Improved Control of Microbial Exposure Hazards in Hospitals: A 30-Month Field Study

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Abstract

The microbial colonization of environmental surfaces in hospitals and other buildings can produce infective, allergenic, and toxigenic risks for occupants. Traditional disinfectant/sanitizer formulations do not provide sustained control of microbial contamination at low levels and their extended use is potentially dangerous to man and the environment.

This study evaluates the effectiveness of a new class of antimicrobial agents that covalently bond to surfaces and are not chemically reactive with the microbial cells. This organosilicon antimicrobial, 3-trimethoxysilylpropyldimethyloctadecyl ammonium chloride (ÆGIS™ Antimicrobial), produces antimicrobially active surfaces on a variety of substrates.

After modifying the interior surfaces of a flood-damaged hospital with this antimicrobial, we evaluated airborne microbial concentrations for 30 months. The results show a significant and sustained reduction of viable airborne microorganisms.

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Introduction

The use of chemical disinfectants to reduce microbial colonization of hospital surfaces can be traced to the 1860's when Joseph Lister atomized a 5% Phenol solution to control "hospital gangrene." Since that time, there have been many advances in the design of antimicrobial/disinfectant chemistries to provide an increasing toxic arsenal for our war on germs. Methods to deliver antimicrobials have also improved significantly. Micro-aerosol dispersion, micro-encapsulation, and impregnation of the biocide into a variety of polymeric resins have been used to expand the capabilities of these agents and to reduce toxic consequences for man and the environment.

These advances gave rise to many types of antimicrobial agents with varying disinfect ion mechanisms, but the basic principle of microbial destruction has not changed. Although antimicrobial agents today are more toxic and can be delivered effectively in a variety of ways, each is defined by the principle of chemical reactivity with the cell or its components. And each requires dissociation of the disinfectant from the surface and intimate involvement in one or more components of the life processes of the cell.

Since the principle of disinfection did not change, the new antimicrobial agents shared the same limitations. The agent had to leach or diffuse into the surrounding environment for association with a cell; diffusion reduced the concentration below the effective dose, leading

to resistance and adaptation; and, diffusion required solubility of partitioning, resulting in exposure consequences for man and the environment.

The first change in the principle of disinfection occurred in 1969 with the development of organosilicon antimicrobials. Using an alkoxysilane-coupling agent reacted to a quaternized amine, Plueddemann was able to covalently link this novel antimicrobial directly to surface molecules. The bound monomers then reacted with each other to form a cross-linked polymer of extremely high molecular weight, thereby producing an essentially permanent antimicrobial surface.

Speier and Malek (1) were able to demonstrate the antibacterial, antifungal, antiviral, anti-algal, and anti-protozoal activity of this surface bonded agent against a broad spectrum of microorganisms, even after repeated washings. Isquith et al (2) were able to demonstrate, by radioisotope analysis and bioassay, that its antimicrobial activity did not result from release of the material and is a surface-associated phenomena. This is also supported by its lack of a classic zone of inhibition. Thus, chemical reactivity with the cell or its components was not required for activity.

The immobilization of an antimicrobial agent could produce self-sanitizing surfaces that provide significant advantages over conventional approaches to disinfection. Since antimicrobial activity does not involve release of the material and the material remains present at the same concentration, Gettings (3) was able to show that resistance and adaptation do not occur. This not only extends the predicted activity of the agent, but minimizes the possibility of cross-linked antibiotic resistance, as well. Since the antimicrobial remains chemically bonded to the surface molecules, there is a low potential for irritational, toxic, or other human exposure consequences. The permanent attachment of the antimicrobial to the surface molecule also minimizes the environmental risks associated with conventional antimicrobial usage.

The modification of interior surfaces with a bound antimicrobial agent could prevent the development of microbial reservoirs in a building. The destruction of airborne microorganisms upon contact with antimicrobial surfaces would further reduce human exposure potential, producing an environment with lowered risk of allergenic, infective, or toxigenic consequences for building occupants.

Hayes and White (4) have shown that antimicrobial activity can be imparted to a variety of substrates with this agent and Kemper et al (5) have shown that antimicrobial activation of interior building surfaces with this agent reduces airborne microbial concentration. This potential was further explored to determine the usefulness of this technology in a variety of building conditions, treatment surfaces, and levels and types of microbial contamination.

The present study was conducted to determine the level of microbial control possible from the comprehensive use of the material in a severely contaminated building, and to assess the duration of effective control.

Background

The study building is a 12-story comprehensive cancer center and research institute located in Columbus, Ohio. Just prior to its opening in January, 1990, a ruptured water pipe on the 12th floor flooded the building with an estimated 500,000 gallons of water. Ceilings, walls, carpeted floors and upholstered furnishings were either wet or exposed to high humidity.

