

MICROORGANISMS IN CARPET

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ABSTRACT

The carpet industry and their suppliers have noted a loss of market share in commercial settings such as schools and hospitals over the past several years. This has occurred most notably in the southeastern U.S. where humidity is high and environmental conditions support the growth of mold and mildew. It was estimated in 1999 that the carpet industry was losing an estimated \$2 million annually due to the perceived relationship between soft floor coverings and an increase in the presence of mold, mildew and illnesses.

The paper serves as a review of the current literature on microorganisms in the indoor environment and the impact of carpet on their presence. Much of the research completed in this area has focused on allergens of dust mites, cockroaches, and pet dander. However, there is limited information on microorganisms cultured from indoor air samples, which is the focus of this review. The information is presented in three sections: 1) a discussion of allergens and pathogens that are linked with allergies, illness and infections, 2) a general overview of microorganisms and antimicrobial chemicals, specifically the finishing of textiles and 3) carpet related testing to reduce the presence of microorganisms in carpets.

INTRODUCTION

Carpet and rugs are soft floor coverings that are recognized for their versatility as they provide both decorative and functional advantages to interior spaces. Carpet is a key decorative element and provides the foundation of decorating through the use of color and texture. Physically, carpet provides thermal and acoustical insulation, is a non-slick surface that prevents slipping when walking, cushions falls, and reduces leg and foot fatigue when walking or standing (www.carpet-rug.com/). Carpet also affects the psychological impact of a space by de-institutionalizing commercial and industrial environments. In schools carpet can be related to improved student achievement scores. A study by Folden and Tanner (2002) reported that students who had access to carpeted classrooms scored higher on standardized tests.

Recently the carpet industry has lost market share in commercial settings due to perceived relationships between carpeted areas and an increase in illness, asthma and allergies. The use of soft floor coverings in schools, hospitals and other health care facilities has long been controversial as carpet is thought to contribute to the presence of microorganisms in the indoor environment.

The paper serves as a review of the current literature of the research in this area. Much of the research completed in this area has focused on allergens of dust mites, cockroaches, and pet dander. Some research studies have included microorganisms, which is the focus of this review. The information presented here is in several sections: 1) a discussion of allergens and pathogens that are linked with allergies, illness and infections, 2) a general overview of microorganisms and antimicrobial chemicals, specifically the finishing of textiles and 3) carpet related testing to reduce the presence of microorganisms in carpets.

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Allergens, pathogens and illness

It is well established that inhalant allergens play a major role in allergic asthma and allergic rhinitis. Over the past 30 years the prevalence of asthma has been increasing in the United States and many other parts of the world. Allergists have become more focused on identifying and measuring indoor allergens and multiple sources have been recognized (Platt-Mills, 1994). Allergens are commonly categorized as outdoor versus indoor allergens (Patel and Bush, 2000), and there is a known relationship between the presence of outdoor and indoor allergens. Typically, as the concentration of outdoor allergens increase, they are more likely to be found indoors. Many times there are seasonal changes in allergen presence as well (Goh, 2000).

The most common outdoor allergens, which result in rhinitis symptoms, include tree pollen, grasses, weeds, and certain fungi (e.g., *Alternaria* and *Cladosporium*). Many of these result in seasonal allergies, and the symptoms are neither year-round nor consistent. Indoor allergens often produce symptoms continually; however, the symptoms are less drastic in nature than that of reactions to outdoor allergens, making diagnosis more difficult. Although there are hundreds of fungal species in the environment, three classes are important from an allergic standpoint: Zygomycetes (e.g., *Rhizopus*, *Mucor*), Basidiomycetes (e.g., rust, smut, *Ganoderma*), and Ascomycetes (e.g., *Cladosporium*, *Penicillium*, *Aspergillus*, *Alternaria*, *Epicoccum* (Bush and Patel 2000).

House dust mites, cat dander, cockroaches, and fungi are important sources of indoor allergens (Gehring et al. 2001, Platt-Mills, T.A.E., 1994). Gehring et al. (2001) stated that dust mite, cockroach and cat dander are the most common allergens related to childhood asthma and illness and therefore are of particular importance. There have been numerous studies evaluating the presence of these allergens in indoor air. The importance of fungi as an allergen is also well known, and researchers have shown that fungi will produce many symptoms in the allergic individual. Childhood asthma and respiratory symptoms are highly related to domestic fungal exposure. About 5% of individuals are predicted to have some allergic airway symptoms from molds over their lifetime (Hardin et al., 2003, Rogers, 1991 and Pei-Chih et al., 2000). The role of fungi in allergic rhinitis and other respiratory allergies is well established. The most important indoor allergenic fungi are the molds *Penicillium* and *Aspergillus* (Bush and Patel, 2000 and Hardin et al., 2003).

It is also an accepted fact that there is a relationship between the presence of outdoor allergens and indoor allergens. The majority of the indoor airborne fungal population is derived from outdoor sources, in particular from regional vegetation, which is known to strongly affect the nearby airborne fungal concentrations. However, when suitable conditions are present (relative humidity, temperature, air exchange rate) fungi may also flourish on indoor man-made structures (Hargreaves et al., 2003).

In addition to allergies and asthma, infections can also be transmitted by allergens containing pathogens. This type of transmission is of concern in medical facilities such as hospitals and extended care facilities (nursing homes). Those with compromised immune systems are susceptible to infection via this method. Typically these pathogens will attach to particles such as shed skin cells, lint, or dust particles or in aerosols from coughing and sneezing. The particle may originate from infected or colonized patients, but may also have been introduced into the hospital environment by shoes, through open windows, from building works or from potted plants. The risk of acquiring airborne nosocomial infections from infected particles that have been whirled up is usually considered to be low because it has been difficult to demonstrate a correlation between counts of airborne bacteria and clinical infection (Schaal, 1991). When discussing allergens, fungi are of interest, and when discussing nosocomial infections, bacteria are of increased concern.

Measurement of indoor air quality with respect to microorganisms is of particular importance in tropical environments due to the extensive use of air-conditioning systems and the potential implications for human health. This study has revealed a number of interesting relationships between the concentrations of fungal spores and bacteria in relation to both environmental and human factors (Goh et al., 2000).

