ANTIMICROBIAL TREATED CONSTRUCTION MATERIALS AND AIR FILTERS REDUCE FACILITY BIOBURDEN AND IMPROVE AIR QUALITY IN A HEALTHCARE ENVIRONMENT

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Background

The continued evidence of the presence and spread of pathogenic organisms on environmental surfaces in acute, ambulatory, short-term and long-term healthcare facilities and in the home, suggests that additional cleaning and maintenance protocols are needed. The gold standards of "good hand washing" and daily disinfecting of critical surfaces do not appear to be able to combat the increasing rate of hospital-acquired infections.

Nosocomial Infections

In the twenty-year period between 1975 and 1995, nosocomial or hospital acquired infections increased by 36%. A review of studies reported in two specific conferences on the topic, revealed the magnitude of the problem (APIC 2000; CDC 2000). The papers presented at these conferences provide evidence of increasing infection rates, a shift in infection type and additional locations where these infections are being spread. In addition to being found in most hospitals, nosocomial infections are common among patients admitted to acute rehabilitation units. Rates have been reported as high as 17% and were found to significantly contribute to patient morbidity (Mylotte 2000). Similar concern was voiced in a study involving a VA psychiatric facility (Risa et al. 2000). Nosocomial invasive aspergillosis is associated with high morbidity and mortality in patients with blood related illnesses (Raad et al. 2000). Various fungal infections found in immunocompromised patients were traced to problems during construction renovations of healthcare facilities (Drusin et al. 2000; Donelan et al. 2000; Rebmann et al. 2000). In coastal regions, that are prone to hurricanes, high humidity and moisture levels, patients are subjected to increased risk of nosocomial infections (Ober et al. 2000). Zhan et al. (2003) surveyed 20% of US hospitals and found that hospital acquired infections increase the average patient's stay by almost 10 days, increases the cost per patient by more than $38,000 US and increase their risk of death by more than 4%. This study resulted in the Joint Commission on Accreditation of Hospital Organizations (JCAHO 2004) to revised the standards for 2004. Zoutman et al. (2003) reported a similar study of Canadian hospitals. In 2003 the Province of Ontario was suddenly exposed to a severe epidemic of SARS. Over the six months from the infection's arrival until the last patient was discharged from hospital, 375 cases were recorded (OMH. 2004). At the height of the outbreak thousands of people, including health care workers, mostly in the Toronto area were quarantined for 10-day periods at home and given specific advice on preventing family members from infection. This was one of the extreme examples of a hospital acquired infection.

Resistive Strain Organisms

There is an increasing awareness by infection control personnel that touch surfaces can play a major role in the spread of microorganisms. Of particular concern is the potential spread of antibiotic-resistant organisms such as vancomycin-resistant enterococci (VRE), which is known to be transmitted from surfaces (Temple et al. 2000). This resistant organism is on the increase in hospitals throughout the United States. A study of upholstered chairs found that VRE are capable of prolonged survival on fabric seat cushions. In many hospitals, cloth-styled covering is preferred by management to increase patient comfort while in the hospital or long term care facility. However, these create potential reservoirs for the nosocomial transmission of VRE (Noskin et al. 2000). In another study, Mermel et al. (2000) found that at a number of cultured sites within patients' rooms, the highest rates of VRE were found on patient telephone handsets. Additional VRE organisms were found on bed rails, over-

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bed tables and sink faucets. This was further supported by studies conducted by Rutala et al. (2000) and by Diekema et al. (2004). Another resistive strain namely, methicillin-resistant staphylococcus aureus (MRSA), was found on computer keyboards and computer mice used in the medicine wards and other acute care areas (Valena et al. 2000). MRSA was also found on hospital bed handsets (Young, J.M. et al. 2005) including call buttons and TV remote control devices. A further study of hospitals in Pennsylvania (Volavka, M. 2005) found that more than 11,600 patients got infections while in hospitals over a one year period. These infections led to 1500 (13%) deaths and over $2 billion in hospital charges.

