfect storm*" for growth in prevalence of resistant organisms.

1-Srinivasan A. (2020) 'The Intersection of Antibiotic Resistance (AR), Antibiotic Use (AU), and COVID-19for the Presidential Advisory Council on Combating Antibiotic-Resistant Bacteria' (presentation). Presidential Advisory Council on Combatting Antibiotic Resistant Bacteria (PCARB) Sept 9, 2020 https://www.hhs.gov/sites/default/files/srinivasan-covid-and-amr-overview.pdf . Accessed 11/17/20

Airborne transmission of MDROs

Airborne transmission of Multi-Drug Resistant Organisms (MDROs) is underappreciated. A *small* sample of studies:

- MRSA counts remain elevated up to 15 minutes after bed making [1]
- *"In this study, it was confirmed that MRSA could be acquired by medical staff and patients through airborne transmission."* [2]
- Microbiological surveillance study: Infected patients could spread significant amounts of A. *baumannii* to ICU air, strains could survive in air for week, likely infect new patients after some months.[3]



US spent $1,120B in 2020 on surface disinfectants, but comparatively little on the air which contaminates everything.

1-Shiomori T, et a;. Evaluation of bedmaking-related airborne and surface methicillin-resistant Staphylococcus aureus contamination. J Hosp Infect. 2002 Jan;50(1)

2-Shiomori T, et al. Significance of Airborne Transmission of Methicillin-Resistant Staphylococcus aureus in an Otolaryngology Head and Neck Surgery Unit. Arch *Otolaryngol Head Neck Surg.* 2001;127:644-648

3-Yakupogullari Y, et al. Is airborne transmission of Acinetobacter baumannii possible: A prospective molecular epidemiologic study in a tertiary care hospital. Am J Infect Control. 2016 Dec 1;44(12):1595-1599.

A. *baumannii* colonization via airborne route

Study in 53 ICU rooms, 1500-bed teaching hospital, Munoz-Price, et al, found:

- A clear association between air colonization with *A. baumannii* in the room and colonization status of the patient. Because the air ducts in the room were not colonized (with one exception), it is highly likely that patients were the sources of the Carbapenem resistant strains found in the air.

- 52% of the patient rooms, colonized with A. *baumannii,* contained Carbapenem resistant strains of the organism.

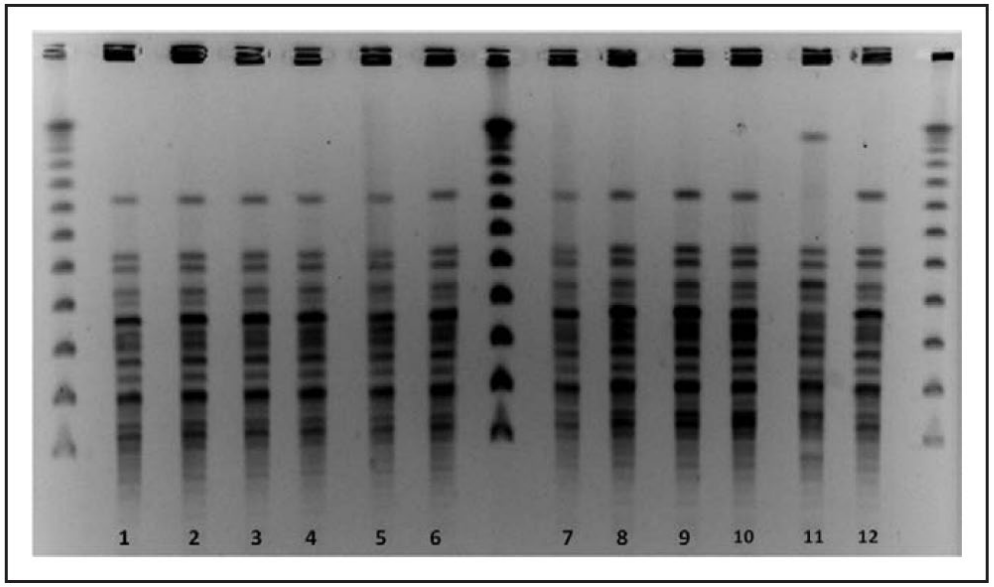


Figure 3. Pulse field gel electrophoresis on air and clinical isolates. (1–9) Environmental *Acinetobacter baumannii* isolates; all from air samples except for line 3 that corresponds to the isolate obtained after swabbing an intake air duct. (10–12) Carbapenem-resistant *A. baumannii* clinical isolates from patients present in the unit on the day air cultures were performed. Isolates 7, 8, and 9 corresponded to the air of the patients with clinical isolates 10, 11, and 12, respectively.

Munoz-Price LS, et al, Aerosolization of A. baumannii in a trauma ICU. Crit Care Med. 2013:41(8):1915-8.

Current approach to environmental decontamination is sub-optimal

In a commentary in *Critical Care Medicine* on the Munoz-Price study, the authors wrote:

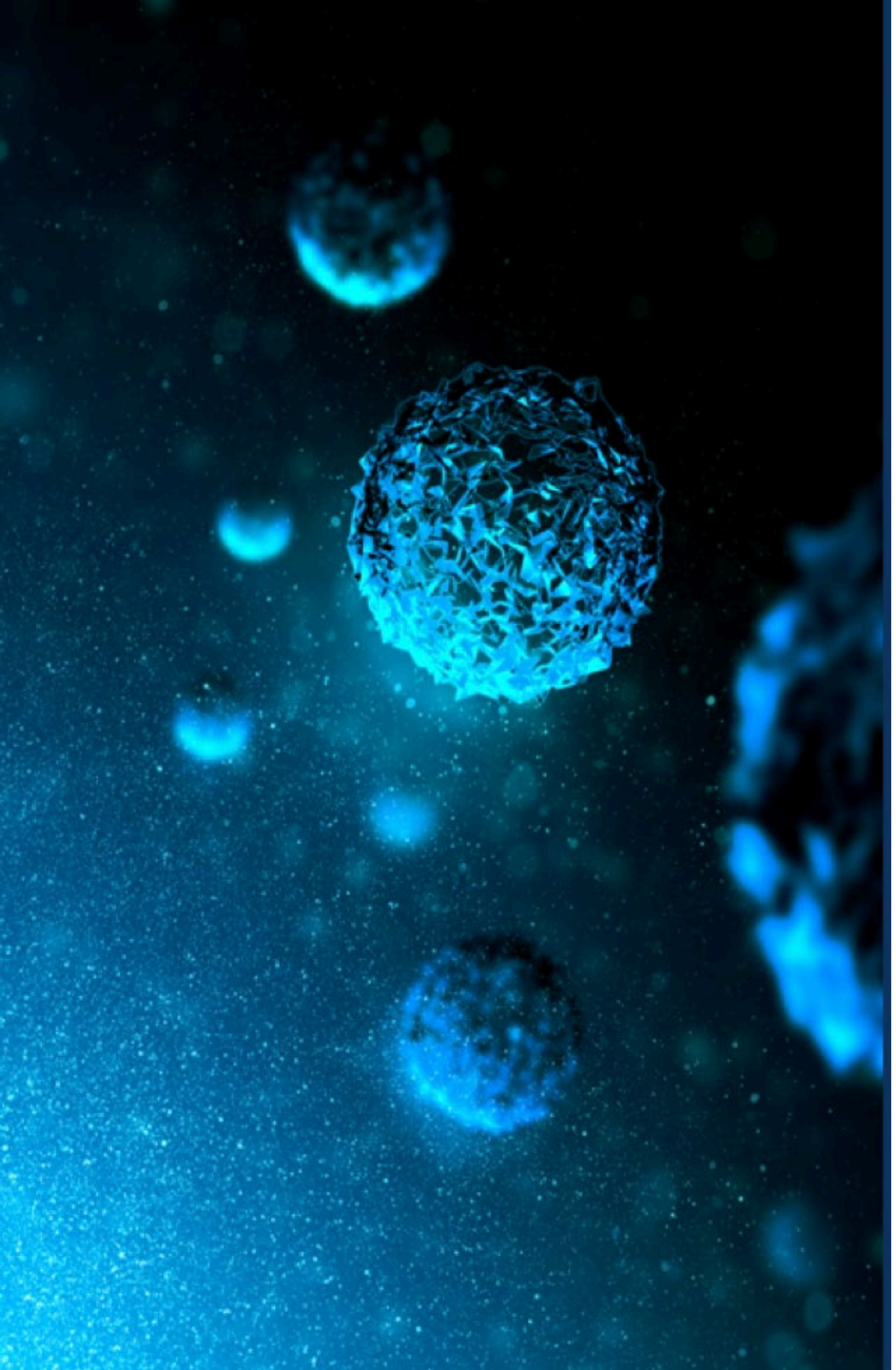
"These findings are **alarming** and suggest that environmental decontamination focusing on surfaces will not fully prevent *A. baumannii* transmission…it seems likely that *A. baumannii* in the air above and around patients has the potential to contribute to infection transmission in several ways:

1) *by re-contaminating surfaces in a room after environmental services have disinfected surfaces, but not the air in the room;*

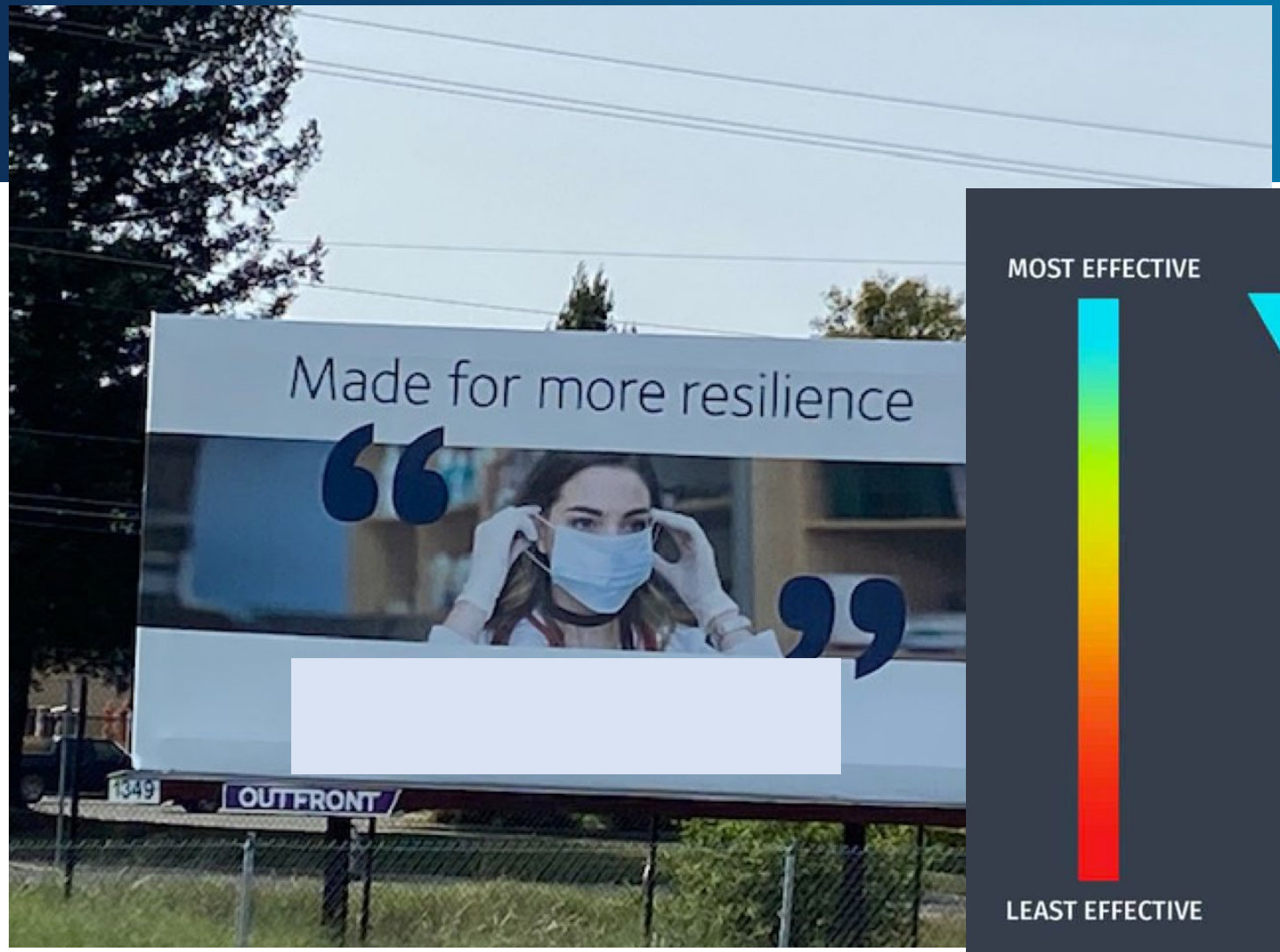
2) by spreading organisms from one colonization site on a patient to multiple sites on the same patient, as airborne bacteria settle out of the air;