Indoor fungi/microorganisms

Each indoor environment is unique and is characterized by its own sources. Indoor air is a complex mixture of bio-aerosols and non-biological particles. Among the most important of these are human and animal occupants that

shed skin scales and other fragments, mold spores, viruses, and bacteria. Any occupied environment will contain these kinds of airborne particles in levels dependent on the activity of the occupants as well as ventilation rates and patterns in the space (Burge, 1995). The mold spores present in all indoor environments provide the most common source for indoor bio-aerosols. Indoor air contains a complex mixture of bio-aerosols such as fungi, bacteria and allergens, as well as non-biological particles including products from various combustion processes (Hargreaves et al., 2003). This paper focuses on the fungi and bacteria. These are known as microorganisms and require water to exist.

According to Burge (1995), a common source for indoor bio-aerosols is accumulated dust. House dust is complex and contains non-biological as well as biological components. These components may include dead organisms, skin scales, other arthropod and mammalian effluents, soil, other material tracked in from outdoors, pesticides, cleaning agents, and organisms such as bacteria, fungi and arthropods that use many of these materials for food. Most of these living populations depend on the availability of water. Although dust is a primary reservoir and a potential source for bio-aerosols, some state it has not been adequately studied. Only house dust mites have received significant attention (Burge, 1995)

The need for microorganisms to have water has resulted in the association between the presence of dampness and mold growth in buildings. Relationships between damp housing and increased presence of micro-fungi have been reported by their occupants (Dotterud et al., 1995). When comparing those living in damp versus dry dwellings, those living in damp dwellings complain of increased nausea, blocked noses, respiratory symptoms, headaches, and fever (Patel and Bush, 1989). Any substrate in a building that becomes sufficiently wet can support the growth of some organism and will become a source of bio-aerosols (Burge, 1995). Bacteria and fungi commonly grow on wet building and decorating materials such as wallboard, wood, insulation, wallpaper, carpet, etc. Although dampness may indicate potential mold growth, it can also be an indicator of other allergen presence such as dust mite infestation and bacterial growth. The allergens (mold, bacteria, bacterial endotoxins and dust mites) contribute to the illness. If moisture can be minimized by control of relative humidity and water intrusion, then microorganism presence will also be minimized. These observations suggest that indoor fungal growth is often a result of construction faults in the house, such as poor ventilation, increased absolute indoor humidity (AIH) and inadequate cleaning (Dotterud et al., 1995). Occasionally, microorganisms are present as a result of unique events such as water damage. Occupants of water-damaged buildings have described several nonspecific symptoms such as eye irritation, coughing, fatigue, nausea, and headaches, which can be related to microorganisms accumulated on the carpet surface and within the carpet structure (Hales, 1986). Although recent studies have documented increased inflammation in the nasal fluids of persons living in damp buildings, it was determined that mold spores themselves were not responsible for these changes (Hardin et al., 2003, Platt and Bush, 1989 and Nevalainen et al., 1991).

There have been a number of studies conducted in all parts of the world that have evaluated the factors that impact the presence of microorganisms in indoor environments. These studies have been completed in a number of building types including schools, homes, libraries and hospitals. Urban and suburban areas have been compared, and studies in a number of different countries have been completed.

Goh et al. (2000), measured and reported the concentration of airborne fungal spores and bacteria as related to room temperature, humidity and occupancy levels within a library building in Singapore. The elevated levels of indoor bacteria were primarily attributed to the number of library occupants. They proposed that the increased human shedding of skin cells, ejection of microorganisms and particulates from the respiratory tract, and the transport of bacteria on suspended dust particles from floor surfaces accounted for the strong positive correlation between occupancy levels and the concentration of bacteria in internal air.

Measurements to determine microbiological indoor air quality were performed in six apartments in the Taipei, Taiwan area. Air samples were collected from the living rooms, bedrooms, kitchens and bathrooms and the outdoor environment. There was no information provided on the indoor characteristics (i.e., carpets, furnishings, HVAC information). The health-related fungi that were the primary isolates from all areas samples included *Aspergillus*, *Penicillium*, and *Cladosporium*. It was determined that indoor fungi concentrations in Taipei were significantly higher than those observed in San Francisco and Edinburgh, and comparable to those found in Finnish moldy homes. The higher numbers were thought to be due to the high temperature and high relative humidity in Taiwan (Li and Yu, 1993). A second study related to indoor and outdoor airborne fungi by Pei-Chih et al. (2000) was also reviewed. Air samples were collected from 76 homes in southern Taiwan. Their research showed that there was a

significant difference in the presence of fungal air spores in suburban versus urban homes in the summer but not in the winter. This was related to the type of structure (single dwelling versus apartment type dwelling)

A microbial characterization of indoor air performed in classrooms of 10 primary and nursery schools located in Paris was reported by Mouilleseu et al. (1993). Indoor air quality depends on many factors. Because of the diverse potential sources of pollutants (furnishings, activity, etc.), ventilation efficiency and outdoor air quality are among factors of greatest interest. Bacteria contamination reflects occupancy, air change efficiency and activity. However, some other important reservoirs of bacteria exist in the premises. As a function of maintenance and humidity, surfaces of supports, water leakages, false ceilings, and air conditioning systems may provide favorable conditions to the multiplication of microbes that find their nutrients and their dispersion in the atmospheric environment by active or passive ways. Human and environmental reservoirs have a continuous or discontinuous emission rate. The researchers concluded that the microbial levels observed in schools are similar to those in other indoor environments (i.e., homes and day care centers).

A study by Gehring et al. (2001) was conducted in two German cities and dust samples were collected from over 400 homes to determine indoor exposure to mite and cat allergens and endotoxins. Dust samples were collected from the living room floor, the bedroom floor, and from the mattress surface according to the standardized protocol. In over 40 of the homes, there were not separate bedrooms (both the bedroom and living room were designated as the living room). Endotoxins were only measured in the areas designated as the living room. The article did not state the floor surface present. There were positive correlations between higher levels of endotoxin levels in homes of subjects with the lowest educational level and cat allergens in the mattress dust and endotoxin concentrations in the living room floor dust.

In the community of Sor-Varanger, northern Norway, air samples of house-dust-mite sensitized and control children were collected from homes and schools. The indoor air samples were cultured, and humidity, temperature and carbon dioxide concentrations were measured. Results from the culturing showed that the 5 most common fungal genera from homes were penicillium, yeasts, aspergillus, mucor, cladosporium, with penicillium being most common. In the schools, penicillium also occurred most frequently, followed by yeasts (Mucor and cladosporium). Aspergillus and alternaria were absent in the schools. The researchers noted that the lowest number of aerospores found in the schools and the highest aerospore counts were related to high indoor humidity. Pets and damp indoor conditions were more frequent in homes on HDM-sensitized children. Parental smoking and carpet occurred equally in both the control and HDM-sensitized groups. The researchers also noted that indications of poor ventilation were thought to relate to higher aerospore counts as well (Dotterud et al., 1995).