Additional Factors

In a survey article by Weinstein (1998), nosocomial infections in the US were estimated to have cost $4.5 billion in the year 1995. This article indicates a growing concern based on the increase of antibiotic-resistant microorganisms, such as (MRSA) and (VRE). The shift from inpatient to outpatient care leaves the more vulnerable patients within the hospitals, especially the immunocompromised patients. This increases the opportunities and likelihood of nosocomial infections. These factors, when combined with the renovation of aging hospitals, which increases the risk of airborne fungal and other infections (PHTS 2000), suggest that a better approach is needed to cleaning and maintaining healthcare facilities in the future.

Evidence of Supplementary Protection

With the current industry increase in cost-cutting measures and staffing constraints, some standards are not being practiced as fully as one would hope (Harris et al. 2000). In an attempt to combat this, various approaches have been taken to provide supporting measures to assist the healthcare worker and to provide cleaner surroundings. Indeed, new hand care preparations (Gould 2000) are being developed to assist the healthcare worker. Some of these contain the well-known antimicrobial agent, triclosan (Hoffmann et al. 2000) that has been used in hand soaps for many years. In an attempt to provide continuous antimicrobial action on surfaces, a novel application incorporating triclosan into the surface material used on a hospital over-bed table was reported by Van Enk and Lam (2000). This study showed that such surface treatment was capable of reducing many species of viable or living organisms on the surface within 60 minutes, as compared to more than four hours for the untreated control surface. This was an interesting application of an antimicrobial agent that was integrated into the construction material.

Environmental Surfaces

The realization that environmental surfaces can play a major role in the spread of resistive strains, has led to studies that find inadequacies in current methods of disinfection (Pentella et al. 2000). Many comparative studies have been reported. These studies used standard chemicals as well as new antimicrobial products for surface treatment (Lisay et al. 2000; Tessarin et al. 2000; Rutula et al. 2000). In addition to hospitals, increasing evidence of VRE is being found in long term care facilities (Lai et al. 2000) and in home care settings (Manangan et al. 2000; Greene et al. 2000). Evidence of airborne organisms, inadequate air quality, inadequate hand washing and environmental contamination in Neonatal Intensive Care units (Kassis et al. 2000; Burke et al. 2000) and pediatric care facilities (Goldman et al. 2000) have each been reported.

The Need for Added Protection

With this background and the projection of increased nosocomial infection rates, the question of how to keep the healthcare environment cleaner, and in a more sustainable state of readiness, lead the authors to be challenged beyond simply improving the current cleaning methods. The principal motivation was to provide methods of additional control of the bioburden within a healthcare environment, beyond the regularly scheduled maintenance and cleaning protocols. The idea of

providing treatment of the physical environment that would be sustaining and perhaps bridge the periods of use between regular cleaning periods, was worthy of study. The search for various antimicrobial agents that would lend themselves to environmental treatment, led the authors to the use of triclosan, the agent mentioned above. When the authors began the preliminary studies in 1995, a limited number of products containing triclosan were available for application. However, no information existed beyond laboratory findings, that triclosan could control 'real world' bioburden, to the degree needed in a healthcare environment.

Antimicrobial Agent - Triclosan

Triclosan is a diphenyl ether (5-chloro-2-[2,4-dichlorophenoxyl] phenol) and like other chlorine-based chemicals, it acts as a cell wall penetrant. It disrupts the microbial cell wall, disturbing the metabolic process, leading to the death of the organism. Although McMurray et al. (1998) suggest that some organisms may be insensitive to triclosan and could result in the development of resistant strains of organisms, considerable counter evidence and scientific argument dispels this position (FDA 1997, CSMA 1998, Jones 1999). The latter references indicate that currently used antimicrobial agents like triclosan, have very different action mechanisms than antibiotics. Additional studies also indicate that there is no existing clinical evidence to suggest that these agents, as used in 'real world' applications, are either mutagenic or prone to create resistive strains of organisms (Russell 2002, McBain et. al. 2002, Fraise 2002). An extensive review of the literature on bacterial resistance to topical antimicrobial products by Jones (1999), clearly indicates that there is no scientific evidence that triclosan has an influence on the development of resistive strains of organisms. Indeed, Jones et al. (2000) verifies that triclosan was clinically effective in reducing MRSA isolates from surgical wounds as well as reducing the percentage of ciprofloxacin-resistant MRSA strains.