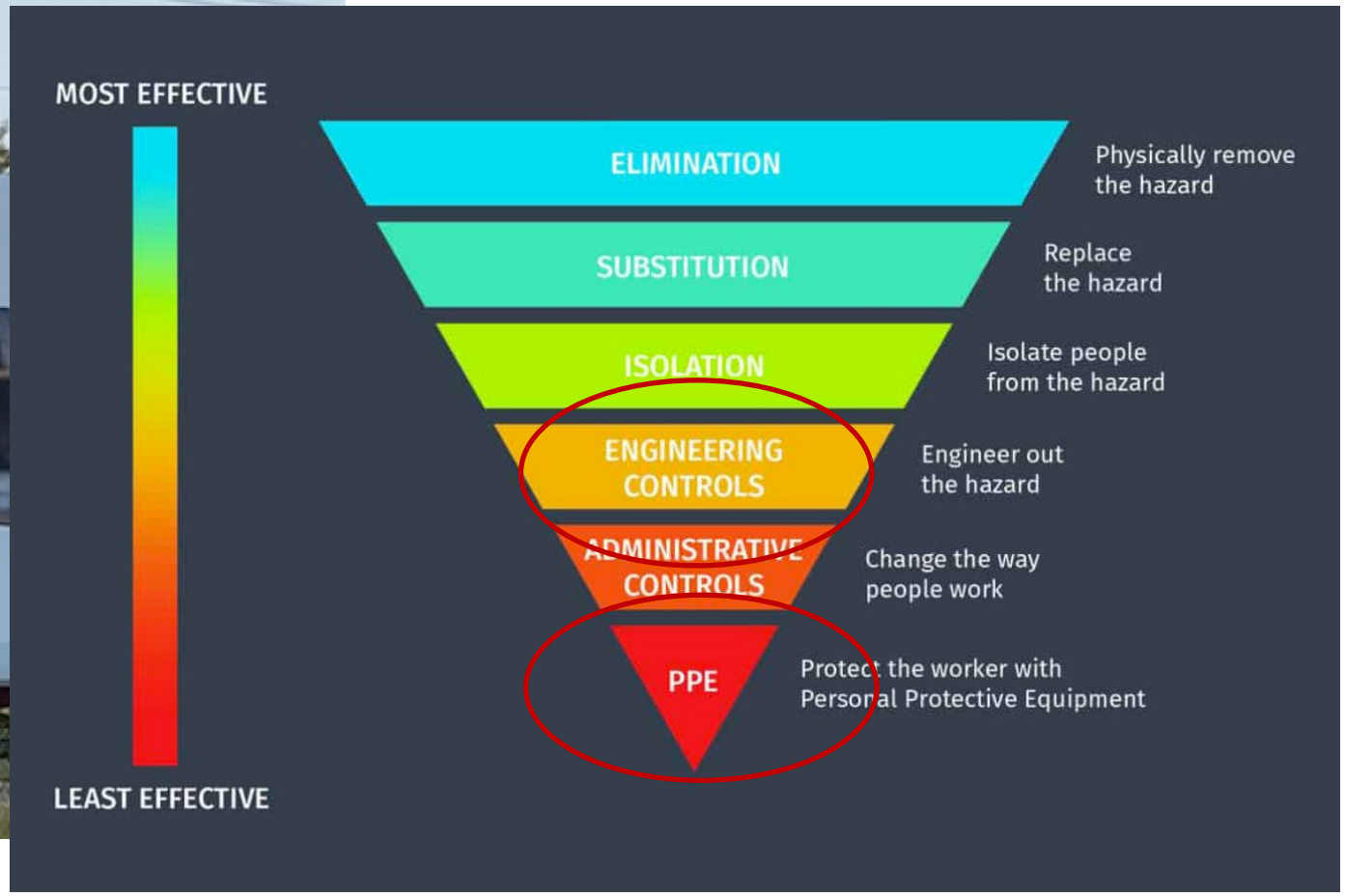
3) airborne contamination of healthcare providers' clothes and hands, even if adequate hand hygiene is done before patient contact.

Spelling B, Bonomo RA, Airborne Assault: A New Dimension in *Acinetobacter baumannii* Transmission. Crit Care Med. 2013:41(8)10.1097



Ventilation:
The First Line of Defense





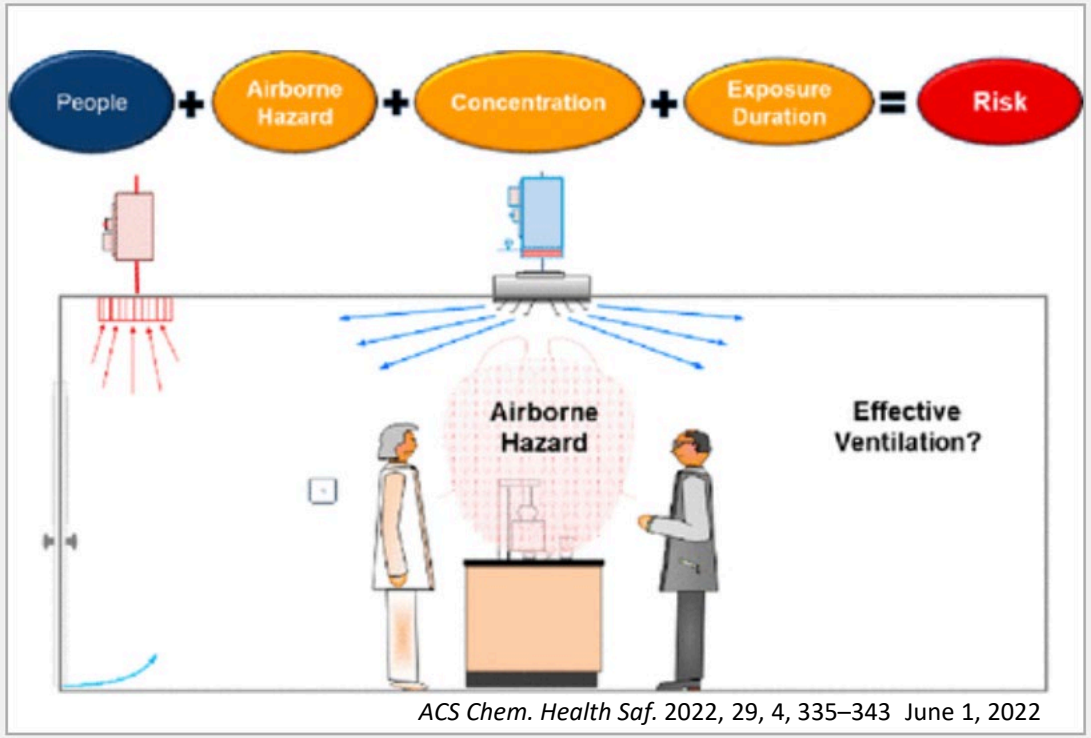
NIOSH *Prevention through Design:* Control risks at the source, as early as possible in the lifecycle of design, redesign or retrofit.

NIOSH Hierarchy of Controls. https://www.cdc.gov/niosh/topics/hierarchy/default.html.

Role of ventilation in control of airborne transmission

Role of ventilation in airborne transmission of infectious agents in the built environment - a multidisciplinary systematic review 2007:

There is **strong and sufficient evidence** to demonstrate the association between ventilation, air movement, control of airflow direction and transmission/spread of infectious diseases to support use of negatively pressurized **isolation rooms**, in addition to the **use of other engineering control methods**.

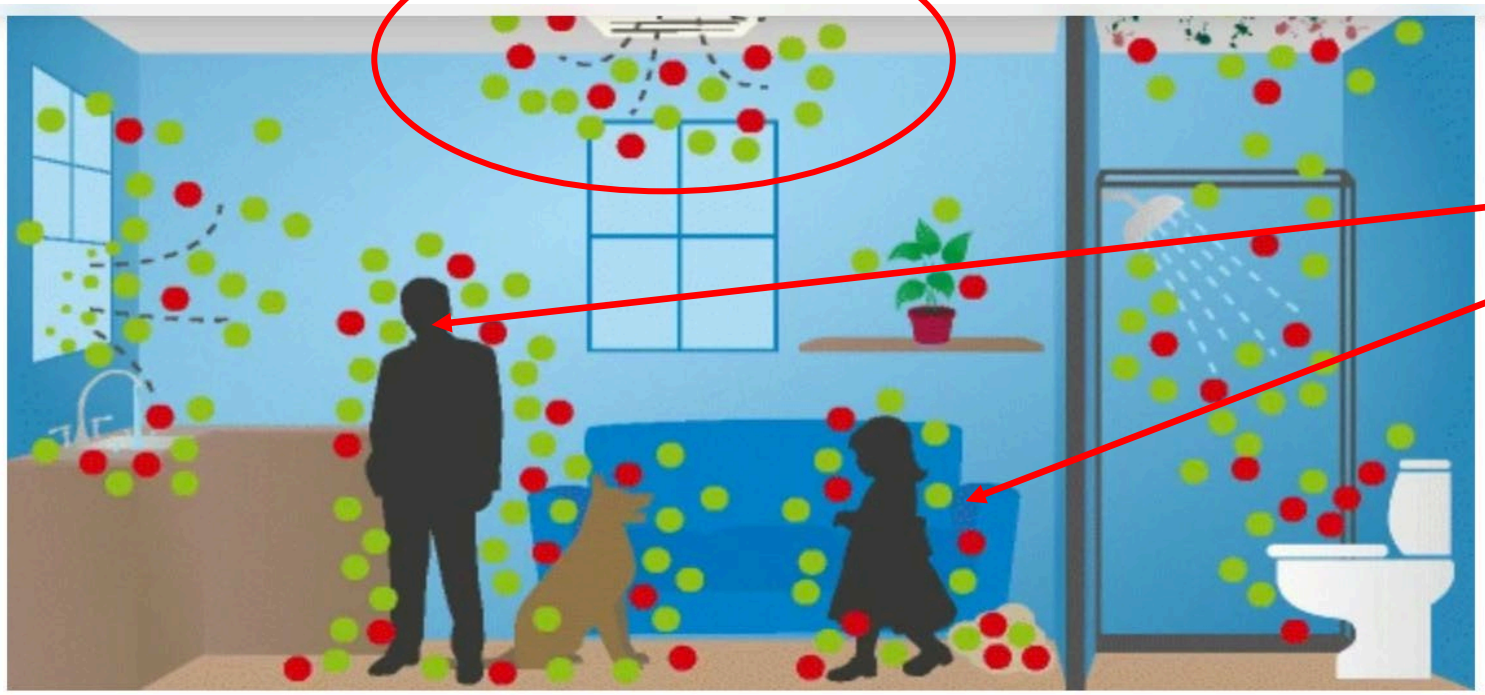


ACS Chem. Health Saf. 2022, 29, 4, 335–343 June 1, 2022

However, the lack of sufficient data on the specification and quantification of the **minimum ventilation requirements** in hospitals, suggest existence of a knowledge gap.