Air samples from living rooms and bedrooms were collected from fourteen homes in a suburb of Brisbane, Australia, to determine the correlation between indoor airborne fungal concentrations and non-biological particle concentrations. Therefore, non-biological particles may be serving as carriers of fungal allergen molecules into the lung independently of the whole fungal spore. There were not statistically significant associations between the fungal spore and sub-micrometer particle concentrations, but there were statistically significant relations between fungal spores and super micrometers particles concentrations. The majority of the indoor airborne fungal population is derived from outdoor sources, in particular from regional vegetation, which is known to strongly affect the nearby airborne fungal concentrations. However, when suitable conditions are present (relative humidity, temperature, air exchange rate) fungi may also flourish on indoor man-made structures. The following measurements were taken: air samples from the bedroom and living room, and a hand-held vacuum was used to collect dust samples in the bedroom from lower bedding (mattress), upper bedding (quilt, blanket), and pillows. Dust samples were taken from living room and kitchen floors (no mention of presence of carpet – floor covering was not identified). Most frequently isolated fungal genus was Cladosporium, followed by Alternaria, and Penicillium (Hargreaves et al., 2003).

Lewis et al. (1994), measured fungal air spore counts from over 500 dwellings in two cities in Scotland and found extremely high spore counts. Over 152 different molds were isolated from these air spores. Their findings indicated a potential effect on health for occupants of damp, moldy dwellings via the respiratory route. Previous research had shown that over 12 percent of the public housing in these two cities was affected by the presence of mold.

The relationship between microorganisms and textiles in the indoor environment

Over the past 15 years dust mites, cockroaches and cats have been identified as major sources of indoor allergens. Since the 1960's, the prevalence of asthma has been increasing in the United States and many other parts of the world. As allergists have become more focused on identifying and measuring indoor allergens, multiple sources have been recognized and three sources of allergens have been fully characterized: dust mites, cockroaches, and cats. Pei-Chih et al. (2000) stated that future studies to clarify the relationship of childhood asthma and environmental characteristics are necessary.

Although there are a number of research articles that report on the relationship between indoor allergens and childhood asthma, few of these actually identify carpet or other textile products as a source for these allergens. Gehring et al. (2001) stated that dust mite, cockroach and cat dander are the most common allergens related to childhood asthma and illness, and therefore, they were of particular importance. In this research, dust samples from the living room floor, from the bedroom floor, and from the mattress surface were collected according to the standardized protocol from apartments in the study. Although samples from floors were taken, the article does not mention the specific floor surface.

Researchers continue to show that childhood asthma and respiratory symptoms are highly related to domestic fungal exposure, differences in lifestyle, and residential characteristics, factors associated with asthma prevalence and levels of domestic fungal concentrations. Pei-Chih et al. (2000) recommended that future studies be conducted to clarify the relationship of childhood asthma and environmental characteristics in specific regions of Taiwan.

Although several authors have recommended the removal of carpet and other textile-related products, such as upholstered furniture, fabric drapes and stuffed toys (Patel and Bush, 2000 and Custovic et al., 2002), there are no supporting references that actually show that removal of these products reduces the presence of fungal air spores.

Custovic et al. (2002), state that carpet and sofas represent a huge reservoir of mites, mite allergens, and food for mites; however, there is no reference showing this has actually been studied. In this reference, the reduction of fungal allergen exposure is also discussed and recommendations including proposing that hardwood floors are the ideal solution, but there are no references supporting their recommendations. The authors do mention the relationship between fungal growth and moisture, but not with moisture to carpet. The majority of today's carpet is made of synthetic fibers that in general have low moisture regain (CRI Carpet Primer, 2003).

In reviewing several of the previously discussed research findings reported in this paper, even when carpet is identified, there are no direct relationships between carpet and the presence of fungal spores (Dotterud et al., 1995, Hargreaves et al., 2003.)

This does not mean that bacteria and fungi are not present on floor surfaces, including carpet. They can be deposited on floor surfaces through a variety of methods. The most common include foot traffic, food and drink spills, and bodily fluid deposition (through coughing, sneezing and human or animal waste). Some microorganisms found on floors and in carpet are airborne; they can be transported through heating or cooling systems or can be carried by people in from the outside.

In the medical field the use of carpet in hospitals has been controversial for many years. From as long ago as 1850, when Florence Nightingale wrote, "For a sick room a carpet is perhaps the worst expedient could by any possibility have been invented...A dirty carpet literally infects the room." (Nightingale, 1969), to research publications in the 1970's and 80's when a rapid buildup of bacteria in carpet was found (Anderson, *et. al.*, 1982 and Litsky, 1973). Micro-organism counts from the air just above the carpet surface were higher when walking on or vacuuming the carpet than air samples taken from rooms with tiled floors (Litsky, 1973). Also, when air samples were taken directly above the flooring, the microbial counts from just above carpet floors were greater than those from above bare floors, and patients staying in carpeted rooms had colonized bacteria like that found in the air samples (Anderson, 1982). However, Shaffer and Key (1970) concluded from their research that evidence was not found to show that reservoirs of bacteria develop in carpet, and therefore, there was no basis for recommending or not recommending carpet. In evaluating these studies, different sampling techniques were used, which influenced the results. Shafer and Key used surface sampling and Litsky used plug samples.

However, in 1985, the Center for Disease Control removed their recommendations against use of carpet in patient-care areas since there was not epidemiological evidence showing that carpet influenced the nosocomial infection rate in hospitals. The Center for Disease Control does not consider whether to use carpet as an infection control issue. (Wise, 1994). This is not to say that microorganisms are not present in carpet. The question is: do they cause a significant health concern?

