Is low indoor humidity a driver for healthcare-associated infections?

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SUMMARY
The essential and preventive role of indoor climate management for infection control in hospitals will be discussed with special emphasis on relative humidity. Each year in the US and worldwide, healthcare-associated infections kill more people than do automobile accidents (Reed and Kemmerly, 2009; Anderson, 2013). New data are presented showing an association between indoor humidity above 40 percent and reduced healthcare-associated infections. Current infection prevention strategies are discussed with consideration of this new insight.

PRACTICAL IMPLICATIONS
Managing indoor air relative humidity in hospitals could prevent a significant percentage of healthcare-associated infections. This prevention strategy is equally applicable to office and residential buildings.

KEYWORDS
Healthcare-associated infections (HAIs), Indoor Air Quality (IAQ), Relative Humidity (RH), built environment microbiome, control of airborne microbes

1 INTRODUCTION

In the US and Europe, errors during in-patient medical care is a leading cause of death (James, 2013). A significant portion of this staggering statistic are deaths due to new infections, called nosocomial or healthcare-associated infections (HAIs), that patients acquire while in the hospital. At least 10% of all patients who enter an inpatient healthcare facility for treatment will develop a HAI (Classen et al. 2011). Tragically, in the US alone, the number of deaths from these infections is over 100,000 annually. What are the factors behind this situation and what more can we do to control the epidemic?

HAIs occur in an environment of biological extremes coexisting within limited physical space. Vulnerable patients often have decreased immune defenses from illnesses, medications, or loss of skin integrity from surgery, indwelling medication lines or injuries. In contrast to the patients, bacteria, viruses and fungi which originate from the patient's own micro-flora, other people in the hospital, or reservoirs in the build-environment can be more virulent than pathogens found outside the hospital. This virulence, manifested as increased infectivity, results from anti-microbial medications and housekeeping disinfectants attempting to eradicate all pathogens. Micro-organisms that survive these powerful selection pressures (survival of the fittest) rapidly reproduce and repopulate the environment with communities of decreased diversity yet increased virulence through medication resistant genes and transmission modes keenly adapted to the indoor environment. These evolutionary cycles occur in the presence of visitors and healthcare staff who are also shedding microbes from their respiratory tract, garments, shoes and skin - adding to the microbial communities in a hospital. Serious problems have evolved as, unwittingly, hospitals have now become reservoirs and vectors for the infectious microorganisms that cause ubiquitous HAIs.

Current infection control protocols focus largely on hand, instrument and surface hygiene, as well as on cough etiquette and facial masks. These strategies target the interruption of transmission through contact- and short distance, large-droplet spray. They do not, however, immobilize tiny, aerosolized droplets which can spread infectious microorganisms across significant distances and for extended periods through the air. Droplets with diameters less than 5 µm, called droplet nuclei, are easily inhaled and can plunge into deep layers of the respiratory tract. Two review articles (Eames et al. 2009; Fernstrom and Goldblatt, 2012) conclude that 10 to 33 percent of all HAIs move through the air at some point between the initial source, the reservoir and the secondary patient. Until transmission of these tiny infectious aerosols is controlled, even excellent adherence to existing contact hygiene protocols will not curtail the HAI epidemic.

This study was designed to increase understanding of the relationship between the indoor environmental conditions, the composition and dynamics of microbial communities, and patient clinical outcomes. The University of Chicago, Hospital Microbiome Project, performed culture-independent analyses of pathogen genotypes to map microbes from humans, building surfaces, air and water in a newly constructed hospital, and continued for over one year. Indoor climate parameters which could influence microbial communities, and therefore the occurrence of patient HAIs, were monitored simultaneously. These results were then cross-analyzed with patient diagnoses and length of stay to isolate building conditions which were associated with patient HAIs.

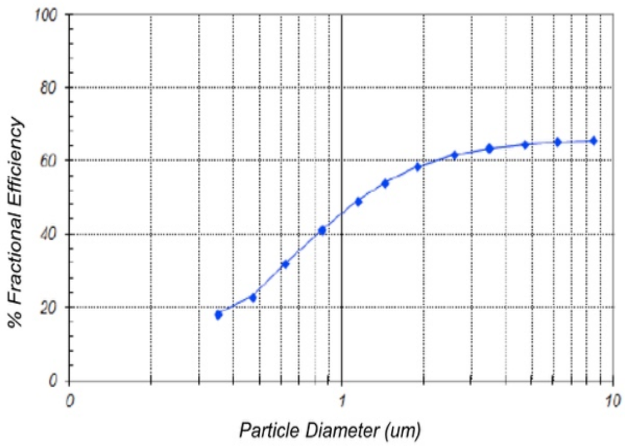
2 MATERIALS/METHODS

Ten patient rooms and the supporting nursing stations on two floors in a newly constructed hospital were monitored for both microbial and building factors beginning two months before the hospital became operational in February 2013 and continued for a year after opening, for a total of 14 months. Hospital floors with two different inpatient populations were selected. One floor was for oncological patients who had longer treatment times and the other was for surgery patients with expected shorter treatment times of a few days.

Microbial communities were measured and mapped through DNA quantification. For this investigation, trained technicians from the medical center obtained samples from the following sites: 1. patient and staff skin; 2. building, furniture, medical and other stationary and mobile equipment surfaces; 3. Airborne microbes in the exhaust air of patient rooms. One patient room on each level was sampled daily while all other environments where sampled weekly. Technicians collected the samples by rubbing sterile swabs, pre-moistened with 0.15M saline solution, on the surface sites of interest. After collection, samples were immediately frozen at -20° pending shipment to Argonne National Laboratory on dry ice (Ramos and Stevens 2014). Over six thousand microbial samples were obtained and evaluated.