After assuring that its structural integrity had not been compromised, attention focused on restoring the microbiological quality of the building to levels consistent with its intended use, particularly in Bone Marrow Transplant and other areas where immunosuppressed patients would be housed. Despite high efficiency air filtration and widespread use of a chlorine-based disinfectant fog throughout the building and its ventilation system, large numbers of fungi and bacteria were retrieved from the air in all areas of the hospital. Large numbers of water-associated bacteria, such as Acinetobacter sp., as well as fungi were retrieved from carpeting.

Prior to the flood, hospital and university researchers had designed a study protocol to investigate the effect of surface modification with silane antimicrobials on infection rates within Bone Marrow Transplant, Hematology and Oncology areas in the hospital. The flood and subsequent microbial contamination preempted the study. But, investigation of various antimicrobial systems to achieve sustained microbial control during the study provided an important tool for use in remediation and beyond.

The present study was conceived to evaluate the effectiveness of this technology as an active interdictive method for control of gross microbial colonization under extreme conditions and to assess the duration of activity achieved during restoration.

Materials and Methods

Microbiological Sampling

Microbial retrievals were obtained using an Andersen 2-stage viable impact sampler and a New Brunswick high volume sampler. The Andersen sampler was loaded with plastic petri dishes containing 20ml Malt Extract Agar and operated for 18 minutes at calibrated volume of 1 cubic foot per minute. The New Brunswick sampler was loaded with a plastic petri dish

containing Malt Extract Agar and operated for 1 hour at a calibrated volume of 50L per minute.

Exposed petri dishes were incubated at 30°C for 120h. Colony Forming Units (CFU's) were enumerated at 48 and 72 hours, with final counts reported as those recorded at 72h.

Pre-treatment samplings were performed at cart height (30") with the Andersen sampler at 209 sites. The first post-treatment samplings were performed at cart height at 643 sites. The second and final samplings were performed at cart height and floor level simultaneously using a remote probe on the New Brunswick sampler. Sample site locations for the second and final post-treatment samplings were randomly selected by floor using a random number generator.

Surface Modification

All accessible interior surfaces (including carpeting, ceilings, walls, above ceiling space, furnishings, elevator shafts, mechanical and electrical chases) were treated with the organosilicon antimicrobial 3-trimethoxysilylpropyldimethyloctadecyl ammonium chloride (*Æ*GIS™ Antimicrobial) (6) in water in accordance with the manufacturer's application specifications. The applications were randomly tested for uniformity and penetration throughout the treatment process.

Results

The results of the samplings are presented to Table 1. Two of the post-treatment sampling periods contain data from retrievals at floor level. These data are included as additional information and should not be used to compare pre-post microbial levels.

Pre-treatment retrievals were in a range of 721 – 2,800 CFU's/m^3. Of the 209 sample sites, 122 (58%) sites produced 2,800 CFU's/m^3, the upper detection limit of the sampler.

Post-treatment sampling during the seven months following restoration of the building produced an average of 4.1 CFU's/m^3 at 643 sites. Retrievals were in a range of 0-25 CFU's/m^3. Of the sample sites, 289 sites (45%) produced 0 CFU's/m^3; an additional 231 sites (36%) produced retrievals in a range of 1-5 CFU's/m^3.

The second post-treatment samplings were performed in 1991 at 82 sites randomly selected by floor. The samplings produced retrievals in a range of 0-9 CFU's/m^3, with an average retrieval of 0.8 CFU's/m^3. 40 sites (48%) produced 0 CFU's.

The final post-treatment samplings were performed in 1992 at 86 sites randomly selected by floor. The samplings produced retrievals in a range of 0-4.7 CFU's/m^3, with an average retrieval of 0.4 CFU's/m^3. 56 sites (65%) produced 0 CFU's.

Each of the 24 Bone Marrow Transplant patient rooms were negative for microorganisms during all of the post-treatment samplings.

Figure 1 shows the retrieval averages of pre and post-treatment samplings in the building.

Figure 2 shows the calculated reduction in microbial retrievals during the 30-month study period.

Discussion

The microbial colonization of interior surfaces in buildings, particularly carpeting, is well known. The aerosolization of large numbers of bacteria and fungi from these microbial reservoirs has also been repeatedly demonstrated. Yet, the range of acute and chronic effects of airborne microorganisms and their metabolites on morbidity and mortality has not been fully explored.

Despite the fact that, with a few major exceptions, airborne transmission of bacterial infections still remains a hypothesis which lacks both proof and universal acceptance, the infective, allergenic, toxigenic, and other untoward potentials of these organisms are increasingly confirmed. The medical significance of airborne microbial contamination in hospitals, schools, offices, and other buildings is likely to be much greater than traditional beliefs suggest.