The testing from over 20 years ago by Anderson and Litsky may not be valid when considering the carpet of today. There has been a dramatic change in the components used in carpet today from the 1970's and before, and applying results from these studies to situation today is questionable. Carpet composition has changed dramatically since the 1970's. Most carpets today used in commercial settings such as schools or healthcare facilities are produced from synthetic materials including nylon, polypropylene, polyester and SBR. Unlike materials used historically in carpet, such as wool, cotton and jute, these synthetic fibers do not support the growth of microorganisms. In 1968 approximately 51% of the fibers used in carpet were natural or man-made cellulosic fibers compared with 1999 when only 0.4% of the fibers were in this category (CRI Carpet Primer, 2003, Current Industrial Report Services, 1971). Their chemical composition does not inherently provide the nutrients or retain moisture at the level required to support microorganism growth. The synthetic products also have low moisture regain, and, therefore, excess moisture is not present in the components of soft floor coverings produced today. Wool, cotton and jute all have relatively high moisture regain (15%, 10% and 10% respectively). Wool and cotton are not resistant to microorganism attack; and jute, although resistant to microorganism attack, will deteriorate rapidly when exposed to moisture. Although carpet made from synthetic fibers does not sustain microorganism or insect life, if food is present, the microorganisms are attracted to this food. So a key factor in reducing microorganisms in the carpet or other environments is to eliminate nutrient sources such as food and water.

To address the issue of reducing microorganisms in carpet, it is important to have a general understanding of microorganisms and antimicrobial treatments used in the textiles area. In the remainder of this paper, an overview of microorganisms, antimicrobial agents, their use in textiles, and testing to evaluate antimicrobial activity is presented. Finally, a review of current research related to microorganisms in carpet and their transfer to humans through dermal contact is reviewed.

Microorganisms – An Overview

Microorganisms are essential to the existence of life. Some are directly involved with the maintenance of human health and others cause disease. A pathogen is any microorganism having the capacity to cause disease in a particular host and disease is the end product of an infectious process. The survival of a pathogen requires infection. Disease is the damage done to a host as a result of its interaction with the infectious agent. Symptoms of disease can reflect part of the microbe's strategy for survival within the host. For example, coughing and sneezing promote the transmission of the influenza virus.

Microbial diversity can be seen in terms of variations in cell size and morphology, metabolic strategies, motility, cell division, development biology, adaptation to environmental extremes, and many other structural and functional aspects of the cell. A great variety of microorganisms have been found on carpet and of interest here are those classified as bacteria and fungi. Microorganisms in general are very small. Bacteria are typically smaller than fungi and are about 1 to 5 μm long and completely invisible to the naked eye. A more complete understanding of the various microorganisms of concern is necessary to develop mechanisms to inhibit their growth and reduce their presence in carpet.

Bacteria exist primarily as single cells. They are characterized by having a cell wall outside the cell membrane. The cell wall provides shape and rigidity to the cells. Depending on the cell wall structure, bacteria can be classified as gram negative or gram positive. The cell wall of a gram positive cell consists of many polymer layers of peptidoglycan connected by amino acid bridges. Approximately 90% of the gram positive cell is composed of peptidoglycan. Gram negative bacteria have a much thinner cell wall, which is comprised of only 20% peptidoglycan.

The term fungi is used to encompass a very broad range of organisms. It is estimated that there are 100,000 species of fungi, and about 150 of these are generally recognized as primary pathogens of man and animals. They can cause

a broad spectrum of infections, ranging from systemic and potentially fatal diseases to localized cutaneous, subcutaneous, or mucosal infections. In addition to these generally recognized pathogens, numerous other fungi have caused lesions under circumstances of abnormal patient susceptibility (Kwon-Chung & Bennett, 2002). Fungi may occur as a single cell (yeast) or as a complex network of interconnected lines of cells joined end to end (hyphae or mycelia). Fungi generally have a cell wall, which is more complicated than the bacterial cell wall. Some fungi growing as hyphae/mycelia may be called molds. Some kinds of fungi may occur either as yeast or as mold under different conditions. Many fungi form spores, which are relatively resistant to heat and chemicals. Fungi are classified as Eukarya and obtain their energy from organic compounds in soil and water. Fungi are thought to play a major role in the breakdown of dead organic matter.

One article reviewed for this paper stated the following: “Water is the essential ingredient for mold growth. Most species aren’t picky eaters; as long as they can wash it down with a little water, many will feed on anything containing cellulose.” (The Truth about Molds, 2003)

ANTIMICROBIAL AGENTS

An antimicrobial agent is a chemical that kills or inhibits the growth of microorganisms. To effectively inhibit microorganism growth, the antimicrobial agent must interrupt the growth cycle. Some important targets in the growth cycle include the cell wall, cytoplasmic membrane, protein synthesis, and nucleic acid synthesis (Brock et al., 1994). Depending on those microorganisms the chemical agents are designed to attack, antimicrobial agents can be further classified as bactericides, fungicides, disinfectants, antiseptics, chemotherapeutic agents, and antibiotics. The sensitivity of microorganisms to antimicrobial agents varies. Gram positive bacteria are usually more sensitive to antibiotics than gram negative bacteria. A broad spectrum antibiotic will act on a wider range of microorganisms than just a single group. Some agents have an extremely limited spectrum of action, being effective for only one or a few species. Likewise, different antimicrobial agents vary in their selective toxicity. Some have similar effects on all types of cells, and others are more toxic to microorganisms than animal tissues.

Chemicals used to impart antimicrobial activity can be described in several ways. One is by the mechanism used to destroy the microorganisms (destruction of the cell wall); the other is by its chemical class. Some antimicrobial chemicals have a combination of destruction methodologies and/or chemicals. Due to the differences in bacteria and fungi cell membranes and walls, the actions of disorganizing or inhibiting cell wall synthesis are different for different microorganisms (Ryan, 1994).

Cell membrane inhibitors disorganize the structure or inhibit the function of cell membranes. The integrity of the cytoplasm and outer membranes of bacteria is vital so compounds that disorganize the membranes can rapidly kill the cells. In fungi, these chemicals interfere with the function and biosynthesis of membrane sterols. The cell wall synthesis inhibitors used in anti-bacterial agents prevent a step in the synthesis of bacterial peptidoglycan. For fungi, the actions of inhibiting cell wall synthesis occur in the synthesis of chitin, glucan or mannoprotein of the fungal cell wall. These antifungal agents exert their selective toxicity against bacteria because human cells lack cell walls. Beta lactam antibacterials are the representative products as cell wall synthesis inhibitors.

Protein synthesis inhibitors are therapeutically useful antibiotics. They prevent a step in the complex process of protein synthesis. Their attack takes place at one of the events occurring on the ribosome and never at the stage of amino acid activation or attachment to a particular tRNA. Most protein synthesis inhibitors have an affinity or specificity for 70S (as opposed to 80S) ribosomes, and in this manner they achieve their selective toxicity.