Li Y, et al. Role of ventilation in airborne transmission of infectious agents in the built environment - a multidisciplinary systematic review. Indoor Air. 2007 Feb;17(1):2-18.

What about HEPA/MERV Filtration?



Sources of microbial bioaerosols in the built environment may include humans; pets; plants; plumbing systems; heating, ventilation, and air-conditioning systems; mold; resuspension of settled dust; and outdoor air. The *green* and *red dots* represent microorganisms that may be beneficial or detrimental to human health, respectively. Artwork by Tim Skiles

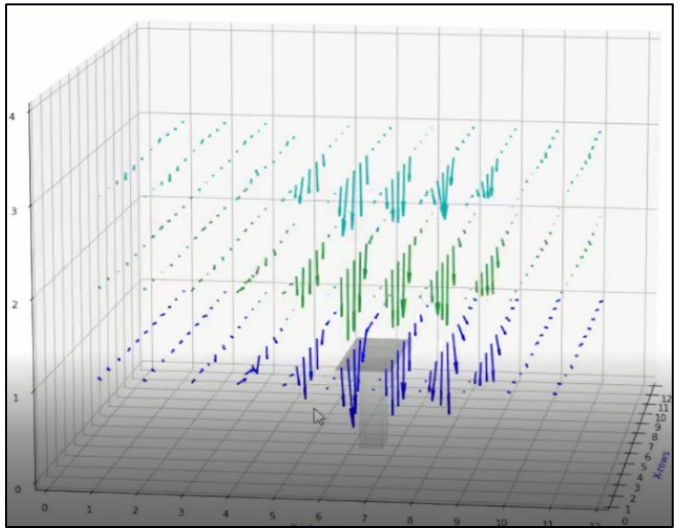
The primary source of bacteria:

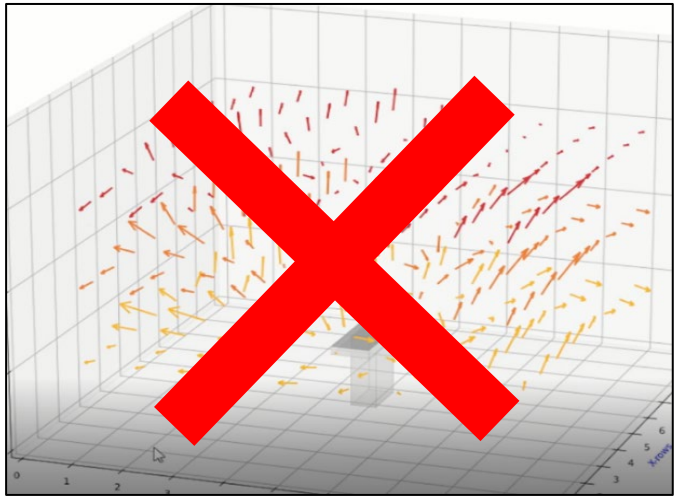
Humans disperse over 10M skin squames per day, over 1M contain bacteria.

Prussin, A.J., Marr, L.C. Sources of airborne microorganisms in the built environment. *Microbiome* **3**, 78 (2015).

Characteristics that minimize the presence of airborne bioburden in a space

- Positive pressure: Avoids flow of air from contaminated areas into adjacent areas (AIIR, OR)
- Direction: Consistent, perpendicular, downward flow (unidirectional) sweeps air down to exhaust vents
- Velocity: Air must be driven at speed that ensures
    1) uni-directionality
    2) high enough to overcome, obstacles and heat convection from staff
    3) minimize turbulence
- Temperature & Humidity: Can also influence transmission





Even when operating within parameters, no indication of performance, actual airborne bioburden (CFUs).

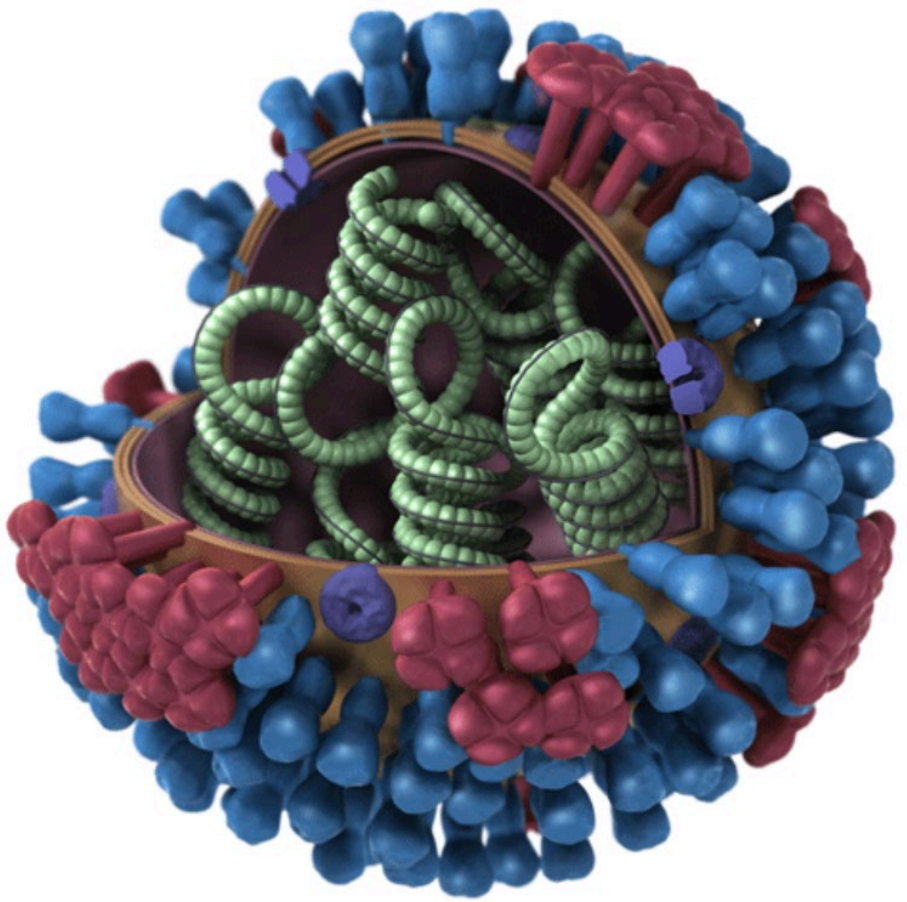
Standards/guidelines for management of airborne contamination
Minimum requirements - date to the 1960s

FGI & ASHRAE 170	CDC
• Air pressure relationships (positive/negative pressure based on risk and patient population (AIIR, OR) • Air Exchange Rate (ACH) • Filtration • Temperature • Humidity	• Relationship to adjacent area (positive/negative pressure – AIIR/OR) • Minimum ACH based on area (6-20 ACH) • Exhausted or recirculated • Relative humidity

US standards are **silent** on what constitutes a ”safe” level of airborne contamination. Prescribe the **controls, without identifying the goal**.

Is more frequent ACH the answer?

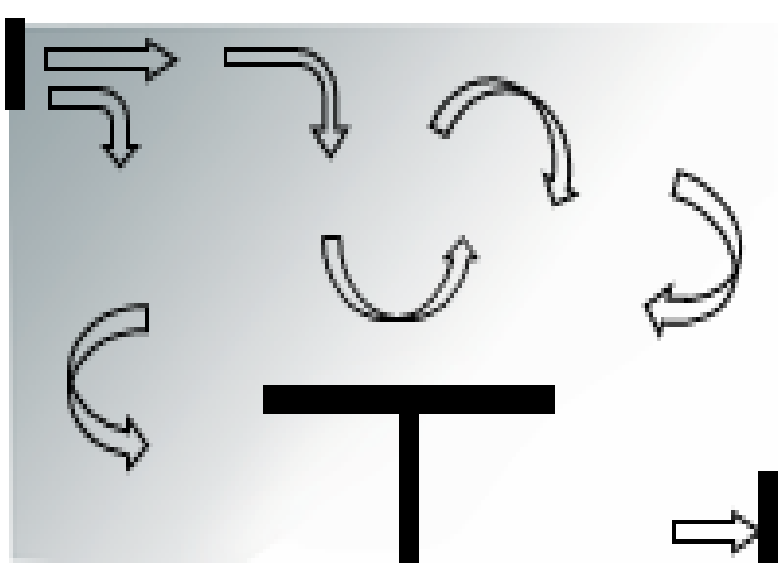
"While the concentration of airborne infectious particles falls with increased air changes per hour, even very frequent air changing…….does not radically reduce the airborne infectious particle count ."



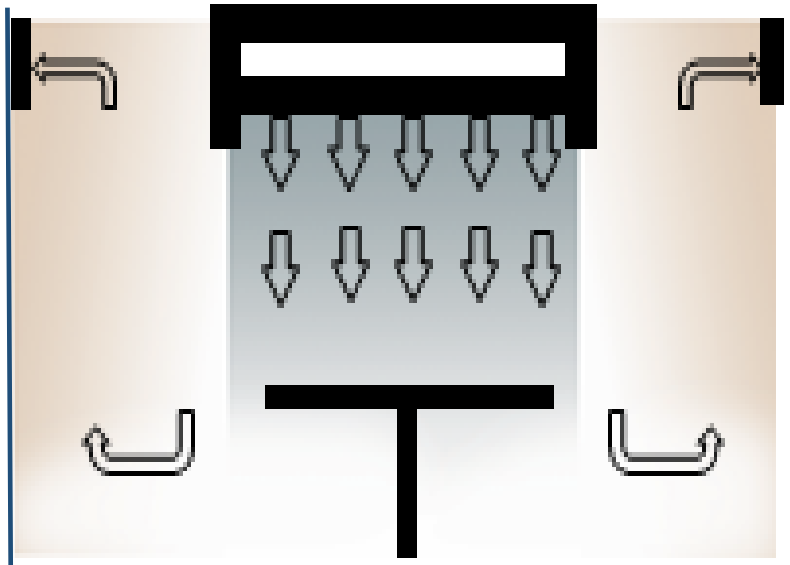
Influenza A virus with subtypes. CDC

Galson E, Guisbond J. Hospital sepsis control and TB transmission. *ASHRAE Journal*. 1995;37(5):48–52

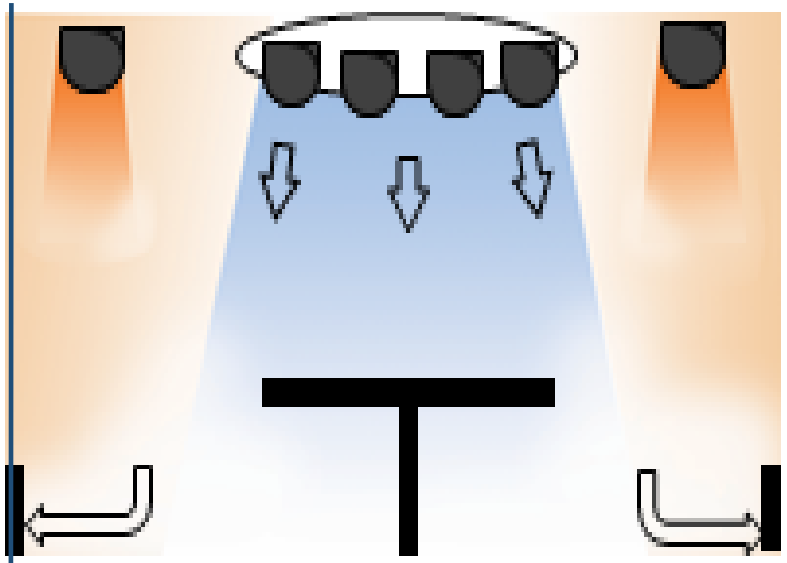
Three types of ventilation concepts



Turbulent mixed Airflow (TMA)