It is worthy to note that triclosoan can be incorporated into the voids of any polymeric structure (Medlin 1997), as well as being suspended in certain liquid compounds. Such potential use of an antimicrobial agent makes it attractive for sustained treatment. This was one of the underlying motivations for using it in the present study. The concept was to have all construction materials, fixtures, medical instruments, and contents within the healthcare delivery areas, either surface treated or constructed with an antimicrobial agent as an integral part of the product. A limited number of polymer products containing triclosan were available for this study. The goal was to test these and where necessary, to develop others. These included surface sprays and coating liquids.

Over a period of three years, the authors used various triclosan-treated products and applied them to different problem areas throughout the main campus. These included concrete floor surfaces in the decontamination and food services areas; carpet underlay in maternity areas where spills created obnoxious odors and in shower areas where dampness led to continuous growth of microorganisms and degradation of carpet backing; in bathrooms on toilet seats, sanitary napkin dispensers, sinks and faucets and waste baskets; on counters, floors and isolettes in the Neonatal Intensive Care Unit; and on floor drain covers and mortar joints on bathroom floors and walls. In every application studied, the use of triclosan-treated items resulted in a reduction of surface bioburden.

With the success of these preliminary 'real world' tests, the authors began planning for a larger application of the treatment. During this planning period, management decided to construct a new outpatient facility, consisting of two floors, each containing 25,000 square feet (2315 m^2) of floor space. This building provided an excellent site for the expanded project. It was scheduled to open in January 1998, at which time this study began.

The Building

The skeletal structure of the building was that of a two storied, standard steel beam system with open web steel joists, erected on reinforced concrete foundation walls and footings. The building envelope consisted of brick veneer with the interior consisting of metal studded partitions with drywall. All concrete floors were concrete slab, either on fill or suspended on metal decking. The building was constructed on a sloped site with the second level serving as the front of the building and providing a ground level main entrance. This level had two identical wings that flanked the main entrance of the

building, each with 12500 square feet (1157 m^2) of floor space. In addition to hallways and restrooms, each wing contained patient waiting and exam rooms, faculty and medical resident offices, as well as nursing and administration areas. Since the building had two wings with identical layouts, each being used for identical outpatient care, it provided a unique opportunity to conduct a controlled study. The lower level housed the labs and support services with exit at the rear of the building. The HVAC system consisted of four main areas. The lower level was served by two separate but equally sized AHUs, each rated at 10,000 CFM. The upper level was served by two equally sized but separate units, each rated at 14,000 CFM. All units were balanced, and had separate outside air intake zones. The building was completed in December 1997 and opened on schedule in January 1998. All antimicrobial treatment of the test wing was completed before the building was opened for occupancy.

Treatment

Since the main object of the study was to see what effect the treatment of an entire environment would have on the total bioburden, it was imperative to treat all surfaces including the floors, ceilings, walls, doors, all touch hardware, air filters and all fixtures. The fixtures included sinks, counter tops, examination tables, medical instruments, desks, telephone handsets, computers, filing cabinets, chairs, tables and touch hardware etc. Where possible, existing commercial antimicrobial products were used. For some applications (such as floor wax, protective carpet underlay fabric and paint), special products were developed. No treatment was made to any item within the control wing.

Testing Procedures

Standard microbiological swab and air samples were taken throughout both wings. These tests were scheduled on a rotating basis so that each item and location tested on the treated wing had a corresponding test site on the control wing. Both tests were conducted on the same day and as close as possible in time. Over the 18-month test period, each site was tested approximately every two weeks. There were 45 surface and 10 air sites sampled on each wing, for a total of 110 data point locations. Each week, specific sites were tested. These were rotated on a two-week schedule throughout the 18-month test period.

Surface samples were taken using standard microbiological swabs, covering four square inches (2581 mm^2) and using standard culturing protocols. The results were reported in terms of the total number of colony forming units (cfu) of microorganisms appearing on the agar plates following the incubation period. Air samples were taken using a standard Anderson air sampler. These results were recorded in cfu per cubic foot of air sampled. Although each site on each wing was monitored over the entire test period, only average values for all sites within a wing, for any one period, were used for comparison. For example, at six months the average of the 10 air samples taken in the treated wing at that time, were averaged and compared to the average of the corresponding 10 sites in the control wing. This provided a single value that represented the entire wing, even though the distribution of values within the wing may differ somewhat from month to month. The same comparison of average values was made for the surface swab tests.