The indoor building conditions were monitored by continuous, direct measurements of room temperature, relative humidity, CO_2 concentrations, illuminance, and occupancy. For occupancy monitoring, non-directional infrared beam-break sensors were installed at each patient room door to record the number of times the beam was broken by a person crossing the threshold. Passive air sampling was done in each patient room by collecting airborne particle-bound microbes. A sheet of medium efficiency HVAC filter media was selected, cut into 2 x 2 ft. pieces, and placed on the exterior of each patient room return grille on the white drop-ceiling frame and attached with custom-built magnets. The filter media was removed, preserved for microbial extraction, and replaced on a weekly basis. (Ramos and Stevens, 2014)

Table 1. Efficiency curve for filter media used in passive air sampling.



Statistical analysis through SPSS was run to detect significant correlations between the environmental measurements, patient HAI outcomes based on discharge ICD-9 codes and hospital recorded length of stay (LOS).

3 RESULTS

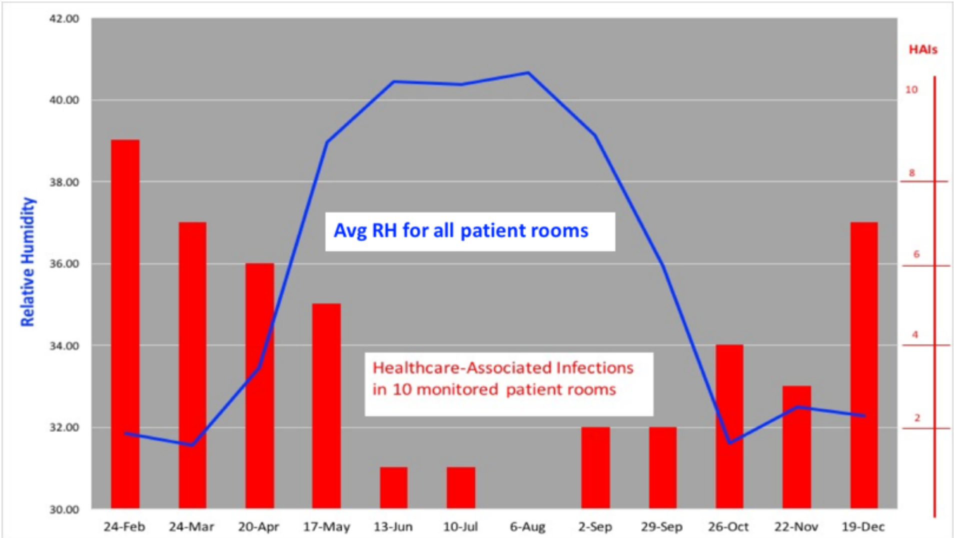
The results showed that, soon after the hospital became operational, the floor and nursing station surfaces had a significant increase in the relative abundance of human-skin associated genera and a decrease in Acinetobacter and Pseudomonas, which dominated pre-opening samples.

Patient skin samples were the least diverse, while surfaces that were contacted by occupants and the outdoors by fresh air supply, shoes, garments and medical activities were the most diverse.

Within a patient room, higher temperatures and illuminance were consistently associated with greater microbial dis ~~similarity~~ between patient's skin and surfaces while higher relative and absolute humidity consistently correlated with greater microbial similarity. Skin-associated microbial similarity between staff members, working on the same floor, showed a seasonal trend with the greatest similarity in late summer/early fall, and least in winter. The higher the humidity, the greater the nose and hand-associated microbial similarity between staff.

Patient HAIs were inversely associated with relative humidity as an independent variable in the respective patient care rooms. Low relative humidity was correlated with more patient HAIs.

Table 2. Correlation between average indoor relative humidity and the number of patient HAIs in 10 patient rooms over the course of one year.



SPSS analysis: T < 0.02

4 DISCUSSION

The hospital is an extremely complex milieu for microbes due to frequent cleaning, rapid turnover of patients and the use of antimicrobial drugs. This study provided important data to better understand the interactions in the following areas:

1. Improved understanding of microbial transmission between human skin, unanimated surfaces, air and water
2. Deeper insight into indoor air characteristics affecting deposition, re-suspension and transmission of pathogens across human skin, unanimated surfaces, air and water
3. Identification of indoor air characteristics which influence HAIs, length of stay, morbidity and mortality of patients

This study demonstrates that microbial communities are influenced by indoor building parameters, driven by seasonal local climate. A strong correlation between the microbial communities associated with ~~human occupants~~ and those recovered from unanimated surfaces was revealed. Indoor relative humidity was the most statistically significant, independent variable with impact on this link.

5 CONCLUSIONS

The data demonstrate a clear association between microbial sharing of occupants, patient HAIs, and indoor building conditions. Of all the environmental parameters, indoor humidity is the most significant driver. Specifically, the data show that RH below 40 percent is associated with an increased prevalence of patient HAIs.

In addition to current standard hygiene protocols, maintaining the indoor RH at 40-60 percent may be ~~the most~~ effective and cost-efficient, yet underestimated, tool to decrease the spread of infectious microorganisms and HAIs, improve patient outcome and decrease length of stay.

Hospital engineers and facility managers now have additional data to guide their building management. Through maintaining humidity and temperatures within the optimal preventive range, newly acquired patient infections and excessively long hospitalizations can be reduced.

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