Uni-directional/Laminar Airflow (UDF/LAF)

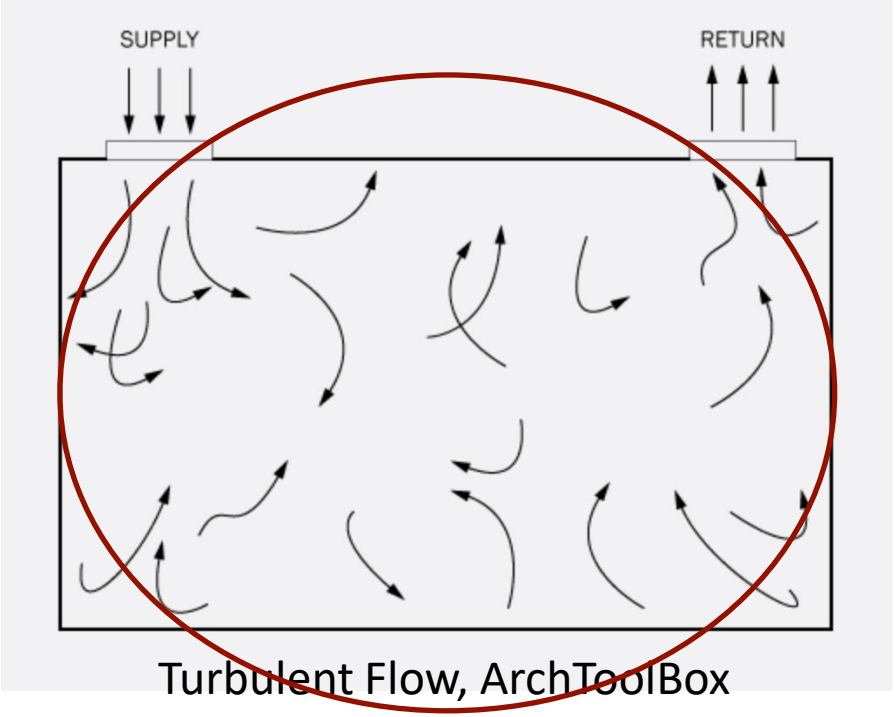


Temperature-controlled AirFlow (TcAF)

Differ in how airflow direction and velocity are managed.

Turbulent Mixed Airflow (TMA)

- Based on dilution principle: Filtered air streamed into space provoking *turbulent* mixing of clean air with contaminated air.
  - ➢ **Key parameter: Number of ACH**
- Air moves in an unpredictable manner, dictated by pressure and temperature differences. Air molecules constantly collide, contaminating air as particles are transported around the room before leaving via the return grille.[7]
- Inefficient - scales linearly, to halve CFU-level, requires 2X airflow.



Turbulent Flow, ArchToolBox

Where is TMA used?

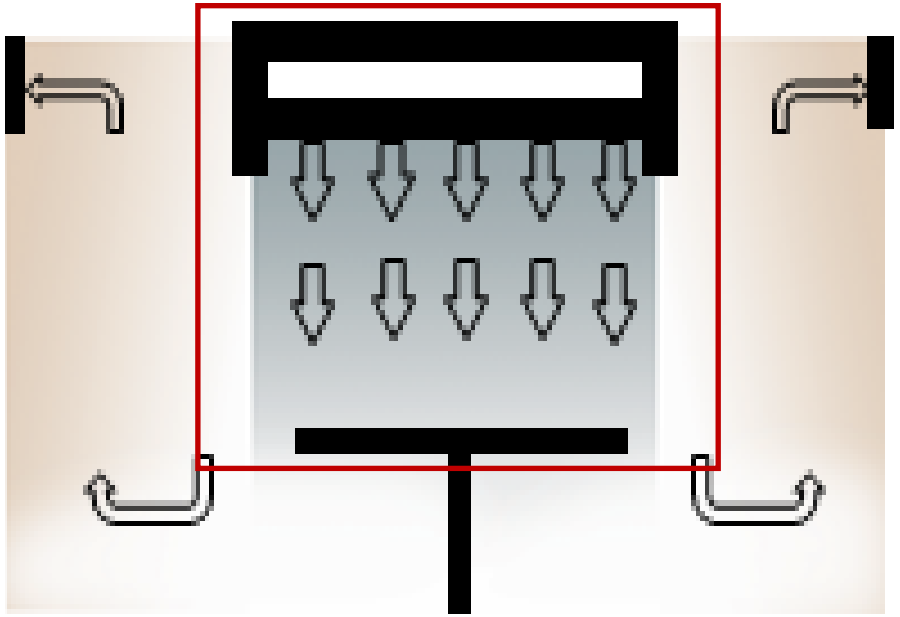
Everywhere except isolation, OR and specialized environments.

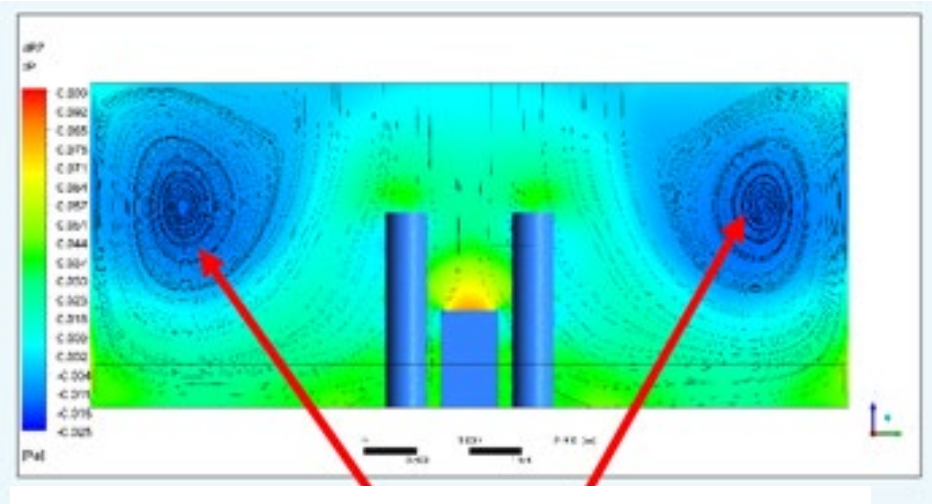
Laminar/UDI – Specialized environments (OR, pharmaceutical compounding)

- Air should flow in a straight, unidirectional path, steady velocity and parallel streamlines
- Creates a limited *clean zone* (<10CFU/m^3)
- Easily *disrupted by objects in pathway,*

  challenged by *vortices in the periphery*
- Mean values of airborne CFUs outside

  protected zone: *55-fold higher* than values inside [1]
- Based on growing body of evidence, no longer recommended by CDC or WHO for joint arthroplasty [2,3]





CFD Simulation –Royal Inst. Tech, Sweden

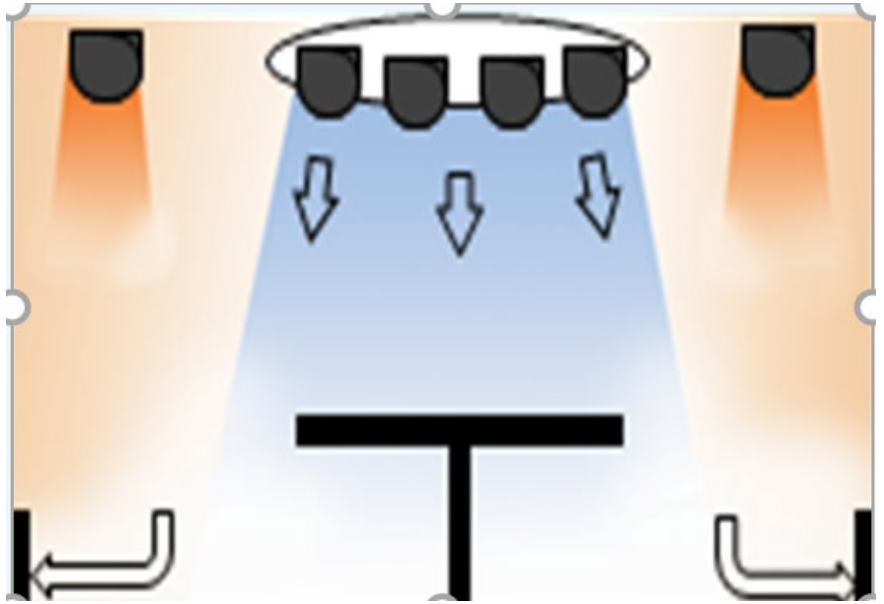
1-Benen T, Wille F, Clausdorff L. Influence of different ventilations systems upon the contamination of medical devices. *Hyg Med*. 2013; 38–41

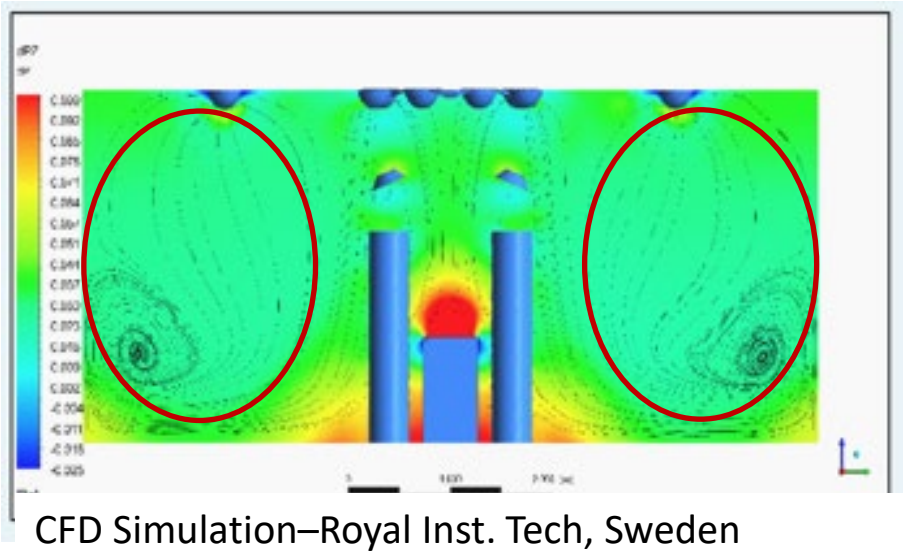
2-Berríos-Torres SI, Umscheid CA, Bratzler DW, et al. Centers for Disease Control and Prevention Guideline for the Prevention of Surgical Site Infection, 2017. *JAMA Surg.* 2017;152(8):784–791

3 -Global guidelines on the prevention of surgical site infection. World Health Organization. 2016. http://www.who.int Accessed July 9, 2020.