Nucleic acid inhibitors affect the synthesis of DNA or RNA, or bind DNA or RNA so that their messages cannot be read. In either case the growth of cells is blocked. The majority of these antimicrobial agents is unselective and affects animal cells and bacterial cells alike, and therefore, have no therapeutic application.

Competitive inhibitors are mostly all synthetic chemotherapeutic agents. Most are ‘growth factor analogs’ that are structurally similar to a microorganism growth factor but do not fulfill its metabolic function in the cell.

Chemicals that impart antimicrobial activity

Antimicrobial compounds include alcohols, oxidizing agents, heavy metals, acids, aldehydes, surfactants and antibiotics. Broughton et al. (1999) presented a thorough review of the current chemicals used in textile applications and the following information is from this review.

Alcohols: Alcohols are membrane active agents and they usually have to be used in high concentrations to be effective antimicrobial agents. Disruption of the cell membrane is the mechanism of cell growth inhibition.

Oxidants: Halogens are common oxidizing agents used in the antimicrobial treatment of textiles. Although the reactions of halogens in water are complex, any species that can release halogen as an element, radical or cation, has antimicrobial properties. Oxidation of the cell walls and accompanying changes in permeability are the theorized mechanisms of antimicrobial action for halogens. Reactions with other cell components, such as thiols, are possible. Organic peroxides can be antimicrobial agents, but most are too unstable to be used in textile applications. They are commonly used in washes and disinfectants. If the peroxides are stabilized they can be applied to fabrics and have been shown to have some antimicrobial effectiveness.

Heavy Metals: Heavy metal salts can inhibit cell growth in several ways. They can react with enzymes and with nucleic acids and/or complex with protein. Some heavy metal ions must be complexed in order to be transported across the cell membrane. Once inside, they compete with the normal metallic ions in enzyme catalysts, and disrupt cell metabolism. Silver and mercury ions interact with thiol groups on proteins. Reactions of heavy metals occur in species other than the target micro-organisms, which has resulted in limiting their use. Some of the heavy metals are particularly neurotoxic to humans, and most have some ecotoxic effects. Most of the heavy metals are toxic and considered hazardous for use where there is the possibility of ingestion, inhalation, or disposal in the environment. Except for the metallic elements found in abundance in the earth's crust, the use of heavy metals is declining, and their use in consumer textiles is limited.

Acids: Low pH in the media facilitates the antibacterial action of many other agents. In the undissociated state, acids may alter the cell membrane, induce leakage of cell components, and interfere with enzymatic processes in the cell. Acids are better able to penetrate the cell wall in the undissociated state, but their disruption of some of the chemical processes may proceed faster in the dissociated state. Phenols are the largest group of acidic compounds used as antimicrobial agents. They can operate by complexation with, or precipitation of, proteins, amino acids and some enzyme systems as well as by disrupting membrane permeability. Substituted phenols are more effective than phenol itself, particularly if the substitution promotes surface activity. The presence of electron-withdrawing groups on the ring enhances the acidity of phenol, and non-polar substituents may increase its surface activity, both of which enhance efficacy. Substituted bis-phenols such as hexachlorophene became very popular in soaps, cosmetics and textiles, because of the relative selectivity toward microorganisms; however concerns about neurotoxicity and potential absorption through the skin resulted in their use being banned worldwide. The newest popular compound of this type, triclosan, has appeared in a number of cosmetic, soap and textile applications.

Electrophiles: Aldehydes are electrophiles and react with the nucleophiles in the bacterial cell. Aldehydes also react with amines and thiol groups found in the cell. Formaldehyde has historically been used in many textile finishing processes as a cross linking agent. Its use is decreasing, as there is concern over its release into the atmosphere and subsequent inhalation by humans.

Surfactants: Surfactants consist of polar, hydrophilic sections attached to non-polar, oleophilic segments, and are commonly used in many stages of textile processing. Surfactants can be classified as anionic, nonionic, and cationic. Anionic surfactants are most active in acid media and attack the bacterial cell membrane. They are most effective against gram positive bacteria. Nonionic surfactants are relatively inactive against microbial targets, except for those surfactants containing groups like phenol, which are biocidal in their own right. The effects on the cell membrane are often reversible, particularly at low concentrations.

Cationic surfactants are the most active antimicrobial agents among surfactants, having activity against gram negative and gram positive bacteria, as well as against algae, fungi, and lipophilic viruses. Cationic surfactants include quaternary ammonium or phosphonium salts attached to alkyl groups. Quaternary amines are often substantive to textile fabrics and provide a semi-durable effect even if not chemically bound to the surface of the fabrics. Improved attachment to the fabric surface can be obtained through the use of organosilicon groups when they react with reactive groups on the fiber surface.

Other nitrogen-containing compounds (aliphatic amines, diamines, guanidines, and biguanines) have action similar to quaternary amines. Frequently the antimicrobial activity can be retained even when the functional groups are introduced into polymeric materials as monomers or by grafting.

THE USE OF ANTIMICROBIAL AGENTS IN THE TEXTILE INDUSTRY

The application of antimicrobial agents to textiles is completed for two reasons: 1) to prevent antimicrobial attack which results in degradation of the textile, and 2) to obtain the aesthetic functions (suppressing or killing odor causing bacteria), hygienic functions (preventing skin infections and related infections usually caused by dermatophytic fungi), or medical functions (suppressing or killing pathogenic and/or parasitic microorganisms). This paper focuses on the second of these.

Most of the reported antimicrobial finishes applied to textile products, such as socks and underwear for health and hygienic reasons, are successful in achieving the desired results. The antimicrobial chemicals used for this purpose include alcohols, oxidizing agents, heavy metals, acids, phenols, aldehydes and antibiotics. Currently available antimicrobial chemical and conventional methods used to treat these textile products have not been shown to impart durable antimicrobial properties to carpet. This is due to the complexity of microorganism growth on carpet, as previously discussed. Generally the principles of an "ideal" antimicrobial reagent for a textile product have been proposed and include: effectiveness against a wide range of microorganisms, antimicrobial activity throughout the life of the product, low toxic or non-toxic to humans at the concentrations used, colorless and odorless, effective at low concentrations, inexpensive and easy to apply, resistant to sunlight, does not leach from the textile, no side effects, and compatible with water repellent and flame retardant agents, dyes and other textile auxiliaries (Paul, 1990). Although many antimicrobial chemicals are available on the market, few of them meet all of the requirements for antimicrobial finishing on carpet.