A cursory review of the literature compels one to reassess the importance of effective microbial control measures in our buildings:

Charley (7) reported a decrease in infection rates following clean air precautions in the operating room;

Rhame et al (8) have shown a direct correlation between the concentration of airborne Aspergillus spores in hospital air and the incidence of aspergillosis among immunosuppressed patients;

Arnow et al (9) reports "our findings strongly suggest that the inanimate hospital environment is a major determinant of the risk of endemic or epidemic nosocomial aspergillosis";

Brundage et al (10) observed a 50% increase in respiratory infections among recruits housed in energy efficient buildings with re-circulated air when compared to recruits housed in older, drafty buildings;

Spengler et al (11) reported a 40-100% increase in respiratory illness among children in homes with moisture and mildew problems;

Several studies (12, 13, 14, 15) have implicated airborne microbial contaminants in the development of Building Related Illnesses and Sick Building Syndrome.

There is an abundance of empiric and anecdotal data that amplify the need to control human exposure to airborne microorganisms and microbial metabolites. However, the availability of good scientific data on safe, efficacious control methods is more elusive. Our search for improved methods of disinfection/microbial control led to an array of products and processes. Yet, each possessed limiting characteristics that rendered them unacceptable for our purpose:

All traditional disinfectant products have a vapor pressure, potentiating occupant exposure concerns; The duration of antimicrobial activity of traditional disinfectants is relatively short (ranging from a few minutes to several days) unless incorporated within a substrate with slow-release characteristics; Although many disinfectant formulations appear to possess increased activity against specific classes of microorganisms, this selectivity precluded broad-spectrum control.

None of the disinfectant chemistries available could demonstrate, by published data or interpretation of their disinfection mechanisms, a reduced potential for the development of microbial resistance. The development of microbial resistance would not only reduce the duration of effective activity of the antimicrobial, but presents additional concerns in a hospital environment, as well. The idea of microorganisms conferring antimicrobial resistance to antibiotic tolerance is neither new nor unpredictable. As Russell et al (16) described in "Principles and Practices of Disinfection, Preservation, and Sterilization," increased resistance to antimicrobial and antiseptic preparations (as demonstrated by increased Minimum Inhibitory Concentration) was directly linkable to the number of antibiotics to which the microbial strains were resistant. Nor is it surprising that the authors concluded about the use of QACs and other cationic preparations "These results suggest to us that a policy which relies heavily on the use of cationic antisepsis is likely to select for a hospital flora of notoriously drug-resistant species.

Location		Pre-Treatment	1990	1991		1992	
				M-101[1]	M-303[2]	M-101	M-103
Total Building	Average:[3] Sites	2,655.2 209	4.1 643	1.8 83	0.8 82	0.7 105	0.4 86
Ground Floor	Average: Sites:	2,708.8 29	2.7 76	2.7 7	1.0 7	1.0 7	0.3 7
1st Floor	Average: Sites:	2,614.0 14	16.0 76	1.0 7	0.6 7	1.0 7	0.7 7
2nd Floor	Average: Sites:	2,642.3 19	0.9 72	1.1 7	0.8 7	1.3 7	0.9 7
3rd Floor	Average: Sites:	2,691.9 20	4.8 48	1.0 10	0.6 10	0.3 24	0.3 8
4th Floor	Average: Sites:	2,658.4 22	1.6 68	0.6 11	0.4 11	0.7 13	0.3 11
5th Floor	Average: Sites:	2,618.0 9	2.1 19	2.0 7	1.2 7	0.5 7	0.1 7
7th Floor	Average: Sites:	2,758.0 12	4.7 40	2.3 7	0.5 7	0.4 7	0.0 6
8th Floor	Average: Sites:	2,640.6 17	1.2 58	1.1 7	0.5 7	0.4 7	0.0 7
9th Floor	Average: Sites:	2,627.0 19	0.8 61	N/D 0	N/D 0	0.8 7	0.2 7
10th Floor	Average: Sites:	2.608.0 17	1.3 48	1.6 7	0.5 7	0.9 7	0.9 7
11th Floor	Average: Sites:	2,619.6 13	4.5 36	0.9 8	1.1 7	1.1 7	0.8 7
12th Floor	Average: Sites:	2,633.6 18	6.3 43	7.0 7	2.3 7	0.8 7	0.2 7

Filtration, particularly with high efficient particulate air (HEPA) filters, has been claimed to provide significant control of transient microbial populations (17), but it is also reported that the effectiveness of this control method is limited by the development of propagative sources of microorganisms within the hospital. This is consistent with our pre-treatment sampling data, during which, despite central and terminal HEPA filtration in Bone Marrow Transplant patient rooms, microbial retrievals remained above 70 CFU's/ft3 (18).

Conclusions

The data from this study show that significant control of airborne microorganisms results from the modification or interior building surfaces with an organosilicon antimicrobial. Even when evaluated under severe environmental conditions, the antimicrobial activity of these modified surfaces provides substantive reduction of airborne microbial concentration.

The initial reduction of airborne microorganisms and the sustained control of microbial levels during the 30 months of this study are unprecedented in the literature. When viewed collectively, the safety, efficacy, and durability of this

technology provide a unique opportunity to control the risks associated with microbial contamination in buildings.

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