Temperature-controlled Air Flow (TcAF): Operating room, pharmacy, radiology, central sterile supply

- HEPA filtered air dispersed from air showers at 1.5°C cooler than ambient room temperature
- Temperature differential creates gravity-driven down-flow, consistent throughout the space
- Fall speed of the air (>0.25 m/s), counteracts heat convention from staff, lamps & obstacles
- Air supplied in the periphery prevents stagnation zones
- Maintains *entire room* at <10CFU/m^3
- Temperature /humidity: Set at any level to ensure patient safety, staff comfort

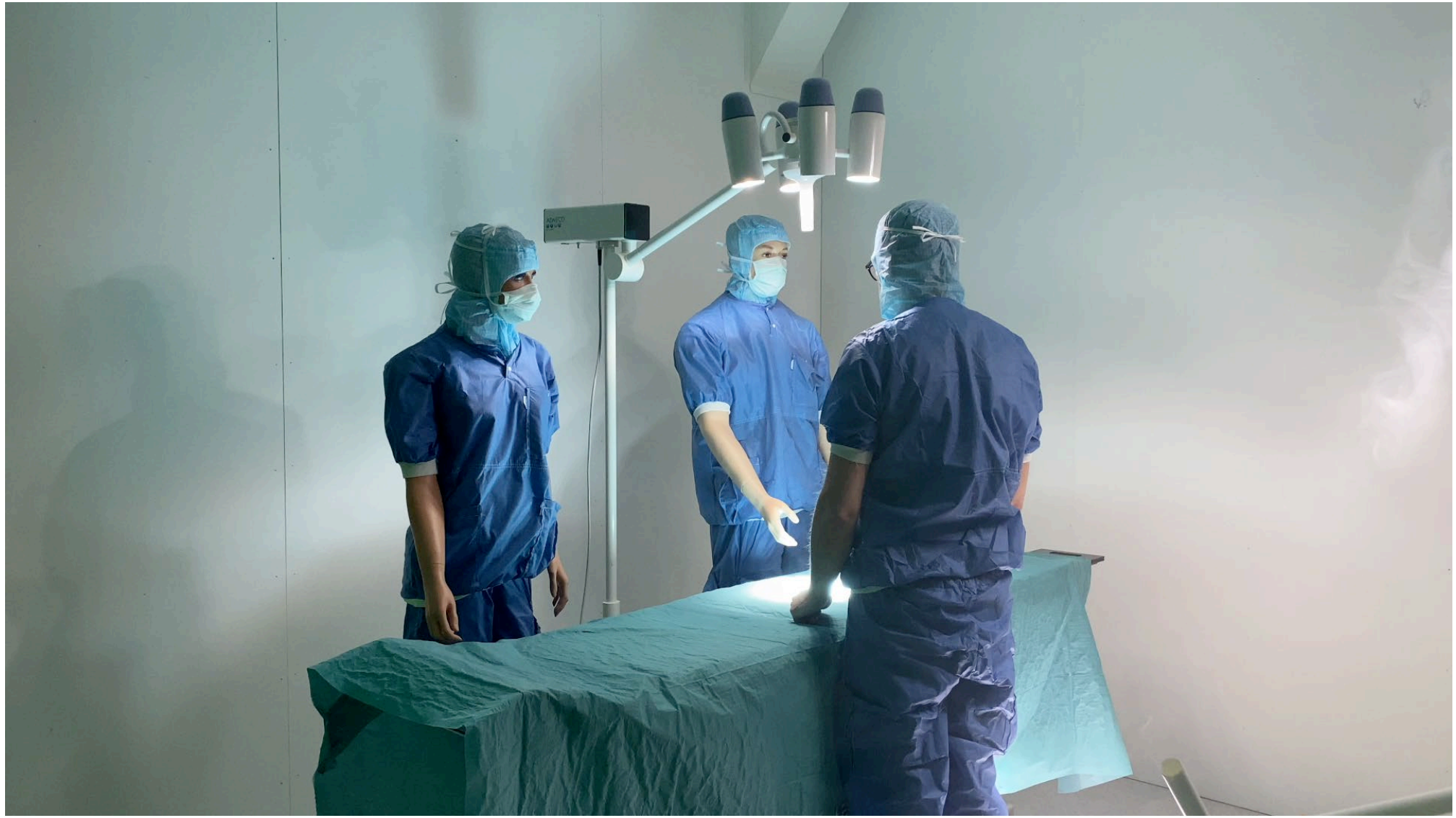




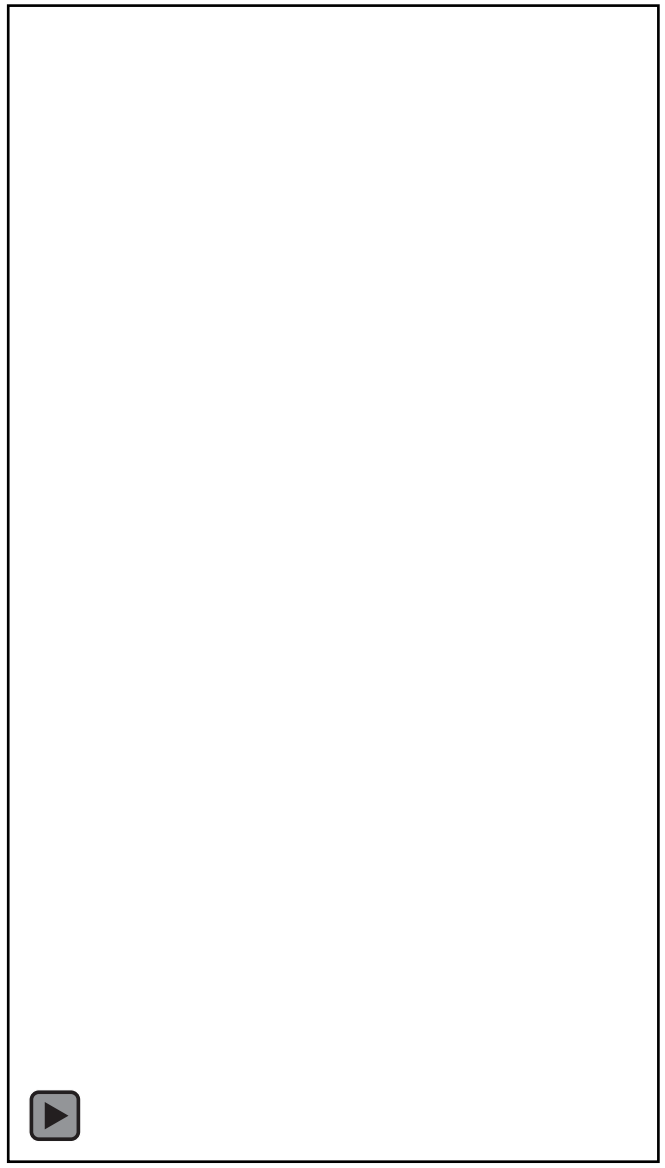
CFD Simulation–Royal Inst. Tech, Sweden

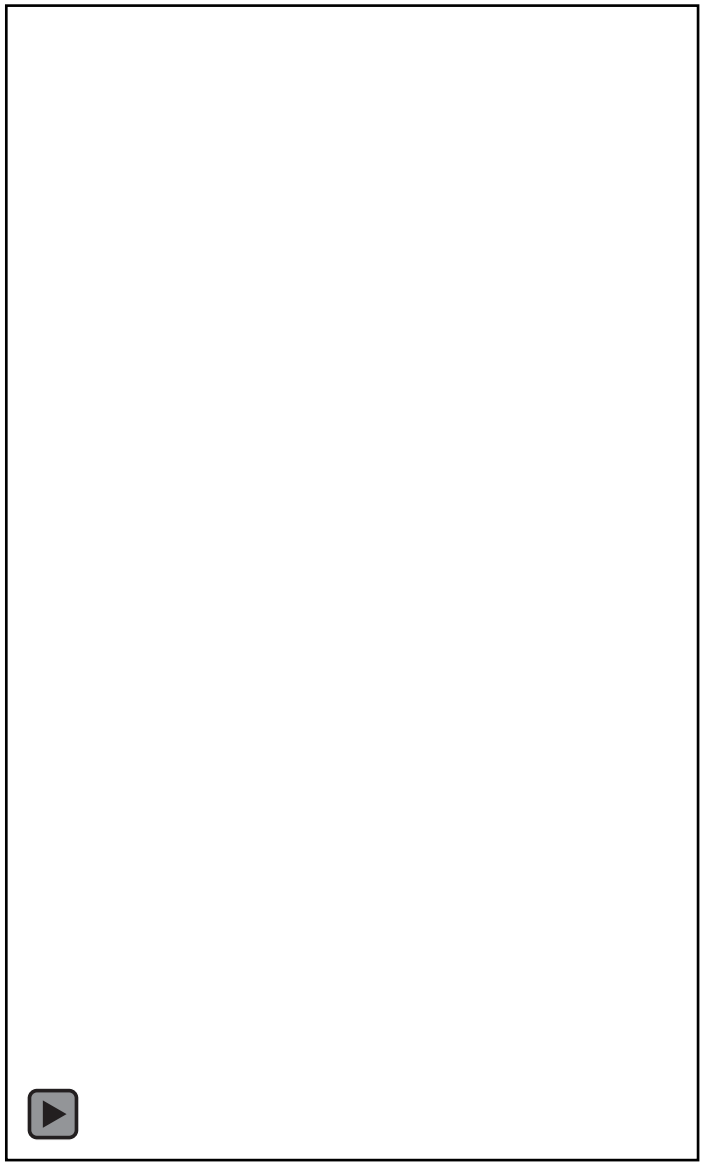
Alsved M, et al. Temperature-controlled airflow ventilation in operating rooms compared with laminar airflow and turbulent mixed airflow. J Hosp Infect. 2018 Feb;98(2):181-190

Turbulent Mixed Airflow (TMA)



Laminar Airflow (LAF)



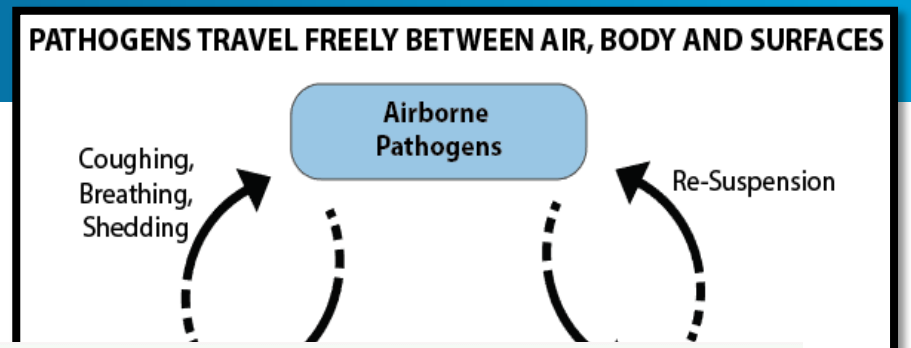


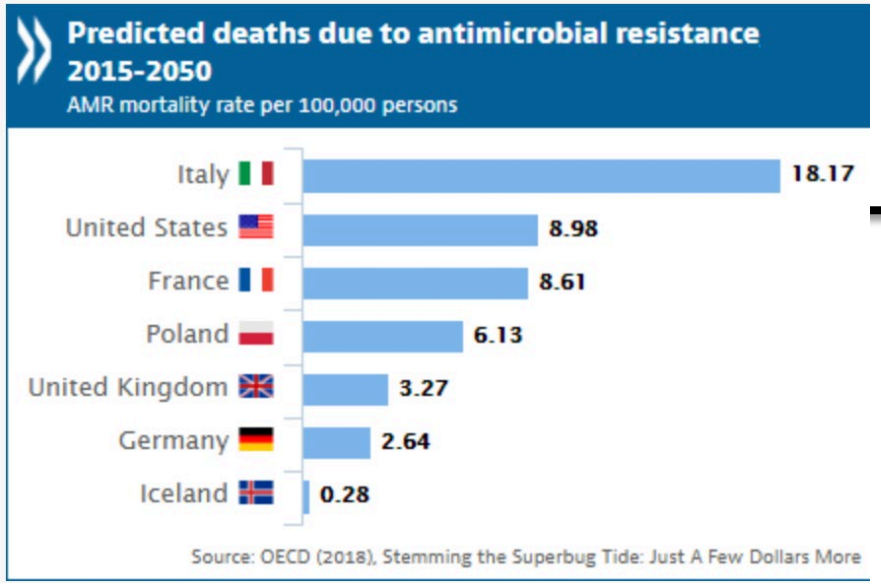
Temperature-controlled Airflow (TcAF)

A risk-based Approach to Air Quality Management

Why Now?