Some of the challenges in making a textile product with antimicrobial effectiveness were listed by Broughton et al. (1999) and include:

- 1) selecting an agent that will kill the selected microorganism,
- 2) attaching the antimicrobial agent to the textile in at least a semi-permanent manner,
- 3) insuring the attachment does not inhibit the antimicrobial activity, insuring a durable effect or easy regeneration,
- 4) insuring that the product is not excessively toxic to humans or the environment,
- 5) insuring that microbial life does not develop immunity to the agent, and
- 6) demonstrating the antimicrobial effect to regulators and institutional legal advisors and retention of other desirable fabric properties, depending on use.

All of the treatments which have broad-spectrum antimicrobial activity also provide some measure of protection to the textile itself. Initially, the industry largely ignored the toxicity problems related to the antimicrobial chemicals and continued to use various agents that were toxic to most life forms. Among the early treatments used to impart microbial resistance in cellulosic fabric are cadmium, copper chromium mercury, tin and zinc salts or organometallic compounds, phenols and various phenol derivatives, ammonium and phosphonium compounds, amino-formaldehyde resins, various tars and creosote compounds and chemical modification of cellulose (Marsh, J.T., 1966 and Hamlin, M., 1953).

Delivery systems

Beside the selection of chemicals, the delivery system of the antimicrobial chemical is critical. The antimicrobial delivery systems are used to deliver the effective antimicrobials to textiles. They are the controlled release system, the regeneration system, and the barrier blocking system (Lewin, 1984).

There are two approaches for the controlled release mechanism: chemical and physical. In the chemical approach, the antibacterial or antifungal agent is hydrolyzed by the presence of moisture, which can be introduced by a number of methods including laundering and perspiration. The rates of release are sufficient to kill or inhibit the growth of microorganisms. In the physical approach, the active agent is sandwiched between two layers of protective plastic by the micro-encapsulation process. This is a common method for imparting antimicrobial abilities to textiles. Instead of hydrolysis by water or another chemical reaction, the active component of the antimicrobial agent is released by the presence of water or ultraviolet light.

In the regeneration system, active antimicrobials can be continually regenerated by laundering or exposure to ultraviolet light. Although the reservoir of the antimicrobial chemical is limited, the surface remains effective for long periods of time.

In the barrier or blocking systems, different films or coatings are used. One method commonly used is inert physical barrier films laminated to the fabrics or coatings that are impervious to transmission of microorganisms.

Application of antimicrobial chemicals to textiles

There are five techniques commonly used when applying antimicrobial agents to textiles. Some are appropriate when applying the agent to the fiber. Other techniques are appropriate when applying the agent to the yarns, fabrics or final products (socks or carpets) (Lewin, 1984). To produce fibers with inherent antimicrobial characteristics, the antimicrobial agent can be incorporated into the polymer solution prior to extrusion or incorporated into the spinning bath (for fibers produced via wet spinning). A second method of adding antimicrobial agents to fibers is by using graft polymerization methods. The fibers are treated to create a positively or negatively charged functional group on the fiber, and then immersed into a solution of counter charged ions. Micro-encapsulation of the antimicrobial agent within the fiber matrix is the third method. Such a physicochemical technique provides textiles with resistance to microorganisms when antimicrobials are released slowly from capsules. The remaining two methods are commonly used to treat textiles that are in the yarn, fabric or final product form. Applying an antimicrobial solution to the fabric using a pad-dry-cure method involves immersing the textile into an antimicrobial containing solution where a water soluble, or slightly water soluble, layer is deposited onto the fabric and then the liquid is removed by evaporation. Chemicals can be applied to textiles using treatments with resins, condensates or cross-linking agent. The resins and cross-linking agents are believed to improve the durability of the finish. Common cross-linking agents include urea-formaldehyde, melamine-formaldehyde, or other types of nitrogenous resins. In some cases the antimicrobial chemical will form a covalent bond with the fiber and, when the linkage break, the antimicrobial agent is released.

Specific textile products and applications

Dow-Corning produced a series of quaternary amines that could be fixed to a surface via silicone chemistry. Aegis Environments, a spin off company, developed technology under the trade name Microprobe Shield[®] and textile products are available from Dr. Scholls[®], Brillo[®], Odor Eaters[®], Almac Franklin Sports[®] and others. There are also a number of companies that supply textile/nonwoven finishes based on the technology including Goulston, Transoceanic Trade and others.

Triclosan, sold under the name Microban[®], is available in a variety of fiber and textile products. Most often it is incorporated into the fiber.

Biguanides, were developed for textile applications by Zeneca, and are available under the trade name Reputex[®] for the treatment of textiles from Textile Biocides. The textile treatment works best on cellulosic fibers and is available in the fiber from Acordis[®]. A number of other manufacturers use the product as a fabric finishing agent.

Research Associates sells a variety of antimicrobials under the name Ultrafresh[®]. Their formulated products include iodine releasers, organotin compounds, isothiazalones, quaternary ammonium compounds and triclosan. Textile products using Ultrafresh[®] technology are available from Milliken and others.

DuPont is offering a group of antimicrobial powders under the name MicroFree[®]. The products are inorganic pigments with an antimicrobial silver, copper oxide or zinc silicate, coating and an outer layer to control diffusion of the antimicrobial. The powders are designed for dispersion in polymer/fiber systems.

Interface, Inc. developed an organic substituted ammonium phosphate sold under the name Intersept[®] and is used in the Interface carpet products. The chemical has been licensed for application in air filtration fabrics, upholstery, ceiling tiles, and for inclusion in a number of applications not related to textiles.

Inclusion of the antimicrobial compounds in the fiber is often preferred for durability; however, surface deposition of the compound requires less of the material. In addition, most of the antibacterial action occurs on the surface of the textile or in the region adjacent to the textile. Inclusion of the antimicrobial in the print binder, nonwovens, or carpet backing latex are reasonably durable alternatives to inclusion in the fiber. Treatment of the fabric surface is viable and allows the use of compounds whose chemical or thermal stability does not allow them to be melted and extruded with all fibers. Fiber substantively, often induced by ion exchange or direct covalent bonding with the fiber surface, offers enhanced durability.

A number of companies that produce textile chemicals offer antimicrobial finishes which may be applied in the fabric manufacturers' facility. Finishers will apply these materials and do some antimicrobial testing for those companies that do not wish to develop this expertise in-house.