Results and Discussion

Surface Samples

A review of biological swab tests for touch and building surfaces in both wings, showed a consistent reduction of colony forming units (cfu) within the treated wing throughout the test period. The range of reductions and the average for each type of surface tested are summarized in Table 1. It is apparent that surfaces that were touched more frequently had greater reduction in the bioburden. This supports earlier tests by others (Medlin, 1997) who reported that triclosan exhibits increased effectiveness when continuously challenged. This was more clearly demonstrated in the present study in a separate set of tests involving items like telephone handsets and computers. These tests were conducted over a six-month period only. Three different telephones and computers located in the control wing were selected

for separate study toward the end of the main study. These were treated with a surface spray containing triclosan. The average reductions in bioburden are presented in Table 2 for the 7-day and 6-month test periods. The effect of repeated handling of these devices resulted in an increase in antimicrobial activity. This lead to a greater reduction in surface bioburden as compared to surfaces that were not touched as frequently, such as walls, floors and ceilings as reported in Table 1.

Table 1. Reduction in cfu on Surfaces in Treated Wing

Surface Treated Test Items (number of sites tested)	Range of Reductions in cfu Compared to Control Wing	Average Reduction in cfu Compared to Control Wing
Fixtures and Components (15)	25 to 91 %	55 %
Medical Instruments (10)	0 to 80 %	45 %
Furniture (5)	0 to 85 %	50 %
Wall Paint (5)	10 to 50 %	25 %
Floor tile (5)	30 to 55 %	40 %
Ceiling tile (5)	15 to 35 %	20 %
Total (45)	0 to 91 %	40 %

Table 2. Reduction in cfu on Telephone and Computer Surfaces

Surface Treated Test Items (number of sites tested)	Seven Days Post-Treatment Ave. Reduction in cfu	Six Months Post-Treatment Ave. Reduction in cfu
Telephone Handsets (3)	55 %	99 %
Computer Keyboards (3)	45 %	85 %
Computer Mice (3)	51 %	82 %

Air Samples

Although touch and building surfaces were monitored over the 18-month test period, the main interest was in the potential reduction of airborne bioburden as a result of total environmental treatment. For the treated wing, commercially available reusable air filters containing impregnated triclosan polypropylene filter fibers were selected. The control wing contained regular pleated-type disposable filters, the same type used throughout the healthcare campus in the majority of its buildings. The reusable air filters on the treated wing were removed, washed and reinstalled every four months. The disposable filters on the untreated wing were replaced every two months. A total of ten locations were selected for air testing on the treated wing with a corresponding ten on the control wing. Additional sampling was taken outdoors, as well as in the main entrance vestibule and waiting area. These were used for additional comparison with values obtained in the wings. The results for the two wings are compared in Table 3 in which the average values are reported at three equally spaced time intervals over the 18-month study period. Three reference values are provided at the bottom of Table 3 that can be used for additional comparison. These values were the average values over the entire test period. The laboratory value was normalized to 1.0 cfu/ft^3 and is used in Table 3 as a base comparison. The air quality in the laboratory was considered as one of the best or preferred levels of air quality on the campus.

It is apparent from Table 3 that the treated wing was maintained at a much ‘cleaner’ level than the control wing throughout the test period. Overall, the results indicate a consistent reduction of

total bioburden with time in the treated wing. There was a consistent reduction and stabilization after 12 months. Air quality was remarkably good and remained close to that found in the microbiology lab. In contrast, the bioburden in the untreated wing appeared to increase continuously with time. Although the level of bioburden in the untreated wing at 18 months was only 42% of the value found in the front entrance vestibule, it was 2.4 times higher than the treated wing and continued to increase. Since this was a new building and the level of airborne bioburden could continue to change with age, it is conceivable that the untreated wing could continue to increase in bioburden well above the value reported. In contrast, it is possible that the treated wing could level out, at or about the level found at the end of this study. That level was only 17% of that of the vestibule and only 16% above the laboratory level. The fact that the bioburden in the treated wing continuously decreased with time while that of the untreated wing continuously increased, does indicate that the antimicrobial treatment was very effective in controlling the bioburden.