- The World Health Organization has declared 6 public health emergencies of international concern since 2014.
- Diseases once controlled have re-emerged; (increase in measles in the US).
- Climate change is altering the movement of hosts and pathogens.
- Population increase places humans and animals closer together, increasing the likelihood of pathogen spillover.





Because MRSA is endemic (2%) in the general US population.

Because volume of surgeries with high airborne contamination SSI risk are growing at an exponential rate.

Why Now?

The Joint Commission

Requirement for water quality management program

January 1, 2022

Rationale: Water systems often have complex distribution pathways with areas of stagnation; exposure to a variety of plumbing materials; and wide variability in temperature, pH, and disinfectant types and levels. These conditions can promote the development of biofilms and opportunistic pathogens such as Legionella, nontuberculous mycobacteria (NTM), and Pseudomonas species. Because of the nature of water systems in health care settings, exposure to the water while in the organization can place patients/residents at risk for infection from waterborne pathogens or at risk of exposure to an outbreak. Moreover, many people being treated at health care facilities, including long-term care facilities and hospitals, have conditions that put them at greater risk of getting sick and dying from these pathogens.

TJC R^3 Report, Issue 32, October 27, 2021

Why Now?

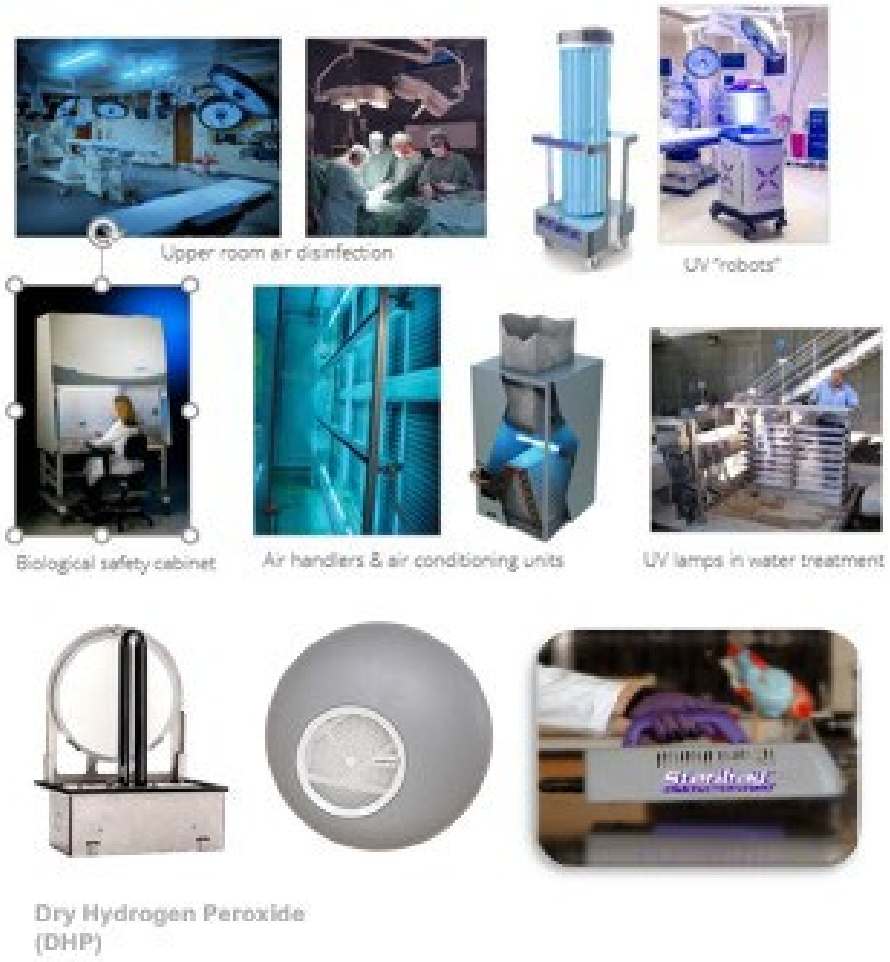
New technologies have entered the market that support a more nuanced approach to air quality management

Approaches

- Remove or degrade gaseous pollutants
- Remove airborne particulates and kill contaminants
- Additions to the environment (UV, H2O2) to reduce airborne contamination

Types of Purification and Disinfection Technology

- Ultraviolet-C disinfection
- 405 nanometer indigo and white LED light
- Excimer lamps emit 222nm wavelengths
- Dry Hydrogen Peroxide
- Portable Room Air Purifiers (HEPA/UV-C and HEPA filter only)



Components of an Air Quality Management Program

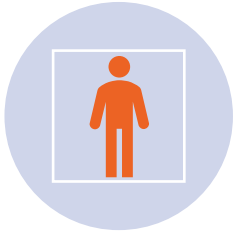
Air Quality Management Program

ESTABLISH AN AIR QUALITY MANAGEMENT PROGRAM

DESCRIBE THE BUILDING AIR SYSTEMS USING TEXT AND FLOW DIAGRAMS

IDENTIFY HIGH RISK AREAS WHERE AIR CONTAMINATION COULD OCCUR

DECIDE WHERE CONTROL MEASURES SHOULD BE APPLIED AND MONITORED



ESTABLISH WAYS TO INTERVENE WHEN CONTROL MEASURES ARE NOT MET

ASSURE THE PROGRAM IS RUNNING AS DESIGNED AND IS EFFECTIVE

DOCUMENT AND REVIEW ALL THE ACTIVITIES THROUGH ENVIRONMENT OF CARE COMMITTEE

Team Member Knowledge, Skills & Competencies

Multi-disciplinary Team Membership

- Infection prevention personnel, including hospital epidemiologists
- Laboratory personnel
- Director of facilities engineering or designated representative
- Risk-management personnel
- Directors of specialized programs (e.g., transplantation, oncology and ICUs)
- Employee safety personnel, industrial hygienists and regulatory affairs personnel
- Environmental services & information systems personnel
- Construction administrators or designated representatives
- Architects, design engineers, project managers and contractors

Risk Management Approach: Where to Start

1. Identify risk of exposure and/or transmission
2. Measure the risk
3. Monitor the risk

WHERE?

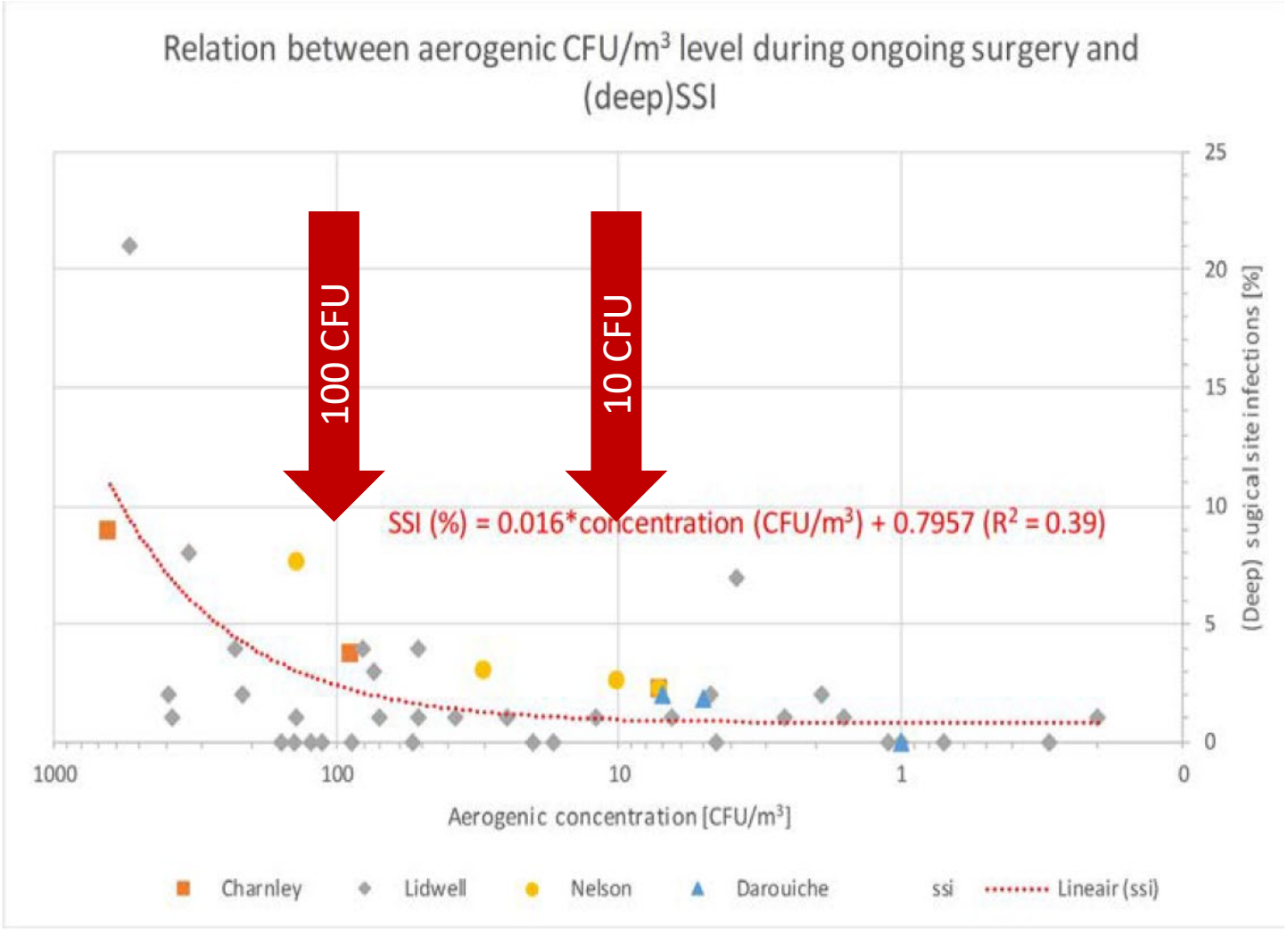
Air Quality Infection Control Risk Assessment Template

IDENTIFY RISK		ANALYZE RISK		ASSESS RISK		MANAGE RISK
Task	Patient or HCP Population	Contributing Factors	Potential for Exposure	Existing Controls	Applicable Standards, Guidelines, Evidence	Proposed/ Supplemental Controls
	• Immune status • Infection/ • colonization • Exposure to hazardous chemicals	• Procedures (AGPs?) • Routine conditions vs. surge	• Low • Medium • High	• Filtration • Temp • Humidity • ACH • Ventilation Concept • Supplemental Tech (UV, mobile unit, etc)	• ASHRAE 170 • CDC • Clinical evidence • Laboratory and other data	

Where to Start? Correlation of Airborne Bioburden and Surgical Site Infection

The Operating Room: The major exogenous source of SSI is transmission by air

- Rooms with over 50CFU/m^3 are 2.6 times more likely to have postoperative infection than rooms with 10-20CFU/m^3 [1]
- SSI rates are rising for infection sensitive, high volume surgeries



1.Charnley J, Eftekhar N. Postoperative infection in total prosthetic replacement arthroplasty of the hip-joint. With special reference to the bacterial content of the air of the operating room. Br J Surg. 1969 Sep;56(9):641-9.
2.Travaseri R. Aerogenic contamination control in operating theatres. Doctoral thesis 2018. Dept. Orthopedic Surgery. Maastricht University, The Netherlands.