Standard testing for antimicrobial effectiveness of carpets

Although there are several standard tests for evaluating the antimicrobial activity of textiles, there is only one specific to carpets. In this section, this test will be described.

AATCC Test Method 174: Antimicrobial Activity Assessment of Carpet is a comprehensive test specifically designed for carpet testing (AATCC, 2001). This test has three parts: Part I provides qualitative results for bacteria, Part II provides quantitative results for bacteria, and Part III provides qualitative results for fungi. In Part I, the carpet is placed in intimate contact with nutrient agar previously streaked with bacteria and then incubated. After the appropriate incubation time, the bacteria growth is observed and if a clear zone of interrupted growth is present underneath and along the sides of the sample, this indicated antimicrobial activity of the specimen. In Part II, carpet samples are inoculated with test microorganisms and incubated. After incubation, the microorganisms are eluted from the carpet samples by shaking in known amounts of liquid. A known quantity of the liquid is plated and the CFUs are measured. The percent reduction in CFUs is calculated. Part III is a qualitative test to determine antifungal activity. The carpet sample is exposed to an inoculated nutrient agar media and allowed to incubate. After incubation, interruption of fungi growth is measured. In Parts I and III, the carpet samples are tested in pile up and pile down orientations.

MICROORGANISMS IN CARPETS – CURRENT AND RECENT RESEARCH

Little published research is available on the presence of micro-organisms in carpet. Although some studies have compared the presence of micro-organisms in rooms with carpet and without carpet, much of the reported research provides information on air quality. Most carpet today that is used in commercial settings is produced from synthetic materials including nylon, polypropylene, polyester and SBR. Unlike materials used historically, such as wool, cotton and jute, these fibers do not support the growth of micro-organisms. Their chemical composition does not inherently provide the nutrients required to support microorganism growth. In addition, these products have low moisture regain, and therefore, excess moisture is not present in the components of modern day soft floor coverings. Wool, cotton and jute all have relatively high moisture regain (approximately 15%, 10% and 10% respectively) and are susceptible to micro-organism attack. Jute, although resistant to microorganism attack, will deteriorate rapidly when exposed to moisture. Insects and micro-organisms that may be present are looking for a food source. Carpet made with synthetic fibers will not sustain insect life. When insects are found on carpet, either the carpet is a

pathway or they are eating something spilled or tracked on the carpet. The best solution is to keep carpet and rugs clean to eliminate the insects' food source. There is little recently reported research that looks at the presence of microorganism in today's carpet.

The influence of temperature and relative humidity on fungi in carpet

The effect of temperature and humidity on microorganism growth in carpet was measured in a controlled environment. Four commercial carpet samples were obtained. The carpet was uncut loop pile texture and of nylon fibers. Two of the carpets were treated with antimicrobial finishes, and two were the same carpet style untreated. The carpet was supplied by U.S. carpet manufacturers and was considered commercial grade. The antimicrobial finishes were selected to have antimicrobial activity on fungi, not bacteria. Carpet 1 had an organic substituted ammonium phosphate antimicrobial treatment in the backing and is commercially available. Carpet 2 was produced specifically for this project and had an Ultrafresh[®] finish on the face and a quaternary ammonium salt in the backing.

Three target microorganisms, all fungi commonly found in carpet in commercial settings, were used in this study and included *Aspergillus Niger*, *Penicillium Funiculosum* and *Cladosporium Herbarium*. Carpet samples were cut and conditioned for a minimum of 8 hours in standard conditions ($72^{\circ}\pm 2^{\circ}$ and $65\% \text{ RH} \pm 2\%$). The samples were then inoculated with a 1 ml micro-organism solution using a pipette, and placed in an environmental chamber for 13 days at three conditioning levels, 1) 85°F and $85\% \text{ RH}$, 2) 85°F and $65\% \text{ RH}$ and 3) 85°F and $50\% \text{ RH}$. Thirteen days was chosen after preliminary studies showed that this number of days allowed for the growth cycle of the microorganisms of interest. The number of colony forming units (CFUs) was determined using a Protocol automatic colony counter on the odd days (1, 3, 5, 7...13) for a 13 day period. Results showed the number of CFUs was influenced by the humidity, the micro-organism and the carpet treatment. In general, there were fewer CFUs at the lower humidity levels; however, the impact of change in humidity was micro-organism specific. At 50% relative humidity, the growth of *p. funiculosum* and *c. herbarium* was reduced in all carpet samples; the growth of *a. niger* was reduced consistently in treated carpet 2. There were fewer CFUs on the treated carpet than on the untreated carpets, and there were greater numbers of *Aspergillus Niger*, followed by *Penicillium Funiculosum* and *Cladosporium Herbarium* at all testing conditions.

The effectiveness of antifungal treated carpets in a classroom: a field study

Two different carpets, each with and without an antimicrobial finish, were installed in two classrooms in an elementary school in north Florida. The carpet was supplied by two U.S. carpet manufacturers and was considered commercial grade. For both carpets, the pile yarns were produced from nylon fibers. The antimicrobial finishes were selected to have antimicrobial activity on fungi, not bacteria. Carpet 1 had an organic substituted ammonium phosphate antimicrobial treatment in the backing, which is commercially available. Carpet 2 was produced specifically for this project and had an Ultrafresh[®] finish on the face and a quaternary ammonium salt in the backing. The school location was selected to expose the carpet to conditions of high temperature and high humidity.

One classroom was a kindergarten classroom and the other was a pre-kindergarten classroom. The carpet was installed according to manufacturers' recommendations in August, prior to the beginning of the school year. Unused carpet samples were used as the control, and then carpet samples were removed from the classrooms approximately every three months for 14 months. The final samples were collected in December, the year following installation. The removed carpet samples were transported from the school to the laboratory for testing within 8 hours of removal. Smaller carpet specimens were removed and the presence of microorganisms in the carpet structures was determined using an extraction method. The carpet specimen was placed in glass jars and solution was added. The jars were capped and shaken vigorously to remove the microorganism from the carpet structure. The extract was poured from the jar and then 10 mls of the extract solution was plated onto an agar filled petri dish. The petri dishes were allowed to incubate and the species of microorganisms were categorized by color, shape and size. In this study the total number of fungal species observed over the 14 month period was 40. For carpet 1, at 4 of 5 of the testing intervals, the treated carpet had less than or equal the number of fungal species present when compared with the untreated carpet. For carpet 2, at each sampling interval, all of the treated carpets had fewer fungal species than untreated carpet samples. These results indicate that antimicrobial finishes reduce the presence of fungal species.