Table 3. Air Samples (Average cfu/ft^3)

Test Interval	Treated Wing	Untreated Wing	Reduction
6 Months	1.36 (48.3)	1.75 (62.1)	22 %
12 months	1.19 (42.0)	2.26 (79.8)	47 %
18 Months	1.16 (40.9)	2.78 (98.1)	58 %

Reference Values: (Microbiology Lab = 1.00 (35.3)) (Vestibule = 6.69 (236.2)) (Outside = 33.37 (1178.0))

Since the total colony count does not differentiate between species of microorganisms, the air samples taken at the end of the study were examined to determine what viable or living fungi and bacteria were present at that time. For the fungi, when compared to the untreated wing, the treated wing contained 63% less bioburden. This was found to be statistically significant at a P-value = 0.0043 using the Mann-Whitney U test of medians. Also, there was no difference in the distribution of predominant genera of viable fungi between the wings. That is, the same percentage distribution of each species was the same in each of the wings even though the absolute numbers of species was less in the treated wing. For bacteria incubated at 35^0C, the median reduction was only 25% and was found not to be statistically significant. Also, there was a difference in the distribution of the predominant genera on each wing.

Conclusion

To the authors' knowledge, this study is the first of its kind involving a healthcare setting. The purpose was to see if the total bioburden or level of microorganisms present in a healthcare environment could be reduced through antimicrobial treatment of surfaces and the air. Since the building was new and contained two identical wings, each containing 12500 square feet (1157 m^2), it offered the authors a unique opportunity to conduct a controlled 'real world' study.

The treatment consisted of using the well known chlorine based antimicrobial agent triclosan, either through the application of existing products or by developing special purpose products. Physical components of the treated wing included permanent and moveable fixtures, medical instruments, furniture, walls, floors, ceilings and air filters. Included were telephones, computers, filing cabinets, sinks, counters, exam tables, doors and hardware etc. Each item in the treated wing had a corresponding control item on the untreated wing that was tested for comparison. A total of 45 items were selected in each wing for testing surface bioburden. There were 10 locations selected for air sampling on each of the two wings.

The results of the 18-month study showed an average of 40% reduction in colony forming units (cfu) for treated surfaces and a 58% reduction of air borne microorganisms. In the case of air sampling, it was interesting to find that the air quality in the treated wing consistently improved, while

that of the untreated wing got progressively worse. The antimicrobial treatment enabled the wing to maintain the level of airborne bioburden to within 16% of that found in the microbiology lab.

Unfortunately, this study cannot be used to determine what effect the triclosan-treated reusable air filters may have had on reducing the airborne bioburden within the treated wing since the triclosan-treated filters were installed at the same time as the other surfaces were treated. Although the authors realized this at the beginning of the study, there was insufficient time and resources to conduct a comparison of the effect of different treatment applications.

During the study period both wings were used for the same type of outpatient care. This was important to the validity of the study, since dissimilar use functions could have affected the test results and negated a direct comparison. Also, since hospital employees conducted all building maintenance and antimicrobial treatment, strict supervision and proper implementation of specific protocols for cleaning and treating was made possible.

The study had to be terminated after the 18-month period, since after one year of occupancy, renovations and functional changes were being scheduled by management. These resulted in the wings being used for very different types of patient care. Also, to reduce operating costs, all maintenance for the building was contracted out and this prevented any further study to be conducted.

What impact this type of environmental treatment could have on the reduction of nosocomial infections in more critical care facilities remains to be seen. The cost of environmental treatment would have to be determined and compared against any reductions in nosocomial infection rates. However, similar treatment approaches could be integrated into infection control activities and studied within a hospital setting. If nothing else, the building and the patient environment could be maintained in a 'cleaner' state of preparedness. Additional comparison of personnel absenteeism rates before and after treatment might also prove interesting, in light of the increasing evidence of the effects of 'sick building syndromes.'

Obviously, as is the case with many studies like the one reported here, more questions can be asked than answers provided. However, the science is here, the products are available, and nosocomial infections are on the increase. Perhaps it is time to consider improving the treatment of the healthcare environment as well as that of the patient.

Dedication

This paper is dedicated to the memory of Robert S. Watterson III, formerly Vice President of Sales, Microban Products Company, Huntersville NC whose dream was to see the construction of cleaner buildings based on the application of 'anitmicrobial treated building products'. Perhaps the results of this study suggest that dreams can come true.

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