WHERE? Risk of Exposure by Department/Service

Low	Medium to High	High
• Administrative Offices • Hospital Social Areas	• Emergency Department • Radiology & Nuclear Medicine • Post Operative Intensive Care or Post Anesthesia • Laboratories • Echocardiography • Physiology Areas • Neonatology and Pediatrics • Long-Term Care • Internal Medicine	• Intensive Care Units • Operating Rooms • Anesthesia Induction Rooms • Oncology (outpatient) • Transplant & Outpatient Clinics (Transplant/Dialysis) • Dialysis Units • Immunosuppressed Patients • Angiography, Hemodynamic & Cardiology • Endoscopy • Pharmacy, Prep, Parental Nutrition • Central Sterile Supply

Adapted from Bonadonna L, et al. Microbial Air Quality in Healthcare Facilities. *Int J Environ Res Public Health*. 2021;18(12):6226.

Standards development in the European Union: Movement to *performance based standards*, limitations on CFUs by risk/service

EU countries are moving away from prescriptive engineering standards to **performance based standards**:

Approach that **prescribes the environmental outcome** expected, **not the means** by which the result is to be achieved.

- Measurement ⟶ Management
- Safer environments for patients and personnel

Fig. 1. Parvizi J, Barnes S, Shohat N, Edmiston CE Jr. Environment of care: Is it time to reassess microbial contamination of the operating room air as a risk factor for surgical site infection in total joint arthroplasty? Am J Infect Control. 2017 Nov 1;45(11):1267-1272

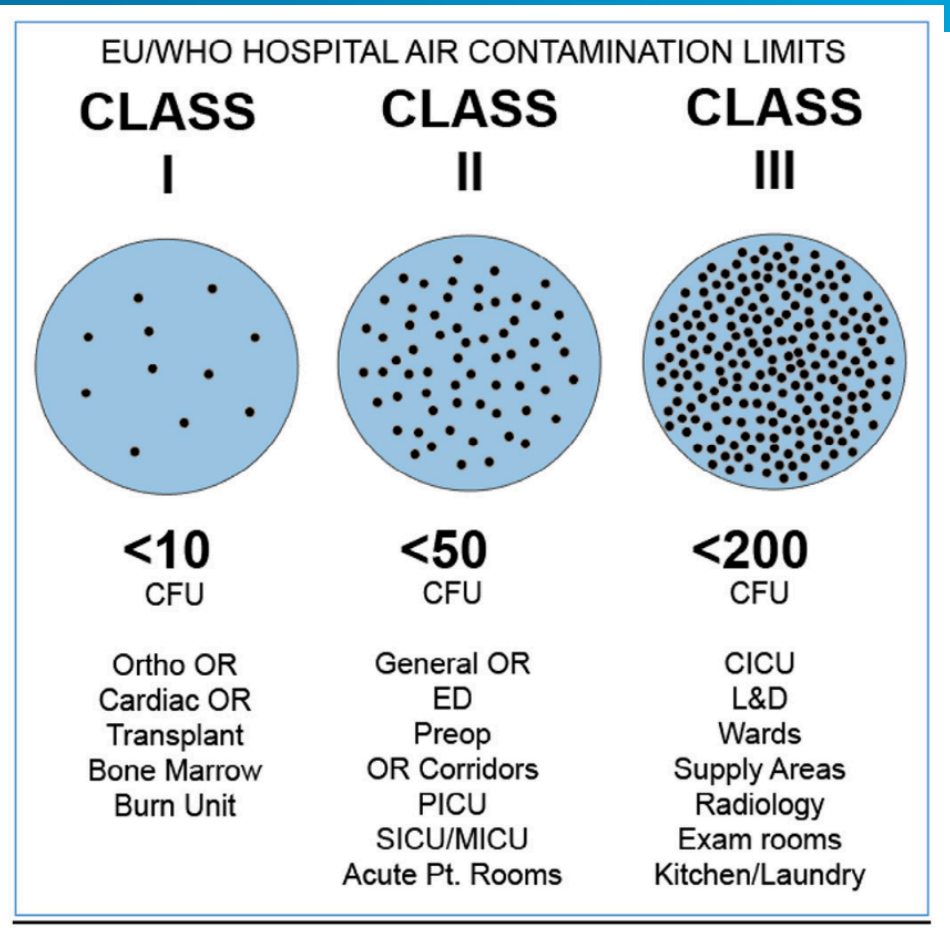


Fig 1. Propose EU-WHO standards for contamination of hospital room air: class I, <10 CFU; class II, <50 CFU; and class III, <200 CFU. Hospital OR fall within class I standards. 39 CFU, colony forming units; ED, emergency department; EU, European Union; Preop, preoperative; Pt., patient; OR, operating room pediatric intensive care unit (PICU); surgical intensive care unit (SICU); medical intensive care unit (MICU); cardiac intensive care unit (CICU) and labor and delivery (L&D). WHO, World Health Organization.

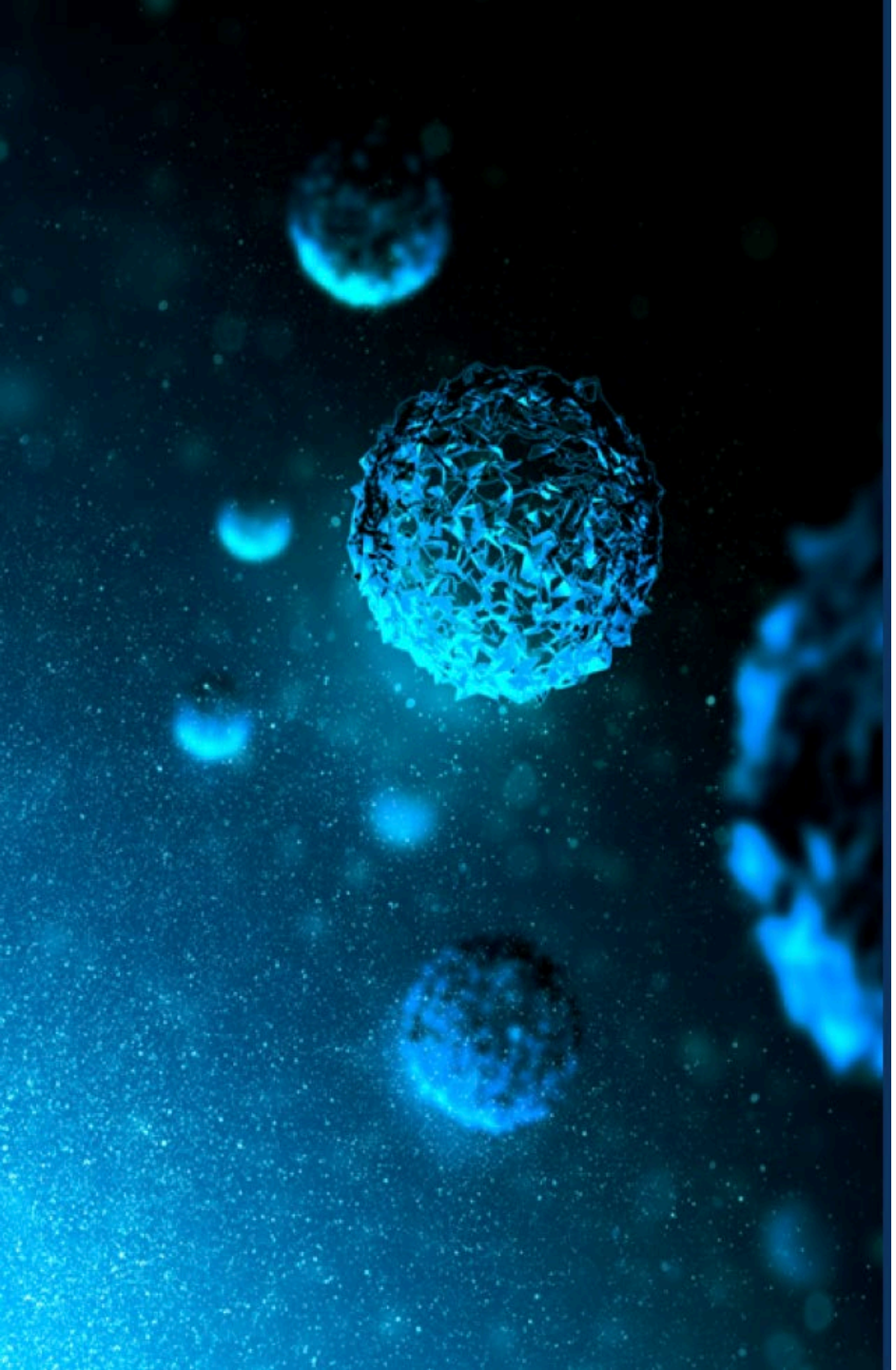
U.S. Standards/guidelines for management of airborne contamination
Prescriptive not performance-based

FGI & ASHRAE 170	CDC
• Air pressure relationships (positive/negative pressure based on risk and patient population (AIIR, OR) • Air Exchange Rate (ACH) • Filtration • Temperature • Humidity	• Relationship to adjacent area (positive/negative pressure – AIIR/OR) • Minimum ACH based on area (6-20 ACH) • Exhausted or recirculated • Relative humidity

Prescribe the **means** by which a result is to be achieved without describing the **result.**
US standards are **silent** on what constitutes a ”safe” level of airborne contamination.

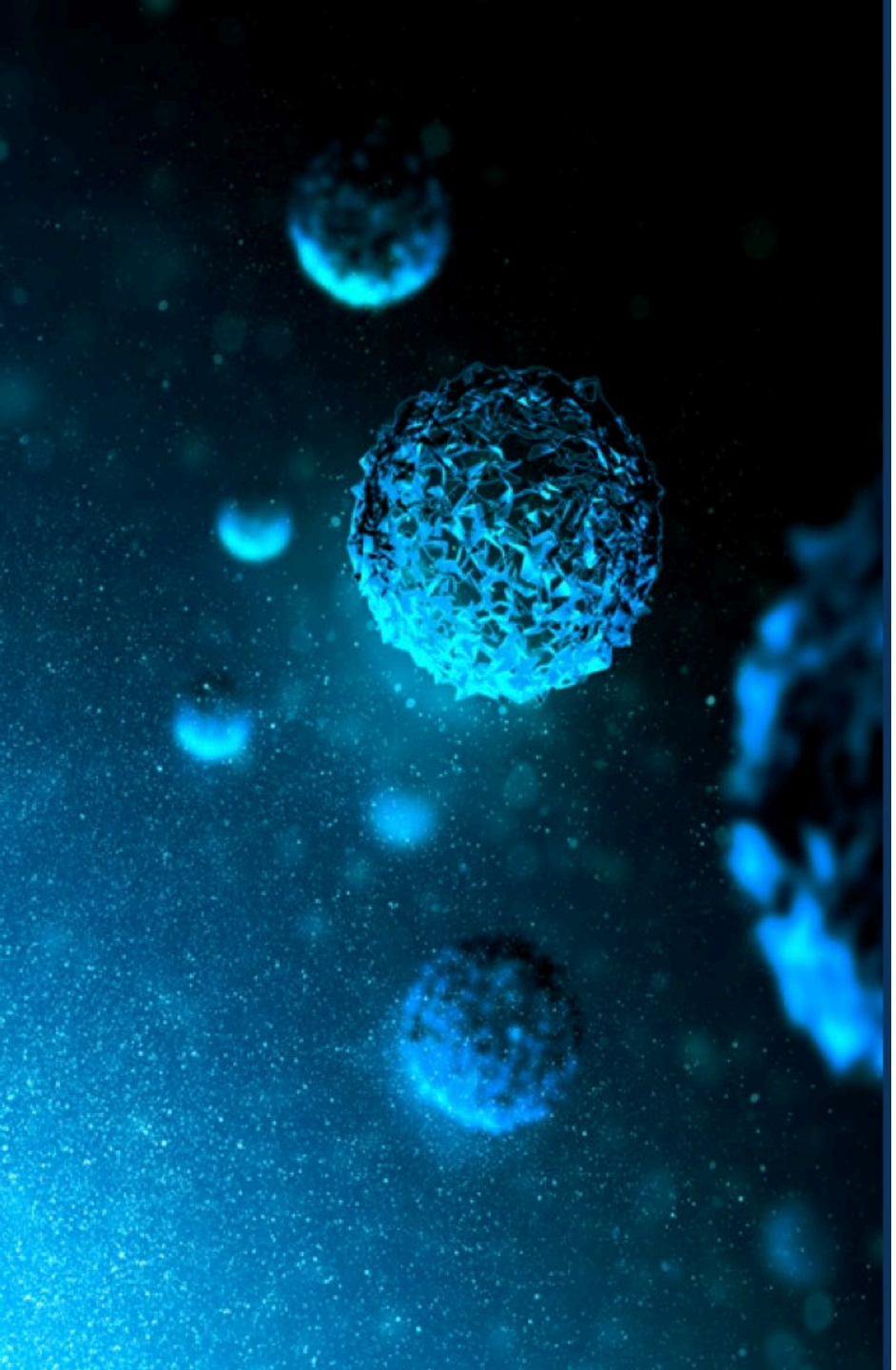
Movement to performance based standards: Countries with limitations on OR airborne contamination