New antimicrobial chemical designed for carpet treatment

Based on previous studies, current antimicrobials available for use in the carpet industry were deficient in two areas: 1) activity against either fungi or bacteria, but not both, and 2) lack of effectiveness after use and cleaning. A new chemical has been synthesized that, when applied to carpets, shows effective antifungal and antibacterial effectiveness initially and after simulated cleaning. The chemically treated carpet, when compared with untreated carpet, shows approximately an 80% or greater reduction rate for bacterium *S. aureus* and *E. coli* after 10 shampoo cleanings at 6, 12 and 24 hour contact times. The reduction of fungi, although not as great as for the bacteria, ranged from 12% to 40% after 10 shampoo cleanings at 6, 12, and 24 hour contact times, is still greater than non-treated carpets (Yao and Leonas, 2003). A U.S. patent for this chemical has been applied for through the University of Georgia Research Foundation.

Dermal transfer of contaminants from carpets to humans

Another area of interest is the transfer of carpet contaminants to humans through dermal contact. Micro-organisms and other chemicals of concern essentially have three pathways into the human body. The first is by inhalation and the second is by ingestion, and the third is by transfer to the skin. Microorganisms can be transferred to humans and cause disease by any of these methods.

The human body does have mechanisms in place to act as barriers to prevent this. There are seven typical openings into the human body. At each entrance, there are barriers in place to prevent entrance of foreign objects, including micro-organisms. Bodily fluids at the body openings have a relatively low pH that destroys the micro-organism. Normal human flora makes the environment competitive. If the individual has a suppressed immune system, then infection is more likely to occur. Inhalation occurs when micro-organisms are in the air, but that is not within the scope of this paper. However, we do know that if the microorganism is trapped in the carpet, then it is not circulating in the air. Transfer by the human body is of interest and concern. Although there have been few published studies evaluating the transfer of microorganisms from carpet to the skin, there are studies that evaluate the transfer of other contaminants such as pesticide and dirt from flooring (Ross, 1991, Lewis, 1994, Camann, 1996, Lewis, 1999, Clothier, 2000 and Rodes, 2001). The skin is the largest barrier and sloughs when dead, carrying away any contaminants. However, if the skin is damaged, then contaminants can easily enter the body. There have been a number of studies that have evaluated the transfer of particles other than microorganisms to skin (Lu and Fenske, 1999, Rodes et al., 2001, Lewis, et al., 1999, Camann et al., 1996). In these studies, the researchers looked at pesticide transfer and used various exposure methods including hand press, hand drag, wipe, polyurethane coated foam rollers and vacuum systems. The ease of removing a particle from the surface is controlled by the adhesive forces and has been reviewed by Rodes et al. (2001). Common methods of measuring particles in the carpet include vacuuming, hand drags, and wipes with various receptive materials.

The Carpet and Rug Institute is currently funding a study at the University of Georgia to study the transfer of viable microorganisms from carpet surfaces to skin and skin-like materials. (Leonas and Annis, 2003). This study has two components. The first component is to determine dermal transfer and the second is to develop a mechanized method of simulating transfer that mimics that of human actions. In this paper, the first component will be reported on.

The purpose of the dermal transfer component of this study was to determine if transfer of microorganisms from carpet to human skin does occur, what variables might influence this transfer, and to establish a baseline for comparison with transfer from the Materials Evaluator. Variables of carpet texture, microorganism, and method of contact between the receptor (human finger pads) and the carpet were selected for evaluation for this phase of the study. The experimental design for this component of the research is 2 x 4 x 2 x 10 with two carpet textures, four microorganisms, two transfer methods, and 10 replications of each combination making up the project design.

The two carpets used in this study were received from Mohawk Carpets and had similar carpet characteristics. The looped pile carpet was a 28-ounce product, nylon 6, solution dyed, and had a Scotchgard® treatment. The cut pile carpet was a 30-ounce product, nylon 66, post dyed, and had no topical finishes added. The mean pile height for both carpets was 5mm and the mean tufts /in² was 102. Neither carpet had antimicrobial treatments.

The microorganisms evaluated in this project include those commonly found on carpet: two bacteria (*s. aureus* and *e. coli*) and two fungi (*a. niger* and *c. herbarium*). Each microorganism was grown in individual broths and one ml

of the microorganism broth was inoculated onto the carpet surface in a figure 8 pattern using a pipette. The inoculated carpet samples were incubated a predetermined length of time to allow for the growth of the target microorganism. The carpet samples were then removed from the incubator and the transfer process began.

Prior to the human participant being allowed to participate in the dermal transfer component of the study, their hands were inspected for any cuts, wounds or skin conditions. If the hands passed inspection, they were cleaned with antimicrobial soap and then sanitized with ethanol to ensure no contaminate microorganisms were present. The human participant then completed either the sliding or compression exposure protocol. The sliding transfer protocol required the participant to slide the middle and ring fingers over the surface of the carpet in a figure 8 motion for approximately 10 seconds. The compression transfer protocol requires the participant to place the middle and ring fingers of the right hand in the center of the carpet sample and gently hold them there for 10 seconds. After each exposure test, the participant will elute both his middle and ring finger. The elution is completed with 1 ml of a 0.85% saline solution for each finger. A tube containing the eluant is placed over the fingertip pad and inverted 20 times over a 20 second period. The elution of each finger is combined and then serially diluted and plated. The plated eluant is incubated and the number of colony forming units (CFUs) counted. The total CFUs represent the transfer of microorganisms from the carpet to a human hand. After initial studies, it was determined that the pressure used in the sliding and compression transfer protocols greatly influenced the amount of microorganism transferred; therefore, a pressure sensor was used, and the amount of pressure in both components of the human transfer portion of the study was maintained at 2.5 pounds (\pm 0.5 pounds).

At this time, approximately 50% of the testing is completed and the preliminary results show that transfer of microorganisms from carpet to human fingertips does occur. From the results to date, the following generalizations can be made: 1) the bacteria (*e. coli* and *s. aureus*) transfer more readily than the fungi (*a. niger* and *c. herbarium*), 2) more *e. coli* is transferred than *s. aureus*, and 3) 75% of the time, (across all microorganisms, all carpet textures), the slide transfer method resulted in higher microorganism transfer than the compression method. Please note, these generalizations are based on the results we have at this time and may change when the testing is completed. Additional studies to compare variables of carpet characteristics, alternate flooring materials, and force are of interest.

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