Country	CFU Limits	ISO Clean Room	Document	Comments
Australia	Class 6, ISO 14644-1	ISO Class 6	ANZ/NZS ISO 14644-1	
Sweden	≤10 CFU/m^3 for procedures utilizing implants		Standards Institute Teknisk Specification SIS-TS 39	
Netherlands	≤10 CFU/m^3 for procedures utilizing implants			Mean value of ≤5 CFU/m3 targeted, to ensure ≤10 CFU/m3
Germany	Recommended <4 CFU/m^3, limit of <10 CFU/m^3		Standard DIN 1946-4-2008 Standard VD 2167	3 classes of rooms
Switzerland	<10, 50 & 200/CFU/m^3 depending on risk			3 classes of rooms by risk
France	≤20 CFU/m^3		NF S 90-351	2 classes of rooms
UK	≤35CFU/m^3 rooms at rest, <10 for ultraclean rooms, not to exceed 180CFU/m^3 for more than 5 min		British Standard 52-95-1	
Wales	<10 CFU/m^3		HTM 03-1	
Italy	<180 CFU/m^3		ISPESL 2010	
Russia	<5 CFU/m^1 at OT, <20 CFU/m^1 periphery		GOST R 52539	5 classes of rooms including CFU limitations in ED
South Africa		Class 5, ISO 14644-1	Design of mechanical installations (Core Standards 2006)	



Why have we not had air quality management plans in healthcare?

- Measurement of airborne contamination was **difficult and costly**.
  - New technology is making measurement more feasible.
- Because we weren't **required to** evaluate or address the air. CDC does support targeted testing of air. Measure only what you can't manage.
  - New monitoring technologies, new mitigation strategies, new technologies are changing our capabilities.
- Beyond TB, chickenpox and measles***, denial*** of the contribution of airborne microbial contamination to transmission. It took ***more than a year*** for WHO and CDC to acknowledge that SARS-Cov-2 is airborne.



What you can do today

Avoid common shortcuts which can increase risk of HAI, transmission of MDROs and airborne transmission risk:

- No coil cleaning
- Reconditioning air rather than exhausting
- Lack of monitoring of proper ventilation functions
- Purchase of poor-quality filters
- No practice to check for air-leaks

https://www.fda.gov/media/98639/download

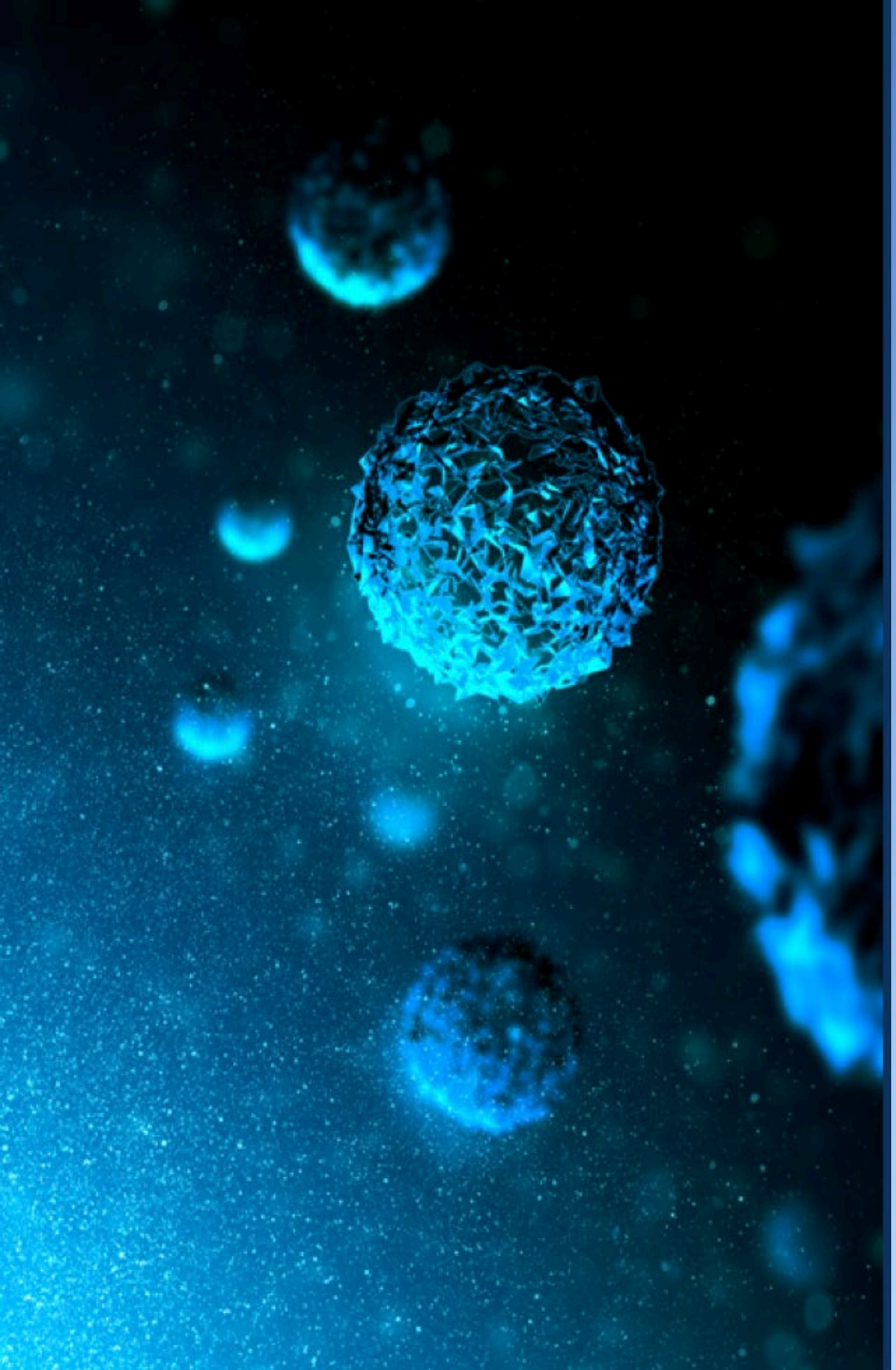
What we covered

1. Discussed the correlation of airborne contamination and transmission of organisms of concern, HAIs, AMR.

2. Reviewed the current approach to air quality management in healthcare facilities.

3. Went beyond the one-size-fits-all orientation to airborne microbial risk and considered the risk of exposure by department or service.

1. Outlined the components an air quality management program.



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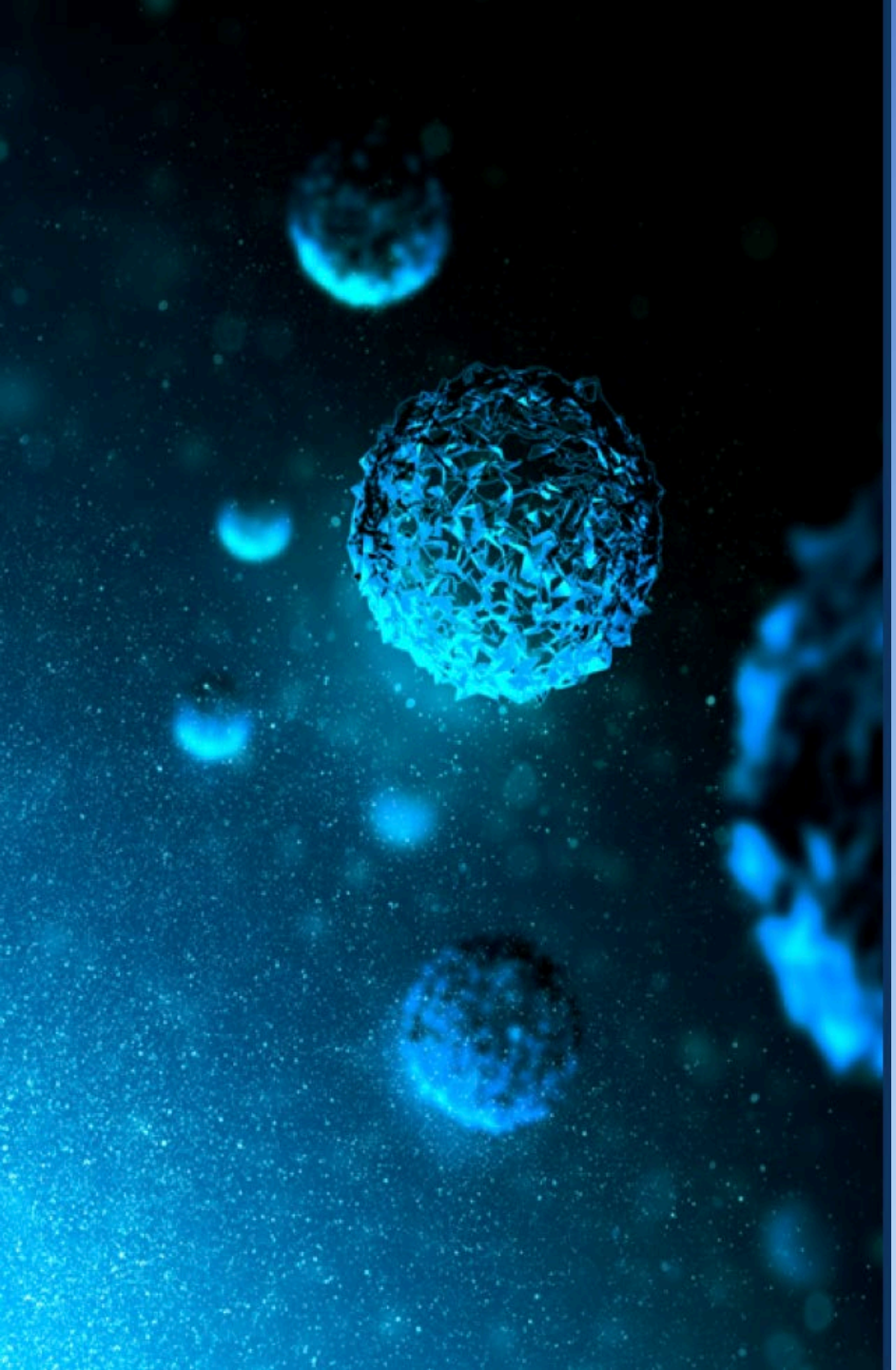
Discussion



Thank You

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